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AUDIT REPORT

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MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN) PROJECT

OFFICE OF INSPECTOR GENERAL

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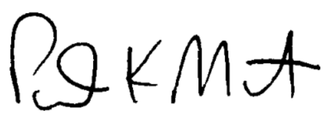

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Inspector General

Acronyms

CDR	Critical Design Review
CRM	Continuous Risk Management
EVM	Earned Value Management
FY	Fiscal Year
GAO	Government Accountability Office
GRAIL	Gravity Recovery and Interior Laboratory
HEPS	High Efficiency Power Supply
JCL	Joint Cost and Schedule Confidence Level
KDP	Key Decision Point
MAVEN	Mars Atmosphere and Volatile Evolution
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
PDR	Preliminary Design Review
OIG	Office of Inspector General
SIR	System Integration Review
SRB	Standing Review Board
UFE	Unallocated Future Expenses

OVERVIEW

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN) PROJECT

The Issue

Selected by NASA in 2008, the Mars Atmosphere and Volatile Evolution (MAVEN) Project is scheduled to launch in November 2013 at an expected cost of $453 million. MAVEN will study how the loss of carbon dioxide, nitrogen dioxide, and water from the Martian atmosphere occurred over time, which will provide insight into the history of the Red Planet's atmosphere, climate, and habitability. The Project represents the last mission undertaken as part of NASA's Mars Scout Program, an Agency initiative that competitively selected relatively low-cost robotic missions to Mars that NASA discontinued in 2010.[1]

In a September 2012 report, the NASA Office of Inspector General (OIG) identified a series of challenges that NASA managers face in meeting project cost, schedule, and performance goals for Agency projects.[2] These project challenges – overly optimistic cost and schedule estimations, underestimating technical complexity, unstable funding, and limited development opportunities for program managers – hinder NASA's ability to deliver projects on schedule and within cost. While Agency officials acknowledged that these long-standing challenges effect project success, they credit a number of new initiatives, including the use of probabilistic cost and schedule analysis, for helping more recent projects such as Juno and Gravity Recovery and Interior Laboratory (GRAIL) meet cost and schedule goals.[3]

We initiated this audit to determine whether NASA is managing the MAVEN Project to successfully meet cost, schedule, and performance goals. Specifically, we examined whether MAVEN experienced similar challenges to those we identified in our September 2012 report and the role that NASA's recent acquisition and project management initiatives played in managing the Project. Details of the audit's scope and methodology are in Appendix A.

[1] Phoenix, launched in August 2007 and the only other Scout mission, successfully landed on Mars in May 2008 and concluded its mission in November 2008. Each Scout project was required to cost less than $485 million.

[2] NASA OIG, "NASA's Challenges to Meeting Cost, Schedule, and Performance Goals" (IG-12-021, September 27, 2012).

[3] The Juno mission launched on August 5, 2011, is scheduled to arrive at Jupiter in July 2016 and will investigate the structure and history of the planet. GRAIL launched on September 10, 2011, and ended its mission of studying the Moon's interior in December 2012.

Results

MAVEN Project managers successfully addressed challenges that have hindered other NASA projects by using a disciplined management approach to achieve cost, schedule, and performance goals. Specifically, the mission's experienced Project manager demonstrated strong leadership and project management skills while proactively recruiting experienced staff. In addition, the Project management team closely followed NASA acquisition policies, which resulted in effective oversight and administration of the Project to date. Moreover, development efforts were aided by the use of heritage technology that had flown successfully on previous NASA missions, and the Project was not subjected to the type of funding instability that has plagued other NASA projects.[4] In addition, the team effectively utilized newly implemented management initiatives and tools to facilitate timely and well-informed decisions, used innovative contract management to motivate contractor performance, and developed comprehensive risk mitigation plans. Collectively, these efforts have controlled Project costs, proactively managed risk, and established adequate reserve levels that favorably position the Project to mitigate any remaining programmatic challenges and meet the planned November 2013 launch date.

MAVEN Managers Successfully Mitigated Common Project Management Challenges

In our September 2012 report, we identified four factors that appear to present the greatest challenges to successful project outcomes at NASA – NASA's culture of optimism, underestimating technical complexity, funding instability, and limited opportunities for project managers' development. We found that MAVEN managers have been able to overcome these challenges by forming a strong and experienced leadership team; emphasizing the use of heritage technologies that did not require significant modifications; receiving a stable funding profile; and effectively using sound project management methodologies, tools, and contracting initiatives.

Experienced Leadership. We found that the Project manager had approximately 17 years of experience and had been associated with MAVEN since the Project's inception in 2006. In addition, the Project manager and principle investigator selected teams of experienced scientists, subsystem project managers, instrument developers, integrators, and senior leaders from each of the organizations involved in the mission. According to the Project manager, he encouraged team members to maintain open communication to ensure that all parties understood the cost, schedule, and performance goals and were accountable for working to achieve those goals.

Use of Heritage Technology. We found that Project managers emphasized the use of heritage, flight-qualified hardware and software flown on eight previous interplanetary

[4] Heritage technologies are hardware, software, and systems developed for previous projects that are adapted for use on other projects.

missions, thereby avoiding the cost and schedule challenges often associated with developing new technologies. In addition, Project management's adherence to original specifications meant that in most cases the heritage technologies required minimal modification to meet the form, fit, and function requirements of the MAVEN mission. Management's technical implementation plan also incorporated substantial technical requirements in excess of minimum Project specification margins, did not rely on any new technology development, and included targeted descope options, all of which were key factors that contributed to MAVEN's positive status.

Stable Funding. Nearly 75 percent of the individuals we interviewed for our September 2012 audit reported that funding instability was among the most significant challenges to project management at NASA. Funding instability includes situations in which a project receives less money than planned or funds are disbursed on a schedule different from planned and can be the result of external decisions made by the President and Congress or internal decisions made by Agency officials. This instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes.

NASA's Project Management Handbook describes a typical project funding profile as one that ramps up quickly in the early phases of a project, then peaks during final design, fabrication, and assembly.[5] We reviewed MAVEN's funding profile and found that it matched the profile described and the Project was not subjected to the type of funding instability that has hampered development efforts on other projects. In fact, MAVEN consistently received funding at or above the requested amounts throughout its life cycle, unlike many other NASA projects.

MAVEN Effectively Used Project Management Methodologies, Tools, and Contracting Initiatives

MAVEN's cost, schedule, and technical performance are currently on target with original planning estimates largely because project managers adhered to NASA's project management policies and successfully implemented initiatives that facilitated timely and well-informed decision making.[6] Specifically, Project managers used independent reviews to evaluate their overall project plan, probabilistic cost and schedule estimations to confirm budget adequacy, an innovative contract management technique to motivate contractor performance, and a comprehensive risk mitigation plan to meet cost, schedule, and performance goals.

Standing Review Board. NASA policy provides overall direction for how project managers should execute their responsibilities. The policy outlines NASA's management structure; the life cycle for spaceflight projects; the roles and responsibilities of and relationships between team members; and management requirements by life-cycle phase.

[5] "NPR7120.5, NASA Space Flight Program and Project Management Handbook," February 4, 2010.

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

The policy also requires an independent review of the project at appropriate milestones. One element of this independent review process is the Standing Review Board (SRB), a group composed of experts from outside the project whose job is to provide an independent assessment of the project as it advances through its key decision points.

We found that MAVEN management actively engaged the SRB throughout the Project's life cycle and that the SRB reviewed risks in mission complexity, Government furnished equipment, waiver approval, launch vehicle selection, system engineering staffing, power system development, and assembly, test, and launch operations. The SRB determined that MAVEN had an excellent team in place, effective communication, minor technical risks, and an achievable schedule. The independent assessment team also agreed to within one percent of the Project manager's cost and schedule confidence estimates. Collectively, the positive findings of the SRB contributed toward NASA's decision to confirm MAVEN for entry into the Final Design and Fabrication phase.

Joint Cost and Schedule Confidence Level. MAVEN Project managers confirmed the adequacy of the Project's funding through an analysis produced by a Joint Cost and Schedule Confidence (JCL) review.[7] A relatively new initiative, the JCL is a cost estimating methodology that establishes the probability of a project being completed at its estimated cost and on schedule. NASA has cited the probabilistic analysis with helping projects such as Juno and GRAIL meet their cost and schedule goals. Since August 2010, the annual JCL for MAVEN has indicated that the Project has more than a 90 percent probability of launching within the budget provided and on the planned schedule.

Earned Value Management. Project managers also effectively used earned value management (EVM), a tool for measuring and assessing project cost, schedule, and technical performance.[8] For example, the Project's cumulative schedule performance indicated that work activities were slightly behind schedule due to unanticipated developmental issues with two of its three instrument suites – the Neutral Gas and Ion Mass Spectrometer (Mass Spectrometer) and the Particles and Fields Package. In addition, some spacecraft work was delayed while awaiting the transition of personnel from the Juno and GRAIL missions to MAVEN. However, EVM data showed that the delayed spacecraft work resulted in a cumulative cost underrun. Managers subsequently applied these funds to obtain the additional work hours needed to get the Project back on schedule after Juno and GRAIL launched in August and September 2011, respectively. Consequently, managers maintained schedule progress to preserve the required delivery

[7] As described in NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012, the JCL analysis combines a project's cost, schedule, and risk profiles and produces the probability that cost will be equal to or less than the targeted cost, and schedule will be equal to or less than the targeted schedule date. The JCL review is intended to help inform management of the likelihood of a project's success. NASA requires that a JCL be performed for all projects with estimated life-cycle costs greater than $250 million.

[8] EVM is an integrated management control system for assessing a project's technical progress. Used correctly, EVM can help provide project management with objective, accurate, and timely data to support effective decision making.

margins while maintaining adequate schedule margins to meet any additional unexpected delays.

Innovative Approaches to Contract Management. We found that MAVEN managers used innovative contract management practices to motivate contractor performance in support of cost, schedule, and performance goals, particularly through use of "risk pool" funds to control costs. A risk pool is a segment of funds that MAVEN Project management treats both as unallocated future expenses (UFE) and as part of the Project's budget.[9] The Project Manager allocates these funds to address issues that would likely benefit from proactive risk mitigation activities to reduce future technical or schedule risk, such as addressing an unexpected and uncharacteristic test issue that was beyond the scope of the testing contemplated when the contract was negotiated. Identifying specific costs likely to arise at the inception of the Project enabled the contractor to submit an aggressively priced proposal without exposing the Project to cost overruns as a result of high-probability risks.

Risk Management. MAVEN management's proactive risk mitigation strategies have also helped the Project achieve cost, schedule, and technical goals. We found that MAVEN management analyzed, controlled, and communicated mission-level Project risks in accordance with applicable criteria and guidelines. MAVEN management used a consistent, structured, and rigorous methodology for continuous management of the Project's risks. Specifically, we found that the MAVEN Continuous Risk Management (CRM) process had sufficient process controls to effectively manage risks.[10] By properly applying Agency risk management processes and sound risk mitigation strategies, MAVEN Project management has been able to address Project risks in a timely manner.

We reviewed the Project's risk management database and found that all 97 mission-level risks were actively managed in accordance with NASA risk management requirements. Additionally, we found that Project managers are aggressively addressing single-point failure risks – components or elements that if a failure occurs, the mission fails or is significantly degraded. For example, risk mitigation for the High Efficiency Power Supply (HEPS) Card – the spacecraft's power supply – included incorporation of technical requirements in excess of minimum Project specifications, rigorous inspections and testing on a secondary card obtained from the Juno Project, and additional testing of the HEPS primary and secondary flight cards.

[9] The term unallocated future expense or UFE replaces the now obsolete term previously referred to as "cost reserves." A UFE is the portion of estimated cost required to meet a specified confidence level that cannot yet be allocated to the specific project Work Breakdown Structure sub-elements because the estimate includes probabilistic risks and specific needs that are not known until these risks are realized.

[10] CRM is a systematic and iterative process that identifies, analyzes, plans, tracks, controls, communicates, and documents risks associated with implementation of designs, plans, and processes.

MAVEN is Well-Positioned to Address Remaining Risks

The MAVEN Project is currently moving toward its systems integration and testing phase, which includes utilization of hardware, software, procedures, and facilities required to perform the integration and testing of the Project's systems, payloads, spacecraft, launch vehicle and services, and mission operations. Integration of project components and subsystems requires assembly of hardware and software elements into operational assemblies or systems. Due to the complexity of space systems, integration and testing may produce unexpected results that could require further analysis, testing, or design changes.

However, we found that the Project was carrying a higher level of cost and schedule reserves into the final design and fabrication phase of Project development than goals stated in Goddard Space Flight Center requirements.[11] MAVEN Project management has been able to maintain this higher level of cost reserve due to cost underruns achieved early in the Project life cycle. Against the cost estimate to complete Project development, as of November 2012, MAVEN management held approximately 32 percent of costs as UFEs and 2.6 months of schedule margin.

Although risks remain to MAVEN's cost, schedule, and technical performance, in our judgment Project reserves were adequate to mitigate against most unforeseen expenses and events. Project management's experienced leadership team, use of heritage technologies, implementation of sound project management practices (including the use of JCL), innovative contract management practices, and aggressive risk mitigation strategies have enabled MAVEN to overcome common NASA project management challenges and minimize cost increases and schedule delays.

Management Action

Although we made no specific recommendations for the MAVEN Project management team, we encouraged the Associate Administrators for NASA's Mission Directorates and the Agency's Chief Engineer to analyze MAVEN's project management successes, identify what tools have helped project management minimize common project development issues, and apply these lessons to other NASA development projects.

The Associate Administrator for the Science Mission Directorate agreed and stated that post-launch the Directorate would work with the Chief Engineer to capture the lessons learned and share them using NASA's knowledge sharing tools, including an ASK Magazine article and a Chief Knowledge Officer case study. Management's full response is reprinted in Appendix B.

[11] Goddard Procedural Requirements 7120.7, "Schedule Margins and Budget Reserves to be Used In Planning Flight Projects and In Tracking Their Performance," May 4, 2008.

CONTENTS

INTRODUCTION

Background

NASA selected the Mars Atmosphere and Volatile Evolution (MAVEN) Project in September 2008 as one project in the Mars Scout Program, an Agency initiative that competitively selected relatively low-cost robotic missions to Mars.[12] NASA officials selected MAVEN as having the highest science value and the lowest implementation risk. Once launched, the Project will explore the Martian upper atmosphere and ionosphere and their interactions with the Sun and solar wind (see Figure 1).[13] Scientists will use the data MAVEN collects to study how the loss of volatile compounds such as carbon dioxide, nitrogen dioxide, and water from the Martian atmosphere has occurred over time, which will give them insight into the history of the Planet's atmosphere, climate, and habitability.

Figure 1. Artist's concept of MAVEN in orbit of Mars.

Source: NASA

MAVEN will obtain measurements the National Academy of Sciences listed as a high priority in its 2003 Decadal Survey on planetary exploration.[14] Specifically, the scientific mission objectives are to: (1) determine how the loss of elements from the Mars atmosphere to space has affected the Martian climate over time; (2) determine the current state of the upper atmosphere and interactions with solar wind; (3) determine the current rates of escape of Mars' atmospheric elements to space and the processes controlling them; and

[12] This announcement solicited proposals for space flight science investigations that could include remote observations from Mars-orbiting spacecraft; missions that deploy aerial or landed systems to study the Martian atmosphere, surface, interior, geo-potential fields, and/or deep subsurface; and sample return missions. Projects in the Mars Scout Program, which NASA cancelled in 2010, had a cost cap of $485 million.

[13] Solar wind is the stream of charged particles (protons, electrons, and heavier ionized atoms) emanating from the Sun in all directions at very high speeds.

[14] National Academy of Sciences, "New Frontiers in the Solar System: An Integrated Exploration Strategy 2003-2013," 2003. The Survey placed heavy emphasis on Mars exploration including a mission to study the upper atmosphere of Mars.

(4) determine the ratios of stable isotopes that will tell Mars' history of loss of these atmospheric elements over time.[15]

The MAVEN mission is led by a principal investigator, who is located at the University of Colorado and has responsibility and accountability to the Mars Program Office at the Jet Propulsion Laboratory (JPL) and the Mars Exploration Program at NASA Headquarters for successful mission execution. The principal investigator delegates day-to-day development and operational decision-making authority to a project manager who is located at Goddard Space Flight Center (Goddard).

NASA's Project Life Cycle. NASA policy provides overall direction for how project managers should execute their responsibilities, including the life cycle for spaceflight projects; roles and responsibilities of and the interrelationships between project team members; and management requirements for each life-cycle phase.[16] NASA has also developed a handbook to aid project managers in implementing these high-level requirements.[17] 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 2, NASA divides the life cycle of its spaceflight projects into two major phases – formulation and implementation – which are further subdivided into Phases A through F. Phases A and B consist of project formulation and C through F project implementation. This structure allows managers to assess the progress of their projects at key decision points (KDPs) in the process.[18] 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 project cancellation.

[15] An isotope is two or more varieties of the same chemical element. Isotopes have different masses because they have different numbers of neutrons, thus they have different physical and chemical properties. Stable isotopes are chemical isotopes that are not radioactive, meaning they do not decay spontaneously.

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

[17] "NPR 7120.5, NASA Space Flight Program and Project Management Handbook," February 4, 2010.

[18] A KDP is 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 2. 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 and 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), project managers develop and define requirements, cost and schedule projections, acquisition strategy, project design, and complete development of mission-critical technology. Projects are required to demonstrate evidence of technology maturity and document the information in technology readiness assessment reports. Project managers must also establish and be accountable for compliance with the terms of a management agreement that defines the parameters and authorities over which the project manager has control.

The formulation phase ends with a preliminary design review (PDR), which demonstrates whether the project's preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints. The PDR also establishes the basis for proceeding with detailed design of the project. At the PDR, project managers are required to present full baseline costs and schedules, as well as risk assessments, management systems, and performance metrics. In addition, a Standing Review Board (SRB) conducts an independent assessment of the project's readiness to proceed to implementation.[19] 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, cost and schedule baselines are established as part of the KDP C review process, against which the project is thereafter measured.

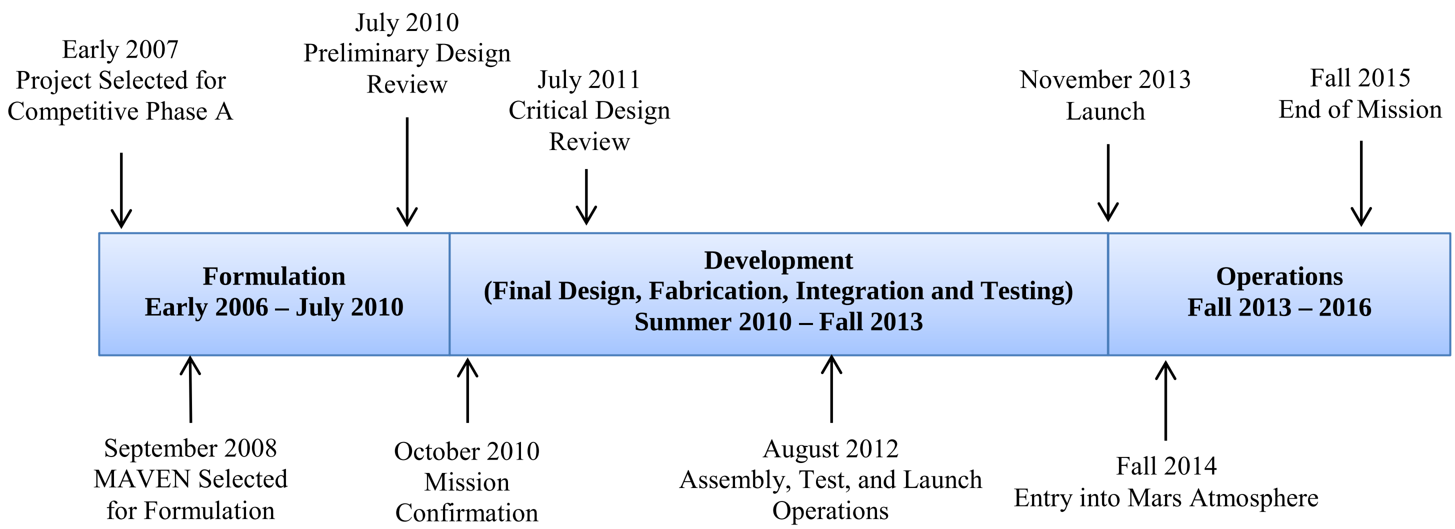
During Phase C, project managers prepare their final design, fabricate test units that resemble the actual hardware, and test those components. Subsequently, a second design review called the critical design review (CDR) is held to demonstrate whether the design

[19] An SRB 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.

is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing and whether the technical effort is on track to meet performance requirements within identified cost and schedule constraints. After CDR, a system integration review takes place to assess the readiness of the project to start flight system assembly, test, and launch operations. 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.

MAVEN Life Cycle and Components. As shown in Figure 3, NASA selected the MAVEN Project for competitive formulation development in early 2007 and for flight development in September 2008. Due to planetary alignment, the optimal launch window for a mission to Mars occurs every 26 months. MAVEN's 20-day launch window extends from November 18 through December 7, 2013. Assuming launch occurs within this window, the spacecraft should enter orbit around the Red Planet in late September 2014 and collect data for at least one year.

Figure 3. MAVEN Timeline (not to scale)



NASA capped all projects in the Mars Scout Program at a maximum of $485 million. NASA limited MAVEN to a life-cycle cost of $452.9 million for its design, development, and operation. NASA estimated that the launch services costs would run an additional $187 million. These costs include the Atlas V 401 rocket built by United Launch Alliance, payload processing, launch vehicle integration, mission unique launch-site ground support, and tracking, data, and telemetry services. MAVEN will launch from Complex 41 at Cape Canaveral Air Force Station in Florida.

MAVEN will carry three instrument suites:

The *Neutral Gas and Ion Mass Spectrometer* (Mass Spectrometer) will measure the composition of Mars' atmosphere. Goddard personnel are building the Mass Spectrometer.

The *Remote Sensing Package* (Remote Package) will determine characteristics of the planet's upper atmosphere. The University of Colorado's Laboratory for Atmospheric and Space Physics is building the Remote Package.

The *Particles and Fields Package* (Particles Package) consists of six instruments designed to measure properties of Mars' upper atmosphere, solar wind and solar energetic particles, magnetic fields, and solar extreme ultraviolet radiation. The University of California at Berkeley Space Sciences Laboratory is building the Particles Package, with support from Goddard and the Laboratory for Atmospheric and Space Physics.

NASA awarded the Lockheed Martin Corporation (Lockheed Martin) a cost-plus-award-fee contract for development of the spacecraft, integration and test of the full observatory, and launch and mission operations. JPL will provide navigation support, use of the Deep Space Network, and telecommunications relay hardware and operations. The MAVEN Project Office at Goddard is responsible to the principal investigator for management of the MAVEN Project through all mission phases.

NASA's Project Management Challenges. As part of a September 2012 review that examined the major challenges facing NASA project managers, the NASA Office of Inspector General (OIG) interviewed 85 individuals involved in all levels of project development including current and former Administrators, Associate Administrators, Center Directors, and project managers and staff. Based on those interviews, the OIG identified four issues that present NASA with its greatest challenges to successfully meet cost, schedule, and performance goals:[20]

Optimistic Agency Culture – A culture of optimism and a "can-do" spirit permeate all levels of the NASA workforce. While essential to overcoming the technological challenges inherent to many NASA projects, this culture can lead managers to overestimate their ability to overcome the risks to deliver projects within an established budget and timetable. For example, NASA project managers often underestimate the time and costs 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.

Underestimating Technical Complexity – Project managers cited the technical complexity inherent in most NASA projects as a major challenge to meeting cost and

[20] NASA OIG, "NASA's Challenges to Meeting Cost, Schedule, and Performance Goals" (IG-12-021, September 27, 2012) (Project Management Report).

schedule goals. Because NASA projects often involve new and unique technologies, managers lack historical data, cost models, lessons learned, and other information to help estimate the effort needed to develop the required technologies. In addition, NASA projects often involve combining several interdependent technologies and the resulting complexities can be difficult to predict.

Funding Instability – More than 75 percent of the individuals we interviewed stated that funding instability – whether resulting from decisions made by the President and Congress or internally within NASA – was one of the most significant challenges to project management. For example, inadequate funding in the early phases of a project's life cycle decreases managements' ability to address key risks at project inception.

Limited Project Manager Opportunities – Most project managers and senior officials we spoke with said that experience and on-the-job-training are key factors in a project manager's ability to manage cost, schedule, and performance goals effectively. However, they expressed concern that NASA does not have a sufficient number of small missions to provide adequate training grounds for new project managers; that the Agency's in-house capabilities have declined as it increasingly relies on contractors to support project development; and that NASA engineers spend most of their time overseeing contractor efforts rather than building spaceflight components and therefore have limited opportunities to gain practical "hands-on" experience.

The OIG concluded that 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. Moreover, 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 project management elements are not present.

Joint Cost and Schedule Confidence Level. NASA recently implemented a 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. The JCL analysis 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. The 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.[21]

[21] NASA Policy Directive (NPD) 1000.5A, "Policy for NASA Acquisition," January 15, 2009.

Objectives

We initiated this audit to determine whether NASA is managing the MAVEN Project to successfully meet cost, schedule, and performance goals. Specifically, we examined whether MAVEN experienced similar challenges to those we identified in our September 2012 report and the role that NASA's recent acquisition and project management initiatives played in managing the Project.

See Appendix A for details of the audit's scope and methodology, our review of internal controls, and a list of prior coverage.

SOUND PROJECT MANAGEMENT PRACTICES PUTS MAVEN ON TRACK TO MEET MISSION GOALS

To date, MAVEN Project managers have successfully overcome project management challenges that have hindered other NASA projects. Specifically, the Project manager is an experienced individual who demonstrated strong leadership and project management skills and recruited and adeptly utilized a cadre of experienced staff. In addition, the Project management team closely adhered to NASA acquisition policies, effectively utilized recently implemented management initiatives and tools to facilitate timely and well-informed decisions, used innovative contract management to motivate contractor performance, and developed comprehensive risk mitigation plans. Moreover, the Project has enjoyed a relatively stable funding stream and relied on heritage technologies that required minimal modification to meet mission requirements. Collectively, these factors helped the team control costs, proactively manage risk, and establish adequate reserve levels that should mitigate remaining programmatic risks and enable the team to meet the planned November 2013 launch date.

MAVEN Managers Successfully Mitigated Common Project Management Challenges

Management Assembled an Experienced Team. Since its inception, the MAVEN Project has had only one Project manager. This individual joined NASA in 1987 and had approximately 11 years of project management experience when he became the MAVEN Project manager in 2006. The manager selected and organized teams of experienced scientists, subsystem project managers, instrument developers, integrators, and senior leaders from each contributing organization. The manager told us that the depth and length of the team's experience was integral to successfully meeting the Project's cost, schedule, and performance goals.

According to the MAVEN Project manager, the MAVEN Project management team that includes the principal investigator and key representatives from Goddard, Lockheed Martin, the University of Colorado, the University of California at Berkeley, and JPL, established and have maintained open communications to ensure that all parties understand cost, schedule, and performance goals and are accountable for achieving those goals. The Project manager told us he laid the groundwork for open communication during concept and technology development and met weekly via teleconference throughout all phases of the Project. In addition, representatives from each participating organization attend monthly management reviews where they discuss technical, cost, and schedule updates. The Project management team also meets quarterly for status reviews and for meetings with the Project Science Group to discuss science-related matters.[22] At these meetings, the Project management team delivers status reports and hears the status reports and concerns of scientists and the other participants. According to the Project manager, this approach promotes a team response to issues and reinforces accountability among team members.

In addition to the full Project management team, smaller teams and individuals work closely with their counterparts in working groups that NASA formed in the early stages of the Project (e.g., Systems Engineering Working Group, navigation team, launch vehicle, mission operations). Finally, the full Project management team has met at key points during the development phase to discuss lessons learned and use that information going forward.

Use of Heritage Technologies Maximized to Increase Reliability and Limit Risk. We found that MAVEN management's use of heritage technology that required minimal modifications to meet Project requirements helped avoid the cost and schedule challenges often experienced by projects that require development of new technologies or must substantially modify heritage technologies. For MAVEN, Project managers said they used heritage technology to the greatest extent possible and they planned for and used flight-qualified hardware and software that had flown on eight previous interplanetary missions. The MAVEN spacecraft incorporates structures, mechanisms, and avionics from previous Lockheed Martin interplanetary missions, including Juno and the Gravity Recovery and Interior Laboratory (GRAIL), which in turn evolved from the Mars Reconnaissance Orbiter and the Mars Global Surveyor.[23] Similarly, MAVEN's instruments are based on instruments used in previous planetary and Earth-orbiting missions, which provided significant cost and schedule risk reduction during development and environmental testing. MAVEN's ground system, mission operations, Deep Space Network communications approach, and planetary protection implementation will also use existing infrastructure, processes, tools and personnel proven on previous and ongoing Mars missions.

According to MAVEN Project management, the use of components with a history of successful operation in similar interplanetary environments has provided confidence in the Maven spacecraft design and increased reliability. Management also noted that although using heritage components does not eliminate the requirement for test-as-you-

[22] The Project Science Group is chaired by the MAVEN principal investigator. Membership includes the project scientist, the MAVEN instrument leads, science working groups leads, co-investigators, and interdisciplinary scientists.

[23] Juno launched in August 2011 on a mission to improve understanding of the solar system's beginnings by revealing the origin and evolution of Jupiter. GRAIL launched in September 2011 with the primary objective of determining the structure of the lunar interior to advance understanding of the thermal evolution of the Moon and extend knowledge gained from the Moon to the other terrestrial planets. NASA's Mars Reconnaissance Orbiter, launched in August 2005, is on a search for evidence that water existed on the surface of Mars for a long period of time. The NASA Mars Global Surveyor arrived at Mars in September 1997, and contributed numerous findings to the understanding of the planet over a 9-year period, including signs of past, persistent water such as an ancient delta and currently active water features in the gullies of canyon walls.

fly environmental testing prior to launch, it increases the likelihood that such testing will be successful and therefore minimizes risk to cost and schedule.[24]

MAVEN Project management also emphasized the importance of employing personnel with experience in building specific hardware, stating that for MAVEN the personnel building the spacecraft and instrument hardware have built the same or similar hardware on previous planetary missions. MAVEN managers noted that it is typically easier and more efficient to do something the second time around, while recognizing and incorporating the earlier lessons learned in the process.

In our judgment, Project management's use of flight-qualified hardware and software from previous interplanetary missions that required minimal modification played a critical role in setting the Project on the path to achieving cost, schedule, and performance goals.

Stable Funding Contributed to Meeting Goals. Funding instability was the challenge most often cited by the individuals we interviewed for our Project Management Report. Funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes. For example, managers may be forced to invest time and effort to re-plan tasks to fit unexpected funding profiles, defer critical tasks to later phases of development, or descope or discontinue lower priority tasks to keep project costs within the revised budget profile. Inadequate funding in the early phases of a project decreases management's ability to identify and address key risks. When planned funding does not materialize, project managers may delay development of critical technologies to a time when integration of those technologies may be more difficult or the cost of material and labor may be greater. Ultimately, management often decides to delay the project's launch.

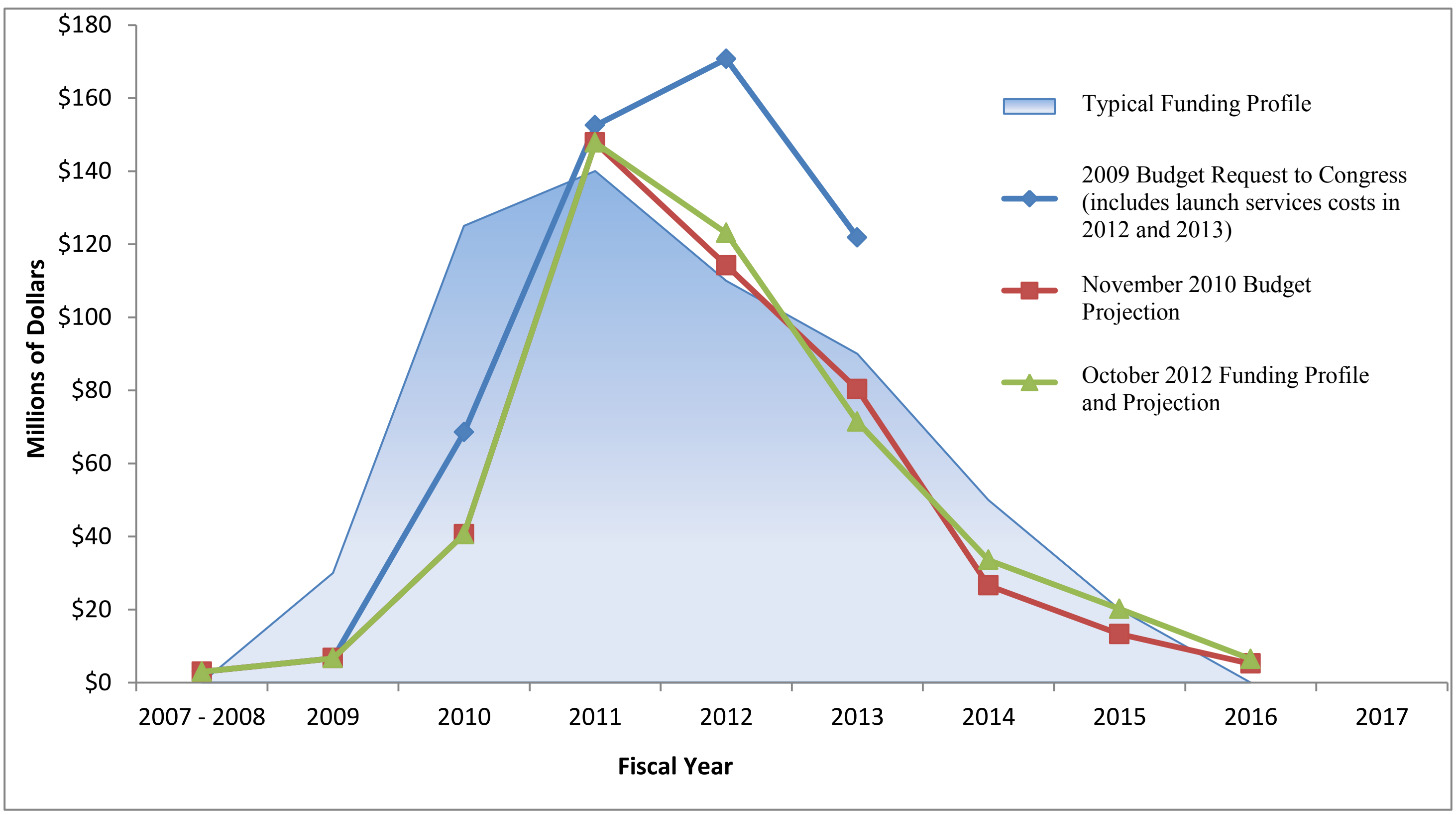
NASA's Project Management Handbook describes a typical project funding profile as one that ramps up quickly in the early phases of a project, then peaks during final design, fabrication, and assembly. In our September 2012 report, we illustrated how a lack of funding and changes to the expected funding profile early in a project's development resulted in a 3-year launch delay of NASA's Global Precipitation Measurement mission (see Table 1).

[24] The principle of test-as-you-fly means that ground tests and simulations should accurately reflect the planned flight-mission profile.

Table 1: Global Precipitation Measurement Budget and Launch Date Changes (dollars in millions)			
Program Operating Plan Year	**Fiscal 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**

Conversely, as shown in Figure 4, we found that the MAVEN Project received funding that closely matched the profile described in the Handbook and did not experience the type of funding instabilities that have hampered development efforts on other NASA projects.[25] Furthermore, the Project received funding equal to or greater than the requested amounts throughout its life cycle to date. This has contributed to the Project's cost, schedule, and technical performance aligning with original planning estimates.

Figure 4. MAVEN Funding Profile



[25] FY 2009 budget request was for the yet unnamed Mars Scout 2013 mission that would later become MAVEN. November 2010 and October 2012 figures do not include launch services costs.

MAVEN Effectively Used Project Management Methodologies, Tools, and Contracting Initiatives

MAVEN Actively Engaged its Standing Review Board to Validate Project Plans. NASA policy requires an independent review of projects at specified milestones in its life cycle. One element of this independent review process is a Standing Review Board (SRB) staffed with individuals who come from areas outside of the project's programmatic or institutional authorities. One of the functions of an SRB is to assess whether a Project's preliminary designs meet all requirements within acceptable risk levels and applicable cost and schedule restraints.

MAVEN underwent a comprehensive review by an SRB – including cost and schedule experts from the Independent Program Assessment Office, academia, industry, government and nonprofit organizations – in July 2010, at PDR.[26] The SRB members attended selected MAVEN peer reviews and design reviews, and SRB cost and schedule analysts worked with the project to understand the cost, schedule, and risks of the Project. The SRB reviewed risks in mission complexity, government furnished equipment, waiver approval, launch vehicle selection, system engineering staffing, power system development, and assembly, test, and launch operations. The SRB concluded that the Project had an excellent team in place, effective communication among team members, minor technical risks, and an achievable schedule. In addition, the Board's cost and schedule confidence estimates were within 1 percent of the Project manager's estimates. Collectively, the positive findings of the SRB contributed to NASA's decision to confirm MAVEN for entry into the Final Design and Fabrication phase.

Joint Cost and Schedule Confidence Level Confirms Adequacy of MAVEN Budget. The adequacy of MAVEN's funding was affirmed through development of a Joint Cost and Schedule Confidence Level (JCL), a relatively new analysis intended to assess the likelihood of a project's success that NASA requires for all projects with estimated life-cycle costs greater than $250 million.[27] The JCL combines a project's cost, schedule, and risk profiles and analyzes the probability that its cost will be equal to or less than the planned cost, and its schedule will be on time or sooner than the targeted date. NASA management officials stated that the probabilistic analysis has helped projects such as Juno and GRAIL meet cost and schedule goals.

[26] The primary role of NASA's Independent Program Assessment Office is to facilitate an internal, independent review of the Agency's programs and projects at key decision points in the life cycle to support approval decisions by the Agency leadership and to ensure mission success.

[27] NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012, states that budgets should reflect a 70 percent probability the project could be completed for that budget request or lower and on or before the baseline schedule. At a minimum, projects are to be funded at a level that is equivalent to a confidence level of 50 percent.

According to NASA policy, projects are required to develop JCLs for the project's life-cycle cost and schedule associated with the initial life-cycle baselines. We found that MAVEN's JCL process began approximately 10 months before the Project's October 2010 confirmation, was open and transparent, and included data exchanges and process-check meetings with the Independent Program Assessment Office. Furthermore, although MAVEN was not required to maintain or provide a JCL after confirmation, MAVEN management continued to collaborate with the Independent Program Assessment Office to determine and update the JCL at each of the subsequent life-cycle reviews.

MAVEN's analysis showed an 87 percent JCL that MAVEN would launch on time and within the available budget. MAVEN's SRB performed a parallel JCL assessment at the PDR prior to Mission Confirmation and repeated that exercise for MAVEN's CDR in July 2011 and in each case the Project scored a JCL of at least 91 percent. The SRB also performed MAVEN's System Integration Review (SIR) in June 2012 that also showed a JCL of 92 percent.[28] The summary findings from the SRB assessments are illustrated in Table 2.

Table 2. Summary of Standing Review Board JCL Analysis

SRB Assessments	Assessment Date	Confidence Level of Launching by End of Launch Window	Confidence Level of Launching within Budget Plus Reserves	Joint Cost/Schedule Confidence Level
PDR	August 2010	93%	More than 70%	91%
CDR	August 2011	94%	More than 70%	96%
SIR	August 2012	92%	More than 70%	92%

The relatively high JCL compared with NASA's requirement of 70 percent indicates an overall confidence from the SRB members that MAVEN will be completed on budget and on schedule. The fact that follow-up assessments have reflected similarly strong JCL levels also raises confidence that the results are an accurate reflection of the state of the Project.

Earned Value Management Informs Decision Making. Project managers also used earned value management (EVM) to monitor cost and schedule metrics and make informed management decisions. EVM is an integrated management control system for assessing what a contractor or field activity is achieving with program dollars. EVM

[28] NPR 7120.5E calls for an independent review of the project or program at specified life-cycle milestones. The CDR is held during the latter half of a project's implementation phase and its purpose is to demonstrate the maturity of the design to support proceeding with full-scale fabrication, assembly, integration, and testing. The SIR review evaluates the readiness of the project to start flight system assembly, test, and launch operations and takes place after the CDR and just prior to the beginning of test and integration activities.

integrates technical, cost, and schedule information with risk management; allows objective assessment and quantification of program performance; and helps predict future contractor performance based on trends. EVM is also designed to provide management with objective, accurate, and timely data for effective decision making.

We found that the MAVEN Project's approach to using EVM was consistent with Goddard's best practices for project implementation, was documented in the MAVEN EVM Plan, and met applicable NASA project management requirements. MAVEN Project managers used EVM to evaluate the progress of major components and the Project as a whole, including the observatory and the three instrument packages. Actual costs for MAVEN were imported from the Project's financial system into the earned value cost engine and were used to develop the overall cost estimate. Variances between actual and estimated costs were captured in monthly variance narratives and submitted in monthly status reports. MAVEN's Project manager said this EVM information enabled him to validate data from other sources and quantify the impact of schedule and cost variances.

MAVEN management used EVM to make informed and timely cost and schedule decisions. For example, the Project's cumulative schedule performance indicated that work activities were slightly behind schedule due to unanticipated developmental issues with two of its three instrument suites – the Mass Spectrometer and the Fields Package. In addition, some spacecraft work was delayed while the team waited for personnel from the Juno and GRAIL missions to transition to MAVEN. However, EVM showed that this delayed work resulted in a cumulative cost underrun. Managers used these funds to offset the schedule delays caused by the delay in receiving personnel from Juno and GRAIL. Consequently, managers successfully maintained schedule progress to preserve the required delivery margins, while maintaining adequate schedule margin to meet additional unexpected delays.

MAVEN Project management also used EVM data to identify new project risks and adjust risk characterization based on the likelihood of any given risk occurring. For example, through continuous monitoring of EVM schedule performance and cost performance indices, Project management was able to identify a new cost and schedule risk for development of the Mass Spectrometer more than 6 months prior to it becoming an issue, and therefore were able to take action to reduce the impact of this delay.

Use of "Risk Pool" Funds to Motivate Contractor Performance. One of the relatively new tools that contributed to MAVEN's current success in limiting cost increases and schedule delays was the implementation of a contracting "risk pool." A risk pool is a segment of funds in MAVEN's cost-plus-award fee contract that Project management treats both as unallocated future expenses (UFE) and as part of the Project's budget.[29,30] The Project manager allocates these funds for issues that might reasonably occur within the course of the project where proactive risk mitigation activities are likely to reduce future technical or schedule risk. Examples might include development of spare cards not originally contemplated, or addressing an unexpected and uncharacteristic test issue that was beyond the scope of the testing contemplated when the contract was negotiated. Use of risk pool funds to resolve issues require prior Project manager approval and Project management must adjust the records to show the transfer of UFE to available funds under the contract. However, because these funds are already incorporated as part of the contract, they do not require a costly contract modification that would be required without a risk pool.

Use of the risk pool approach provides the flexibility to maintain UFE at the Project level. With MAVEN, this approach allowed Lockheed Martin to aggressively price its contract for development and operations while limiting the risk of cost overruns due to "known unknowns."[31] During original contract negotiations, Lockheed Martin provided an optimistic base proposal for MAVEN systems acquisition and operations phases, which included an appendix of priced risk items evaluated as part of the final contract's estimated cost. Risk items described in the appendix are specifically excluded from the base proposal and, to the extent that they or similar events occur, generally require allocation of UFE.

Allocation of UFE from the risk pool for a particular issue that was not included in the original Project budget is at the discretion of the MAVEN Project manager. MAVEN Project personnel evaluate risks as they come to fruition and, if the risks are deemed appropriate for coverage by the risk pool, funds are allocated to Lockheed Martin accordingly.

MAVEN is one of the first projects that NASA has implemented using the risk pool concept. According to the Deputy Project Manager/Resources and MAVEN Contracting Officer, use of the risk pool promoted good discussion between Project management and the contractor regarding risk mitigation relative to MAVEN's overarching objectives and streamlined the contract change process; thus, preserving critical schedule days. Based on the tool's success in this Project, NASA officials said they plan to implement a similar

[29] The term unallocated future expense or UFE replaces the now obsolete term previously referred to as "cost reserves." A UFE is the portion of estimated cost required to meet a specified confidence level that cannot yet be allocated to the specific project Work Breakdown Structure sub-elements because the estimate includes probabilistic risks and specific needs that are not known until these risks are realized.

[30] The risk pool approach was proposed and negotiated as part of Lockheed Martin's cost-plus-award-fee contract. NASA did not negotiate the risk pool approach for MAVEN's cost-reimbursement contracts with the universities and as such, unplanned risk mitigation activities are handled as contract changes.

[31] The term "known unknowns" refers to an awareness that there is not a full accounting or understanding of all the issues that will arise during the course of a project.

risk pool strategy in upcoming contract negotiations for the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer mission.[32]

MAVEN's Implementation of Continuous Risk Management. NASA's policy for risk management states that risk "is the potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly established and stated performance requirements."[33] These risks can be related to mission execution or safety, technical, cost, and schedule issues.

NASA's project managers are supposed to use Continuous Risk Management (CRM) as part of their overall risk mitigation process to manage project risks. The CRM process includes six steps:

- Identify: Identify contributors to risk (shortfalls in performance relative to baseline performance requirements);
- Analyze: Estimate the likelihood and consequence of the risk occurring through analysis, including uncertainty in the likelihood and consequence, and, as appropriate, estimate aggregate risks;
- Plan: Decide on risk disposition and handling, develop and execute mitigation plans, and decide what will be tracked;
- Track: Track observables relating to performance measures (e.g., technical performance data and scheduling variances);
- Control: Control risk by evaluating tracking data to verify effectiveness of mitigation plans, making adjustments to the plans as necessary, and executing control measures;
- Communicate and Document: Communicate and document the preceding activities throughout the process.

MAVEN's Risk Management Plan. The MAVEN Risk Management Plan describes the overall risk management process, procedures, and organizational roles for the Project. The plan states that as an integral part of Project management, CRM will assist the Project management team in performing risk-informed decision making, optimizing resource allocation, and coordinating trade studies against cost, schedule, and performance goals. The plan governs the management of risks that the Project may encounter during formulation, implementation, and operation, as well as how technical, cost, schedule, and other forms of risk will be determined, analyzed, managed, and

[32] Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer is a planned NASA mission to launch a spacecraft to an asteroid in September 2016. The mission will use a robotic arm to obtain samples from the asteroid that may better explain the solar system's formation and how life began.

[33] NPR 8000.4A, "Agency Risk Management Procedural Requirements," December 16, 2008.

communicated. The plan further establishes the Risk Management Module as the tool used to manage the Project's CRM process.

The MAVEN Project's Risk Management Module is an automated risk management tool and risk information database developed by Goddard, maintained on an intranet, and customized by the Project to meet its specific requirements and track risk data gathered from a variety of project sources. All Project members have access to the Risk Management Module and are encouraged to use the tool to track risks at the Project, system, subsystem, or instrument level. Any Project member can create a record at any stage during the Project. Management of the Risk Management Module is the responsibility of the MAVEN Risk Management Coordinator.

We found that MAVEN Project management used a consistent and structured methodology for systematically analyzing mission-level risks. Specifically, we found that managers implemented effective controls over the CRM process and all 97 risks recorded in the Project's risk management tool were managed in accordance with applicable requirements. Included among these risks were "High Voltage Arcing in Instruments," "Missed Launch Window in 2013," and "Single Point Failures on High Efficiency Power Supply (HEPS) Card." In addition, risks are included in monthly status reports showing ranking, probability, expected UFE impact by fiscal year, and expected schedule impact.

Project management developed timely and responsive risk mitigation strategies to manage and control Project-level risk exposure. For example, MAVEN Project managers and the Goddard Center Management Council were closely monitoring a mission-level risk entitled "[Mass Spectrometer] Schedule/Cost Performance (medium risk)." MAVEN Project management used EVM data to monitor cost and schedule performance for the risk. Additionally, the Mass Spectrometer instrument delivery schedule for spacecraft assembly, test, and launch operations is reviewed on a monthly basis. The Mass Spectrometer schedule erosion risk is proactively mitigated to gain back schedule reserves by identifying longer workday and weekend work opportunities; careful scrutiny of all remaining tasks and their respective durations by the responsible engineer team leaders; and by working with MAVEN and Goddard management to identify areas for additional support. The Project also carries a lien of $1.2 million for FY 2012 and $400,000 for FY 2013 to mitigate against cost, schedule, and technical risks associated with developing the Mass Spectrometer.

Project Managers Mitigate Single Point Failure Risks. The MAVEN Project contains 34 single-point failures – components or elements that if a failure occurs, the mission fails or is significantly degraded with an adverse impact on Level 1 requirements because of that single failure.[34] Goddard Technical Standards state that risks must be identified, appropriately characterized, managed, and tracked as a means to eliminate single-point failures. From a risk management perspective, acceptance of some single-point failures

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

may be prudent, but it is essential to understand the associated risks and receive approval from senior management. Managers established the following conformance criteria to accept single-point failures in the MAVEN design:[35]

- Passive parts with technical requirements that exceed minimum project specifications;

- Parts used for short flight operational time;

- Impracticality of adding redundancy because of mass, volume, and technical constraints.

Goddard's Technical Standards state that robust design approaches make the elimination of single-point failures desirable. However, when a risk cannot be avoided, projects should take steps to understand the impact of the risk. Special mitigation strategies, such as design change or additional testing, are employed to reduce risk and approval to accept the risk must be received from senior management. In some cases, a design waiver may be warranted to accept the risk if the single-point failure cannot be eliminated from the MAVEN design.

The HEPS Card. All but one of the single-point failure risks, the HEPS card, was accepted based on the Project's conformance criteria. The HEPS card – MAVEN's only power system for the spacecraft – is a complex circuit board. Project officials are concerned about possible HEPS card malfunctions because of its single-point failures and the fact that a single operator, rather than an automated assembly process, is responsible for assembly of the card. Failure of the HEPS card during testing could cause significant cost and schedule impacts. In addition, a failure during flight could result in permanent loss of spacecraft electrical power and mission failure.

The MAVEN team expects senior management to accept the HEPS card single-point failure risk with a waiver of the conformance criteria due to broad analysis, application of robust design margins, extensive testing, and the critical need for the HEPS card as part of the MAVEN design.

Mitigation of HEPS Card Risk. MAVEN Project management commissioned Lockheed Martin to conduct a study on the impact of a redesign and rebuild of the HEPS card. The assessment showed that such a rebuild would involve significant cost, schedule, and technical risks. As a result, the MAVEN Risk Management Board decided to accept the

[35] An accepted risk is defined as a risk that Project management opts to accept on the basis of any of the following criteria: (1) The risk has been mitigated to an acceptable level as deemed by Project management (implies minimal impact to the Project if the risk conditions occur). (2) The risk cannot be further mitigated without undue impact to cost, schedule, or technical performance. (3) The risk lies outside of Project control. (4) No further mitigation options are available for the risk. Note: An accepted risk may be any type of risk, but in all cases, continued efforts to mitigate are not deemed practical.

risk of using the card as designed and to mitigate that risk by employing a number of additional measures.

One of the risk mitigation strategies employed by the MAVEN team was to conduct numerous tests to ensure that the HEPS card functions properly. In addition, a spare HEPS card was transferred from NASA's Juno Project to the MAVEN Project in the event that the primary MAVEN HEPS card failed during testing. Rigorous inspections and testing are also being performed on this secondary HEPS card to ensure that it is ready for use should the primary HEPS card fail. Although the mitigation measures did not eliminate the single-point failure, they did provide some protection against residual risk for on-orbit failure.[36]

Further, Project management completed testing of the secondary flight card and plans additional testing of the HEPS primary card and management plans to continuously monitor the HEPS card risk through completion of the spacecraft environmental testing. The Project's Risk Management Board will subsequently revisit the risk for closure and acceptance. Moreover, the fact that NASA successfully used the HEPS card design on a previous Mars mission illustrates why this single-point failure may justify a waiver to accept the risk since the potential failure cannot be eliminated and the HEPS card is a critical component of the overall MAVEN design.

MAVEN is Well-Positioned to Address Remaining Risks

The Project is currently carrying a higher level of cost and schedule reserves in the final design and fabrication phase of project development than is normally required by Goddard standards. MAVEN Project management has been able to maintain this reserve due to cost underruns that were achieved early in the Project's life cycle. For example, the Mass Spectrometer Team has identified longer workday and weekend work opportunities to gain back schedule reserves using funds from the earlier cost underrun, avoiding the need to use UFE funds to address schedule delays.

One of the primary risks to any Mars mission is the limited launch window. Due to planetary alignment, a mission to Mars has an optimal launch window that occurs only once every 26 months. To mitigate the risk associated with missing MAVEN's launch window and the associated costs related to such a significant schedule delay, the Project manager identified contingency launch days beyond the 20-day launch period (November 18 through December 7, 2013), which increases the launch opportunity to

[36] Residual risk is any accepted risk with the capacity to affect the Mission's ability to meet Level 1 Requirements (full mission success criteria). Residual risks may include: (1) Risks produced by one-time events. (2) Risks imposed by critical maneuvers. (3) Any technical risk accepted on the basis that mitigation options are not viable or are outside MAVEN control. (4) Unknown risks, those risks that exist in all situations, but are not quantified or tracked. A residual risk must always be an accepted risk and one that cannot be further mitigated without undue impact to cost, schedule, or technical performance. At launch, the overall level of residual risk for the MAVEN mission must fall within the level specified for Class B missions by NPR 8705.4 Risk Classification for NASA Payloads.

December 25, 2013. In addition, officials at the Kennedy Space Center contracted with United Launch Alliance to analyze the cost impact of the extra days and developed trajectory data should the launch date slip beyond the primary 20-day period. MAVEN Project management has appropriately incorporated a risk in the risk management database system and accordingly recorded the potential use of $2.5 million of contingency funding for a launch date slip to a date within the extended launch period.

MAVEN Project managers have not developed a contingency plan for missing the entire launch period and having to stand down for 26 months until Mars and Earth are once again in their optimum positions for another launch attempt. Management identified and carried the risk of missing the launch window early in the Project's development. Accordingly, Project management developed a risk mitigation plan that included enough schedule margin to accommodate late instrument delivery without impacting overall schedule and establishing incentive milestones in the contract structure to complete key milestones early. In addition, critical path instruments were allotted additional schedule reserve.[37] According to Project managers, the JCL analysis, and SRB assessments, the likelihood of missing the 2013 launch period entirely has a low probability of occurring. As a result of these mitigation strategies and the overall concurrence that the risk has a low probability of occurring, the risk was accepted and closed in October of 2010.

One of the mitigation strategies that Project management formulated to avoid missing the launch period was development of a descope plan with decision gates on the master schedule and a mission concept that provides flexibility to launch without any one of the three instruments while still meeting Level 1 science requirements. In addition, UFE funds and schedule margins are available as a result of effective project management, proactive management of contract cost negotiations, and steady funding throughout the Project's life cycle. Against its cost to complete development estimate, MAVEN Project management has consistently maintained UFE above Goddard standards.[38] Furthermore, management created incentive milestones in the contract schedule to complete milestones early and developed an integrated schedule with schedule margin and schedule reserves across all hardware elements comparable to previously successful missions. Cumulatively, MAVEN managers employed these strategies to prevent MAVEN from missing the launch window.

As of December 2012, the MAVEN Project was moving toward its systems integration and testing phase. Integration of project components and subsystems requires assembly of hardware and software elements into operational assemblies or systems. Due to the complexity of space systems, integration and testing may produce unexpected results that

[37] Instruments determined to be on the critical path must be completed on schedule to avoid a delay in the overall project schedule.

[38] Goddard Procedural Requirements 7120.7, "Schedule Margins and Budget Reserves to be Used In Planning Flight Projects and In Tracking Their Performance," May 4, 2008. For example, at the start of Phase B in October 2009, management had 30.9 percent budget reserves compared to the 30 percent goal. In March of 2012, during Phase C, management had 31.7 percent in reserve compared to the 25 percent goal. As of November 2012, management was maintaining approximately 32 percent budget reserve compared to the 25 percent goal, and 2.6 months of schedule margin.

will require further analysis, testing, or design changes. For example, the process of adding magnetic shielding to the altitude control system thruster brackets may result in additional modeling, model validation, and additional testing. Although risks remain to MAVEN's cost, schedule, and technical performance, in our judgment project reserves remain adequate to mitigate against most unforeseen expenses and events.

Conclusion

Project management's experienced leadership team, use of heritage technologies, implementation of sound project management practices (including the use of JCL), innovative contract management practices, and aggressive risk mitigation strategies have enabled MAVEN to overcome common NASA project management challenges and minimize cost increases and schedule delays. While risks remain as the Project transitions into testing and integration, management has placed the Project on a solid path to achieving its cost, schedule, and performance goals.

Recommendations, Management's Response, and Evaluation of Management's Response

Although we did not offer any recommendations to the MAVEN Project team, in a draft of this report we encouraged the Associate Administrators for NASA's Mission Directorates and the Chief Engineer to analyze MAVEN's project management successes, identify what tools have helped minimize common project development issues, and apply these lessons to other NASA development projects.

The Associate Administrator for the Science Mission Directorate agreed and stated that post-launch the Directorate would work with the Chief Engineer to capture lessons learned and disseminate them using NASA's knowledge sharing tools, including inclusion in the lessons-learned database, publication in the NASA Engineering Network communities, inclusion in an ASK Magazine article, and as a case study conducted by the Agency Chief Knowledge Officer. He also stated that following those activities, the Directorate will use one of its monthly Program Executive Forums to share lessons learned with other projects. Management's full response is reprinted in Appendix B.

APPENDIX A

Scope and Methodology

We performed this audit from March 2012 through January 2013 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 obtained and reviewed NPD 7120.4D, "NASA Engineering and Program/Project Management Policy;" NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements;" and NPR 8000.4, "Agency Risk Management Procedural Requirements." We performed our fieldwork at Goddard Space Flight Center. We interviewed Goddard MAVEN Project personnel to identify issues relevant to our audit.

Use of Computer-Processed Data. To meet our audit objectives, we relied on data obtained from the MAVEN Risk Management Database. To assess the reliability of the data, we reviewed and evaluated all the risks recorded in the database for compliance with NASA and Project requirements. Based on our professional judgment we selected a sample of those risks and directed specific questions to the Project manager to corroborate the information recorded in the database. We conducted an interview with the Project's reliability engineer to determine if each of the single-point failure risks entered into the database were adequately managed and to corroborate what was stated in the risk management database regarding those specific risks. We obtained information via questionnaires directed to the Project manager and the mission system engineer to determine adequacy of controls over the Project's CRM process. We conducted an interview with and obtained documentation from the Chief of Mission and Safety Assurance at Goddard to determine adequacy of controls over the Project's internally generated Problem Reports and Problem Failure Reports. We concluded that the data was sufficiently valid and reliable to support our audit conclusions.

Review of Internal Controls

We reviewed MAVEN Project management's compliance with spaceflight program and project management requirements. We evaluated the Project's internal monitoring controls for compliance with the NPR 7120.5E process. We interviewed Government personnel with oversight responsibilities for the NASA policy requirements. We determined that the Project has an adequate process-monitoring control.

Prior Coverage

During the past 5 years, the NASA OIG issued one report and the Government Accountability Office (GAO) issued two reports of particular relevance to the subject of this report. Unrestricted NASA and GAO reports can be accessed at http://oig.nasa.gov and http://www.gao.gov.

NASA Office of Inspector General

"NASA's Challenges to Meeting Cost, Schedule, and Performance Goals" (IG-12-021, September 27, 2012)

Government Accountability Office

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

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

MANAGEMENT COMMENTS

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

FEB 19 2013

Reply to Attn of: Science Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Science Mission Directorate

SUBJECT: Response to OIG Draft Report, "*Mars Atmosphere and Volatile Evolution (MAVEN) Project*" (Assignment No. A-12-014-00)

The Science Mission Directorate (SMD) appreciates the opportunity to review and provide comments on the Office of Inspector General (OIG) draft report entitled, "*Mars Atmosphere and Volatile Evolution (MAVEN) Project*" (Assignment No. A-12-014-00), dated January 25, 2013.

In the draft report, the OIG concludes that the Project management's experienced leadership team, use of heritage technologies, implementation of sound project management practices (including the use of Joint Cost and Schedule Confidence Level), innovative contract management practices, and aggressive risk mitigation strategies have enabled MAVEN to overcome common NASA project management challenges and minimize cost increases and schedule delays. While risks remain as the Project transitions into testing and integration, management has placed the Project on a solid path to achieving its cost, schedule, and performance goals, and we are looking forward to the successful launch of MAVEN this fall.

While the draft report contains no specific recommendations to NASA, the OIG encourages the Associate Administrators for NASA's Mission Directorates and the Chief Engineer to analyze MAVEN's project management successes, identify what tools have helped project management minimize common project development issues, and apply these lessons to other NASA development projects. NASA agrees with the recommendation to share the lessons learned from MAVEN to support the success of future missions.

NASA's Office of the Chief Engineer will work with the Science Mission Directorate to conduct a lessons-learned session postlaunch. Following the session, these lessons learned will be promulgated to other Agency projects through several different mechanisms, specifically, an ASK Magazine Article, inclusion of the lessons learned into the lessons-learned database, publication in applicable NASA Engineering Network communities of practice, and inclusion in applicable courses in addition to sharing in various forums, such as the Program and Project Management Board. The NASA Chief Knowledge Officer will also identify MAVEN for a Case Study that will capture and share associated lessons learned and best practices. Once these activities have been completed, the SMD will use one of its monthly Program Executive Forums as an opportunity to share the findings with other projects.

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If you have further questions or require additional information on the NASA response to the draft report, please contact Ellen Gertsen at 202-358-0812.

Charles J Gay

for Dr. John Grunsfeld

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    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

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