SEPTEMBER 27, 2012

AUDIT REPORT

OFFICE OF AUDITS

NASA'S CHALLENGES TO MEETING COST, SCHEDULE, AND PERFORMANCE GOALS

OFFICE OF INSPECTOR GENERAL

National Aeronautics and
Space Administration

REPORT NO. IG-12-021 (ASSIGNMENT NO. A-11-009-00)

MESSAGE FROM THE INSPECTOR GENERAL

Over its 50-year history, NASA has been at the forefront of science and space exploration and is justifiably proud of its numerous scientific discoveries and technological innovations. However, many NASA projects cost significantly more to complete and take much longer to launch than originally promised. In this era of constrained Federal budgets, NASA's ability to deliver projects on time and within budget is more important than ever if the Agency is to maintain a robust portfolio of science and space projects.

This report examines NASA's project management practices to better understand the Agency's challenges to achieving its cost, schedule, and performance goals. In conducting this review, we interviewed 85 individuals, including the Administrator, Deputy Administrator, Associate Administrators, Center Directors, project managers, project staff, former NASA Administrators and staff, and external parties. We also solicited input from other NASA employees through an internal Agency blog. The findings we present in this report are primarily based on our analysis of the input we received and additional information from previous studies conducted by NASA, our office, the Government Accountability Office, and other organizations.

Although we make no formal recommendations in this report, we offer our analysis of each of four major challenges and, in some cases, note actions the Agency may wish to consider to help improve project management.

Each of the challenges identified in this report would benefit from a more comprehensive review. Accordingly, we plan to conduct future audit work in these areas to more closely examine them and offer recommendations for management action.

Final report released by:

Paul K. Martin
Inspector General

Acronyms

EVM	Earned Value Management
FY	Fiscal Year
GAO	Government Accountability Office
GPM	Global Precipitation Measurement
GRAIL	Gravity Recovery and Interior Laboratory
ISS	International Space Station
JCL	Joint Cost and Schedule Confidence Level
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
KDP	Key Decision Point
LDCM	Landsat Data Continuity Mission
MER	Mars Exploration Rover
MSL	Mars Science Laboratory
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
OIG	Office of Inspector General
PDR	Preliminary Design Review

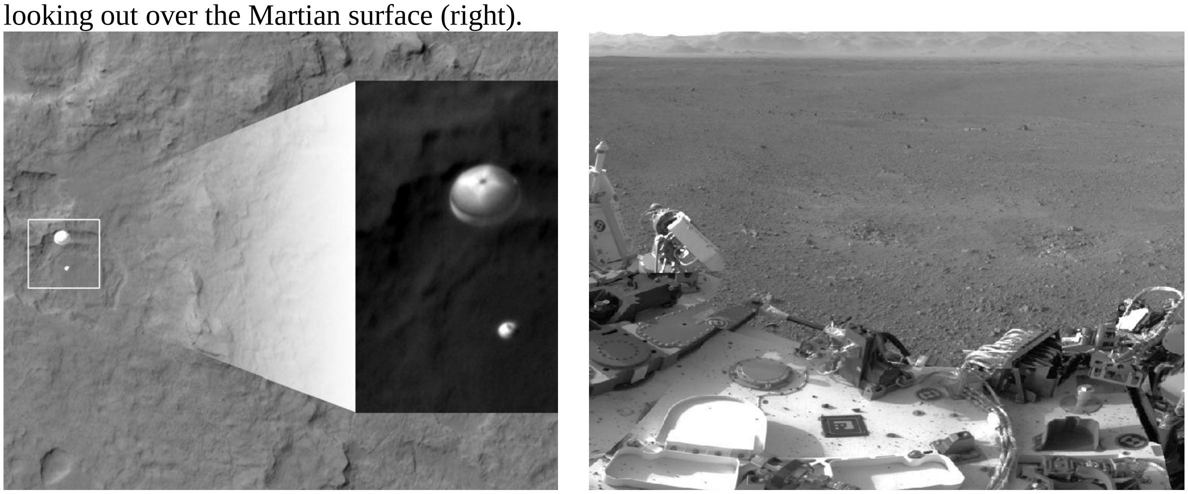
OVERVIEW

NASA'S CHALLENGES TO MEETING COST, SCHEDULE, AND PERFORMANCE GOALS

The Issue

NASA is an Agency with a unique mission that requires leadership, innovation, and creativity to achieve one-of-a-kind, first-of-their-kind technological and scientific advances. Over its 50-year history, NASA has been at the forefront of science and space exploration and responsible for numerous scientific discoveries and technological innovations. For example, since its launch in 1990 the Hubble Space Telescope has helped scientists determine the age of the universe, identify quasars, and prove the existence of dark energy. Hubble's successor, the James Webb Space Telescope (JWST), currently scheduled to launch in 2018, will study the birth and evolution of galaxies while the Mars Science Laboratory (MSL), which successfully landed its Curiosity rover on August 6, 2012, will assess whether the Red Planet is or has ever been able to support life (see Figure 1).

Figure 1. Curiosity as it descends to the surface of Mars (left) and composite photo of Curiosity looking out over the Martian surface (right).



Source: NASA

Unfortunately, in addition to their scientific accomplishments, these and many other NASA projects share another less positive trait – they cost significantly more to complete and took longer to launch than originally promised. For example, in 1977 NASA estimated that it would complete development of Hubble in 1983 at a total cost of $200 million; however, the telescope was not completed until 2 years later at a cost of approximately $1.2 billion. More recently, MSL launched 2 years behind schedule with development costs that increased 83 percent, from $969 million to $1.77 billion. Similarly, in 2009 NASA estimated JWST would cost $2.6 billion to develop and launch in 2014; however, it is now projected to cost $6.2 billion to develop and launch in 2018.

Cost increases and schedule delays on NASA's projects are long-standing issues for the Agency. A 2004 Congressional Budget Office study compared the initial and revised budgets of 72 NASA projects between 1977 and 2000.[1] The initial budgets for these projects totaled $41.1 billion, while their revised budgets totaled $66.3 billion, a 61 percent increase. Moreover, since its first annual assessment of NASA projects in 2009, the Government Accountability Office (GAO) has consistently reported on cost growth and schedule delays in the Agency's major projects. For example, in its 2012 assessment GAO reported an average development cost growth of approximately 47 percent, or $315 million, much of which was attributable to JWST. As GAO noted, cost and schedule increases on large projects like JWST can have a cascading effect on NASA's entire portfolio.

As the President and the Congress work to reduce Federal spending and lower the Nation's budget deficit, NASA's ability to deliver projects on time and within budget is more important than ever. Like most Federal agencies, NASA faces constrained budgets for the foreseeable future. Moreover, the Agency has received a diminishing proportion of the Federal budget – currently about 0.5 percent of the budget compared to a high of 4.4 percent in 1966 – and its annual funding adjusted for inflation is less than it was in 1994.

In addition to the challenging fiscal environment, NASA is at a historic crossroad with respect to the direction of its major programs. With the Space Shuttle Program ending after a 39-year history (Figure 2) and as a new and somewhat undefined path toward human space exploration commences, the Agency is undergoing considerable changes in mission focus. Despite the Agency's substantial achievements over the past 50 years, the ability to manage science and space exploration projects that meet their intended cost, schedule, and performance goals remains elusive. Collectively, these factors both necessitate and provide an opportunity for the Agency to reset itself and take positive steps toward improving program and project management.

[1] "A Budgetary Analysis of NASA's New Vision for Space Exploration," September 2004. Available at http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/57xx/doc5772/09-02-nasa.pdf (accessed August 24, 2012).

Figure 2. The Space Shuttle era ended on July 21, 2011, when Atlantis landed in the early morning hours at Kennedy Space Center in Florida.

Source: NASA

We initiated this review to gain a better understanding of the major challenges NASA project managers face in carrying out their duties. The core of our fact-finding consisted of interviews of 85 individuals from both inside and outside of the Agency, including the current and former Administrators, Associate Administrators, Center Directors, and project managers and staff. In addition, we solicited input from the greater NASA population via a blog.[2] The findings we present in this report are derived primarily from our analysis of the information we received from these sources, as well as additional information we gathered from reports and studies previously completed by NASA, our office, GAO, and other organizations. We anticipate conducting additional work in the future that more closely examines the challenges we identified and offers specific recommendations for management action. Details of our scope and methodology can be found in Appendix A.

[2] The Office of Inspector General blog was available on the NASA website from September 15, 2011, through October 20, 2011.

Results

Multiple factors underlie NASA's historical inability to consistently meet project cost, schedule, and performance goals. However, based on our interviews with 85 individuals involved in all levels of project development, we identified four factors that appear to present the greatest challenges to successful project outcomes.

First, a culture of optimism permeates every aspect of NASA. While essential to producing the types of unique spaceflight projects NASA undertakes, this optimistic culture may also lead managers to overestimate their ability to overcome the risks inherent in delivering such projects within available funding constraints. This, in turn, can lead to the development of unrealistic cost and schedule estimates. Second, project managers indicated that the technological complexity inherent in most NASA projects makes it particularly challenging to meet cost and schedule goals. Third, project managers stated that they routinely struggle to execute projects in the face of unstable funding, both in terms of the total amount of funds dedicated to a project and the timing of when those funds are disbursed to the project. Both forms of funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes. Finally, interviewees expressed the belief that hands-on experience is the most important factor in the development of a project manager but noted a decrease in the number of smaller projects on which aspiring managers can gain this experience. They also expressed concern about a declining number of Agency personnel with development experience and whether NASA can continue to attract technical talent.

These challenges represent real and continuing threats to NASA's ability to complete projects on time and within budget. Although NASA has taken some positive steps to improve project outcomes, enhanced effort and strong leadership will be required to accomplish meaningful change. In our judgment, clear and consistent leadership by the President, Congress, and NASA management is an essential first step toward ensuring project managers are well positioned to complete projects within cost, schedule, and performance estimates. NASA leaders must temper the Agency's culture of optimism by demanding realistic cost and schedule estimates, well-defined and stable requirements, and mature technologies early in development. They must also ensure that funding is phased appropriately, funding instability is identified as a risk, and project managers are appropriately rewarded and held accountable for meeting project cost and schedule goals.

We discuss each of the four main challenges below in more detail.

NASA's Culture of Optimism. It was clear from our interviews that a culture of optimism and a can-do spirit permeate all levels of NASA, from senior management to front-line engineers. According to project managers, this culture is essential to overcoming the extraordinary technological challenges inherent in the development of unique, first-of-their-kind space systems. However, this same optimism can sometimes prevent managers and leaders from making critical assessments of requirements, budgets, and schedules to determine what a project can realistically accomplish within a set budget and timetable. To this point, when asked whether their projects had been successful, every project manager we interviewed answered in the affirmative, regardless of the project's fidelity to cost and schedule goals.

From our discussions with senior NASA officials and project managers, we identified three related ways in which optimism contributes to cost and schedule challenges. First, the mindset has manifested itself in a lack of documented success criteria for cost and schedule performance in NASA projects. We reviewed plans for seven NASA projects and found that while success criteria for each were clearly defined in terms of technical requirements, none contained any success measures related to cost and schedule performance.

Second, NASA's culture of optimism appears to increase the difficulty of developing and maintaining realistic cost estimates. Many interviewees indicated that project managers and senior NASA leaders are often hesitant to admit they cannot overcome technological challenges or meet mission requirements within the funding profile provided.

For example, NASA initiated the MSL mission soon after the successful development and landing of the Mars Exploration Rovers (MERs) (see Figure 3).[3] Senior managers from those projects transitioned into the MSL Project and managed the new project in accordance with the "MER culture" of success. Program officials told us that this attitude contributed to senior managers accepting overly optimistic cost and schedule estimates generated by MSL Project personnel and placing less credence on independent assessments suggesting the Project would need additional funds and more time to overcome technical challenges. Ultimately, the MSL Project missed its first launch window in 2009 and experienced a 2-year launch delay, which significantly contributed to a life-cycle cost increase of $900 million.[4]

Figure 3. Artist concept of a Mars Exploration Rover on Mars.

Source: NASA

[3] The Mars Exploration Rovers – Spirit and Opportunity – were launched in June and July 2003, respectively, and landed on Mars in January 2004.

[4] Due to planetary alignment, the optimal launch window for a mission to Mars occurs every 26 months. MSL was scheduled to launch in a window between September and October 2009. However, in February 2009, because of the late delivery of several critical components and instruments, NASA delayed the launch to November 2011.

Finally, many project managers we spoke with mentioned the "Hubble Psychology" – an expectation among NASA personnel that projects that fail to meet cost and schedule goals will receive additional funding and that subsequent scientific and technological success will overshadow any budgetary and schedule problems.[5] They pointed out that although Hubble greatly exceeded its original budget, launched years after promised, and suffered a significant technological problem that required costly repair missions, the telescope is now generally viewed as a national treasure and its initial cost and performance issues have largely been forgotten.

An optimistic organizational culture is essential to producing the highly complex and unique missions for which NASA is known. However, if not properly tempered this culture can lead managers to underestimate the amount of time and money it will take to overcome the significant technical challenges inherent in many NASA projects. Nurturing the optimism needed to successfully produce an MSL or JWST while guarding against overly optimistic cost and schedule estimates is an ongoing challenge for NASA that will require Agency leaders to review project requirements, budgets, and schedules with a critical eye and find ways to reward project managers who demonstrate successful stewardship of NASA's limited resources.

Underestimating Technical Complexity Increases Cost and Schedule Risk. Project managers cited the technical complexity inherent in most NASA projects as a major challenge to achieving cost and schedule goals. Five factors explain the inherently uncertain nature of estimating costs for the types of space technologies NASA develops. First, because NASA projects often involve technologies that are new and unique, many development efforts do not have readily available historical data, cost models, lessons learned, and other information project managers can use to estimate the effort needed to develop the required technologies. Second, NASA projects often involve combining several interdependent technologies to accomplish novel missions, and the resulting complexities are often difficult to predict. Third, NASA systems generally require more testing than other development efforts because, unlike land-based systems, they function remotely in space where repair or replacement is extremely difficult or impossible. Fourth, because space systems are often one-of-a-kind instruments, NASA cannot produce them in sufficient quantities to benefit from manufacturing economies of scale where the average cost of a product decreases as quantity increases.[6] Lastly, according to many of the interviewees, the quality and availability of parts and instruments procured from some contractors has decreased over time. This affects managers' ability to estimate project costs accurately because a part's poor quality may not be evident until testing has begun, resulting in the need for costly rework or identifying alternative suppliers late in development.

[5] While not attributable to a particular individual, the term "Hubble Psychology" is well known and used extensively throughout NASA.

[6] Economies of scale are factors that cause the average cost of producing something to decrease as the quantity increase, as each additional unit takes on a share of the startup costs.

We acknowledge that space development projects are technically complex and their development costs difficult to assess accurately at the implementation stage of a project's life cycle when managers are required to produce cost and schedule estimates against which their projects will be measured.[7] Nonetheless, in our judgment NASA can take steps to increase the likelihood that its projects will meet cost and schedule goals. Specifically, few projects should proceed to implementation unless requirements are well-defined and stable and the available resources – mature technologies, schedule, and funding – are set.[8] In addition, critical technologies should be matured to the point where a prototype that closely approximates form, fit, and function requirements is demonstrated in a relevant environment. Finally, adequate funding should be available to meet the project's requirements and account for its technical risks.

Funding Instability Can Lead to Inefficient Management Practices. Nearly 75 percent of the individuals we interviewed stated that funding instability was among the most significant challenges to project management.[9] Funding instability includes situations in which a project receives less money than planned or funds are disbursed on a schedule different than planned.

Funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes. For example, inadequate funding in the early phases of a project's life cycle decreases management's ability to identify and address key risks at project inception. Moreover, in the absence of sufficient funding, project managers may have to defer the development of critical technologies to a time when integration of those technologies may be more difficult or when the costs of material and labor may be greater. In some cases, shifting tasks to later project phases may require managers to sustain a workforce longer than originally planned or add shifts in an attempt to make up for lost time, both of which can lead to increased costs. For example, an independent review of the JWST Project noted that deferred work can potentially result in overall costs doubling or tripling due to its impact on other work.[10]

---

[7] NASA divides the life cycle of its spaceflight projects into two major phases – formulation and implementation. Formulation is the period in which Agency personnel, among other tasks, identify how a project supports the Agency's strategic needs, goals, and objectives; assess feasibility, technology, concepts, and risk; build teams; develop operations concepts and acquisition strategies; establish high-level requirements and success criteria. The implementation phase is the period in which personnel execute approved plans for the development and operation of the project and use control systems to ensure conformance to those plans and continued alignment with the Agency's strategic needs, goals, and objectives.

[8] GAO's 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. 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. See GAO, "NASA: Assessments of Large-Scale Projects," (GAO-10-227SP, February 1, 2010).

[9] In addition, 75 blog comments cited funding instability as a challenge to project management.

[10] JWST Independent Comprehensive Review Panel Final Report, October 29, 2010.

Interviewees noted that funding instability originates primarily from two sources: external decisions made by the President and Congress and internal decisions made by Agency personnel. According to interviewees, shifting space policy priorities from the President and Congress and the vagaries of the annual appropriations process are major challenges to project management. For example, NASA transitioned from the Space Shuttle Program to the Constellation Program to the new Space Launch System Program in just 6 years. Moreover, since 1959 NASA has received its annual appropriation at the start of the new fiscal year only seven times, resulting in weeks- or months-long continuing resolutions that generally set funding at the prior year's level. Although it is difficult to quantify the cost and schedule impacts to individual projects, many interviewees said starting the fiscal year without an approved budget can force project managers to delay work, limits the Agency's ability to make necessary program changes, and prevents the Agency from beginning new projects.

While external factors may contribute to funding instability, internal Agency decisions also play a significant role. For example, if the Agency withholds or delays funding from a project, managers must adapt to a more restrictive funding profile and re-plan work. This often means moving tasks such as maturing critical technologies and reducing other risks into the future, which can lead to cost and schedule increases.

Moreover, interviewees stated that when highly visible flagship missions such as the Constellation Program or JWST experience significant cost growth, NASA leadership often takes funds from the budgets of other program areas to cover those increased costs. This not only makes it difficult for the managers of the projects that lose funds, but also has a ripple effect that increases the difficulty of managing the Agency's overall portfolio.

Funding instability has been a long-standing feature of the Federal budget and Agency processes, and given the current fiscal environment is likely to become even more common in the future. We believe that NASA management should increase its efforts to determine the extent to which funding instability impacts NASA projects and clarify the cause and effect relationship between funding instability and project cost increases, schedule delays, and performance problems. Addressing these issues could better facilitate the development of effective risk mitigation plans for managing fiscal disruptions.

Limited Opportunities for Project Managers' Development. Interviewees identified a number of emerging issues that could affect NASA's ability to manage its projects effectively in the future. First, most project managers and senior officials we spoke with said that experience and on-the-job training were keys to a project manager's ability to manage cost, schedule, and performance goals. However, they expressed concern that as the number of large flagship missions has increased, NASA no longer has enough small missions to provide a training ground for new project managers. Project managers described NASA's small projects as invaluable for developing management skills and learning the key elements of project management, including understanding and managing cost, schedule, and performance elements and making appropriate trade-offs among these elements when necessary.

Interviewees also expressed concern about a lack of in-house development experience. Some expressed the view that as NASA has increasingly relied on contractors to support project development, the Agency's in-house capabilities have declined. Moreover, they expressed concern that because NASA contracts the majority of its hardware and software development efforts to private industry, NASA engineers spend most of their time overseeing contractor efforts rather than building spaceflight components. These interviewees believe that as a result NASA engineers have limited opportunities to gain practical "hands-on" experience.

Finally, some interviewees fear that NASA will not be able to attract and retain recent graduates or experienced engineers who are seeking opportunities to design and build hardware and software and integrate systems. The concern is that these individuals will instead choose positions in private industry and that as experienced engineers retire, NASA will lose these core competencies.

To overcome the challenges identified in this report, it is critical that NASA continue to attract and retain high-quality project managers, adequately train and nurture these individuals, and provide them with ample opportunities to hone their skills.

Conclusion

Over its more than 50-year existence, NASA has made significant achievements exploring space, helping understand Earth's environment, and conducting fundamental aeronautics research. However, consistently managing the Agency's science and space exploration projects to meet cost, schedule, and performance goals has remained elusive. Given the anticipated funding challenges for all Federal agencies in the years ahead, changes to the way NASA develops and manages its projects are imperative. At the same time, the Agency is undergoing considerable changes in mission focus, with the end of the Space Shuttle Program and the first steps on a new path toward human space exploration. Collectively, these factors both necessitate and provide an opportunity for the Agency to reset itself and take steps toward meaningful change in the way projects are developed and managed.

To its credit, NASA has taken several steps in the last few years aimed at curbing cost growth and schedule delays, and the Agency has pointed to some early indications of improved cost and schedule performance for recent projects like the Gravity Recovery and Interior Laboratory, Juno, and Mars Atmosphere and Volatile Evolution missions.[11]

[11] The Gravity Recovery and Interior Laboratory mission launched on September 10, 2011, to study the Moon's interior. Juno launched on August 5, 2011, to investigate the origin and evolution of Jupiter and is scheduled to arrive at the planet in July 2016. The Mars Atmosphere and Volatile Evolution mission is scheduled to launch in late 2013 to investigate the Martian atmosphere.

Nevertheless, in our judgment NASA needs a “unity of effort” – strong, consistent, and sustained leadership by the President, Congress, and NASA management – to meet the challenges outlined in this report and achieve more consistent fidelity to cost and performance goals. Articulating a clear, unified, and sustaining vision for the Agency and then providing the necessary resources to execute that vision is a critical cornerstone of success. For their part, NASA leaders must temper the Agency’s culture of optimism by requiring realistic cost and schedule estimates, well-defined and stable requirements, and mature technologies early in project development. In addition, to the extent possible they must ensure that funding is adequate and properly phased and that funding instability is identified as a risk and accounted for in risk mitigation strategies. Finally, they must be willing to take remedial action when these critical elements are not present.

Although technological innovation and mission success as defined by scientific advancement and discovery are central to NASA’s core existence, an appropriate balance must be struck that also recognizes the importance of meeting project cost and schedule goals. Accordingly, we believe that NASA needs to find ways to reward managers for good stewardship of NASA’s resources as enthusiastically as it does for successful technological achievements and to hold managers appropriately accountable for mismanagement of resources. With renewed focus on and appropriate recognition of technical, cost, and schedule risks and rewards, NASA project managers will be better positioned to meet the performance goals expected by Congress and the U.S. taxpayer.

Management’s Response

In response to a draft of this report, NASA generally concurred with the challenges we outlined and stated that the Agency has implemented a number of performance improvement actions. Specifically, the Chief Engineer pointed to an increased management focus during the formulation phase, the application of joint confidence levels, and a refined life-cycle review process to guard against making commitments based on overly optimistic plans. He also stated that NASA now uses Formulation Agreements to document agreed-upon expectations between project managers and the Agency.

The Chief Engineer acknowledged that internal and external funding instability impacts project management and stated that NASA has implemented a number of reviews and agreements to establish expectations with project managers to facilitate open discussion and early identification of impacts resulting from changes in funding due to internal factors. However, he stated that external changes to funding profiles are more difficult to control and the Agency advises project managers to account for continuing resolutions and notify stakeholders when external funding decisions are likely to result in negative outcomes. The Chief Engineer also agreed with the need for maturing and retaining an experienced workforce to lead NASA projects. He pointed out that NASA has been recognized for its project leadership training and other knowledge sharing initiatives and is targeting early career professionals in its recruitment program.

We agree that these initiatives, if properly implemented, could help NASA mitigate the challenges we identified in this report. We also agree with the Chief Engineer that NASA's culture of optimism is necessary for the Agency to accomplish the challenging tasks it undertakes.

However, the Agency's response did not address our primary conclusion regarding the need for strong leadership by the President, Congress, and the Agency to address these persistent challenges. Without such leadership, it will be difficult for NASA to effectively implement the initiatives the Agency has identified, much less overcome the long-standing challenges to meeting the cost, schedule, and performance goals of the Agency's science and space exploration projects.

The Agency's comments in response to a draft of this report are reprinted in Appendix C.

CONTENTS

INTRODUCTION

Background

If it's been a while since our last failure, people who are looking to us to do great things sometimes forget how hard this work is to do.

– Former NASA Chief of Safety and Mission Assurance

NASA is an organization with a unique mission that requires leadership, innovation, and creativity to achieve one-of-a-kind, first-of-their-kind technological and scientific advancements. Supported by investments of $470 billion since its creation over 50 years ago, the Agency has been at the forefront of space exploration and responsible for numerous scientific discoveries and technological innovations. For example, since its launch in 1990 the Hubble Space Telescope has helped scientists determine the age of the universe, identify quasars, and prove the existence of dark energy, and more than 6,000 scientific articles have been published using data gathered by the telescope. Hubble's planned successor, the James Webb Space Telescope (JWST), will study the birth and evolution of galaxies, while the Mars Science Laboratory (MSL) and its Curiosity rover, which landed on Mars on August 6, 2012, will assess whether the Red Planet is or has ever been able to support life.

Unfortunately, in addition to their notable scientific accomplishments, many NASA spaceflight projects share another less positive attribute – they cost significantly more to complete and take longer to develop than originally promised. For example, in 1977 NASA estimated that Hubble would launch in 1983 at a total cost of $200 million. In reality, it took the Agency another 2 years to complete the telescope at a cost of approximately $1.2 billion. More recently, MSL launched 2 years behind schedule, increasing the Project's life-cycle costs by 56 percent, from $1.6 billion to approximately $2.5 billion. Similarly, although in 2009 NASA estimated that life-cycle costs for JWST would be $5.0 billion and the Project would launch in 2014, current projections put the life-cycle cost of the Project at $8.8 billion with a launch date of 2018.

Roles and Responsibilities of Project Managers. NASA relies on a cadre of managers to lead its spaceflight projects. To do their jobs successfully, these managers must coordinate with a broad array of Agency officials, outside contractors, and internal and external oversight entities. In addition, they must exercise a high degree of technical, business, contracting, and management skills to assess the risks, feasibility, and technical requirements of their projects; develop operations and acquisition strategies; establish high-level requirements and success criteria; and prepare plans, budgets, and schedules. The likelihood that a project will meet its cost, schedule, and performance goals depends, in large part, on the ability of project managers to master these skills and successfully balance sometimes competing priorities.

While these managers play a central role in ensuring that projects stay on course, they also operate within a larger Agency management structure that can significantly influence the success or failure of their projects. For example, the Administrator establishes the Agency's strategic priorities and is responsible for the successful implementation of policies and programs that support those priorities. The Associate Administrators of the Aeronautics Research, Human Exploration and Operations, and Science Mission Directorates manage their Directorates' program portfolios; are accountable for the success of the projects in that portfolio; and define, fund, evaluate, and oversee the implementation of those programs and projects to ensure they meet schedule and cost constraints.[12] Finally, Center Directors provide resources, workforce, and facilities to support the programs and projects housed at their Centers.

NASA's Project Life Cycle. NASA policy provides overall direction for how project managers execute their responsibilities.[13] The policy outlines NASA's management structure; the life cycle for spaceflight projects; the roles and responsibilities of and the interrelationships between team members; and management requirements by life-cycle phase. NASA has also developed a handbook to aid project managers in implementing these high-level requirements. The handbook provides information on best practices to assist managers with problem solving and risk management in taking a project from concept and design to development and production.

As shown in Figure 4, NASA divides the life cycle of its spaceflight projects into two major phases – formulation and implementation – which are further divided into phases A through F.[14] Phases A and B consist of formulation and C through F implementation. This structure allows managers to assess the progress of their projects at key decision points (KDPs) in the process.[15] Generally speaking, projects that stay within the parameters of their plans and other governing agreements proceed to the next phase. Those that deviate significantly from these plans and agreements undergo a Termination Review that can lead to cancellation.

[12] NASA's programs are generally composed of a number of individual projects (missions) that support a specific goal or objective. For example, the Mars Exploration Program currently consists of the Mars Odyssey, Mars Exploration Rovers, Mars Express, Mars Reconnaissance Orbiter, and MSL missions.

[13] NASA Procedural Requirements (NPR) 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012.

[14] NASA defines formulation as the period in which Agency personnel identify how a project supports the Agency's strategic goals; assess feasibility, technology, concepts, and risk; build teams; develop operations concepts and acquisition strategies; establish high-level requirements and success criteria; prepare plans, budgets, and schedules; and establish control systems to ensure performance to those plans and alignment with current Agency strategies. The implementation phase is the period in which personnel execute approved plans for the development and operation of the project and use control systems to ensure performance to those plans and continued alignment with the Agency's strategic goals.

[15] A KDP is defined as the point in time when the Decision Authority – the responsible official who provides approval – makes a decision on the readiness of the project to progress to the next life-cycle phase. KDPs serve as checkpoints or gates through which projects must pass.

Figure 4. NASA Life-Cycle Phases

Formulation			Approval	Implementation				End of Mission
Pre-Phase A: Concept Studies	Phase A: Concept and Technology Development	Phase B: Preliminary Design & Technology Completion	Proceed to Implementation Phase	Phase C: Final Design and Fabrication	Phase D: System Assembly, Integration, Test, and Launch	Phase E: Operations and Sustainment	Phase F: Close-out	Mission Concluded
		Preliminary Design Review (PDR)	Key Decision Point C (KDP C)	Critical Design Review (CDR)				

During formulation Phases A (Concept and Technology Development) and B (Preliminary Design and Technology Completion), projects develop and define requirements, cost and schedule projections, acquisition strategy, and project design and complete development of mission-critical or enabling technology. As needed, projects are required to demonstrate evidence of technology maturity and document the information in technology readiness assessment reports. Projects must also develop, document, and maintain a project management baseline that includes an integrated master schedule and baseline life-cycle cost estimate.[16]

The formulation phase ends with a preliminary design review (PDR), during which project personnel are requested to demonstrate that the project's preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints and establish the basis for proceeding with detailed design. At the PDR, the project is required to present full baseline cost and schedules, as well as risk assessments, management systems, and metrics. In addition, a Standing Review Board conducts an independent assessment of the readiness of the project to proceed to implementation.[17] The formulation phase culminates in management approval to proceed to the next phase, which requires passage through KDP C where an assessment of the preliminary design and a determination of whether the project is sufficiently mature to proceed to Phase C is made. In addition, as part of the KDP C review process cost and schedule baselines are established against which the project is thereafter measured.

[16] The management baseline is the integrated set of requirements, cost, schedule, and technical content that forms the foundation for project execution and reporting that is done as part of NASA's performance assessment and governance process.

[17] A Standing Review Board is composed of independent experts who provide assessments of the project's technical and programmatic approach, risk posture, and progress against the project baseline and offer recommendations to improve performance or reduce risk.

During Phase C, the project prepares its final design, fabricates test units that resemble the actual hardware, and tests those components. A second design review, the critical design review (CDR), occurs in the latter half of Phase C. The purpose of the CDR is to demonstrate that the design is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing and that the technical effort is on track to meet performance requirements within identified cost and schedule constraints. After the CDR, a system integration review takes place during which the readiness of the project to start flight system assembly, test, and launch operations is assessed. Depending on the results of that review, the project may be approved to continue into Phase D, which includes system assembly, integration, test, and launch activities. Phase E consists of operations and sustainment, and Phase F is project closeout.

Cost Increases and Schedule Delays. Cost increases and schedule delays on NASA projects are long-standing issues for the Agency. In 2004, the Congressional Budget Office compared the initial and revised budgets of 72 NASA projects between 1977 and 2000.[18] The initial budgets for these projects totaled $41.1 billion, while the revised budgets totaled $66.3 billion, a 61 percent increase that represented 10.6 percent of NASA's total budget during those years.

Since 2009, the Government Accountability Office (GAO) has made an annual assessment of the status of NASA's major projects. Table 1 shows the average cost growth and launch delay of selected NASA projects as reported by GAO in each of its assessments.[19]

Table 1. Average Cost Growth and Launch Delay of Major NASA Projects 2009–2012

Year	Average Development Cost Growth (millions)	Average Cost Growth (percent)	Average Launch Delay (months)
2009	$ 49.5	13	11
2010	$121.1	19	15
2011	$ 94.3	15	8
2012*	$314.8	47	11

* Excluding JWST, the figures become $79 million, 15 percent, and 8 months, respectively.

Source: NASA Office of Inspector General (OIG) analysis of GAO data

According to GAO, actual average cost growth was even greater than indicated in Table 1 because these figures do not capture cost growth that occurred prior to the point at which NASA established formal cost and schedule baselines in response to a 2005

[18] "A Budgetary Analysis of NASA's New Vision for Space Exploration," September 2004. Available at http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/57xx/doc5772/09-02-nasa.pdf (accessed August 24, 2012).

[19] The major projects GAO selects to assess may change from year to year.

statutory requirement.[20] In addition to requiring establishment of cost and schedule baselines, the statute also required NASA to report to Congress when a project's development cost is likely to exceed the baseline estimate by 15 percent or more or when a milestone is likely to slip by 6 months or more. GAO found that 13 projects for which NASA established baselines prior to 2009 experienced an average development cost growth of almost 55 percent, with a total increase in development costs of almost $2.5 billion from their original baselines.

In its 2012 assessment, GAO reported that the majority of the cost growth in NASA's portfolio was attributable to JWST, with the other projects in the assessment experiencing relatively modest cost growth.[21] Specifically, 14 of the 15 projects in the implementation phase at the time of GAO's assessment experienced average development cost growth of $79 million (15 percent) and schedule growth of 8 months from their baselines. When JWST was included in this calculation, the averages increased to almost 47 percent ($314.8 million) and 11 months, respectively.

Cost and schedule increases on large projects like JWST can have a cascading effect on NASA's entire portfolio. For example, the cost growth and schedule delays associated with JWST and MSL, which together account for approximately 51 percent or $11.4 billion of total life-cycle costs for the 15 projects in implementation included as part of GAO's 2012 assessment, led the Agency to postpone the next large astrophysics project recommended by the National Research Council and may lead to cancellation and reconfiguration of the Agency's other Mars exploration projects.

The OIG, GAO, NASA, and others have repeatedly cited several fundamental and interrelated factors that contribute to poor cost, schedule, and performance outcomes in NASA projects. These factors include inaccurate cost estimates, failure to define requirements adequately, and underestimating the complexity and maturity of technology. In 2009, NASA consolidated the results of 13 reviews and studies performed by the Agency, GAO, and the Rand Corporation between 1973 and 2006 in an effort to determine the reasons for cost growth in its projects. The Agency's analysis identified the 15 factors set forth in Table 2.

[20] National Aeronautics and Space Administration Authorization Act of 2005, Pub.L.No.109-155, 42 U.S.C. § 16613(b)(f)(4), "Baselines and Cost Controls."

[21] GAO, "NASA: Assessments of Selected Large-Scale Projects," (GAO-12-207SP, March 1, 2012).

Table 2. Reasons for Cost Growth in NASA Projects				
Cost Growth Reasons	**1970s**	**1980s**	**1990s**	**2000s**
Inadequate Definitions Prior to Agency Budget Decision and to External Commitments	X	X	X	X
Optimistic Cost Estimates/Estimating Errors	X	X	X	X
Inability to Execute Initial Schedule Baseline	X	X	X	X
Inadequate Risk Assessments	X	X	X	X
Higher Technical Complexity of Projects than Anticipated	X	X	X	X
Changes in Scope (Design/Content)	X	X	X	X
Inadequate Assessment of Impacts of Schedule Changes on Cost		X	X	X
Annual Funding Instability			X	X
Eroding In-House Technical Expertise			X	X
Poor Tracking of Contractor Requirements Against Plans			X	X
Launch Vehicle			X	
Reserve Position Adequacy		X		X
Lack of Probabilistic Estimating		X		X
"Go As You Can Afford" Approach				X
Lack of Formal Document for Recording Key Technical, Schedule, and Programmatic Assumptions				X

Source: NASA Advisory Council Meeting: Report of Audit and Finance Committee, Kennedy Space Center, February 5, 2009.

NASA's Efforts to Improve Acquisition Outcomes. Over the years, NASA has taken a variety of steps to improve the cost and schedule performance of its projects. In 2006, NASA revised its acquisition policies to emphasize the need to gather knowledge on the technical and development feasibility of a project and associated cost and schedule parameters before making commitments to long-terms investments. In addition, NASA codified its Systems Engineering Handbook into a new systems engineering requirements document. Taken together, the revised policies require projects to incorporate key reviews and decision points that serve as gates through which projects must pass before moving to the next stage in their life cycle. That same year, NASA also implemented Earned Value Management (EVM), an integrated management control system for assessing, understanding, and quantifying the technical progress achieved with project dollars. Used correctly, EVM can provide project management with objective, accurate, and timely data to support effective decision making. A March 2008 study by NASA's Science Mission Directorate found that projects using EVM experienced 19 percent growth in development costs compared to 31 percent growth for projects that did not use this tool.[22]

In 2007, the Agency implemented a management review process to monitor project performance including cost, schedule, and technical issues more effectively and took steps to strengthen the accuracy of its cost estimating. More recently, NASA implemented a new cost-estimating policy requiring a new analysis method, known as the Joint Cost and Schedule Confidence Level (JCL), that analyzes the probabilities that a project will be completed at a certain cost and within a certain schedule. It is intended to aid in project management and cost and schedule estimating by enabling the Agency to evaluate more accurately whether projects have an executable plan as they proceed into development. JCL considers all cost and schedule elements, incorporates and quantifies potential risks, assesses the impacts of cost and schedule to date, and addresses available annual resources to arrive at development cost and schedule estimates associated with various confidence levels. NASA policy requires that projects be budgeted at a level supporting a 70 percent probability that the project will be completed at or lower than estimated costs and on or before the projected schedule.[23]

Although all of these initiatives are positive steps toward achieving improved project management, their cumulative effect on project performance is not yet entirely clear.[24]

Changing National Space Policy. Many of NASA's major projects are the product of policy goals established at the national level by the President and Congress. Consequently, throughout its history the Agency's priorities have been subject to the vagaries of both domestic and international politics. For example, the Soviet Union's 1961 flight that put the first man in orbit around Earth spurred President Kennedy to challenge NASA to land a man on the moon by the end of the decade. This challenge and the resulting Apollo Program defined NASA's early years. In January 1972, President Nixon approved development of the Space Shuttle Program, a decision that influenced American space exploration efforts for the next 40 years. In January 2004, President George W. Bush put into motion a multi-decade effort known as the Constellation Program that was to follow the Space Shuttle Program and enable human exploration beyond low Earth orbit.[25] However, following significant cost and schedule overruns and an evaluation by a special committee, President Obama cancelled Constellation in February 2010.[26] In its place, the President called for development of a

[22] "SMD [Science Mission Directorate] Cost/Schedule Performance Study – Summary Overview," March 2008, available at http://www.lpi.usra.edu/pss/presentations/200806/16bruno.pdf (accessed April 2, 2012).

[23] NASA Policy Directive (NPD) 1000.5A, "Policy for NASA Acquisition" (Revalidated March 17, 2010).

[24] We plan to conduct additional audit work in the future to evaluate the implementation and effectiveness of these efforts.

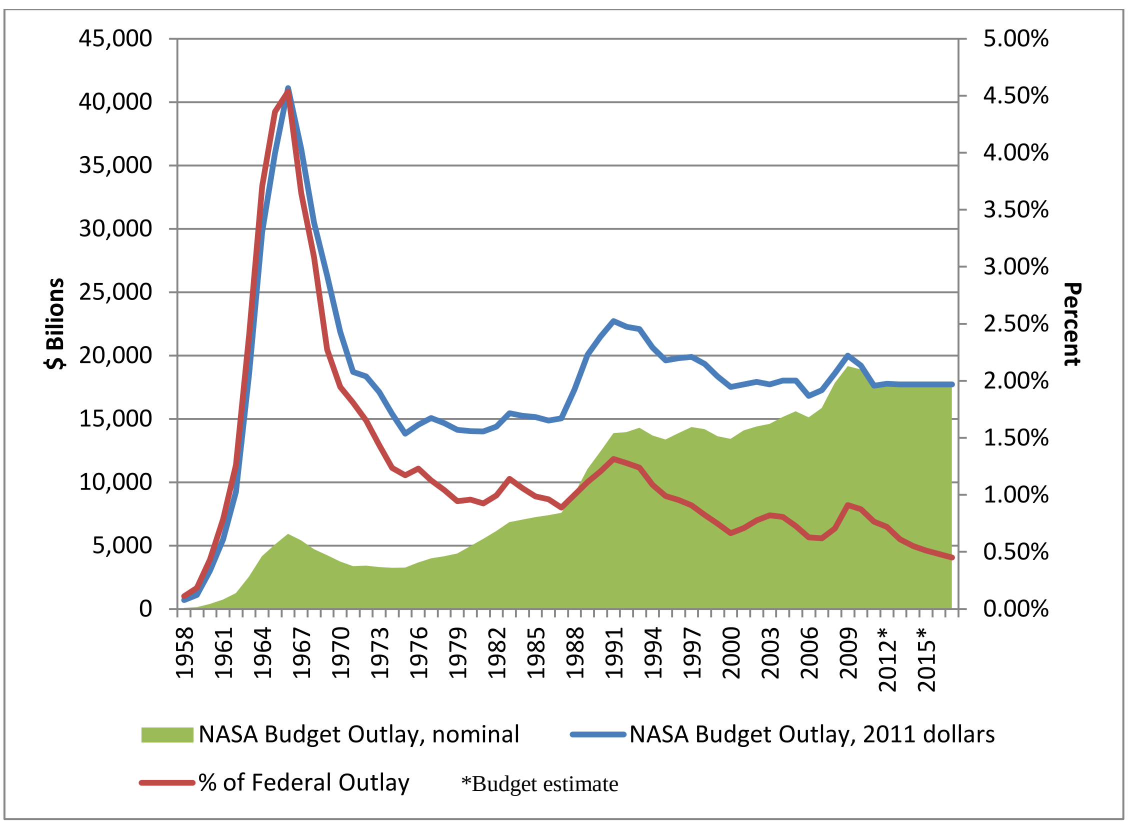
[25] The major components of the Constellation Program were the Ares I Crew Launch Vehicle, Ares V Cargo Launch Vehicle, Orion Crew Exploration Vehicle, and Altair Lunar Lander.

[26] Review of U.S. Human Spaceflight Plans Committee, "Seeking a Human Spaceflight Program Worthy of a Great Nation," October 2009. Available at http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf (accessed June 20, 2012).

new heavy-lift rocket to be ready for construction by 2015 with manned missions to Mars by the mid-2030s. The President's announcement generated extensive debate in Congress about NASA's space exploration goals and the next generation of space vehicles required to meet those goals. Over the next few months, proposals varied widely from preserving Constellation to rebuilding from the ground up a new generation of spaceflight vehicles enabling human space exploration beyond low Earth orbit. In October 2010, the NASA Authorization Act of 2010 confirmed cancellation of the Constellation Program but retained a number of the Program's components, including the Orion Multi-Purpose Crew Vehicle and the J-2X upper stage engine.

Challenging Fiscal Environment. NASA manages its portfolio of projects in a challenging and uncertain fiscal environment. After reaching a high in the late 1960s, NASA's budget has declined as a percentage of the overall Federal budget. As shown in Figure 5, fiscal year (FY) 1966 was the high-water mark for NASA when the Agency received $5.9 billion or 4.4 percent of the Federal budget. By comparison, NASA's FY 2012 funding of $18.2 billion represents only 0.5 percent of the total Federal budget. Similarly, when adjusted for inflation the Agency's annual funding has been on a nearly consistent downward trend for more than 20 years. As the President and the Congress work to reduce Federal spending and the country's budget deficit, NASA is likely to face constrained funding levels for the foreseeable future.

Figure 5. NASA Budget as a Percentage of the Federal Budget



Objectives

Our purpose in conducting this review was to gain a better understanding of the major challenges NASA project managers face in carrying out their duties. The core of our fact-finding consisted of interviews of 85 individuals both within and outside of NASA, including former and current Administrators, Deputy Administrators, Associate Administrators, Center Directors, and project managers and staff in an attempt to identify the “root causes” of NASA’s long-standing struggle to meet project cost, schedule, and performance goals. We plan to conduct additional work in the future to examine more closely the issues we identified and offer specific recommendations for management action. See Appendix A for details of our scope and methodology, our review of internal controls, and a list of prior coverage. See Appendix B for a list of the 85 individuals we interviewed.

CHALLENGES TO MEETING COST, SCHEDULE, AND PERFORMANCE GOALS

Multiple factors underlie NASA's historical inability to meet project cost, schedule, and performance goals. However, based on our interviews with more than 80 individuals involved in all levels of management and project development, we identified four factors that appear to present the greatest challenges to successful project outcomes. The first three are long-standing issues, while the fourth is of more recent origin:

- Culture of optimism.
- Underestimating technical complexity.
- Unstable funding.
- Project manager development.

Below we examine each of these challenges in turn.

NASA's Culture of Optimism Can Result in Unrealistic Projections

NASA does things that have never been done before. We do things that normal people wouldn't even try. We do things that are hard and we hire starry-eyed people.

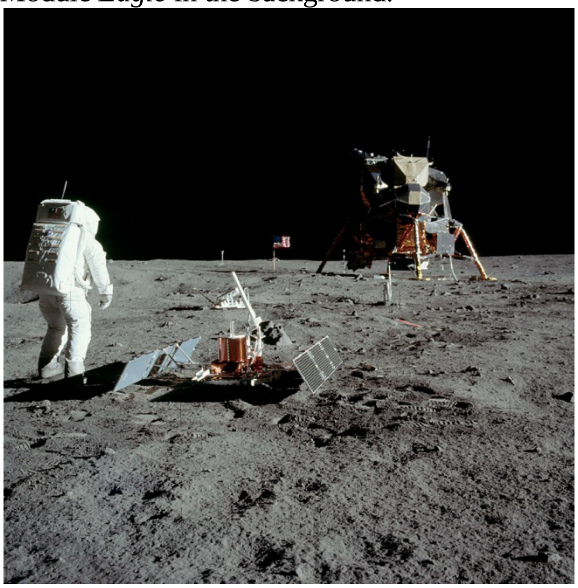
– NASA Project Manager

It was clear from our interviews that a culture of optimism and a can-do spirit permeate all levels of NASA, from senior management to front-line engineers. Although this optimistic organizational culture is essential for realizing groundbreaking scientific achievement, it can also lead to unrealistic projections about what can be achieved within approved budgets and timeframes. In addition, this culture has manifested itself in a tendency to view the success of projects primarily in technical rather than cost and schedule terms. More specifically, NASA's optimistic culture contributes to development of unrealistic plans and performance baselines that fail to account for all relevant risks.

NASA's Culture of Optimism Is Long Standing and Essential to Realizing Extraordinary Scientific Achievement. According to project managers, a culture of optimism is essential to overcoming the extraordinary technical challenges inherent in the development of unique first-of-their-kind space systems. For more than five decades, NASA programs have resulted in remarkable technological advances and scientific discoveries. This legacy has fostered a can-do attitude and a culture of optimism about achieving successful outcomes that permeates all levels of the Agency.

NASA's culture of optimism originated with and has been driven by one of the Agency's greatest achievements – landing the first human on the Moon (see Figure 6). NASA's ability to overcome the technological and scientific obstacles to accomplish this feat has become part of the Agency's culture and has helped foster a belief that NASA can do anything. In later years, this view was reinforced by missions like Voyager (launched in 1977 and still operating at the edges of our solar system), the Space Shuttle, the International Space Station (ISS), and the Hubble Space Telescope. More recently, NASA projects have produced evidence of what may have once been habitable environments on Mars and of the importance of dark matter and dark energy, as well as insights into the formation of black holes and the structure of the universe from its inception. Indeed, it was this can-do attitude that enabled NASA to bring the ailing Apollo 13 safely back to Earth and find a way to fix Hubble's mirror in orbit.

Figure 6. "Buzz" Aldrin on the Moon beside seismic experiment with Lunar Excursion Module *Eagle* in the background.



Source: NASA

In short, the optimistic and focused national goals of the Apollo Program, coupled with the Program's generous funding profile, set the foundation for an organizational culture that believes nothing is impossible despite significant technical hurdles and other challenges. Subsequent accomplishments and technological successes, at significantly greater costs than originally estimated, reaffirmed a mindset that project costs and adherence to schedule were secondary considerations to achieving operational success.

Unrestrained Optimism Can Exacerbate Cost, Schedule, and Performance Problems. Although optimism encourages innovation, it may also prevent leaders from making critical assessments of requirements, budgets, and schedules to determine what a project can realistically accomplish within a set budget and timetable. For example, NASA initiated the MSL mission soon after the successful development and landing of the Mars Exploration Rovers (MERs) Spirit and Opportunity.[27] Senior managers from the MER mission transitioned to MSL and managed the follow-on project under what they described as the "MER culture" of success. This attitude existed not only at the

[27] Spirit and Opportunity were launched in June and July 2003, respectively, and landed on Mars in January 2004.

project level but further up the supervisory chain at the program management level. Program officials told us that this attitude contributed to senior managers accepting the MSL Project's optimistic cost and schedule estimates and placing less credence on independent assessments that suggested the Project would need additional funds and more time to overcome technical challenges. Ultimately, the MSL Project missed its first launch window in 2009 and experienced a 2-year launch delay, which significantly contributed to development costs increasing from $969 million to $1.77 billion and the life-cycle costs increasing from $1.6 billion to $2.5 billion.[28]

From our discussions with senior NASA officials and project managers, we identified three related ways NASA's optimistic culture contributes to cost and schedule challenges: (1) measures of success that do not include cost and schedule factors; (2) establishment of unrealistic cost and schedule baselines; and (3) the expectation that additional funding will be made available if a project runs "short."

Measures of Project Success Do Not Include Cost and Schedule Factors. The Agency's long-standing culture of optimism has resulted in a mindset among NASA managers that emphasizes technological and operational success over cost and schedule fidelity. For example, when asked to define "project success," nearly all the project managers we interviewed responded that a project was successful if it achieved its technical performance goals. No manager mentioned controlling cost and schedule growth as significant measures of success. Moreover, all described their projects as successful even though many had experienced adverse cost and schedule outcomes.

This mindset has manifested itself in a lack of documented success criteria for cost and schedule performance in NASA projects. We reviewed seven project plans and found that while success criteria were clearly defined in terms of technical requirements, none contained any measures related to cost and schedule performance.[29] For example:

- The project plan for the Landsat Data Continuity Mission, a satellite designed to gather global land data and imagery for agricultural, education, business, science, and government uses, includes 17 mission success objectives relating to the type of data to be acquired and the duration of the satellite's mission life.

- The project plan for the Orbiting Carbon Observatory-2, a satellite designed to measure the amount of carbon dioxide in the atmosphere, measures success in terms of the frequency with which the satellite retrieves carbon dioxide estimates and the comparison of these estimates to other space-based and ground-based instruments.

[28] Due to planetary alignment, the optimal launch window for a mission to Mars occurs every 26 months. MSL was scheduled to launch in a window between September and October 2009. However, in February 2009, because of the late delivery of several critical components and instruments, NASA delayed the launch to November 2011.

[29] We reviewed plans for the following projects: Landsat Data Continuity Mission (LDCM), JWST, Mars Atmosphere and Volatile Evolution, Orbiting Carbon Observatory-2, Soil Moisture Active Passive, MSL, and Deep Impact Discovery Project.

- The success criteria for the MSL Project includes the ability to land and navigate on Mars, assess the biological environment and geology of the landing region, and investigate aspects of the planet's past habitability, as well as the Project's ability to archive the acquired data within 6 months of receipt on Earth.

- The Soil Moisture Active Passive mission will collect soil moisture and freeze/thaw measurements of Earth via satellite to enable climate models that predict future trends in water resource availability. The project plan states that the mission will be considered 100 percent successful if it launches into a near-polar sun-synchronous orbit, provides global space-based measurements of soil moisture, and records and validates that data.

To its credit, NASA has taken some steps to include cost and schedule factors in future missions' definition of success. In response to a 2007 GAO report highlighting NASA's lack of emphasis on cost controls and program outcomes, the Agency issued a Corrective Action Plan that established a definition of success for its portfolio of projects. Specifically, the Agency established that success would be defined as completing its portfolio of major development projects within 110 percent of the cost and schedule baseline and meeting Level 1 requirements for 90 percent of the major development projects.[30,31] NASA is hoping to meet this criteria by FY 2013.

However, NASA's definition and stated goals have not yet filtered into the project management culture. Consistent with the information gleaned from our interviews, a July 2011 study by The Aerospace Corporation found that mission success was the only criteria by which NASA project managers measured success.[32] The draft report, which has not been formally issued, encouraged NASA to address this imbalance by incentivizing project managers to deliver projects on-cost and on-schedule. While conceding that mission success will always be the primary criteria by which NASA will be judged, the authors argued that if cost and schedule performance are important to NASA, then that ideal must be made part of the Agency's culture. Ultimately, NASA and The Aerospace Corporation could not come to consensus on the recommendation due to concerns that providing incentives either as a reward or as punishment for adherence to cost and schedule metrics could negatively impact mission success.

Establishment of Unrealistic Cost and Schedule Baselines. NASA's culture of optimism appears to increase the difficulty of developing and maintaining realistic cost estimates. Many interviewees indicated that project managers and senior NASA leaders are often hesitant to admit they cannot achieve mission requirements within the funding profile provided. One area where this is especially prevalent is in the estimation of projects'

[30] GAO, "NASA Plan for Improvement in the GAO High-Risk Area of Contract Management," dated October 31, 2007, and updated through January 31, 2008.

[31] A Level 1 requirement is a project's fundamental and basic set of requirements levied by the Program or Headquarters on the project.

[32] The Aerospace Corporation, "Explanation of Change (EoC) Cost Growth Study Final Results and Recommendations," (Draft Report ATR-2011(5322)-1, July 1, 2011).

technical complexity. For example, NASA project managers are often overly optimistic about the effort required to mature critical technologies or obtain and modify heritage technologies – hardware, software, and systems developed for previous projects that are adapted for use on new projects – and underestimate the cost and schedule reserves needed to address known and unknown risks, optimistically assuming that most risks will not materialize. This can result in significant cost, schedule, and performance problems. As the National Resource Council noted in 2010:

> A project manager or principal investigator who is personally determined to control costs can be of great assistance in avoiding cost growth. People and organizations tend to optimize their behavior based on the environment in which they operate. Unfortunately, instead of motivating and rewarding vigilance in accurately predicting and controlling costs, the current system incentivizes overly optimistic expectations regarding cost and schedule. For example, competitive pressures encourage (overly) optimistic assessments of the cost and schedule impacts of addressing uncertainties and overcoming potential problems. As a result, initial cost estimates generally are quite optimistic, underestimating final costs by a sizable amount, and that optimism sometimes persists well into the development process.[33]

The history of cost reserve estimates for the MSL Project helps illustrate this point. Between 2002 and 2004, an independent cost assessment team issued eight reports analyzing a variety of different scenarios. In four of the reports, the assessment team questioned the reasonableness of the Project's 30 percent cost reserve, which was set in accordance with Jet Propulsion Laboratory (JPL) Project Guidelines, and indicated that a reserve level of 50 to 70 percent would be more prudent given the number of project participants, the complexity of the mission, the aggressive schedule, and the involvement of nuclear material. Similarly, another independent assessment conducted in 2006 as part of the Project's PDR recommended a $105 million increase to reserves to achieve a cost confidence level of 70 percent.

However, Project officials did not follow these recommendations and even cited the 30 percent reserve level as a positive attribute at the confirmation review. It was not until CDR in 2007 that managers admitted reserves were critically low, discordant with the Project's needs, and inadequate by $50–$100 million. NASA management subsequently increased the reserve levels and permitted the Project to pass CDR and move to the implementation phase while NASA's internal assessment team indicated that there was very little chance it would meet the planned launch date. Indeed, in 2009 the MSL Project, having exhausted its budget and reserves, missed the launch window and was forced to set a new launch date more than 2 years later that increased Project life-cycle costs by $900 million. Similarly, the JWST Independent Comprehensive Review Panel cited inadequate reserves and a failure to phase the reserves into the project when needed as contributing factors to cost increases and schedule delays experienced by JWST.

[33] National Resource Council, "Controlling Cost Growth of NASA Earth and Space Science Missions," 2010.

Expectation of Additional Funding. Many project managers we spoke with mentioned the "Hubble Psychology" – an expectation among NASA personnel that projects that fail to meet initial cost and schedule goals will receive additional funding and that subsequent scientific and technological success will overshadow budgetary and schedule problems.[34] Within days of its 1990 launch, Hubble was sending out-of-focus pictures back to Earth due to a flaw in the telescope's giant mirror. In a December 1993 repair mission, astronauts corrected the problem by adding a camera to the telescope. This and subsequent servicing missions extended Hubble's operational life (see Figure 7), but also added billions to the overall cost of the project. Nevertheless, as many of the individuals we interviewed noted, Hubble is now generally viewed as a national treasure and its initial cost and performance issues have largely been forgotten.[35] Based on the Hubble experience and that of other NASA projects, many interviewees expressed the belief that if a mission provides good science data, any previous cost and schedule overages will be forgiven.

Figure 7. Space Shuttle Atlantis' robotic arm lifts the refurbished Hubble Space Telescope from its cargo bay on May 19, 2009.

Source: NASA

To its credit, NASA has recently demonstrated an unwillingness to provide additional funds to allow an over budget project to proceed to implementation. The Gravity and Extreme Magnetism Small Explorer Project was intended to measure the polarization of X-rays emanating from black holes and neutron stars. Capped at $105 million in 2009, at confirmation review Project managers contended that they could complete the Project for $135 million. However, an independent cost estimate found that the Project was likely to cost $150 million and that its 2014 launch would be delayed due to development difficulties with its primary instrument. Consequently, in May 2012 NASA leadership made the decision to terminate the mission.

[34] While not attributable to a particular source or individual, the term "Hubble Psychology" is well known and used extensively throughout NASA.

[35] Hubble development was completed in 1985. However, because of the loss of Space Shuttle Challenger in January 1986, launch of the telescope was delayed until April 1990. Since then, five servicing missions have upgraded the telescope's scientific instruments and operational systems, the most recent in 2009 (see Figure 7).

Managing an Optimistic Culture. NASA's optimistic organizational culture is an essential element to achieving the Agency's highly complex missions. However, as discussed above, such a culture can also result in overly optimistic cost and schedule estimates and minimization of the importance of a project staying within cost and on schedule as measures of success. Nurturing NASA's optimistic culture while tempering the effects of over optimism on budget fidelity requires Agency leadership at all levels to review project requirements, budgets, and schedules with a critical eye and reward project managers who demonstrate keen attention to and stewardship of NASA's limited resources.

Underestimating Technical Complexity Increases Cost and Schedule Risk

We should never attempt to perform system designs until the project requirements have been fully developed and understood. . . . Only after the requirements have been developed in full should the designers be turned on to design to that known set of requirements.

– Comment Received on OIG Blog

Project managers we interviewed cited the technical complexity inherent in NASA projects as a major challenge to achieving cost and schedule goals. As many noted, predicting the problems a project may encounter when developing one-of-a-kind, first-of-their-kind technologies, instruments, and spacecraft, much less anticipating how much money will be needed to overcome those problems, presents extremely complex challenges. However, as discussed below, we believe NASA could take several actions to achieve more accurate cost estimates and help minimize cost growth in Agency projects.

Unique and Complex Technologies. In our judgment, five factors explain the inherently uncertain nature of estimating costs for the type of space technologies NASA develops: (1) unique, first-of-their-kind technologies; (2) interdependent technologies and complex integration issues; (3) increased testing needs; (4) limited quantities; and (5) shrinking industrial base and reduced quality of parts. A discussion of each of these factors follows.

Development of Unique, First-of-Their-Kind Technologies. For many non-NASA development efforts, historical data, cost models, lessons learned, and other information is readily available to help project managers estimate the effort that will be needed to develop necessary technologies. However, because NASA projects often involve technologies that are new and unique, project managers have significantly less information to draw upon in the planning and cost estimating stages of project development. This increases the complexity of developing accurate cost and schedule estimates for many NASA projects.

Interdependent Technologies and Complex Integration Issues. NASA projects often involve combining several technologies to accomplish novel missions. The complexity that may result from the interdependence of these technologies is often difficult to predict, and managers may consequently underestimate the effort required for successful integration.

Increased Testing Needs. Unlike land-based systems, many NASA missions and their associated instruments function remotely in space. Consequently, if something goes wrong the Agency cannot access them easily or at all to attempt repair. As a result, NASA performs extensive testing at great expense prior to launch to reduce risk and increase the likelihood that its technologies and projects will work as designed.

Limited Quantities. Because space systems are generally one-of-a-kind instruments, NASA cannot benefit from economies of scale.[36] In other commercial and government development efforts, for example fighter aircraft, producing higher quantities of the product causes the average cost of each product unit to fall. However, because NASA typically develops unique solutions to complex space challenges, the Agency cannot benefit from such savings.

Shrinking Industrial Base and Reduced Quality of Parts. Several project managers we spoke with told us they have observed a reduction in the availability and quality of contractor-supplied parts and instruments in recent years. They attributed this primarily to the overall consolidation of the space industry and the resulting reduction in competition. The managers explained that this decrease in quality has affected their ability to estimate project costs accurately because a part's poor quality may not be evident until testing has begun, resulting in the need for costly rework or seeking out alternative part suppliers late in development.

In addition to the Hubble example discussed previously, other examples illustrate NASA's tendency to underestimate the costs and level of effort required to develop its projects:

- To meet the science goals of the JWST mission, NASA needed a mirror 6.5 meters (21 feet 4 inches) in diameter that would work at -400 degrees Fahrenheit (see Figure 8). To protect the mirror from the sun and help it maintain this temperature, a sunshield composed of five membranes that could be folded and then unfurled to the size of a tennis court needed to be developed. In 2006, GAO reported that this technology and other associated cooling equipment and instrument development were immature.[37] Subsequently, the development of these technologies was much more difficult and took significantly longer to mature than anticipated.

[36] Economies of scale decrease cost per unit and increase efficiency as the number of units being produced increases.

[37] GAO, "NASA's James Webb Space Telescope: Knowledge-Based Acquisition Approach Key to Addressing Program Challenges," (GAO-06-634, July 14, 2006)

Figure 8. Six of the segments that will make up the primary mirror on JWST are shown completing cryogenic testing at Marshall Space Flight Center.

Source: NASA

- As we reported in June 2011, developmental testing for the National Polar-orbiting Operational Environmental Satellite System Preparatory Project identified technical issues and questions of workmanship that caused considerable retesting of several of the partner-provided instruments and directly contributed to the Project's $304 million cost increase and 5-year schedule delay.[38]

- Because of the size and mission requirements of the MSL rover, project managers had to develop an innovative method of safely landing and powering the vehicle. Previous Mars rovers Spirit and Opportunity used parachutes and airbags for landing and solar panels and rechargeable lithium-ion batteries for their power systems. In contrast, the spacecraft carrying the MSL's Curiosity rover first descended using a parachute and then rockets further slowed and guided the spacecraft before lowering the upright rover on a tether to the surface, much like a sky crane. Additionally, the rover has a radioisotope power system that generates electricity from the heat of plutonium's radioactive decay, which greatly extends the life of the vehicle but was never before incorporated on a planetary rover. Furthermore, MSL project managers had to review and test titanium parts after OIG investigators found that a supplier falsely certified that the material complied with required specifications. This problem required management to audit more than 1,000 hardware items resulting in the identification of 127 suspicious parts for further examination. The added oversight and mitigation resulted in additional cost to the already over-budget project.

[38] NASA OIG, "NASA's Management of the NPOESS Preparatory Project," (IG-11-018, June 2, 2011).

Managing Technical Complexity and Cost Uncertainty. We acknowledge that space development projects are technically complex and their development costs are difficult to assess at the start of implementation when NASA managers are required to establish costs and schedule estimates. Nonetheless, in our judgment few projects should proceed to implementation unless requirements are well-defined and stable and the available resources – mature technologies, realistic schedule, and adequate funding – are set. In addition, the project's critical technologies should be matured to the extent that a prototype that closely approximates form, fit, and function is demonstrated in a relevant environment.[39] Finally, adequate funding should be available to meet the project's requirements and account for its technical risks.

Over the years, the OIG, GAO, and others have reported extensively about the cost and schedule risks associated with projects that proceed to implementation with unproven technologies, inadequate funding, or unstable requirements. Collectively, those reports have identified measures that could help achieve more accurate cost estimates and minimize cost growth in NASA's projects, including: (1) maturing technologies prior to establishing baseline cost estimates; (2) appropriately funding management reserves to match technical risks; and (3) controlling changes to requirements. We discuss each of these issues in more detail below.

Maturing Technologies Prior to Establishing Baseline Cost Estimates. One factor that hinders project managers' ability to make accurate cost and schedule projections is the tendency for both internal and external stakeholders to underestimate the effort needed to complete a project – especially when establishing a project's initial cost baseline – in order to gain support and funding. According to interviewees, this can result from deliberately understated contractor proposals, Agency estimates scrubbed to fit a perceived "approvable" budget profile, efforts of commercial lobbyists, and pressure from Congress. In an address to the American Astronautical Society Goddard Symposium in March 2008, former NASA Administrator Griffin described the problem this way:

> [T]here have been many instances where proponents of individual missions have downplayed the technical difficulty and risk of their individual mission, or grossly underestimated the cost and effort involved to solve the problems, in order to gain "new start" funds for [a] particular project. Everyone knows that, once started, any given mission is nearly impossible to cancel, so the goal becomes that of getting started, no matter what has to be said or done to accomplish it.

According to some interviewees, the "buy-in" decision point – including the initial baseline cost estimate – should be commensurate with the level of project complexity. Specifically, interviewees noted that although it may be realistic for non-complex projects to establish a life-cycle cost estimate and schedule baseline at KDP C, complex projects may have too many unknowns to provide an accurate estimate at that point in the project's life cycle. In addition, as previously noted, interviewees said NASA historically

[39] For example, testing a representative model or prototype in a high-fidelity laboratory or in a simulated realistic environment.

exhibits a culture in which managers expect that additional funding will be provided for technically sound projects despite cost and schedule increases. As a result, some projects may proceed with unrealistic life-cycle cost estimates with the expectation that additional funds will be made available in the future.

NASA's Project Management Handbook discusses the poor outcomes associated with baseline cost estimates that do not match the technical complexity of a project:

> Unfortunately, on some projects both the cost and schedule are created and locked down before the technical scope is understood. This is backward and can lead to buy-in. Buy-in, in this context, is an overly optimistic estimate of cost and schedule used to try to ensure project initiation and funding. This type of buy-in could ultimately lead to either cancellation, because of insufficient resources, or the need for NASA to add resources to complete the project. The latter case will drain program resources and preclude or delay follow-on missions. This premature lockdown of cost and schedule prior to understanding the technical scope can also be imposed top-down by the program on the project. Neither is helpful.[40]

The practice of moving forward prematurely is not exclusive to NASA's large projects. Below are examples of both large and small projects with cost and schedule risks that moved into implementation with unproven technologies.

- A 2011 OIG report found that cost growth and schedule delays in the Advanced Radiation Instrumentation Project resulted from cost estimates and schedule milestones that were not supported by accurate and complete data.[41] Specifically, when the ISS Program approved the Project, it did not have a firm proposal from the contractor responsible for building one of the replacement instruments. When NASA received the proposal 7 months later, the cost of the instrument had nearly doubled from the baseline projection. Only after the Project's PDR did ISS Program management completely understand the scope of work required to deliver the replacement suite of radiation monitoring instruments, when the instruments realistically could be delivered, and how much they would cost. In the end, the suite of instruments was delivered 3 years late, cost $10 million more than the original $16 million estimate, and did not include all originally planned elements.

- MSL was allowed to proceed into the implementation phase with many key technologies, including motor actuators, avionics, and flight software, assessed as immature. The project required several design changes to address technical issues identified after the CDR of the propulsion system, including an electrical shorting of the pins on the avionics processor and a packaging issue that caused a disconnect between key components of the system. Because MSL officials identified the issue after the propulsion system was completed, the Project had to

[40] NPR 7120.5, "NASA Space Flight Program and Project Management Handbook," February 2010.

[41] NASA OIG, "A Review of NASA's Replacement of Radiation Monitoring Equipment on the International Space Station," (IG-11-027, September 29, 2011).

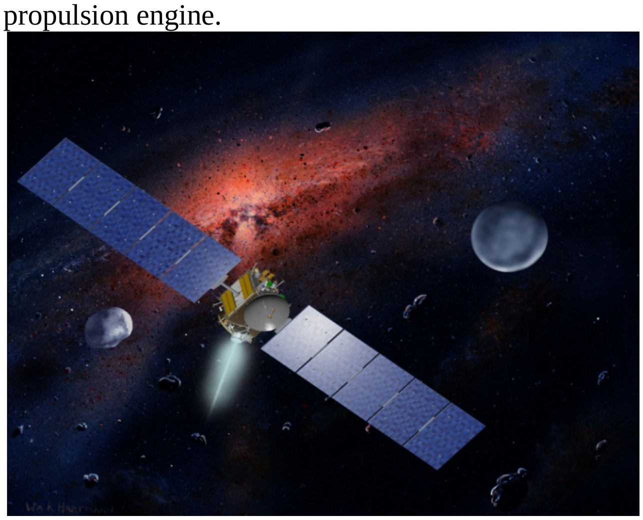
rebuild the propulsion system and adopt a new design, which in turn required rework and retesting of MSL's cruise and descent stages.

- One of Glory's main instruments – the Aerosol Polarimetry Sensor – was assessed as an immature critical technology at the PDR. Despite this fact, management approved the Project to proceed to the implementation phase. Subsequently, the Project experienced numerous issues with development of the sensor, resulting in more than a year's delay in delivery and a cost increase of over $100 million.[42]

The use of heritage technology frequently poses challenges for NASA projects. While the use of heritage technologies can reduce a project's development costs, the complexity associated with required modifications and problems with availability of components used on past projects are often underestimated, which can negatively impact a project's cost and schedule. Heritage technologies often require significant modification before they are suitable for integration into new projects. Moreover, suppliers of the heritage technology may have gone out of business or no longer be able to produce the needed technology because of personnel or other organizational changes. Below we discuss examples of projects that encountered difficulties using heritage technology.

- The goal of Dawn's robotic spacecraft is to study the early solar system by investigating two of the largest remaining asteroids, Vesta and Ceres, which are located between Mars and Jupiter. The Dawn Project planned to use the same ion propulsion system design successfully demonstrated by the Deep Space 1 mission, which operated between1998 and 2001.[43] However, the supplier that provided the ion thruster and the power processing units for Deep Space 1 no longer had the capability to produce the technology when it was needed for Dawn (see Figure 9). Consequently, the cost of these components rose nearly 100 percent from

Figure 9. Artist concept of Dawn using its ion propulsion engine.



Source: NASA

[42] Glory was lost in March 2011 when the fairing protecting the satellite failed to separate from the Taurus XL launch vehicle during ascent, causing the spacecraft to fail to reach orbit.

[43] NASA's Dawn mission was launched in September 2007 to rendezvous and investigate the asteroids Vesta and Ceres. The spacecraft arrived at Vesta in July 2011 and is scheduled to arrive at Ceres in February 2015.

the original estimate and the flight hardware was delivered 8 months later than scheduled.

- The Kepler Project was the first mission designed to look specifically for Earth-sized planets in the "habitable zone" around other stars. To accomplish this mission, Kepler was designed with the largest camera ever launched into space. Although the Project's technologies were considered heritage because they had flown on previous missions, adapting them to the requirements of the Kepler mission proved more difficult than anticipated and contributed to a $78 million cost overrun and 9-month schedule delay.

- The MSL Project relied on several heritage technologies that ultimately had to be redesigned, reengineered, or replaced for use on the Curiosity rover and spacecraft. For example, Project officials initially planned to use a heat shield composed of a lightweight material that had flown on previous missions. However, subsequent testing showed that this material was not suitable for MSL and the Project had to select a new, less mature technology, which resulted in approximately $30 million in cost growth and a 9-month delay in delivery of the heat shield.

Appropriately Funding Management Reserves to Match Technical Risk. Reserves are contingency funding "allocated to and managed by the Program/Project Manager for the resolution of problems normally encountered to mitigate risks while ensuring compliance to the specified program/project scope."[44] In essence, the purpose of reserves is to cover the expense associated with work that managers did not plan for at the beginning of the project but that will almost inevitably be needed due to the complexities inherent in developing spaceflight projects. The reserve percentage varies from project to project, but historically had been limited to 30 percent of a project's estimated overall development costs.[45] Interviewees indicated that many projects begin their life cycle with inadequate reserves so that when unanticipated problems arise the projects face cost overruns and schedule disruptions.

Some project managers we spoke with reported feeling constrained about setting reserve levels higher than 30 percent even when they believed that the complexity of the project required such action. For example, as previously discussed, MSL Project managers resisted raising reserve levels above the 30 percent mark set by JPL Project Guidelines despite several independent cost assessments that recommended reserve levels of 50 to 70 percent of estimated development costs. In fact, NASA managers commented at the

---

[44] 2008 NASA Cost Estimating Handbook, available at http://www.nasa.gov/pdf/263676main_2008-NASA-Cost-Handbook-FINAL_v6.pdf (accessed August 20, 2012).

[45] In 2007, reserve levels began to be based on the amount needed to achieve 70 percent cost confidence rather than a set percentage. This requirement was further refined in 2009 with the introduction of JCL policy, which required reserves, now referred to as Unallocated Future Expenses, adequate to achieve a cost and schedule confidence of 70 percent.

Confirmation Review that establishing reserve levels above 50 percent would appear to be a vote of no confidence in the Project.[46]

Controlling Changes to Requirements. Interviewees cited scope and requirements "creep" as another serious challenge to the ability of project managers to meet cost estimates. "Creep" occurs when engineers develop instrument functionality or robustness greater than the original requirements to increase a system's technical capabilities. The additional work and associated costs can cause a project to exceed its life-cycle cost estimate. Although technology enhancements or increased technical capabilities may provide for a more robust mission, they often come at a significant cost. For example, the Science Mission Directorate added a new design requirement to the MSL at the Project's CDR – the life-cycle stage at which projects should be demonstrating that all requirements have been met and the overall design is mature, stable, and ready for production. The requirement, a sample cache to collect rocks for a future sample return mission, was eventually dropped but not before adding $2 million to an already over-budget project.

Similarly, changing requirements during development can have a negative impact on a project's cost and schedule. For example, as we reported in September 2009, NASA removed but then reinstated after the contract had been signed a requirement for a legacy thermal infrared imaging capability on the Landsat Data Continuity Mission (see Figure 10).[47] This caused cost increases and further delays to the project.

Figure 10. The Thermal Infrared Sensor arrives at the contractor for integration on the spacecraft in February 2012.

Source: NASA

[46] The Science Mission Directorate uses Confirmation Reviews or Confirmation Readiness Reviews to present project readiness status, PDR findings, and a recommendation for project progression to implementation.

[47] NASA OIG, "The Landsat Program Is Not Meeting the Goals and Intent of the Land Remote Sensing Policy Act of 1992" (IG-09-021, September 2, 2009).

Funding Instability Can Lead to Inefficient Management Practices

NASA needs to set reasonable goals and prepare for the contingency that we will not receive the requested funding in the out years. We need to create a doable schedule for projects and then meet it.

– Comment Received on OIG Blog

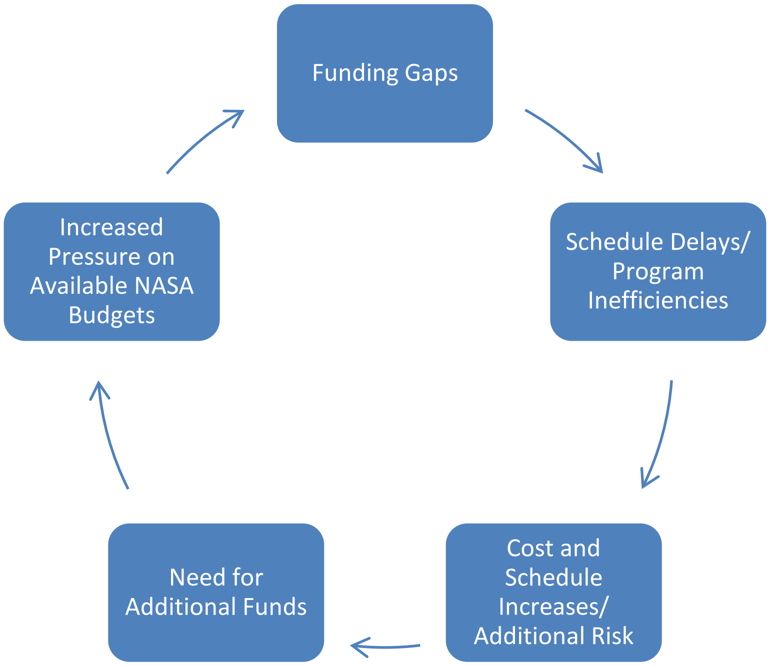
Nearly 75 percent of the individuals we interviewed cited funding instability as among the most significant challenges to project management at NASA.[48] Funding instability includes situations in which a project receives less money than planned or funds are disbursed on a schedule different than planned. Such instability can cause management to delay work and consequently development risks may be identified later in the project's life cycle, which in turn can lead to cost increases and schedule delays. Interviewees noted that funding instability may result from presidential, congressional, or Agency-directed actions.

Inefficient Management Practices. According to interviewees, funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes. In general, managers may be forced to invest time and effort re-planning tasks to fit unexpected funding profiles, deferring critical tasks to later phases of development, or de-scoping or discontinuing lower priority tasks to keep project costs within the revised budget profile. When it occurs in the early phases of a project, inadequate funding decreases management's ability to identify and address key risks. For example, when planned funding does not materialize, project managers may defer development of critical technologies to a time when integration of those technologies may be more difficult or when the cost of material and labor may be greater. For example, the JWST Independent Cost Review Panel noted that deferred work on that Project cost two to three times more than original estimates. In addition, shifting tasks to later project phases may require mangers to sustain a workforce longer than originally planned or add shifts in an attempt to make up for lost time, both of which can lead to increased costs. Furthermore, as some tasks are contingent on completion of other deliverables, shifting tasks to later phases can have a cascading effect on a project's master schedule resulting in even higher costs.

As illustrated in Figure 11, funding instability can create a cycle of perpetual funding shortfalls by triggering schedule delays and program inefficiencies, which in turn lead to additional cost increases and greater risks.

[48] In addition, nearly 18 percent of blog submissions collected for this report cited funding stability as a challenge to project management.

Figure 11. Cycle of Funding Instability



Moreover, shortfalls in high-priority projects may lead to cuts in other projects when the Agency diverts funds from those projects to the higher-priority projects. For example, NASA leadership took funds from the budgets of other programs and projects to cover cost overruns and schedule delays in the Constellation Program, JWST, and MSL. This reactive approach exacerbates NASA's funding challenges and puts further strains on budgets across the Agency.

A comment we received on our blog captured the nature of this challenge:

> The single biggest challenge to managing a project at NASA is budget uncertainty. A project develops a budget to successfully accomplish the implementation of the project and, invariably, through the review process that budget is deemed unaffordable and [the] project is challenged to succeed with less. A typical approach is for the project to be cut in the near years with the cuts replenished in the out years causing the funding profile to be back loaded - the very thing it should not be. Starved for resource[s] early, the project is left to make inefficient decisions – take on technical risks or defer work - that will come home to roost later. On top of that is the annual uncertainty of budget approval - both in amount of budget and timing of approval – so at each fiscal year boundary the project is force[d] to consider changes to their plan that will impact efficient execution of their plan. After a few years the plan the project is executing on looks nothing like the plan – schedule and budget wise – the project embarked on at the beginning. Some of that change can be considered driven by internal events like technologies not panning out as planned, parts issues, etc. but the bulk of it is driven by external forces altering their budget.

Sources of Funding Instability. Interviewees noted that funding instability originates primarily from two sources: external decisions made by the President and Congress and internal decisions made within the Agency. Differing priorities advanced by different Administrations, the back-and-forth compromise inherent in the legislative process, and significant delays in enacting an annual budget affect the amounts of funding NASA receives each fiscal year and when those funds are available. Internally, funds may be disbursed to projects later than planned in a project's life cycle (phasing), the amount of funds disbursed to the projects can be less than the budgeted amount, or projects may be required to make across-the-board reductions so that funds can be shifted to other troubled projects.

External Decisions Made by the President and Congress. According to interviewees, shifting space policy priorities from the President and Congress and the vagaries of the annual appropriations process present major challenges to project management at NASA.[49]

Shifting Space Policy Priorities. Like all Federal agencies, NASA's priorities are subject to change based on the election cycle. However, because NASA projects are typically developed and executed over multiple years, the Agency is particularly sensitive to abrupt changes in its agenda. As the Advisory Committee on the Future of the U.S. Space Program noted:

> Clearly, any program that involves goals demanding 5, 10 or even 30 years for their achievement must enjoy a solid underpinning of broad, enduring support. The alternative is to suffer through a prolonged sequence of projects that are started, stopped, and restarted, only to be modified again and again.[50]

This dilemma is no more apparent than in the twist and turns of NASA's effort to develop a follow-on program to the Space Shuttle. In 2004, President George W. Bush directed NASA to retire the Shuttle and develop spacecraft and launch vehicles to return humans to the Moon by 2020, with the eventual goal of landing on Mars. However, the resulting Constellation Program experienced technical and budgetary issues that resulted in significant cost and schedule overruns. Shortly after President Obama took office in 2009, a special committee found that NASA's plans for human exploration beyond low Earth orbit were "not viable" under the existing funding profile and that major components of the Constellation Program would be significantly delayed. Based on the committee's findings, President Obama cancelled Constellation and proposed a space policy that emphasized the use of commercial companies to provide transportation to low Earth orbit and stressed investment in technologies to enable future human exploration of

[49] If an agency's annual appropriation has not been enacted by the start of the fiscal year, Congress often passes a series of stop-gap funding bills known as "continuing resolutions" to fund agencies for several weeks or months, generally at the same level as the previous year. Continuing resolutions must be passed by both houses of Congress and signed by the President.

[50] Report of the Advisory Committee on the Future of the U.S. Space Program, December 17, 1990, http://history.nasa.gov/augustine/racfup1.htm (accessed August 20, 2012).

space beyond Earth's orbit. The policy did not include plans for NASA to develop a heavy-lift rocket in the near term.

Some members of Congress disagreed with the President's proposal and inserted language in an appropriation bill that prevented NASA from terminating Constellation-related contracts without congressional approval. Congress and the President reached a compromise in October 2010 with the enactment of an Authorization Act that gave NASA the go-ahead to terminate Constellation but preserved some of the Program's major components in the form of a heavy-lift architecture and a multi-purpose crew vehicle (see Figure 12) to take astronauts beyond low Earth orbit.

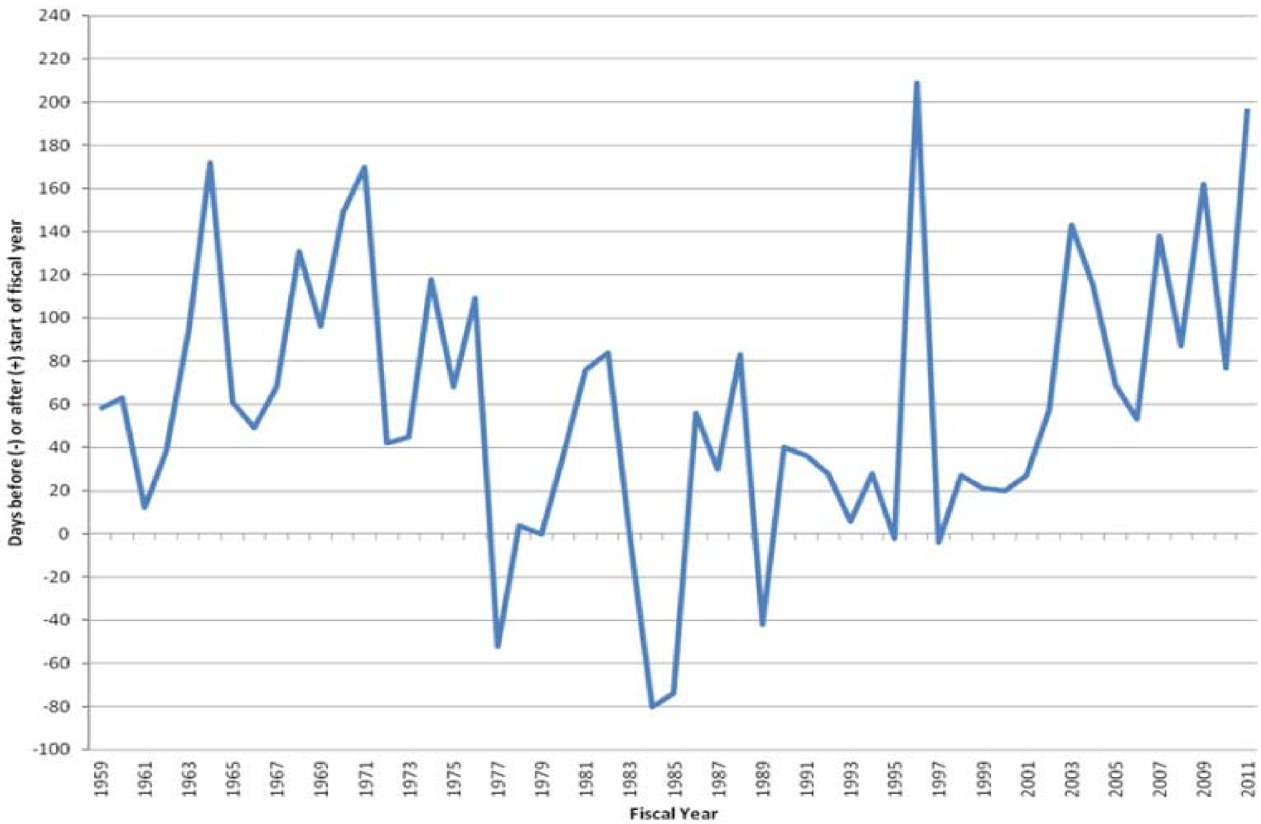
Figure 12. The Orion Multi-Purpose Crew Vehicle being assembled and tested at a Lockheed Martin's facility in Colorado.

Source: NASA

Even after enactment of this legislation, the Administration and Congress continued to debate the relative funding levels and priority that should be given to the heavy-lift program versus NASA's efforts to develop a commercial space transportation capability. For example, NASA's 2012 appropriation contained $406 million to develop a commercial crew transportation capability, less than half the $850 million the Agency had requested. As a result, NASA revised its commercial crew acquisition strategy and announced that there would be a 2-year delay in the operational deployment of the capability.

Continuing Resolutions. Since its creation in 1959, NASA has received its annual appropriation at the start of the new fiscal year only seven times (see Figure 13). Most years the Agency has operated under weeks- or months-long continuing resolutions that generally set funding at the prior year's level.

Figure 13. Enactment of NASA Appropriations



According to interviewees, starting the fiscal year without an approved budget can have both immediate and long-term repercussions for NASA projects. First, when a project that was counting on increased funding to accomplish planned tasks is held to the previous year's funding levels, work may be delayed, which can affect the project's ability to stay on cost and schedule.

Second, continuing resolutions may carry forward language from previous years' appropriations that limit the Agency's ability to make necessary program changes. For example, as previously discussed, a series of continuing resolutions in FY 2011 perpetuated a restriction in NASA's 2010 appropriations law that prevented the Agency from cancelling the Constellation Program or terminating related contracts. In a January 2011 letter to Congress, the OIG noted that due to this restriction NASA was spending $215 million on Constellation projects that the Agency would otherwise have considered cancelling or significantly scaling back.

Third, when operating under continuing resolutions NASA cannot begin new projects. In December 2010 testimony before the Senate Committee on Commerce, Science and Transportation, NASA's Chief Financial Officer discussed the challenges NASA faced while operating under a continuing resolution as it attempted to set a new path following cancellation of the Constellation Program.[51] In addition, she noted that NASA and the Department of Energy could not fund the restart of Plutonium-238 production and identified projects in the Chief Technologist's Office and the Aeronautics Research Mission Directorate whose schedules were negatively impacted by continuing resolution limitations.[52]

Internal Decisions Made Within the Agency. While external factors contribute to funding instability, according to many interviewees internal Agency decisions also play an important role. Within the confines set by the Agency's annual appropriation laws, NASA managers decide when and how resources are dispensed. Agency decisions to withhold or delay funding from certain projects often force project managers to push key project tasks to the future, which can lead to schedule delays and cost increases.

Receiving Less Funding than Requested. If a project receives less money than expected, managers must adapt to the more restrictive funding profile and re-plan work. This may mean moving tasks – such as maturing critical technologies and reducing other risks – into the future. As previously discussed, delaying such tasks may mean that project personnel do not identify significant technical and development challenges until later in the project's life cycle, which can lead to cost and schedule increases.

Kepler is an example of a project that suffered cost increases and schedule delays due to internal NASA funding decisions. NASA management cut $35 million from the Kepler Project's FY 2005 budget, forcing the cessation of significant work, interrupting the overall flow and scheduling for staff and production, and requiring a renegotiation of contracts. This 1-year funding shortfall contributed to an overall 20-month delay in the Project's schedule and about $169 million in cost growth. Furthermore, to accommodate these increases NASA took money from the Wide-Field Infrared Survey Explorer Project, which caused cost increases and schedule delays in that Project – an effect discussed in further detail below.

In addition to receiving an adequate overall amount of funding, projects are also dependent on receiving funding at the right times during the project's life cycle. If funding profiles are not synchronized with the required work effort, projects can suffer cost growth. Specifically, predictable phasing and receipt of funds can help managers direct projects more effectively by optimizing staff schedules, enabling better management of funds to cover obligations, and enhancing the ability to track remaining margins and reserves more accurately.

[51] "Statement of Elizabeth M. Robinson, Chief Financial Officer, National Aeronautics and Space Administration, before the Committee on Commerce, Science and Transportation, United States Senate," December 1, 2010. Available at http://www.nasa.gov/pdf/503001main_NASA%20testimony%20for%20SCST%20hearing%20on%2012-1%20FINAL%20(11-30-10).pdf (accessed August 20, 2012).

[52] Plutonium-238 is used as a fuel to power electrical systems on NASA missions when solar power is not practical, such as for the MSL or missions to the outer planets.

Conversely, unpredictable phasing and receipt of funds can lead to inefficiencies. As previously noted, unstable funding may make it difficult for a project to obtain sufficient resources to address technological issues in the early project phases. Furthermore, to maintain continued operations with limited funding, project managers are sometimes forced to shift tasks to later project phases, which may mask cost impacts and increase risk.

For example, an unstable funding stream has extended the development schedule of the Capsule Parachute Assembly System Project associated with the Orion space capsule (see Figure 14). The Project's FY 2011–FY 2013 test plan included high altitude parachute deployment testing to validate models and parachute loads. However, because the adjusted FY 2012 budget could not support these tests, they had to be deferred and replaced with lower altitude parachute deployment tests. Although the lower altitude tests were necessary, this change in test sequencing means that the Project will need to repeat several of the lower altitude tests once the high altitude tests are completed. Although it is difficult to determine at this point the effect this will have on cost, it is clear that the Project lost the efficiency of performing the tests in the preferred sequence and that managers will have to repeat some testing later in the development cycle.

Figure 14. Test of Orion's parachute assembly system following release from an Air Force C-17 cargo plane on February 29, 2012.

Source: NASA

Across-the-Board Cuts to Help Troubled High-Priority Projects. Interviewees stated that when highly visible flagship missions like the Constellation Program or JWST experience cost growth, NASA leadership often takes funds from the budgets of other missions to cover those increased costs. This not only makes it difficult for project managers to manage their projects, but also has a ripple effect that increases the difficulty of managing the Agency's overall portfolio. A former NASA official commented that paying for overruns on poorly run projects by cutting back or delaying projects that stayed within their budgets effectively penalizes the projects that performed well from a budget perspective.

For example, while still in the formulation phase NASA reduced the Global Precipitation Measurement (GPM) Project's budget by approximately $270 million from what was planned for FYs 2005 through 2008 to accomplish other goals in the President's Vision for Space Exploration.[53,54] As illustrated in Table 3, as a result of these funding cuts the acquisition cycle for GPM increased, which in turn caused a 3-year launch delay and cost growth in excess of 50 percent for one of the Project's primary instruments.

Table 3: GPM Budget and Launch Date Changes Due to Budget Reductions (dollars in millions)			
Program Operating Plan Year	**FY 2004 President's Budget Submission**	**Final Approved FY Funding**	**Estimated Launch Date**
FY 2005	$44.2	$29.1	June 2010
FY 2006	$99.3	$24.7	December 2012
FY 2007	$155.9	$28.8	June 2013
FY 2008	$143.8	$89.7	June 2013
FY 2005–2008 Total	**$443.2**	**$172.3**	**3-year launch delay**

Similarly, in FY 2012 NASA moved $156 million from other projects within the Science Mission Directorate and from the Cross-Agency Support account to cover significant life-cycle cost increases in the JWST Project.[55] Other missions, such as the Wide-Field Infrared Survey Telescope, have been postponed to make funding available for JWST.[56] In another example, NASA announced in 2012 that it was pulling out of an agreement with the European Space Agency on two future Mars missions and planned to reevaluate its Mars exploration strategy to accommodate a more restricted funding profile.

Managing Funding Instability. Whatever its origin, lack of stable funding creates inefficiencies and makes it more difficult for project managers to effectively manage the cost, schedule, and performance risks of their projects. However, funding instability has been a long-standing feature of the Federal budget and Agency processes, and given the current constrained fiscal environment is likely to become even more common in the future. Furthermore, interviewees noted that the Agency itself sometimes underestimates the cost and schedule needed to complete a project in order to gain initial support and funding.

[53] The Vision for Space Exploration was a plan announced in 2004 by President Bush in the aftermath of the Space Shuttle Columbia disaster. Under the plan, NASA returned the Space Shuttles to flight to complete construction of the International Space Station, retired the Space Shuttle Program, and then began developing the next generation of crew transportation vehicles for exploration of the Moon and Mars.

[54] NASA initiated the GPM mission in 2001 to build upon the success of the Tropical Rainfall Measuring Mission and provide more accurate measurements of global precipitation. The GPM Project has undergone changes in scope and in October 2011, due to instrument development issues NASA re-planned the mission with a launch in June 2014.

[55] The total amount was split evenly between the Science Mission Directorate and Cross-Agency Support. NASA's Cross-Agency Support funds the operation and administration of Agency-wide services such as human capital management, security, and maintenance of real property assets that cannot be directly aligned to a specific program or project requirement.

[56] The Wide-Field Infrared Survey Telescope is a NASA observatory designed to settle essential questions in both exoplanet and dark energy research.

Given these issues, we believe that NASA management should increase efforts to determine the extent to which funding instability impacts NASA projects and to clarify the cause and effect relationship between funding instability and project cost increases, schedule delays, and performance problems. In our judgment, squarely addressing these issues would facilitate development of effective risk mitigation plans for managing fiscal disruptions in NASA projects. In the absence of effective risk mitigation plans, unstable funding will likely continue to be a disruptive feature of project management.

Project Manager Development Opportunities Are Limited

NASA does too few development programs to get people the acquisition experience they need.

– Comment Received on OIG Blog

Interviewees identified a number of emerging issues that could affect NASA's ability to manage its projects in the future effectively. First, they stated that the limited number of small and mid-size projects in NASA's current portfolio allows too few opportunities for Agency personnel to gain experience managing a project's cost, schedule, and technical performance efforts. For example, Explorer and Discovery missions provide less experienced project managers the opportunity to lead smaller, lower risk, cost-capped missions.[57] However, the Agency has sponsored fewer of these missions and spaced them farther apart than originally planned. Second, the interviewees expressed concern that an increased reliance on contractors to design and build projects has led to a decline in Agency personnel with development experience. Finally, interviewees stated that NASA engineers are primarily operating as overseers of work performed by contractors rather than gaining experience building instruments and spacecraft in-house. As a result, interviewees fear NASA will have an insufficient number of experienced project managers in the future to effectively manage the Agency's high-priority projects.

Project Management Development. Agency officials described the role of project manager as one of the most difficult jobs at NASA. One summarized the needed skill set as requiring the aptitude of a politician and the experience, discipline, and insight to know when to ask those with more experience for help. Interviewees cited attributes such as technical expertise, leadership skills, interpersonal skills, integrity, experience, an understanding of the budget process, and both a programmatic and institutional knowledge base as essential elements for a project manager. Additionally, Agency officials said project managers must have a good balance of cost, schedule, and technical knowledge to make informed decisions when these priorities are in conflict.

[57] Explorer missions are small to medium-sized science missions costing up to $180 million, including launch vehicle costs, that are capable of being built, tested, and launched in a relatively short time interval. Discovery missions are planetary science missions with total costs not to exceed $425 million, excluding launch vehicle costs.

We found that most of NASA's current project managers are seasoned professionals: 80 percent of the project managers interviewed had over 20 years of project management experience and 78 percent were formally certified as project managers. Most project managers and senior officials we spoke with commented that experience and on-the-job training more than formal training are key attributes to enabling personnel to manage the cost, schedule, and performance goals of a NASA project successfully. One project manager noted that "taking classes will give you the tools, but where you really learn is listening to guys – men and women – talk about their experiences, and how they overcame their issues; what worked and what didn't." Project managers also commented on the value of mentoring, noting that it was the most important part of their professional development. Eighty-three percent of the project managers we interviewed said they were mentored either through NASA's formal mentoring program or informally as they progressed through their careers.

Reduced Number of Small Missions. Interviewees expressed concern that as the number of large flagship missions has increased over the years, NASA no longer has enough small missions to provide a training ground for new project managers. In 2006 the National Research Council reported on this issue, stating that NASA's imbalance of small and large science projects would have significant impacts on the ability of the Agency to meet its science mission goals.[58]

Project managers said the decline in the number of small development projects deprives NASA of an important pipeline to train new and rising project managers. Specifically, managers described NASA's small projects as invaluable training grounds for developing management skills and learning the key elements of project management, such as understanding and managing cost, schedule, and performance elements and making appropriate trade-offs among these elements when necessary. For example, a project manager for JWST began his career with NASA in 1979 serving as a team member on the Hubble Space Telescope Project. After Hubble, he became the project manager for the Solar Radiation and Climate Experiment and later the project manager for the Landsat Data Continuity Mission prior to becoming the project manager for JWST.[59] Although project managers receive training and project management certification, interviewees raised a concern that without these smaller projects to develop essential project management skills NASA managers will not be adequately equipped to effectively manage larger and more complex projects in the future.

Loss of In-House Development Personnel. Interviewees also expressed concern about a lack of personnel with development experience. Some expressed the view that as NASA has increasingly relied on contractors to support project development, the Agency's in-house technical capabilities have declined. To this point, a project manager at Kennedy Space Center noted that there were people with development experience on

[58] National Research Council, "An Assessment of Balance in NASA's Science Programs," 2006.

[59] The Solar Radiation and Climate Experiment, launched on January 25, 2003, provides measurements of incoming X-ray, ultraviolet, visible, near-infrared, and total solar radiation.

Apollo who transitioned to the Shuttle Program, but after 30 years of Shuttle operations there is nobody with development experience left at the Agency to work on the next generation of spaceflight vehicles.

In addition, interviewees indicated that the skills necessary to manage a project during its formulation and development are very different from the skills needed to manage an operational project. Several Center Directors noted that it is a common practice to change managers when a project transitions from formulation to implementation.

Interviewees also expressed concern that because NASA contracts out the majority of its hardware and software development efforts to private industry, NASA engineers spend most of their time overseeing contractor efforts rather than building space flight components and systems themselves. While much of the Agency's hardware and software development has always been contracted to private industry, interviewees expressed the opinion that the proportion of work being performed by private industry is becoming increasingly unbalanced. These interviewees believe that as a result NASA engineers have limited opportunities to gain practical hands-on experience.

Finally, some interviewees stated they fear that NASA will not be able to attract and retain recent graduates or experienced engineers who are seeking opportunities to design and build hardware and software and integrate systems. Instead, these individuals will choose positions in private industry, and as experienced engineers retire, NASA will lose this core capability.

Conclusion: Strong Leadership Required to Accomplish Meaningful Change

Over the years, NASA has made significant achievements exploring space, helping understand Earth's environment, and conducting fundamental research in aeronautics disciplines. However, consistently managing the Agency's science and space exploration projects to meet cost, schedule, and performance goals remains elusive. Given the anticipated funding challenges likely for all Federal agencies in the years ahead, changes to the way NASA develops and manages its projects are imperative. At the same time, the Agency is undergoing considerable changes in mission focus, with the end of the Space Shuttle Program and the first steps on a new path toward human space exploration. Collectively, these factors both necessitate and provide an opportunity for the Agency to reset itself and take positive steps toward meaningful change in the way its projects are developed and managed.

To its credit, NASA has taken several steps in the last few years aimed at curbing cost growth and schedule delays. For example, the Agency has implemented new policies requiring probabilistic cost and schedule analysis that produces a Joint Cost and Schedule Confidence Level (JCL) to assist managers with cost and schedule estimating while enabling the Agency to evaluate more accurately whether projects have an executable plan as they proceed into implementation. NASA believes that this focus on probabilistic analysis has helped projects such as the Gravity Recovery and Interior Laboratory, Juno, and the Mars Atmosphere and Volatile Evolution meet cost and schedule goals.[60] Furthermore, in response to a 2007 GAO report highlighting NASA's lack of emphasis on cost controls and program outcomes, the Agency issued a Corrective Action Plan that established a definition of success that includes completing all development projects within 110 percent of the cost and schedule baseline and meeting Level 1 requirements for 90 percent of the major development projects in its portfolio.[61,62] NASA is hoping to achieve the Corrective Action Plan's criteria for success by FY 2013 by implementing the policies and processes on new projects while tracking and reporting the measures for existing projects.[63]

Moreover, NASA's new program and project management policy requires that project plans document baseline and threshold values for the performance metrics to be achieved at each key decision point (KDP) and mission success criteria associated with the program-level requirements that, if not met, trigger consideration of a Termination Review.[64] Further, project plans are required to document how the project will periodically report cost and schedule performance and provide a mitigation and corrective action plan in the event the project exceeds development cost estimates. Recently, NASA seems to be holding project managers more accountable for meeting cost cap agreements as evidenced by its decision in May 2012 to cancel the Gravity and Extreme Magnetism Small Explorer mission because development costs were likely to exceed the project's agreed-upon budget.

In our judgment, meeting the challenges outlined in this report can only be realized through a "unity of effort" that includes strong, consistent, and sustained leadership by the President, Congress, and NASA management. Clear and consistent leadership from the President and Congress is an essential first step toward ensuring that project managers are positioned to complete projects within cost, schedule, and performance estimates. Articulating a clear, unified, and sustaining vision for the Agency and providing the necessary resources to execute that vision is a critical cornerstone of success.

For their part, NASA leaders must temper the Agency's historic culture of optimism by requiring realistic cost and schedule estimates, well-defined and stable requirements, and

[60] The Gravity Recovery and Interior Laboratory mission launched on September 10, 2011, to study the Moon's interior. Juno launched on August 5, 2011, to investigate the structure and history of Jupiter and is scheduled to arrive at the planet in July 2016. The Mars Atmosphere and Volatile Evolution mission is scheduled to launch in late 2013 to investigate the Martian atmosphere.

[61] GAO, "NASA Plan for Improvement in the GAO High-Risk Area of Contract Management," dated October 31, 2007, and updated through January 31, 2008.

[62] A Level 1 requirement is a project's fundamental and basic set of requirements levied by the Program or Headquarters on the project.

[63] NASA's current set of major development projects were all underway prior to implementation of the Corrective Action Plan. These projects will gradually be completed (NASA's typical timeline for development is 4 years) and replaced with projects that will be fully subject to the Plan.

[64] NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012.

mature technologies early in project development. In addition, they must ensure that funding is adequate and properly phased and that funding instability is identified as a risk and accounted for in risk mitigation strategies. Finally, they must be willing to take remedial action – up to and including termination – when these critical project elements are not present.

Although technological innovation and mission success as defined by scientific advancement and discovery are central to NASA's core existence, an appropriate balance needs to be struck that also recognizes the importance of meeting project cost and schedule goals. Accordingly, we believe that NASA needs to find ways to reward managers for good stewardship of NASA's resources as enthusiastically as it does for successful technological achievements. Likewise, NASA leadership should hold managers appropriately accountable for mismanagement of resources. With renewed focus on and appropriate recognition of technical, cost, and schedule risks and rewards, NASA project managers will be better positioned to meet the performance goals expected by Congress and the U.S. taxpayer.

Management's Comments and Evaluation of Management's Comments

Management's Comments. The Chief Engineer generally concurred with the challenges we outlined and stated that the Agency has implemented a number of performance improvement actions. Specifically, the Chief Engineer pointed to an increased management focus during the formulation phase, the application of joint confidence levels, and a refined life-cycle review process to guard against making commitments based on overly optimistic plans. He also stated that NASA now uses Formulation Agreements to document agreed-upon expectations between project managers and the Agency.

The Chief Engineer acknowledged that internal and external funding instability impacts project management and stated that NASA has implemented a number of reviews and agreements to establish expectations with project managers to facilitate open discussion and early identification of impacts resulting from changes in funding due to internal factors. However, he stated that external changes to funding profiles are more difficult to control and the Agency advises project managers to account for continuing resolutions and notify stakeholders when external funding decisions are likely to result in negative outcomes. The Chief Engineer also agreed with the need for maturing and retaining an experienced workforce to lead NASA projects. He pointed out that NASA has been recognized for its project leadership training and other knowledge sharing initiatives and is targeting early career professionals in its recruitment program.

Evaluation of Management's Comments. We agree that these initiatives, if properly implemented, could help NASA mitigate the challenges we identified in this report. We also agree with the Chief Engineer that NASA's culture of optimism is necessary for the

Agency to accomplish the challenging tasks it undertakes. However, the Agency's response did not address our primary conclusion regarding the need for strong leadership by the President, Congress, and the Agency to address these persistent challenges. Without such leadership, it will be difficult for NASA to effectively implement the initiatives the Agency has identified much less overcome the long-standing challenges to meeting the cost, schedule, and performance goals of the Agency's science and space exploration projects.

APPENDIX A

Scope and Methodology

We performed this review from February 2011 through August 2012 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.

We conducted interviews across multiple levels of current and former NASA management and two parties external to NASA in order to collect opinions and attitudes about NASA project management practices and to identify project management practices and challenges that contribute to ongoing cost overruns, schedule delays, and performance shortfalls. In addition, we reviewed project plans and project management criteria to determine compliance with project success criteria, and internal controls as they related to the overall audit objective.

For the audit's survey phase, we conducted structured interviews of four levels of project management (project manager, deputy project manager, deputy project manager for resources, and head technical representative) on selected projects. The projects were selected judgmentally according to geographical location and recommendations from NASA Headquarters:

- Global Precipitation Measurement, Goddard Space Flight Center
- Gravity Recovery and Interior Laboratory, Jet Propulsion Laboratory (JPL)
- Landsat Data Continuity Mission, Goddard

For the audit phase, our approach changed to interviewing only project managers because we found in the survey phase that responses between the four levels of project management generally were consistent. The change in our approach allowed the team to obtain more interviews of a greater number of project managers. Project managers were chosen by statistical sampling from the six NASA development Centers:

- Goddard Space Flight Center
- Jet Propulsion Laboratory
- Johnson Space Center

- Kennedy Space Center
- Marshall Space Flight Center
- Stennis Space Center

The sample universe consisted of 129 former and current NASA project managers, regardless of certification. We developed the universe of 129 project managers from lists provided by each of the NASA development centers, which we reconciled against the list provided by Headquarters to determine accuracy. For selecting project managers for interview, we used the attribute sample design with the method of selection being simple random sample. Our sample size was determined by using *Winstats 1.0* and the universe of 129 project managers with an estimated attribute error rate of 10 percent and a desired precision or standard error rate of 5 percent. As a result, *Winstats 1.0* projected a sample size of 41 project managers based on an 80 percent confidence level, with an estimated mean of 10 percent and estimated 30 percent standard deviation.

In addition, we interviewed the Administrator, Deputy Administrator, Associate Administrators, Center Directors, a former NASA Administrator, former senior NASA staff, and external parties. Overall, we interviewed 85 personnel. For a list of interviewees, see Appendix B.

From these interviews, we identified four common themes related to NASA project management challenges, as discussed in the report:

- Optimistic organizational culture.
- Technical complexity of NASA projects.
- Unstable funding.
- Project manager development.

During the course of the audit, we also solicited input from the greater NASA workforce via a blog. We received a total of 687 responses via the blog: 243 direct responses, 390 "thumbs up" (like or agree) responses, and 54 "thumbs down" (dislike or disagree) responses to the posted comments. Comments received via the blog were consistent with the comments received during interviews with the 41 project managers.

Use of Computer-Processed Data. In order to identify the universe of project managers for this audit, we assessed the reliability of computer-processed data by comparing lists of project managers from Headquarters and six NASA Centers. We also analyzed Internet generated blog responses via http://wwwl.nasa.gov/offices/oig/agencyinput/index.html from September 21, 2011, through October 20, 2011. The blog was monitored by OIG personnel for appropriate content and duplicate responses. Although we did not test the general or application controls of any of these systems, we compared results and monitored the data, to the extent possible, to determine that the data was valid and reliable to support our objectives and conclusions.

Review of Internal Controls

We reviewed NASA policies and procedures related to project management to determine NASA's internal controls for project managers' responsibilities for monitoring and oversight of cost, schedule, and performance requirements. We found that NASA Procedural Requirements require projects to have quantifiable and measurable performance metrics and to document the success criteria that, if not met, trigger consideration of a Termination Review. We found that NASA policy supports technical performance success criteria. However, Agency policy does not provide mission success criteria that holds projects accountable for cost and schedule performance. In addition, project plans reviewed supported that mission success is defined in terms of technical specifications only. Specific internal controls reviewed included:

- NASA Procedural Requirements (NPR) 7120.5D, "Space Flight Program and Project Management Requirements," March 6, 2007
- NASA Interim Directive 7120-97, "NASA Space Flight Program and Project Management Requirements," September 28, 2011, for NPR 7120.5D
- NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012
- NPD 1000.5, "Policy for NASA Acquisition," Revalidated March 17, 2010
- NASA's GAO High-Risk Corrective Action Plan Executive Summary, September 26, 2008

Project plans reviewed for mission success criteria:

- Deep Impact Discovery Project
- James Webb Space Telescope
- Landsat Data Continuity Mission
- Mars Atmosphere and Volatile Evolution
- Mars Science Laboratory
- Orbiting Carbon Observatory–2
- Soil Moisture Active Passive

In addition, for the survey phase we reviewed NASA's Procurement Management Review Reports (formerly Procurement Management Surveys) website by Center and year. We reviewed Management Review Reports for Goddard (calendar years 2007 and 2009) and JPL (calendar years 2005 and 2008) and found no reviews pertaining to project management practices of the Global Precipitation Measurement, Landsat Data Continuity Mission, or the Gravity Recovery and Interior Laboratory Projects.

Prior Coverage

The NASA OIG has issued seven reports and GAO has issued 12 reports, listed below, related to project management practices. The reports describe significant challenges project managers face regarding cost overruns, schedule delays, and ineffective management practices of large-scale projects. Two of the GAO reports identified NASA and Department of Defense cultural systemic weaknesses in their acquisition processes and cost growth in agency projects In addition, we reviewed five reports by other entities, such as a Mishap Investigation Board, that we found of particular significance regarding project management practices. Unrestricted NASA and GAO reports can be accessed at http://oig.nasa.gov and http://www.gao.gov.

NASA Office of Inspector General

"A Review of NASA's Replacement of Radiation Monitoring Equipment on the International Space Station" (IG-11-027, September 29, 2011)

"NASA's Challenges Certifying and Acquiring Commercial Crew Transportation Services" (IG-11-022, June 30, 2011)

"NASA's Management of the Mars Science Laboratory Project" (IG-11-019, June 8, 2011)

"NASA's Management of the NPOESS Preparatory Project" (IG-11-018, June 2, 2011)

"Review of NASA's Tracking and Data Relay Satellite System" (IG-10-023, September 21, 2010)

"The Landsat Program Is Not Meeting the Goals and Intent of the Land Remote Sensing Policy Act of 1992" (IG-09-021, September 2, 2009)

"Final Memorandum on Audit of NASA's Global Precipitation Measurement Project" (IG-08-016-R, March 31, 2008)

Government Accountability Office

"NASA: Assessments of Selected Large-Scale Projects" (GAO-12-207SP, March 1, 2012)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-11-239SP, March 3, 2011)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-10-227SP, February 1, 2010)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-09-306SP, March 2, 2009)

"High-Risk Series: An Update" (GAO-11-278, February 2011)

"NASA: Projects Need More Disciplined Oversight and Management to Address Key Challenges" (GAO-09-436T, March 5, 2009)

"High-Risk Series: An Update" (GAO-07-310, January 2007)

"NASA's James Webb Space Telescope: Knowledge-Based Acquisition Approach Key to Addressing Program Challenges," (GAO-06-634, July 14, 2006)

"Best Practices: Better Support of Weapon System Program Managers Needed to Improve Outcomes" (GAO-06-110, November 2005)

"NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management" (GAO-04-642, May 2004)

"NASA Program Costs: Space Missions Require Substantially More Funding Than Initially Estimated" (GAO/NSIAD-93-97, December 1992)

"Weapons Acquisition: A Rare Opportunity for Lasting Change" (GAO/NSIAD-93-15, December 1992)

Other

The Aerospace Corporation: "Explanation of Change (EoC) Cost Growth Study Final Results and Recommendations," Aerospace Report No. ATR-2011(5322)-1, July 1, 2011 (draft report not publicly available)

National Resource Council, "Controlling Cost Growth of NASA Earth and Space Science Missions," 2010, available at http://www.nap.edu/catalog.php?record_id=12946 (accessed August 26, 2012)

Other (continued)

The Casani Report: "James Webb Space Telescope (JWST) Independent Comprehensive Review Panel (ICRP)," October 29, 2010, available at http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf (accessed August 20, 2012)

The Congressional Budget Office, "A Budgetary Analysis of NASA's New Vision for Space Exploration," September 2004. Available at http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/57xx/doc5772/09-02-nasa.pdf (accessed August 26, 2012)

Mars Climate Orbiter Mishap Investigation Board: "Report on Project Management in NASA," March 13, 2000, available at http://science.ksc.nasa.gov/mars/msp98/misc/MCO_MIB_Report.pdf (accessed August 20, 2012)

INTERVIEWS

The lists below contain the names of those people we interviewed for this audit. The positions cited are those held by the interviewees at the time of our interviews. Their positions or titles may have since changed.

NASA Headquarters Staff

Interviewee	Position
Charles Bolden	Administrator
Lori Garver	Deputy Administrator
Christopher Scolese	Associate Administrator
Jaiwon Shin	Associate Administrator for Aeronautics Research
Douglas Cooke	Associate Administrator for Exploration Systems
William Gerstenmaier	Associate Administrator for Space Operations
Michelle Gates	Aerospace Technician, Engineer Program Management
Lynn Cline	Deputy Associate Administrator for Space Operations
Kathleen Gallagher	Operations Research Analyst, Space Operations
Edward Weiler	Associate Administrator for Science
Charles Gay	Deputy Associate Administrator for Science
Michael Luther	Deputy Associate Administrator for Science
Dan Woods	Director, Strategic Integrations and Management
Michael Ryschkewitsch	Chief Engineer
Gregory Robinson	Deputy Chief Engineer

Center Management

Interviewee	Position	Center
Robert Strain	Center Director	Goddard
Arthur (Rick) Obenschain	Deputy Center Director	Goddard
Kelly Ferrell	Chief of Staff	Goddard
Michael Coats	Center Director	Johnson
Charles Elachi	Center Director	JPL
Robert Cabana	Center Director	Kennedy
Robert Lightfoot	Center Director	Marshall
Eugene Trinh	Center Director	NASA Management Office (NMO)
Norman Schutzberger	NMO Oversight	NMO
Patrick Scheuermann	Center Director	Stennis
Ken Human	Associate Center Director	Stennis

Former NASA Management

Interviewee	Current Position	Former NASA Position
Michael Griffin	Eminent Scholar and Professor Mechanical and Aerospace Engineering University of Alabama in Huntsville	Administrator
Craig Steidle	Rear Admiral and Visiting Professor Aerospace Engineering United States Naval Academy	Associate Administrator for Exploration Systems
Alan Stern	Director, Florida Space Institute	Associate Administrator for Science

External to NASA

Interviewee	Position
John Logsdon	Professor Emeritus of Political Science and International Affairs at George Washington University's Elliott School of International Affairs
Marcia Smith	President of Space and Technology Policy Group, LLC

Initial Interviews (by Project)

For initial interviews, we chose three projects and discussions were held with the project manager, deputy project manager, deputy project manager for resources, and the technical lead. See Appendix A for Scope and Methodology.

Interviewee	Position	Project	Center
Ardeshir Azarbarzin	Project Manager	Global Precipitation Measurement (GPM)	Goddard
Candace Carlisle*	Deputy Project Manager	GPM	Goddard
Jacquelyn Fiora	Deputy Project Manager for Resources	GPM	Goddard
David Ward	Mission Systems Engineer	GPM	Goddard
David Lehman	Project Manager	Gravity Recovery and Interior Laboratory (GRAIL)	JPL
Tom Hoffman	Deputy Project Manager	GRAIL	JPL
Marjorie Raymond	Project Business Manager	GRAIL	JPL
Humphrey Price	Project Systems Engineer	GRAIL	JPL
Phillip Sabelhaus	Project Manager	Landsat Data Continuity Mission (LDCM)	Goddard
William Ochs	Project Manager (former)	LDCM	Goddard
Del Jenstrom	Deputy Project Manager	LDCM	Goddard
Lorrie Eakin	Deputy Project Manager for Resources	LDCM	Goddard
Evan Webb	Lead Mission Systems Engineer	LDCM	Goddard

*Interviewee also selected as part of the statistical sample of project managers.

Project Manager Interviews (Statistical Sample)

After initial project interviews were conducted (see "Initial Interviews"), we determined for a better representation of Agency Project Management we should interview project managers at the six NASA development centers: Goddard (including Wallops), Johnson, JPL, Kennedy, Marshall, and Stennis. The statistical sample identified 41 project managers for interviews. See Appendix A for Scope and Methodology.

Interviewee	Position	Project	Center
Preston Burch	Associate Director	Joint Polar Satellite System (JPSS)	Goddard
Candace Carlisle	Assistant Engineer	Global Precipitation Measurement (GPM)	Goddard
David Carter	Supervisor Assistant – Engineer Program Management	Ground Network	Goddard
Frank Cepollina	Associate Director	Satellite Servicing Capabilities Office	Goddard
Nicholas Chrissotimos	Associate Director	Explorers and Heliophysics Project Division	Goddard
Elizabeth Citrin	Deputy Associate Director	Joint Polar Satellite System (JPSS)	Goddard
Roger Clason	Supervisor Assistant – Engineer Program Management	Explorations and Space Communication Project	Goddard
John Durning	Assistant – Engineer Program Management	James Webb Space Telescope (JWST)	Goddard
Bryan Fafaul	Supervisor Assistant – Engineer Program Management	GLORY	Goddard
Kevin Grady	Supervisor Assistant – Engineer Program Management	Wide-Field Infrared Survey Telescope (WFIRST)	Goddard
David Mitchell	Supervisor Assistant – Engineer Program Management	Explorers and Heliophysics Project Division (MAVEN)	Goddard
Robin Krause	Deputy Project Manager	GOES-R Ground	Goddard
Richard Pickering	Deputy Program Manager	GOES-R	Goddard
Albert Vernacchio	Supervisor Assistant – Engineer Program Management	Space Network Ground Segment Sustainment (SGSS)	Goddard
Jeffrey Volosin	Assistant Launch and Flight Operations Manager	Explorations and Space Communication Project	Goddard
Wynn Watson	Project Manager	Earth Science Mission Operations (ESMO)	Goddard
Christopher Johnson	Project Manager	Crew Exploration Vehicle (CEV) Parachute Assembly System	Johnson
Kathleen Laurini	Project Manager	Altair Lunar Lander	Johnson
James Lewis	Project Manager	Low Impact Docking System	Johnson
Daryl Peltier	Project Manager	Space Shuttle Program Flight Software	Johnson
John Shannon	Project Manager	Space Shuttle Program	Johnson

Dan Swint	Project Manager	NASA Integrated Enterprise Management, Aircraft Management Module	Johnson
Ralph Basilio	Project Manager	Orbiting Carbon Observatory II	JPL
John Callas	Project Manager	Mars Exploration Rover	JPL
Kent Kellogg	Project Manager	Soil Moisture Active and Passive	JPL
Timothy Larson	Project Manager	EPOXI (Deep Impact) and Stardust Next	JPL
Gaylon McSmith	Project Manager	Mars Odyssey	JPL
Glenn Shirtliffe	Project Manager	Jason-1	JPL
Peter Theisinger	Project Manager	Mars Science Lab	JPL
Philip Varghese	Project Manager	Mars Reconnaissance Orbiter	JPL
Parag Vaze	Project Manager	Jason-3 and Ocean Surface Topography Mission (Jason-2)	JPL
Charles Gambaro	Project Manager	Vehicle Assembly Building	Kennedy
Larry Schultz	Program Manager	Ares/SLS Mobile Launcher	Kennedy
Dennon Clardy	Mission Manager	Discovery New Frontiers	Marshall
Michael Kynard	Ares Upper Stage Engine Element Manager	Ares/Space Launch System (SLS)	Marshall
Jim Reuter	Project Manager	Ares/Space Launch System (SLS)	Marshall
Jody Singer	Deputy Program Manager	Space Launch System (SLS)	Marshall
Freddie Douglas III	Project Manager	Office of Safety and Mission Assurance	Stennis
David Liberto	Project Manager	AJ-26/RS-68 Liaison Role	Stennis
Jay Pittman	Chief	Range and Mission Management Office	Wallops
Ronald Walsh	Assistant Launch and Flight Operations	Range and Mission Management Office	Wallops

MANAGEMENT COMMENTS

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

September 21, 2012

Reply to Attn of: Office of the Chief Engineer

TO: Assistant Inspector General for Audits

FROM: Chief Engineer

SUBJECT: Response to Office of Inspector General (OIG) Draft Report "NASA's Challenges to Meeting Cost, Schedule, and Performance Goals" (Assignment No. A-11-009-00)

The Office of the Chief Engineer appreciates the opportunity to review and provide comments on the OIG draft report entitled "NASA's Challenges to Meeting Cost, Schedule, and Performance Goals" (Assignment No. A-11-009-00) dated August 28, 2012.

In the draft report, the OIG identifies the following four challenges to meeting cost, schedule, and performance goals:

- NASA's Culture of Optimism Can Result in Unrealistic Projections
- Underestimating Technical Complexity Increases Cost and Schedule Risk
- Funding Instability Can Lead to Inefficient Management Practices
- Project Manager Development Opportunities Are Limited

NASA generally concurs with the four main challenges described in the draft report and has already implemented a number of performance improvement actions to address them. In summary, the report clearly relates: the high complexity of NASA projects; the associated complications of managing cost and schedule performance; the impacts of a changing environment influenced by both internal and external stakeholders; and the importance and effect of optimism necessary to successfully deliver complex one-of-a-kind missions.

NASA believes that the culture of optimism is necessary to successfully accomplish the challenging tasks the Nation has asked of us. We also recognize that sufficient checks and balances must be in place to ensure that we have realistic plans when we begin execution. NASA has implemented numerous improvements including: enhanced formulation activities; application of joint confidence levels; clarification of expected maturity levels throughout the life cycle; and refined monthly and life-cycle review processes. The increased focus on sufficient formulation prior to making an Agency commitment enables NASA to establish commitments that are not based on an overly optimistic plan. The focus on sufficient maturity and refined performance assessment processes during implementation allows NASA to more readily identify when a project is not performing and mitigate negative performance when necessary.

2

NASA is chartered to tackle extremely difficult technical challenges which are daunting by definition to predict and estimate. Those technical challenges and the interdependency within complex projects lead to difficult decisions involving risk and the trade space to meet requirements. NASA now requires development of a Formulation Agreement (FA) which documents a project's plan to mature technology and buy down risk. Included in a Project's FA is a section entitled Technology Readiness and Assessment, which describes the specific activities and risk mitigation plans, the responsible organizations, models, and key tests to ensure that the critical technology maturity reaches Technology Readiness Level (TRL) 6 by Preliminary Design Review (PDR). The FA requirement is in addition to the Technology Development Control Plans already included in a project's Program Plan and Project Plan. The Agency strives to advance the TRL in its research and early formulation for projects thereby reducing risk, which leads to better cost and schedule estimation by confirmation.

As the study points out, funding instability is caused by both external and internal drivers. Several updates were made to NASA's Spaceflight Program and Project Management Requirements. For example, the FA was also implemented to mitigate the challenge of inadequate funding in formulation driven by internal decisions. The FA documents the agreement and expectations between the Agency and the program or project manager. The Program and Project Plans serve the same purpose during the implementation phase. Additionally, the Decision Memo has been institutionalized to document key decisions throughout the project life cycle. The Management Agreement (MA) contained within the Decision Memo defines the parameters and authorities over which the program or project manager has management control. Changes in funding profiles may impact the MA. The MA should be viewed as a contract between the Agency and the program or project manager. Per NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," a divergence from the MA that any party identifies as significant, is to be accompanied by an amendment to the Decision Memo. These changes to internal practices facilitate identification of impacts, open discussion regarding resolution path, and document changes to the agreements. External drivers are more difficult to influence or control. U.S. Government policies and priorities may change over time, and Continuing Resolutions have become the norm and are increasingly in place for longer periods of time. NASA seeks to keep external stakeholders informed when external decisions impact a project's ability to deliver on NASA's Agency Baseline Commitment. NASA also advises projects to take the probability of a Continuing Resolution into consideration when developing and refining plans at the beginning of a fiscal year.

NASA agrees with the IG's observations regarding the importance of having a skilled and experienced workforce and the need to attract and retain recent graduates. NASA has been globally recognized by the Project Management Institute as a program and project management training leader. The NASA Academy of Program/Project and Engineering Leadership (APPEL) offers a robust program including on-line and classroom courses, masters forums, project-specific performance enhancement, case studies, and knowledge sharing forums. Additionally, with the increased growth of international collaboration in NASA's missions, NASA has worked with its partner space agencies to create an International Program/Project Management Committee, under the auspices of the International Astronautical Federation to facilitate an open sharing of knowledge, lessons learned, and best practices to provide an opportunity to share our respective experiences in working together in future endeavors. NASA also instituted a project management certification program, which places heavy emphasis on adequate experience as a prerequisite for being selected as a program or project manager. Project managers for large-scale projects demonstrate their experience either on smaller projects or as sub-system managers on larger efforts. Although there are limited in-house development opportunities, it has not been difficult to identify project managers with the appropriate level of experience. Finally, to address early career new hires, NASA is in the midst of executing a recruitment program which streamlines the hiring process and targets college job fairs so that offers can be extended in the Fall of 2012 for immediate hire upon graduation.

The Agency's philosophy for performance improvement is multifaceted and based upon continuous improvement of our processes, procedures, and training. NASA recognizes that the continuing refinement, improvement, and implementation of sound acquisition practices, policies, and processes are essential to mission success.

Again, thank you for the opportunity to review and comment on the subject draft report. If you have further questions or require additional information on the NASA response to the draft report, please contact Sandra Smalley at (202) 358-4731.

Michael Ryschkewitsch
Chief Engineer

cc:
HQ/Administrator/Mr. Bolden
- Deputy Administrator/Ms. Garver
- Associate Administrator/Mr. Lightfoot (Acting)
- Chief of Staff/Mr. Radzanowski
- Office of Evaluation/Ms. Petro
- OCFO/Dr. Robinson
- HEOMD/Mr. Gerstenmaier
- SMD/Dr. Grunsfeld
- ARMD/Mr. Shin

GSFC/Mr. Scolese
JSC/Mr. Coats
JPL/Mr. Elachi
- NASA Management Office/Dr. Trinh

KSC/Mr. Cabana
MSFC/Ms. Henderson (Acting)
SSC/Mr. Scheuermann

REPORT DISTRIBUTION

National Aeronautics and Space Administration

Administrator
Deputy Administrator
Associate Administrator
Chief of Staff
Chief Engineer
Chief Financial Officer
Associate Administrator for Aeronautics Research
Associate Administrator for Human Exploration and Operations
Associate Administrator for Science
NASA Advisory Council's Audit, Finance, and Analysis Committee
Director, Goddard Space Flight Center
Director, Jet Propulsion Laboratory
Director, Johnson Space Center
Director, Kennedy Space Center
Acting Director, Marshall Space Flight Center
Director, NASA Management Office
Director, Stennis Space Center

Non-NASA Organizations and Individuals

Office of Management and Budget
- Deputy Associate Director, Energy and Science Division
  - Branch Chief, Science and Space Programs Branch

Government Accountability Office
- Director, NASA Issues, Office of Acquisition and Sourcing Management

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
- Subcommittee on Commerce, Justice, Science, and Related Agencies

Senate Committee on Commerce, Science, and Transportation
- Subcommittee on Science and Space

Senate Committee on Homeland Security and Governmental Affairs
House Committee on Appropriations
- Subcommittee on Commerce, Justice, Science, and Related Agencies

House Committee on Oversight and Government Reform
- Subcommittee on Government Organization, Efficiency, and Financial Management

House Committee on Science, Space, and Technology
- Subcommittee on Investigations and Oversight
- Subcommittee on Space and Aeronautics

Major Contributors to the Report:

- Jim Morrison, Assistant Inspector General for Audits
- Ridge Bowman, Director, Space Operations Directorate
- Raymond Tolomeo, Director, Science and Aeronautics Research Directorate
- Diane Choma, Project Manager
- Stephen Siu, Project Manager
- Theresa Becker, Procurement Analyst, Team Lead
- Gina Davenport-Brazeau, Auditor
- Gerardo Saucedo, Management Analyst
- Gary Weishaar, Management Analyst
- Tiffany Xu, Auditor
- John Womack, Investigator
- Arnold Pettis, Data Mining Specialist/Statistician

SEPTEMBER 27, 2012

REPORT NO. IG-12-021

OFFICE OF AUDITS

OFFICE OF INSPECTOR GENERAL

ADDITIONAL COPIES

Visit http://oig.nasa.gov/audits/reports/FY12/ to obtain additional copies of this report, or contact the Assistant Inspector General for Audits at 202-358-1232.

COMMENTS ON THIS REPORT

In order to help us improve the quality of our products, if you wish to comment on the quality or usefulness of this report, please send your comments to Mr. Laurence Hawkins, Audit Operations and Quality Assurance Director, at Laurence.B.Hawkins@nasa.gov or call 202-358-1543.

SUGGESTIONS FOR FUTURE AUDITS

To suggest ideas for or to request future audits, contact the Assistant Inspector General for Audits. Ideas and requests can also be mailed to:

Assistant Inspector General for Audits
NASA Headquarters
Washington, DC 20546-0001

NASA HOTLINE

To report fraud, waste, abuse, or mismanagement, contact the NASA OIG Hotline at 800-424-9183 or 800-535-8134 (TDD). You may also write to the NASA Inspector General, P.O. Box 23089, L'Enfant Plaza Station, Washington, DC 20026, or use http://oig.nasa.gov/hotline.html#form. The identity of each writer and caller can be kept confidential, upon request, to the extent permitted by law.