

February 2005

NASA'S SPACE VISION

Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources



G A O

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Highlights of [GAO-05-242](#), a report to congressional requesters

Why GAO Did This Study

In 2003, the National Aeronautics and Space Administration (NASA) initiated the Prometheus 1 project to explore the outer reaches of the Solar System. The Prometheus 1 spacecraft is being designed to harness nuclear energy that will increase available electrical power from about 1,000 watts to over 100,000 watts and enable the use of electric propulsion thrusters.

Historically, NASA has had difficulty implementing some initiatives. NASA's failure to adequately define requirements and quantify the resources needed to meet those requirements has resulted in some projects costing more, taking longer, and achieving less than originally planned. Prometheus 1 will need to compete for NASA resources with other space missions—including efforts to return the shuttle safely to flight and complete the International Space Station.

GAO was asked to determine (1) whether NASA is establishing initial justification for its investment in the Prometheus 1 project and (2) how the agency plans to ensure that critical technologies will be sufficiently mature at key milestones.

What GAO Recommends

GAO is making recommendations aimed at ensuring that NASA prepares a sound business case for Prometheus 1. NASA concurred with our recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-05-242.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Allen Li at (202) 512-3600 or Lia@gao.gov.

NASA'S SPACE VISION

Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources

What GAO Found

NASA is in the process of establishing initial justification for its investment in the Prometheus 1 project but faces challenges establishing preliminary requirements and developing accurate cost estimates. Decision makers will not get their first comprehensive picture of the project's requirements and the resources needed to meet those requirements until the preliminary mission and systems review, scheduled for summer 2005. Defining the project's requirements and developing life-cycle cost estimates by then could be challenging, given the short time frames. The fidelity of this information should improve by the preliminary design review scheduled for 2008. At that time, NASA has the opportunity to use these more refined requirements and cost estimates to establish a sound business case for its investment in the Prometheus 1 project. According to Prometheus 1 project management, a flat funding profile is inadequate to ramp up for the planned 2015 launch of Prometheus 1, the project's first spacecraft to its original destination of Jupiter's Icy Moons. By matching requirements to resources a sound business case would allow NASA to determine whether trade-offs in the design of the spacecraft or the agency's expectations are needed to avoid outstripping available resources. Significant program cost and schedule increases in past programs can be traced to not matching requirements with resources at preliminary design review.

While development of the Prometheus 1 technologies is under way, each will require extensive advancement before they are mature enough to support reliable cost estimates. NASA is preparing technology development plans that include measurable criteria to ensure the Prometheus 1 technologies are on track for meeting NASA's maturity requirements through the end of the preliminary design phase.

GAO's best practices work has shown, however, that establishing a formal business case based on a knowledge-based approach that includes matching requirements and available resources—which include technical and engineering knowledge, time, and funding—and controls to ensure that sufficient knowledge has been attained at critical junctures within the product development process is an essential part of any product development justification. NASA's current policy does not require projects to develop knowledge-based business cases that match requirements to available resources and include controls to ensure that sufficient knowledge has been attained. Therefore, the agency had not planned to develop such a business case for Prometheus 1.

Since GAO provided our draft report to NASA for comment, the agency released its fiscal year 2006 budget request that includes changes to Prometheus 1. If properly implemented, these changes could be positive steps in addressing the findings and recommendations in this report.

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Abbreviations

AR&D	autonomous rendezvous and docking
JIMO	Jupiter Icy Moons Orbiter
JPL	Jet Propulsion Laboratory
MCT	maturity criteria tables
NASA	National Aeronautics and Space Administration
PDR	preliminary design review
PMSR	preliminary mission and systems review
SLI	Space Launch Initiative
TRL	technology readiness levels

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United States Government Accountability Office
Washington, DC 20548

February 28, 2005

The Honorable Daniel K. Inouye
Co-Chairman
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable John McCain
United States Senate

In 2003, the National Aeronautics and Space Administration (NASA) initiated the Prometheus 1 project to explore the outer reaches of the Solar System in the hopes of finding answers to some of humankind's most profound questions about life and its origins. The Prometheus 1 spacecraft is being designed to harness nuclear energy that will efficiently increase available electrical power from about 1,000 watts to over 100,000 watts and enable the use of electric propulsion thrusters. The availability of nuclear power at this magnitude will fundamentally change NASA's capability to explore deep space.

While NASA has been successful in missions such as Mars Pathfinder and Exploration rovers, the agency has had difficulty implementing a number of other costly initiatives because it was overly optimistic in what could be achieved within available resources. NASA's failure to adequately define requirements and quantify the resources needed to meet those requirements has resulted in some projects costing more, taking longer, and achieving less than originally planned. Prometheus 1 will compete for NASA resources with other space missions—including, in the near term, efforts to return the shuttle safely to flight and completing the International Space Station.

Cognizant of the outlook for a constrained federal budget for the foreseeable future and NASA's difficulty in implementing some major programs within projected resources, you asked us to review the Prometheus 1 project to determine (1) whether NASA is establishing initial justification for its investment in the Prometheus 1 project and (2) how the agency plans to ensure that critical technologies will be sufficiently mature at key milestones.

To address our objectives, we obtained and reviewed Prometheus 1 plans, schedules, risk assessments, budget documentation, technology maturity

assessments, and technology development plans. We conducted further qualitative and quantitative analyses of these documents and compared them to criteria established in NASA and Jet Propulsion Laboratory (JPL) policies governing development programs and in GAO's best practices body of work (see GAO Related Products). Our work was conducted between April 2004 and January 2005 in accordance with generally accepted government auditing standards.

Since our draft report was provided to NASA for comment, a significant change has been made to the Prometheus 1 project. NASA's fiscal year 2006 budget request includes changes to the Prometheus 1 project that directly address the findings and recommendations of this report. These changes are briefly outlined in the Agency Comments section of this report.

Results in Brief

NASA is in the process of establishing initial justification for its investment in the Prometheus 1 project but faces challenges preparing preliminary requirements and cost estimates. NASA wants to have a defined set of preliminary system requirements and an initial estimate of the life-cycle cost for Prometheus 1 by summer 2005—when the project enters into the preliminary design phase. While the project office has drafted cost guidelines and a technical baseline for use in developing an initial life-cycle cost estimate, due to the early nature of the project, the development of this estimate is just under way. Before Prometheus 1 can move forward into the preliminary design phase, NASA must make funding decisions. At this time, however, the level of funding NASA needs to execute the project is not fully defined. NASA requested \$438 million for fiscal year 2005, but according to project officials, the “flat line” estimate for the next few years would need to be increased to reflect project needs of a mission to Jupiter's Icy Moons. A business case providing an understanding of the potential return on such investment would be helpful to decision makers for determining whether continued investment—currently estimated by the Congressional Budget Office at about \$10 billion¹—is warranted. Developing a sound business case that includes matching requirements with expected resources, would enable NASA to make early trade-offs either in the preliminary design of the spacecraft or in the agency's expectations to avoid outstripping available resources. While NASA will

¹This estimate is based on conducting the Jupiter Icy Moons Orbiter Mission. The Congressional Budget Office did not consult with NASA to develop this estimate.

have information available to match preliminary requirements to expected resources, the fidelity of this information is not expected to be completely defined until the preliminary design review (PDR), currently scheduled for 2008.

NASA plans to ensure critical technologies are mature by demonstrating subsystem prototypes before the end of the preliminary design phase. There are several technologies, however, whose maturity will influence NASA's ability to develop initial requirements and reliable resource estimates. The Prometheus 1 design conceived for the mission to Jupiter's Icy Moons relied on advancements in several breakthrough technologies, including nuclear electric power and propulsion, high power communications, radiation-hardened electronics, and autonomous rendezvous and docking (AR&D). NASA is preparing technology development plans that include measurable criteria to ensure each technology is on track for meeting the maturity requirements through the end of the preliminary design phase. While development of these technologies is under way, each will require extensive advancement before they are mature enough to provide the revolutionary capabilities of the Prometheus 1 spacecraft.

Our past work on the best practices of product developers in government and industry has found that development of a sound business case based on matching requirements to resources is a key factor in successfully addressing such challenges. Despite the fact that the Prometheus 1 project is in the very early stages of development, the use of a sound business case that includes well-defined requirements, realistic cost estimates, and mature technology is an essential part of any product development investment justification. NASA's current policy does not require projects to develop formal knowledge-based business cases that match requirements to available resources and include controls to ensure that sufficient knowledge has been attained. NASA had not planned to develop such a business case. Subsequent to our draft being provided to NASA for comment, the agency announced in its fiscal year 2006 budget request that it was conducting an analysis of alternatives to identify a new mission with reduced technical, schedule, and operational risk. As NASA will be establishing a new justification for the Prometheus 1 project, we are recommending that the NASA Administrator establish a sound business case for the Prometheus 1 project wherein resources are matched to requirements and controls are in place to ensure that sufficient knowledge has been attained at critical phases of the product development process.

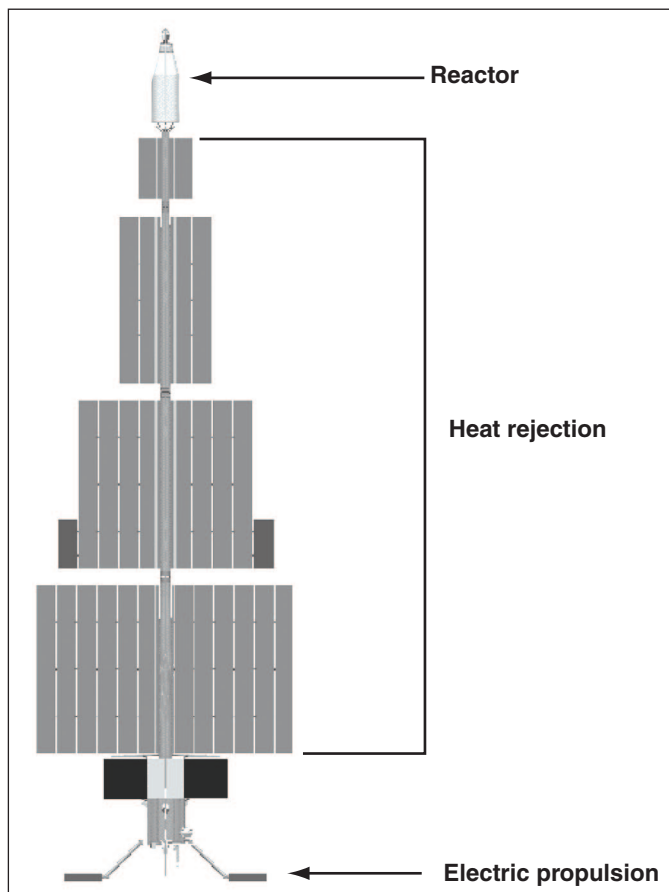
Background

The Prometheus 1 project is part of NASA's Prometheus Nuclear Systems and Technology program² to develop nuclear power technologies capable of providing power and propulsion for a new generation of missions. The Prometheus 1 spacecraft is being designed to use nuclear power and electric propulsion technologies to explore the outer reaches of the solar system. The Jupiter Icy Moons Orbiter (JIMO) mission—a 4 to 6-year study of three of Jupiter's moons: Callisto, Europa, and Ganymede—was the original destination identified by NASA.³ The JIMO mission's overarching science objectives were to (1) investigate the origin and evolution of the three moons; (2) scout their potential for sustaining life; and (3) determine the current rate of movement of surface ice and the rates at which the moons are weathered. With an unprecedented level of power, Prometheus 1, the first in a potential series of spacecraft, is expected to support the use of high capability science instruments and high power communications systems to provide scientists with an unprecedented amount of scientific information. Figure 1 depicts the notional Prometheus 1 spacecraft.

²The Prometheus Nuclear Systems and Technology program stems from the former Nuclear Systems Initiative to develop nuclear power for deep space exploration.

³Subsequent to being provided a draft of this report for comment, NASA announced that it was conducting an analysis of alternatives to identify a new mission.

Figure 1: Prometheus 1 Spacecraft



Source: NASA.

NASA contracted with the Jet Propulsion Laboratory (JPL) to manage the Prometheus 1 project and to manage development of the science mission payload. In turn, JPL awarded a \$400-million contract for the initial development of the Prometheus 1 spacecraft to Northrop Grumman Space Technology in September 2004. NASA is collaborating with the Department of Energy's Office of Naval Reactors to develop and handle all issues related to the spacecraft's nuclear reactor.

The Prometheus 1 project will have to compete for funding with other NASA programs. In January 2004, the President charged NASA with implementing a new strategy for space exploration—which includes the Prometheus 1 project—while simultaneously returning the shuttle to flight status and completing the International Space Station. NASA laid out its

plan for implementing the strategy in its fiscal year 2005 budget request. In essence, NASA's implementation plan holds aeronautics, science, and other activities at near constant levels and transitions funding levels currently dedicated to the Space Station and shuttle programs to the space exploration strategy as the Space Station and shuttle programs phase out. This plan was predicated upon NASA's annual funding level receiving increases to about \$18 billion a year by fiscal year 2008 and then remaining near that level, except for inflation, through at least 2020.

Best Practices Reveal Elements of a Sound Business Case for Product Development

In the last several years, we have undertaken a best practices body of work on how leading developers in industry and government use a knowledge-based approach to develop products that reduces risks and increases the likelihood of successful outcomes. Development of a sound business case based on this best practices model enables decision makers to be reasonably certain about their products at critical junctures during development and helps them make informed investment decisions.

Our best practice work has shown that developing a sound business case based on matching requirements to resources is essential to implementing a knowledge-based approach. A sound business case includes the following elements

- well-defined requirements,
- preliminary design,
- realistic cost estimates, and
- mature technology.

A knowledge-based business case also involves the use of controls or exit criteria to ensure that the required knowledge has been attained at each critical juncture. It ensures that managers will (1) conduct activities to capture relevant product development knowledge, (2) provide evidence that knowledge was captured, and (3) hold decision reviews to determine that appropriate knowledge was captured to allow a move to the next phase. If the knowledge attained at each juncture does not confirm the business case on which the effort was originally justified, the program does not go forward.

Use of this approach has enabled leading organizations to deliver high quality products on time and within budget. Product development efforts that have not followed a knowledge-based business case approach can be frequently characterized by poor cost, schedule, and performance outcomes.

Although NASA does not require projects to develop a formal business case based on matching requirements to resources, JPL project implementation policy,⁴ which establishes JPL's institutional structure for implementation and management of JPL flight projects in accordance with NASA policies, does require projects to develop documentation that includes elements essential to a sound business case. For example, before entering the preliminary design phase, JPL projects are required to develop preliminary requirements, a conceptual design, realistic cost estimates, and technology development plans. JPL projects are required to update and improve the fidelity of information in these documents by PDR. The information in these documents could provide NASA decision makers with the information necessary to support sound business case decisions based on matching requirements to resources at preliminary mission and systems review (PMSR) and PDR.

In September 2004, the Congressional Budget Office reported that if NASA's costs for implementing the strategy were similar to prior analogous NASA programs—such as Apollo, Viking, and Mars Exploration Rover—NASA's funding needs could increase by 15 to 23 percent—or \$40 billion to \$61 billion—over the 16-year estimate. The Congressional Budget Office concluded that if funding were held constant, NASA would likely have to either eliminate mission content or delay schedules.

Initial Justification for Prometheus 1 Project Could Form the Basis of a Sound Business Case

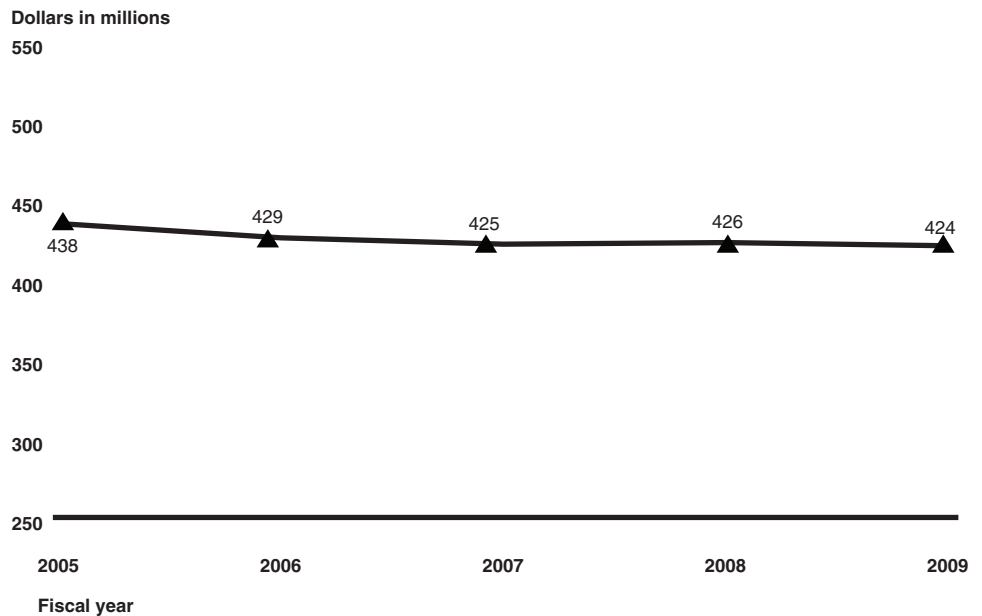
NASA is still in the process of preparing initial justification for the Prometheus 1 project to enter the preliminary design phase. Consequently, at this time the level of funding NASA needs to execute the project is not fully defined. According to project officials, however, funding levels would need to be increased to support the planned launch of Prometheus 1 to Jupiter's Icy Moons. While NASA plans to have defined preliminary system requirements and an initial estimate of the life-cycle cost for Prometheus 1 by summer 2005—when the project enters the preliminary design phase—the agency faces significant challenges in doing so.

⁴JPL's Project Implementation Policy establishes JPL's institutional structure for implementation and management of JPL flight projects in accordance with NASA Procedural Requirements 7120.5B, NASA Program and Project Management Processes and Requirements, which governs all NASA development programs and projects.

Project Management Believes Current Funding Is Insufficient to Support Launch of Prometheus 1

According to Prometheus 1 project management, current funding is inadequate to support a 2015 launch of Prometheus 1 as initially planned. Following small funding increases from fiscal years 2005 through 2007, the budget profile⁵ becomes relatively flat through fiscal year 2009 (see fig. 2). Project officials believe that the current profile would need to be increased beginning in fiscal year 2007 to reflect project needs of a Jupiter Icy Moons mission. Decision makers will not get their first comprehensive picture of the project's requirements and the resources needed to meet those requirements—the first basis for funding decisions—until PMSR scheduled for summer 2005. While the fiscal year 2006 request includes an updated Prometheus 1 funding profile, a funding profile based on life-cycle cost estimates—which NASA plans to have when it enters the preliminary design phase—will not be included until NASA's fiscal year 2007 request.

Figure 2: NASA Prometheus 1 Fiscal Year 2005 Budget Request Profile



Source: GAO.

⁵Between 10 and 15% of the budget shown is allocated to Advanced Systems and Technology Development activities supporting current and future missions.

Short Time Frames and History Foretell Difficulty in Defining Requirements and Developing Life-Cycle Cost Estimates

The Prometheus 1 project office is required to develop preliminary requirements by PMSR. Defining the project's requirements and developing life-cycle cost estimates by then could be challenging, given the short time frames and NASA's past difficulties developing requirements and estimates. While it is not unusual for a project at this stage in acquisition to still be defining requirements, several factors could make it difficult for NASA to develop preliminary requirements by PMSR. The contractor, Northrop Grumman, was only recently selected, and according to project officials, input from both the contractor and Office of Naval Reactors is needed to finalize the preliminary ground, space, and launch systems requirements mandatory for PMSR. In addition, NASA continues to refine its requirements. For example, Prometheus 1 project management increased requirements for reactor lifetime, reactor power, and propellant tank capacity to ensure that the Prometheus 1 spacecraft and reactor designs could be used to support follow-on missions. Currently, project managers are working with broad NASA requirements for deep space exploration and more refined project requirements specific to the Prometheus 1 ground, space, and launch systems.

NASA is also required to have an initial life-cycle cost estimate for Prometheus 1 at PMSR.⁶ However, because the estimate is based on a conceptual design, preliminary system requirements, and detailed technology development plans that are not yet complete, it will be difficult for NASA to develop an estimate in the short time available by PMSR.

The project office is working with Northrop Grumman to merge and finalize the conceptual design. Once the conceptual design is finalized, the project office will update the work breakdown structure⁷ and develop a "grass roots" estimate of the spacecraft cost. However, project officials do not expect to receive cost estimates from the Office of Naval Reactors and Northrop Grumman, which are also needed to develop the estimate, until the end of February 2005. The JPL Costing Office will prepare a separate cost estimate based on its experiences with prior programs, and both JPL and NASA will contract for additional independent cost estimates.

⁶NASA guidance requires that life-cycle costs be estimated, assessed, and controlled throughout a program's life cycle. The estimates are to be prepared to support major program reviews and the development of budget submissions.

⁷A work breakdown structure is a product oriented division of hardware, software, services and project unique tasks that organizes and defines the product to be developed and serves as the basis for estimating both cost and schedule.

Adding to these complexities, NASA has historically had difficulty establishing life-cycle cost estimates. In May 2004, we reported that NASA's basic cost-estimating processes—an important tool for managing programs—lack the discipline needed to ensure that program estimates are reasonable.⁸ Specifically, we found that 10 NASA programs that we reviewed in detail did not meet all of our cost-estimating criteria—based on criteria developed by Carnegie Mellon University's Software Engineering Institute. Moreover, none of the 10 programs fully met certain key criteria—including clearly defining the program's life cycle to establish program commitment and manage program costs, as required by NASA. In addition, only three programs provided a breakdown of the work to be performed. Without this knowledge, we reported that the programs' estimated costs may be understated and thereby subject to underfunding and cost overruns, putting programs at risk of being reduced in scope or requiring additional funding to meet their objectives. In this report we recommended that NASA take a number of actions to improve its cost-estimating practices. NASA concurred noting that our recommendations validated and reinforced the importance of activities underway at NASA.

**Business Case Allows
Match of Needs to
Resources and Facilitates
Informed Decision Making**

By PDR—which occurs at end of the preliminary design phase and is scheduled for 2008—the fidelity of the information is expected to improve and could allow NASA to develop a business case that would match requirements with resources and provide decision makers with the information needed to determine whether continued investment in the project is warranted. However, in the past NASA has had difficulties developing the realistic requirements and cost estimates needed to develop a sound business case.

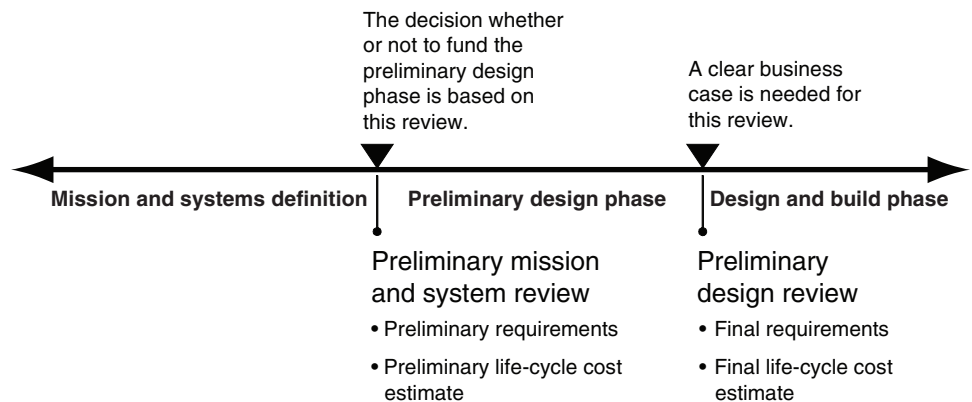
To help ensure program requirements do not outstrip resources, leading commercial firms obtain the right knowledge about a new product's technology, design, and production at the right time. We have issued a series of reports⁹ on the success these firms have had in estimating the time and money to develop new and more sophisticated products—the kinds of results that NASA seeks. Our best practice work has shown that developing business cases based on matching requirements to resources

⁸GAO, *NASA: Lack Of Disciplined Cost Estimating Processes Hinders Effective Program Management*, [GAO-04-642](#) (Washington, D.C.: May 28, 2004).

⁹GAO, *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, [GAO-01-288](#) (Washington, D.C.: Mar. 8, 2001).

before program start leads to more predictable program outcomes—that is, programs are more likely to be successfully completed within cost and schedule estimates and deliver anticipated system performance.

Figure 3: Prometheus 1 Milestone Reviews



Source: GAO.

A sound business case includes the following elements—well-defined requirements, a preliminary design, realistic cost estimates, and mature technology. While NASA does not require projects to develop a formal business case based on matching requirements to resources, JPL policy, which implements NASA policy, does require projects to develop documentation that could support formulation of a sound business case. Before a JPL project enters the preliminary design phase, JPL project implementation policy requires that the project develop preliminary requirements, a conceptual design, realistic cost estimates, and technology development plans. This policy also requires that the fidelity of information in these documents improve by PDR.

The requirements and resource estimates NASA is developing for PMSR could form the basis for an initial business case based on matching Prometheus 1 requirements to available resources. However, Prometheus 1 project management plans to continue directing requirements changes to accommodate follow-on missions. While our work shows that the preliminary design phase is the appropriate place to conduct systems engineering to support requirement/cost trade-off decisions, NASA needs to remain cognizant that adding requirements could increase cost and risk. In addition, NASA has had past difficulty developing the realistic requirements and cost estimates needed to develop a sound business case. These difficulties have resulted in the termination of several major efforts

after significant investment of resources. For example, in 2002 NASA terminated the Space Launch Initiative (SLI) program—a \$4.8 billion, 5-year program to build a new generation of space vehicles to replace its aging space shuttle. SLI was a complex and challenging endeavor for NASA, both technically and from a business standpoint. The SLI program faced some of the same challenges that Prometheus 1 is struggling with today, such as the need to develop and advance new airframe and propulsion technologies. SLI did not achieve its goals, in part, because NASA did not develop realistic requirements and cost estimates.

NASA's Plans to Ensure Mature Technologies Rely on Prototype Demonstrations

Leading firms make an important distinction between technology development and product development. Technologies that are not mature continue to be developed in the technology base—they are not included in a product development. Our best practices work has also shown that there is a direct relationship between the maturity of technologies and the accuracy of cost and schedule estimates. NASA's Prometheus 1 technologies are currently immature. The Prometheus 1 project office is preparing technology development plans to guide the development of each key technology during the preliminary design phase.

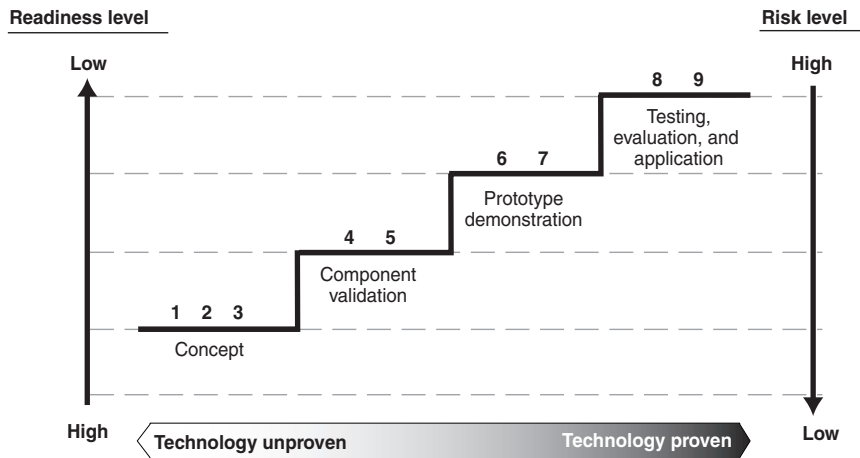
Mature Technologies Are Key to Minimizing Risk

Maturing technologies during the preliminary design phase is a key element of matching needs to resources before entering the product development phase. Our best practices work has shown that technology readiness levels¹⁰ (TRL)—a concept developed by NASA—can be used to gauge the maturity of individual technologies (see fig. 4).¹¹ (See app. I for detailed definition of TRLs.) Specifically, TRL 6—demonstrating a technology as a fully integrated prototype in a realistic environment—is the level of maturity needed to minimize risks for space systems entering product development.

¹⁰Technology readiness levels characterize the readiness of technologies for handoff to project implementers. Nine levels are defined representing concepts from fundamental research level through technologies fully qualified and demonstrated in flight.

¹¹GAO, *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, [GAO-04-386SP](#) (Washington D.C.: January 2004).

Figure 4: Technology Maturity Levels for Product Development



Source: GAO.

While development of Prometheus 1 critical technologies is under way, the technologies will require extensive advancement before they are mature enough to provide the revolutionary capabilities of the Prometheus 1 spacecraft. The overall technology objective for Prometheus 1 is to safely develop and operate a spacecraft with a nuclear-reactor-powered electric propulsion system. To achieve this objective, the spacecraft will require advancement in several technology areas, including, nuclear electric power, power conversion and heat rejection systems, nuclear electric propulsion, high power communications, radiation-hardened electronics, and AR&D. (See app. II for a more detailed explanation of these technologies.) NASA's fiscal year 2005 budget request indicates that these technologies are either at TRL 3 (individual technologies have been demonstrated in a laboratory environment) or TRL 4 (system components have been demonstrated in a laboratory environment). Before NASA conducts the PDR in 2008, it will need to mature the technologies—each of which comes with a unique set of engineering challenges.

To gauge the maturation of the Prometheus 1 technologies, the Prometheus 1 project office is preparing technology development plans, which rely on the use of maturity criteria tables (MCT), a concept similar

to TRLs.¹² The specific maturation criteria for each technology vary greatly, but all technologies are to be matured by PDR to the point that

- developmental models are complete,
- all major risks to each technology are retired,
- all major manufacturing issues are resolved, and
- plans for obtaining life data that will provide confidence that the hardware will meet the mission lifetime requirements are in hand.

Prometheus 1 project officials believe these criteria roughly correspond to a TRL 5 (component and/or breadboard validation in a relevant environment) or a TRL 6 (system/subsystem model or prototype demonstration in a relevant environment). The program office's position is that using MCTs that are equivalent to TRL 5 and TRL 6 at PDR is appropriate because the program office is both the technology developer and product developer and, as such, has a thorough understanding of how mature the technologies need to be at certain points in time as the program progresses. Nevertheless, the dual role of project office as both technology and product developer is not unique, and our best practices body of work shows that a TRL 6 is the level of maturity needed to minimize risks for space systems entering product development.

Conclusions

NASA is quickly approaching one of the most critical phases in its acquisition of Prometheus 1—the preliminary design phase. While the impetus for the changes made to the program—subsequent to our providing a draft of this report to NASA for comment—recognize the technical, schedule, and operational risk of this program, there is still much work to be done. Based on the information presented at PMSR, now scheduled for summer 2005, NASA will need to decide at what level to fund the project. However, NASA will be challenged to develop the information required at PMSR, given the compressed time frames. Although PDR is still several years out, NASA will face significant challenges in meeting this milestone, given the immaturity of the revolutionary technologies that NASA anticipates will be needed to

¹² According to the Prometheus project office, the MCT [system], [also developed by NASA], is an improvement over the TRL [system] because MCT definitions are more detailed and quantifiable and, therefore, provide more clarity to technology developers, managers, and independent reviewers. Project office officials also note that the criteria in the tables have been reviewed through an independent peer assessment to validate that they provide the comprehensive set of measurements that need to be made to verify that a particular maturity has been met in a specific technology.

successfully launch Prometheus 1. While NASA is developing well-defined criteria tables for maturing Prometheus 1 technologies, the many inherent unknowns in developing technologies frequently results in unanticipated difficulties and delays. NASA's current policy does not require projects to develop knowledge-based business cases that match requirements to available resources and include controls to ensure that sufficient knowledge has been attained and therefore the agency had not planned to develop such a business case for Prometheus 1. We have found, however, that establishing a formal business case based on a knowledge-based approach that includes matching requirements and available resources—which include technical and engineering knowledge, time and funding—and controls to ensure that sufficient knowledge has been attained at critical junctures within the product development process is an essential part of any product development justification. The risk associated with failing to meet these challenges is considerable. If NASA decides to move forward without adequate information at PMSR—that matches requirements and available resources and provides NASA decision makers with a clear understanding of Prometheus 1's potential return on investment—Prometheus 1 may be unable to compete for funding within NASA. Ultimately, NASA could find, as it has in the past, that the program must be cancelled after having invested millions of dollars.

Recommendations for Executive Action

We recommend that the NASA Administrator take the following two actions:

- identify at PMSR the level of resources the agency is committing to the project and direct project officials to develop project requirements based on this resource constraint and
- ensure that prior to proceeding beyond PDR (currently planned for 2008) a sound business case is established which includes confirmation that (1) critical technologies have been successfully demonstrated as mature, (2) systems engineering has been conducted to support requirements/cost trade-off decisions, (3) requirements and resource estimates have been updated based on the results of the preliminary design phase, (4) knowledge based criteria are established at each critical juncture to ensure that relevant product development knowledge is captured, and (5) decision reviews are held to determine that appropriate knowledge was captured to allow a move to the next phase.

Agency Comments

In written comments on a draft of this report, NASA's Deputy Administrator stated that the agency concurs with the recommendations, adding that the recommendations validate and reinforce the importance of activities underway at NASA to improve NASA's management of complex technical programs.

Subsequent to our draft report being provided to NASA for comment, significant changes were made to the Prometheus 1 project. NASA's fiscal year 2006 budget request includes changes to the Prometheus 1 project that directly address the recommendations in this report. According to NASA's budget justification, the agency is planning a less complex mission than the original JIMO mission. According to program officials who we consulted with following the release of the budget, eliminating the long reactor lifetime, stringent radiation hardening, multiple launches, and AR&D required for the JIMO mission will allow NASA "to walk before it runs" and significantly reduce cost and technical risks. As a result, NASA has delayed PMSR until summer 2005 and is conducting an analysis of alternatives to identify a relevant mission with reduced technical, schedule, and operational risk. The fiscal year 2006 budget request also reshapes the Prometheus 1 funding profile to provide an orderly increase in developmental activities.

Notwithstanding agreement with our recommendations, the Deputy Administrator stated that NPR 7120.5B requires projects to develop a business case. As we noted in this draft report, we recognize that NASA policy requires the development of elements that could support the formulation of a knowledge-based business case. However, we found no explicit requirement within NPR 7120.5B for NASA projects to develop a business case of any kind. More importantly, while NPR 7120.5B does require that projects establish controls to monitor performance against cost, schedule, and performance baselines and to conduct reviews throughout the project's lifecycle, it does not establish specific knowledge-based controls to ensure that the knowledge necessary to match resources to requirements is in hand before moving forward. For example, whereas NPR 7120.5B requires projects to conduct a preliminary design review before entering NASA's implementation phase, i.e., product development, it does not establish knowledge-based criteria to ensure that technologies needed to meet essential product requirements have been demonstrated to work in a realistic environment. Likewise, NASA policy requires a critical design review during a project's implementation phase but does not include knowledge-based criteria to ensure the design is stable. We have found that such knowledge-based criteria, when tied to major events on a program's schedule, can disclose whether gaps or shortfalls exist in

demonstrated knowledge, which can presage future cost, schedule and performance problems.

In his comments, the Deputy Administrator also noted that the Exploration Systems Mission Directorate is in the process of initiating a number of reforms to its project management policies and specified formulation dates in the coming months. He outlined these reforms and explained how they will allow NASA to address the recommendations in our report. We are encouraged by these planned changes. If properly implemented, they could be positive steps toward implementing a knowledge-based approach to project management.

The Deputy Administrator also requested that the relationship between JPL and NASA project management requirements be explicitly stated in the report. We moved the information from a footnote into the body of the report to clarify that relationship. We also addressed NASA's technical comments as appropriate throughout the report.

Scope and Methodology

To determine whether NASA is establishing justification for the project and ensuring critical technologies are mature, we conducted interviews with NASA Exploration Systems Mission Directorate and Prometheus 1 project officials at NASA Headquarters, Washington, D.C.; Marshall Space Flight Center, Huntsville, Ala.; and the Jet Propulsion Laboratory, Pasadena, Calif. We obtained and reviewed pertinent documents from the agency. We conducted quantitative and qualitative analyses of project schedules, risk assessments, budget documentation, technology maturity assessments and technology development plans. We compared these documents to criteria established in JPL and NASA policies governing developmental programs and to criteria for a knowledge based approach to acquisition described in GAO's best practices body of work. We discussed key project challenges with Prometheus 1 project officials, and conducted GAO team meetings to discuss analyses and developing issues. Our audit work was completed between April 2004 and January 2005.

As agreed with your office, unless you announce its contents earlier, we will not distribute this report further until 30 days from its issuance date. At that time, we will send copies to the NASA Administrator and interested congressional committees. We will make copies available to others upon request. In addition, the report will be available at no charge on the GAO web site at <http://www.gao.gov>.

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841 or lia@gao.gov. Key contributors to this report are acknowledged in appendix IV.

A handwritten signature in black ink, appearing to read "Allen Li". The signature is fluid and cursive, with the first name "Allen" and the last name "Li" clearly distinguishable.

Allen Li
Director
Acquisition and Sourcing Management

Appendix I: Technology Readiness Levels Definitions

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

**Appendix I: Technology Readiness Levels
Definitions**

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

Source: GAO.

Appendix II: Prometheus 1 Critical Technologies

Nuclear Reactor

The nuclear reactor is the key element of the Prometheus 1 spacecraft. Without the power levels supplied by the reactor, the proposed propulsion, science, and communication systems are not feasible. Designing, constructing, and utilizing highly reliable, safe, portable nuclear reactors is not new—nuclear reactors have been used in submarines for almost 50 years. However, the United States has very little experience operating nuclear reactors in a space environment and tackling space unique nuclear application issues. The Office of Naval Reactors, the organizational unit in the Department of Energy responsible for developing nuclear reactors for the Navy, will be responsible for all portions of the Prometheus 1 reactor development effort.

The space environment places significant weight constraints on the reactor design and requires semi-autonomous control. Unlike submarines and aircraft carriers, all spacecraft have serious weight constraints driven by the cost of launching payloads into orbit. Consequently, spacecraft designers put great effort into eliminating weight. Further, where conventional reactors have hands on operators, the Prometheus 1 reactor must be remotely controlled. NASA estimates that control communications will take about 40 minutes to travel one way between Earth and the Jovian system.

Power Conversion

A power conversion system accepts the thermal energy from the reactor and converts it to useful electrical power for the spacecraft. Power conversion is an integral part of any power generation system taking the form of steam turbine generators in terrestrial utility plants and nuclear submarines. NASA is considering two types of power conversion systems—dynamic and static. According to NASA, the dynamic systems under consideration offer the benefits of increased efficiency, reduced weight and mass, and decreased nuclear fuel requirements. The static systems, however, have a technology heritage in prior spacecraft and could offer increased reliability because they have no moving parts.

Heat Rejection

Since the conversion process in a fission reactor is never 100 percent efficient, heat rejection is required to dissipate waste energy. This is usually accomplished with large pumped-water cooling systems on earth. Space based power conversion would require a large radiator system to dissipate the waste heat in the vacuum of space. The requirement to fold the large radiator system into the launch vehicle fairing and deploy it after launch complicates the radiator system design. (See fig. 1.)

Nuclear Electric Propulsion

Operating electric propulsion systems in space applications, including deep space, is not new. There is extensive experience with electric propulsion systems on satellites. In addition, NASA's Deep Space 1 spacecraft was propelled using an electric propulsion ion thruster, similar in nature to the concept being developed for Prometheus 1. The thruster power levels required by Prometheus 1 have been demonstrated in a laboratory environment. The lifetime required by Prometheus 1, however, has not been demonstrated. Furthermore, lifetime testing of existing ion thrusters has demonstrated that these thrusters were approaching "wear out failure"¹ after 30,352 hours. The Prometheus 1 thrusters will need to be qualified for operational durations approaching 120,000 hours. NASA recognizes that they will have to develop models and accelerated aging techniques to demonstrate the lifetime requirement.

Radiation Hardening

All electronic components of the Prometheus 1 spacecraft must be radiation hardened or shielded from radiation produced by the onboard nuclear reactor and the harsh radiation environment of the Jovian system. Shielding electronics and the science packages, requires a heavy metal or some other material, which may not yet be developed, and increases the weight and mass of the spacecraft. The additional weight used to shield the spacecraft lessens the science payload package that can be taken onboard for scientific data collection and research and increases the size and power of the launch vehicle required to launch Prometheus 1 into earth orbit

High Power Communications

The nuclear reactor will provide increased electrical power for communications. This translates to increased bandwidth and data rates. The high power communications system onboard the Prometheus 1 spacecraft, will provide tens of compact disks full of data back to earth. Analogous missions such as Cassini provide only a couple of floppy disks full of data. (A floppy disk typically holds about 1.44 MB of data. A compact disk typically holds about 700 MB of data.) According to project officials, the higher power communications system on the Prometheus 1 spacecraft will require upgrades to the Deep Space Network, which are out of the purview of the Prometheus 1 project.

¹ Wear out failure is the point at which a system stops operating because its mechanical or physical parts are worn to the point they will no longer function.

Autonomous Rendezvous and Docking

There is no launch vehicle in the present or proposed U.S. inventory capable of launching the Prometheus 1 spacecraft, conceived for a mission to Jupiter's Icy Moons, into orbit in one piece. The conceptual design currently shows the Prometheus 1 spacecraft to weigh between 29 and 36 metric tons and be about 58 meters in length. The current concept is to use multiple launches, 2 to 5, to place the spacecraft components in orbit and to use AR&D technology to assemble the spacecraft in orbit. Prometheus 1 is relying on NASA's Demonstration Autonomous Rendezvous Technology and Hubble Robotic Servicing Mission, and the Defense Advanced Research Projects Agency's Orbital Express programs for AR&D technology. These programs use different sensors and approaches to AR&D thereby providing Prometheus 1 with various options for consideration.

Appendix III: Comments from the National Aeronautics and Space Administration

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

February 15, 2005



Mr. Allen Li
Director, Acquisition and Sourcing
Management Team
United States General Accounting Office
Washington, DC 20548

Dear Mr. Li:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on your draft report General Accounting Office (GAO)-05-242, "NASA's Space Vision: Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources."

We concur with your recommendations and note that they validate and reinforce the importance of activities currently underway at NASA to strengthen our management of complex technical programs, including the development of Prometheus 1 and its attendant supporting infrastructure and technologies. However, we would like to clarify the status of our program management practices and policies.

The draft report states that the Jet Propulsion Laboratory's (JPL) project implementation policy requires documentation that includes elements essential to developing a sound business case. However, GAO states that NASA does not require projects to develop knowledge-based business cases that match requirements to available resources. The report also suggests that NASA does not employ controls to ensure that sufficient knowledge has been attained during project development.

As NASA's Federally Funded Research and Development Center (FFRDC), JPL programs and practices are required to conform to NASA requirements. The NASA requirements for program/project management are documented in NASA's "Program and Project Management Processes and Requirements" document (NASA Procedural Requirements (NPR) 7120.5B, dated November 2002). As stated in NPR 7120.5B, NASA requires development of a business case for all of its projects, and JPL has instituted policies and procedures to conform to the NASA requirements. The draft report text does not explicitly acknowledge the fact that JPL's "Project Implementation Policy" is written to conform to these NASA requirements. NASA believes that for the sake of clarity, the relationship between JPL and NASA program/project management requirements should be explicitly stated in the report. We would be happy to discuss this issue further with you or provide you with a copy of the NPR. The NPR is also available online at <http://www.hq.nasa.gov/office/codeq/doctree/71205.htm>.

As you noted, NASA is in the process of conducting conceptual design (Phase A) for the Prometheus 1 project in anticipation of entering preliminary design (Phase B). Concurrent with these activities, NASA's Exploration Systems Mission Directorate (ESMD) is developing detailed program management requirements on why, when, and how to implement NASA programs and projects. These requirements consist of a three document suite based on the Department of Defense (DoD) and NASA best practices cited in your draft report, i.e., well-defined requirements, a conceptual design, realistic cost estimates, and independently reviewed technology development plans. This suite of documents, which also considers lessons learned at NASA, will succinctly define the policies and requirements that all ESMD program/project managers must use in overseeing NASA's exploration activities. ESMD's document suite consists of the Single Acquisition Management Plan (SAMP), the Systems Engineering Management Plan (SEMP), and the Program Management Handbook (PMH).

The SAMP documents the ESMD overarching acquisition strategy. Recognizing that each program has unique challenges, the SAMP discusses application of the ESMD acquisition strategy for each major program under the ESMD's purview. The SAMP explicitly addresses the use of spiral development and implementation of the "Strategy to Task to Technology" (STT) approach for program management. The STT uses an integrated team of stakeholders and an Operational Advisory Group (OAG) to identify and assess user-defined operational needs and priorities. This process is designed to implement the best practices identified in GAO-04-386SP by creating a credible, auditable trail of the ESMD decision-making process.

The SEMP identifies the sequence of systems engineering processes and activities for the technical aspects of ESMD systems engineering and integration management. The intent of the SEMP is to combine DoD and NASA best practices in a way which supports NASA's unique mission and which defines a rigorous process for determining whether proposed solutions meet ESMD requirements.

The PMH defines the organizational roles, responsibilities, and processes required for program management. Processes are defined in terms of program life cycles and are tailored to the characteristics of basic and applied research, technology development, and mission system development. Program life cycles are punctuated by Key Decision Points for transitioning from one program phase to the next. Throughout the PMH, program managers are encouraged to be candid and forthcoming about program status, explicitly including identifying risks and problems without fear of personal consequences.

The ESMD management is committed to providing the best resources and tools available to its staff and consistently stresses the need for credibility, affordability, and sustainability of its programs. The NASA Associate Administrator for Exploration Systems, Craig E. Steidle, has personally visited each NASA Center and JPL to explain the upcoming program management

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practices. He emphasizes that NASA must be prepared to demonstrate a positive return on our resource investments. ESMD goals are to:

1. Convene a diverse group of stakeholders, including designers, operations staff, and technicians to evaluate and identify performance trade-offs early in the program.
2. Apply available technologies to reduce system life-cycle costs, specifically infrastructure development.
3. Mature a technology before employing it.
4. Partner with industry as appropriate.

As a civilian Government agency, NASA's mission is to expand human knowledge of the Earth and phenomena in the atmosphere and space. Consequently, many of NASA's exploration projects require first-of-a-kind technology development. Nevertheless, NASA must ensure that available resources, both human and otherwise, are effectively and efficiently applied in our technology development activities.

The following paragraphs provide the current status and planned approach for addressing each of the GAO recommendations:

Recommendation 1: Identify at Preliminary Mission and Systems Review (PMSR) the level of resources the agency is committing to the project and direct project officials to develop project requirements based on this resource constraint.

NASA concurs with this recommendation and is documenting the ESMD process for transitioning from Phase A to Phase B for all programs under ESMD's purview. JPL's PMSR is an in-depth review of the project conducted shortly before the NASA program review. The project must pass both reviews in order for the project to move forward. The ESMD's PMH requires that program managers define the mission and system concepts, parameters, constraints, and requirements that will enable development of the system and mission on a given schedule to meet established goals within a reasonable cost estimate. Cost estimates are commensurate with the available information at that point in project development. As the project matures and the design progresses, project cost estimates become more refined. Program managers will periodically review program activities against resource constraints, using earned value management techniques, and report actual or anticipated deviations from program costs and/or schedule to senior management for resolution. Stakeholders, including operations, science, engineering, and the OAG staff will review mission objectives, technology requirements, and resource constraints throughout the project life cycle to ensure that requirements can be met within defined resource and technology constraints. Before transitioning to Phase B, ESMD also requires an independent review by an Independent Program Assessment Team to determine whether or not the program is ready to proceed.

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The ESMD's PMH will be issued in February 2005, and the SAMP and SEMP will follow thereafter in the summer of 2005.

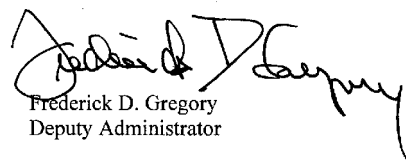
Recommendation 2: Ensure that prior to proceeding beyond Preliminary Design Review (PDR) (currently planned for 2008) a sound business case is established which includes confirmation that (1) critical technologies have been successfully demonstrated as mature, (2) systems engineering has been conducted to support requirement/cost trade-off decisions, (3) requirements and resource estimates have been updated based on the results of the preliminary design phase, (4) knowledge based criteria are established at each critical juncture to ensure that relevant product development knowledge is captured, and (5) decision reviews are held to determine that appropriate knowledge was captured to allow a move to the next phase.

The ESMD will be issuing the PMH in February 2005. The PMH will explicitly define the requirements for transitioning between each phase of a program/project. The PMH defines specific entrance and exit criteria for each program phase and requires periodic reassessment of technology maturity, systems engineering interfaces and requirements, independent cost and technical analysis, value engineering, updating requirements and resource estimates, and analysis of alternatives to determine whether a given program/project should proceed. Earned value management techniques will be used. The PMH also requires documentation of decision bases to ensure that the STT process is credible and auditable. The three-document suite will be revised to incorporate lessons learned as NASA gains experience in implementing this new program management acquisition strategy to ensure that we continue to improve our processes.

We also note that both the report summary page and the report itself cite the Congressional Budget Office's (CBO) project cost estimate as \$10 billion dollars. The CBO estimate was not coordinated with NASA. NASA is currently developing a disciplined process to develop NASA's initial project cost estimate. We are also providing technical comments under separate cover.

Thank you for the opportunity to comment on the draft report. We appreciate your recommendations and will continue to work on improving how we do business.

Cordially,



Frederick D. Gregory
Deputy Administrator

Enclosure

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Allen Li, (202) 512-4841

Acknowledgments

In addition to the contact named above, James Morrison, Jerry Herley, John Warren, Tom Gordon, Ruthie Williamson, Karen Sloan and Sylvia Schatz made key contributions to this report.

GAO Related Products

Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition. [GAO-04-386SP](#). Washington, D.C.: January 2004.

Best Practices: Setting Requirements Differently Could Reduce Weapon Systems' Total Ownership Costs. [GAO-03-57](#). Washington, D.C.: February 11, 2003.

Defense Acquisitions: DOD's Revised Policy Emphasizes Best Practices, but More Controls Are Needed. [GAO-04-53](#). Washington, D.C.: November 10, 2003.

Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes. [GAO-02-701](#). Washington, D.C.: July 15, 2002.

Defense Acquisitions: DOD Faces Challenges in Implementing Best Practices. [GAO-02-469T](#). Washington, D.C.: February 27, 2002.

Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes. [GAO-01-288](#). Washington, D.C.: March 8, 2001.

Best Practices: A More Constructive Test Approach Is Key to Better Weapon System Outcomes. [GAO/NSIAD-00-199](#). Washington, D.C.: July 31, 2000.

Defense Acquisition: Employing Best Practices Can Shape Better Weapon System Decisions. [GAO/T-NSIAD-00-137](#). Washington, D.C.: April 26, 2000.

Best Practices: DOD Training Can Do More to Help Weapon System Program Implement Best Practices. [GAO/NSIAD-99-206](#). Washington, D.C.: August 16, 1999.

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

Defense Acquisitions: Best Commercial Practices Can Improve Program Outcomes. [GAO/T-NSIAD-99-116](#). Washington, D.C.: March 17, 1999.

Defense Acquisition: Improved Program Outcomes Are Possible. [GAO/T-NSIAD-98-123](#). Washington, D.C.: March 18, 1998.

Best Practices: DOD Can Help Suppliers Contribute More to Weapon System Programs. [GAO/NSIAD-98-87](#). Washington, D.C.: March 17, 1998.

Best Practices: Successful Application to Weapon Acquisition Requires Changes in DOD's Environment. [GAO/NSIAD-98-56](#). Washington, D.C.: February 24, 1998.

Major Acquisitions: Significant Changes Underway in DOD's Earned Value Management Process. [GAO/NSIAD-97-108](#). Washington, D.C.: May 5, 1997.

Best Practices: Commercial Quality Assurance Practices Offer Improvements for DOD. [GAO/NSIAD-96-162](#). Washington, D.C.: August 26, 1996.

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