December 2005

NASA

Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes

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NASA

Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes

Why GAO Did This Study

The National Aeronautics and Space Administration (NASA) plans to spend over $100 billion on capabilities and technologies to achieve the initial goals of the President's 2004 *Vision for Space Exploration*. In the past, NASA has had difficulty meeting cost, schedule, and performance objectives for some of its projects because it failed to adequately define project requirements and quantify resources. NASA will be further challenged by a constrained federal budget and a shrinking experienced NASA workforce. To help face these challenges and manage projects with greater efficiency and accountability, NASA recently updated its program and project management policy and is developing an agencywide systems engineering policy.

GAO has issued a series of reports on the importance of obtaining critical information and knowledge at key junctures in major system acquisitions to help meet cost and schedule objectives. This report (1) evaluates whether NASA's policy supports a knowledge-based acquisition approach and (2) describes how NASA centers are implementing the agency's acquisition policies and guidance.

What GAO Recommends

GAO is making several recommendations to help ensure NASA uses a knowledge-based acquisition approach in making informed investment decisions. NASA concurred with GAO's recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-06-218.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Allen Li at (202) 512-4841 or lia@gao.gov.

What GAO Found

While NASA's revised policy for developing flight systems and ground support projects incorporates some of the best practices used by successful developers, it lacks certain key criteria and major decision reviews that support a knowledge-based acquisition framework. For example, NASA's policy requires projects to conduct a major decision review before moving from formulation to implementation. Further, before moving from formulation to implementation, projects must validate requirements and develop realistic cost and schedule estimates, human capital plans, a preliminary design, and a technology plan—key elements for matching needs to resources. However, NASA's policies do not require projects to demonstrate technologies at high levels of maturity before program start. By not establishing a minimum threshold for technology maturity, NASA increases the risk that design changes will be required later in development, when such changes are typically more costly to make. In addition, although NASA's policy does require project managers to establish a continuum of technical and management reviews, it does not specify what these reviews should be, nor does it require major decision reviews at other key points in a product's development. Acquiring knowledge at key junctures will become increasingly important as NASA proceeds to implement elements of the *Vision*. Without a major decision review at key milestones to ensure that the appropriate level of knowledge has been achieved to proceed to the next phase, the risk of cost and schedule overruns, as well as performance shortfalls, increases.

NASA centers have varying approaches for implementing the agency's policies and guidance. Some centers have established product development criteria that are similar to the criteria used in a knowledge-based acquisition, while other centers have not. As a result, each center reports a different level and type of knowledge about a project at key decision points. Centers also rely on project managers and systems engineers to employ good project management and systems engineering practices. However, given the loss of experienced project managers and the decline of in-house systems engineering and technical capabilities, that reliance could be problematic. These situations make it difficult for decision makers to evaluate projects on the same basis and make sound investment decisions and tradeoffs based on those evaluations. A standardized, knowledge-based approach would prepare NASA to face competing budgetary priorities and better position the agency to make difficult decisions regarding the investment in and termination of projects.

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Abbreviations

CADRe	Cost analysis data requirement
CDR	Critical design review
EVM	Earned value management
GPMC	Governing Program Management Committee
GSFC	Goddard Space Flight Center
ITA	Independent Technical Authority
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KP1	knowledge point 1
KP2	knowledge point 2
KP3	knowledge point 3
MSFC	Marshall Space Flight Center
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
PDR	Preliminary design review
Pre-NAR	Preliminary Non-Advocate Review
TRL	Technology readiness level

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United States Government Accountability Office
Washington, DC 20548

December 21, 2005

The Honorable Bart Gordon
Ranking Minority Member
Committee on Science
House of Representatives

The Honorable Mark Udall
Ranking Minority Member
Subcommittee on Space and Aeronautics
Committee on Science
House of Representatives

The National Aeronautics and Space Administration (NASA) plans to spend over $100 billion to develop new capabilities and technologies critical to supporting the initial goals outlined in the President's 2004 *Vision for Space Exploration* (see fig. 1 for a conceptual drawing of NASA's proposed crew vehicle). The *Vision*, which NASA has characterized as bold, includes plans to explore the moon, Mars, and beyond.[1] Despite many successes, such as landing the Pathfinder and Exploration Rovers on Mars, NASA has had difficulty carrying out a number of other missions, such as the X-33, a technology demonstrator for future reusable launch vehicles, because the agency was overly optimistic in what could be achieved within available resources. NASA's failure to define requirements adequately and quantify the resources needed to meet those requirements resulted in some projects costing more, taking longer, and achieving less than originally planned. In addition to these project management challenges, a constrained federal budget and a shrinking experienced project manager and technical workforce, well-versed in systems engineering and architecture design, will present further challenges to NASA in the years ahead.

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[1] The *Vision* includes a return to the moon that is intended ultimately to enable future exploration of Mars and other destinations. To accomplish this, NASA initially plans to (1) complete its work on the International Space Station by 2010, fulfilling its commitment to 15 international partner countries; (2) begin developing a new manned exploration vehicle to replace the space shuttle; and (3) return to the moon as early as 2015 and no later than 2020 in preparation for future, more ambitious missions.

GAO-06-218 NASA Acquisition Policies

Figure 1: Conceptual Drawing of NASA Crew Vehicle Docked with Lunar Lander and Departure Stage in Earth Orbit

Source: NASA/John Frassanito and Associates.

To meet these challenges, NASA recently updated its program and project management policy[2] and is developing an agencywide systems engineering policy. NASA expects that these new polices will help the agency manage its projects with greater efficiency, responsibility, and accountability. We have issued a series of reports on the importance of obtaining critical information and knowledge at key junctures in major system acquisitions before additional investments are made. This work has shown that following a knowledge-based approach helps developers meet cost and schedule objectives in developing new and more sophisticated products—the kinds of results that NASA seeks.

Given the major endeavor that NASA is about to undertake, the agency's history of cost and schedule overruns and technical problems, and the significant challenges the agency currently faces and will likely face, you asked us to (1) evaluate whether NASA's policies support an acquisition

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[2] NASA Policy Directive (NPD) 7120.4C describes the management system by which NASA formulates, approves, implements, and evaluates all programs and projects. NASA Procedural Requirement (NPR) 7120.5C establishes the management system requirements for implementing NPD 7120.4C. NPR 7120.5C governs the formulation, approval, implementation, and evaluation of all agency programs and projects. For purposes of this report, we refer to NPR 7120.5C as NASA's program and project management policy.

approach consistent with best practices identified in GAO's work on system acquisitions and (2) describe how NASA-wide acquisition policies are implemented at the various NASA centers.[3]

To conduct our work, we reviewed and analyzed NASA-wide program and project management policies as they relate to flight systems and ground support projects and systems engineering guidance and compared the policies and guidance with criteria contained in GAO's best practices work on systems acquisition, including space systems. We also interviewed NASA headquarters officials from the Office of the Chief Engineer responsible for the policy and guidance. In addition, we reviewed NASA center-specific program and project management policies and systems engineering policies, as they relate to flight systems and ground support projects, and interviewed officials responsible for implementing those policies. We focused primarily on Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), and Marshall Space Flight Center (MSFC), which manage the majority of NASA's flight systems and ground support projects. Complete details of our scope and methodology can be found in appendix I. We performed our work from May 2005 to November 2005 in accordance with generally accepted government auditing standards.

Results in Brief

NASA's revised policy for developing flight systems and ground support projects incorporates some of the best practices used by successful developers, but the policy lacks certain key criteria and decision reviews necessary to fully support the knowledge-based acquisition framework. For example, NASA's policy requires projects to conduct a major decision review before moving from formulation to implementation. Further, before moving from formulation to implementation, projects must validate requirements and develop realistic cost and schedule estimates, human capital plans, a preliminary design, and a technology plan—all key elements for matching needs to resources before a commitment to major investment is made at project start. However, NASA's policy does not require that projects demonstrate technologies at high levels of maturity at that point. By not establishing a minimum threshold for technology

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[3] NASA consists of NASA headquarters, nine centers, the Jet Propulsion Laboratory (operated under contract to NASA by the California Institute of Technology), and several ancillary installations and offices in the United States and abroad. The implementation of NASA programs and aeronautical and space/earth science research occurs primarily at the centers.

maturity, NASA increases the risk that requirements will not be met and design changes will be required later in development, when such changes are typically more costly to make. In addition, although NASA's policy does require project managers to establish a continuum of technical and management reviews, the policy does not specify what these reviews should be, nor does it require major decision reviews at other key points in a product's development. Acquiring knowledge at key junctures will become increasingly important as NASA proceeds to implement various elements of the *Vision*. Without a major decision review at key milestones to ensure that the appropriate level of knowledge has been achieved to proceed to the next phase, NASA increases the risk of cost and schedule overruns as well as performance shortfalls.

NASA centers have varying approaches to implementing agencywide project management policy and systems engineering guidance for flight systems and ground support projects. Some centers use criteria at key decision points that are similar to the criteria required to ensure a knowledge-based approach is followed, while others lack such criteria. As a result, each center reports a different level and type of knowledge about a project at key decision points. Centers also rely on project managers and systems engineers to employ good project management and systems engineering practices. However, given the loss of experienced project managers and the decline of in-house systems engineering and technical capabilities agencywide, that reliance could be problematic. These situations make it difficult for NASA decision makers to evaluate center projects on a common foundation of knowledge and make sound investment decisions and tradeoffs based on those evaluations. A standardized knowledge-based approach would prepare NASA to face competing budgetary priorities and better position the agency to make difficult decisions regarding the investment in and termination of projects.

To ensure NASA uses a knowledge-based acquisition approach in making informed investment decisions, we are making several recommendations to improve the agency's policies. We are recommending that NASA (1) require the capture of specific knowledge to be used as criteria for allowing projects to enter implementation and proceed through development and to support informed investment decisions and (2) institute additional reviews for flight system and ground support projects during project implementation, which result in recommendations to the appropriate decision authority. In written comments on a draft of this report, NASA agreed with our recommendations. NASA's comments are included in their entirety in appendix III.

Background

Over the past decade, NASA has experienced significant problems with several of its projects, which GAO and others have reported on (see table 1 for some examples of such problems). In addition, in 2002 we reported on several sources of failures in NASA programs, including underestimating complexity and technology maturity, and inadequate review and systems engineering processes. Further, we reported that the sources of these problems were not new and that NASA failed to consistently apply lessons previously learned.[4] The failures identified in our 2002 report were in part the result of the "faster, better, cheaper" approach to managing its major acquisitions, which NASA adopted in the 1990s.[5]

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[4] GAO, *NASA: Better Mechanisms Needed for Sharing Lessons Learned*, GAO-02-195 (Washington, D.C.: Jan. 30, 2002).

[5] The approach was intended to help NASA reduce costs, become more efficient, and increase scientific results by conducting more and smaller missions in less time.

Table 1: Examples of Problems With NASA Programs/Projects

Program/Project description	Reported problems
X-33	
The X-33 was to be an unmanned technology demonstrator, which tested a range of technologies needed for future reusable launch vehicles.	In 1999, GAO reported that technical problems on the X-33 project led to cost overruns of $75 million dollars and over a year's delay in schedule. These problems resulted from NASA developing unrealistic cost estimates in the early stages of the X-33 project and not following its own policies with regard to project and risk management. In February 2001, NASA announced it would provide no additional funding for the X-33 program.
Space Launch Initiative (SLI)	
Approved in February 2001, SLI was designed as a $4.8 billion, 6-year effort to fly a half-scale flight demonstrator intended to validate advanced technologies that would dramatically reduce the cost of putting a pound of payload into space—from $10,000 to $1,000.	In 2002, both the NASA Inspector General and GAO released reports assessing SLI with particular emphasis on requirement definition and implementation of management controls. The NASA Inspector General found NASA did not verify and validate the basic requirements for its second-generation space transportation system. GAO found NASA could not implement key management controls until it defined the SLI's basic requirements. In October 2002, in response to the GAO report, NASA indefinitely postponed the System Readiness Review for SLI.
Comet Nucleus Tour (COUNTOUR)	
NASA's CONTOUR project was intended to visit at least two comets to provide the first detailed look at the differences between primitive building blocks of the solar system and answer questions about how comets act and evolve.	A May 31, 2003 report released by a NASA Mishap Investigation Board (MIB) found that inadequate systems engineering processes and an inadequate review function were root causes of the December 2002 loss of the $159 million NASA COUNTOUR spacecraft. Further, based on the findings related to the CONTOUR project, the MIB board recommended that NASA establish clear standards for conducting and documenting engineering work and associated peer and independent reviews and reevaluate its oversight and review requirements.
Prometheus 1	
The Prometheus 1 project is part of NASA's Prometheus Nuclear Systems and Technology project to develop nuclear power technologies capable of providing power and propulsion for a new generation of missions. It 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 mission was to be a 4-to 6-year study of three of Jupiter's moons.	In February 2005, GAO issued a report on NASA's Prometheus 1 project which found that the agency faced challenges preparing preliminary requirements and cost estimates and that the critical technologies supporting the project would require extensive advancement before they could satisfy requirements. According to Prometheus 1 project management, the approved funding profile for the project was inadequate to support the planned mission, a 2015 launch to Jupiter's Icy Moons. GAO recommended that NASA identify the level of resources the agency is committing to the project and direct project officials to develop requirements based on this resource constraint. NASA has since deferred the Jupiter Icy Moons Orbiter mission, citing concerns over cost and technical complexity.

Source: GAO and NASA.

These problems, along with others, highlighted the need for the agency to reevaluate its approach to cost and schedule estimating, risk assessments, technology development, project reviews, and systems engineering. In 1998, NASA adopted a new program and project management policy, which was revised in 2002. The policy provided significant flexibility, including allowing tailoring and projects to opt out of requirements at the discretion of the project manager. In March 2005—following a series of internal and external assessments of NASA that showed that the agency faced significant problems with project management—NASA again revised its program and project management policy, which includes policy requirements for the development of flight systems and ground support projects.[6] According to NASA officials, further changes to the policy are anticipated in light of new agency leadership.[7]

The March 2005 policy document, NASA Procedural Requirement (NPR) 7120.5C, differs from previous versions of the policy in that it delineates requirements based on four NASA investment areas: Basic and Applied Research, Advanced Technology Development, Flight Systems and Ground

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[6] NPR 7120.5C contains specific requirements for both programs and projects. The policy defines a program as a strategic investment by a Mission Directorate or Mission Support Office that has defined goals, objectives, architecture, funding level, and a management structure that supports one or more projects. A project is defined as a specific investment identified in a *Program Plan* having defined goals, objectives, requirements, life cycle cost, a beginning, and an end. For purposes of this report, we have focused our analysis of the policy as it relates to the traditional development approach to flight systems and ground support projects.

[7] According to the NASA Administrator, evolutionary acquisition processes will not be practiced at NASA. Therefore, NASA officials indicated that evolutionary acquisition for flight systems and ground support projects will likely be deleted in the next version of NPR 7120.5.

Support, and Institutional Infrastructure. The policy also reinstitutes a life cycle phased approach to product development and institutes a project categorization scheme, based on project cost and priority, which denotes the oversight authorities[8] and the level of detail that is needed to support project planning documents. See figure 2 below.

Figure 2: Project Categorization Scheme and Oversight Authorities from NPR 7120.5C

Oversight authorities for NASA projects (dollars in millions)

Priority	Life cycle cost (LCC)		
	LCC < $100M	$100M ≤ LCC < $500M	LCC ≥ $500M
High	Category II	Category I	Category I
Moderate	Category III	Category II	Category I
Low	Category III	Category III	Category II

Oversight authorities for NASA projects

Project category (From previous table)	Governing PMC	Review team lead
Category I	Agency PMC	IPAO
Category II	Mission Directorate PMC	IPAO and/or SMO
Category III	Center PMC	SMO

PMC = Program Management Committee

IPAO = Independent Program Assessment Office

SMO = Systems Management Office

Source: NASA.

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[8] One oversight authority is called a Project Management Committee (PMC). The PMC is defined as one of the hierarchy of forums, composed of senior management, that assesses project planning and implementation, and provides oversight and direction as appropriate. These are established at the agency, mission directorate, center, and lower levels. The Independent Program Assessment Office (IPAO) is the NASA organization responsible for scheduling, organizing, and conducting the independent reviews at the Preliminary Non-Advocate Review (Pre-NAR) and the Non-Advocate Review (NAR) for programs and projects reporting to the agency PMC. The Systems Management Office (SMO) is the center organization responsible for independent review and assessment of projects at the Pre-NAR and the NAR, whose findings are reported to the center PMC.

NASA has also attempted to address some of its cost-estimating weaknesses by instituting a cost analysis data requirement (CADRe) and establishing thresholds for the use of earned value management (EVM).[9] Another major change to the policy is the establishment of the Independent Technical Authority (ITA). According to the policy, the purpose of ITA is to establish sound technical requirements and decisions for safe and reliable system operations separate from the project management and reporting chain. Finally, agency officials told us that while the requirements in previous versions of the policy were easy to tailor, projects now must document compliance with the requirements in a "compliance matrix" and must request and have approved any deviations and/or waivers to requirements.

Although NPR 7120.5C contains some mandatory requirements with regard to systems engineering, according to agency officials, NASA has never had an agencywide systems engineering policy to inform the development of flight systems and ground support projects. Since 1995, in the absence of a policy on systems engineering, project managers and systems engineers have relied on information contained in NASA's *Systems Engineering Handbook* to guide their systems engineering approach on projects.[10] Project managers and systems engineers, however, are not required to follow the handbook. Recognizing the need for a more structured and rigorous approach to systems engineering agencywide, NASA's Office of the Chief Engineer is currently leading the effort to develop a systems engineering policy. The policy is in draft form.

Knowledge-Based Acquisition Framework

Over the last several years, we have undertaken a body of work on how leading developers in industry and government use a knowledge-based approach to deliver high quality products on time and within budget.[11] A knowledge-based approach to product development efforts enables developers to be reasonably certain, at critical junctures or "knowledge
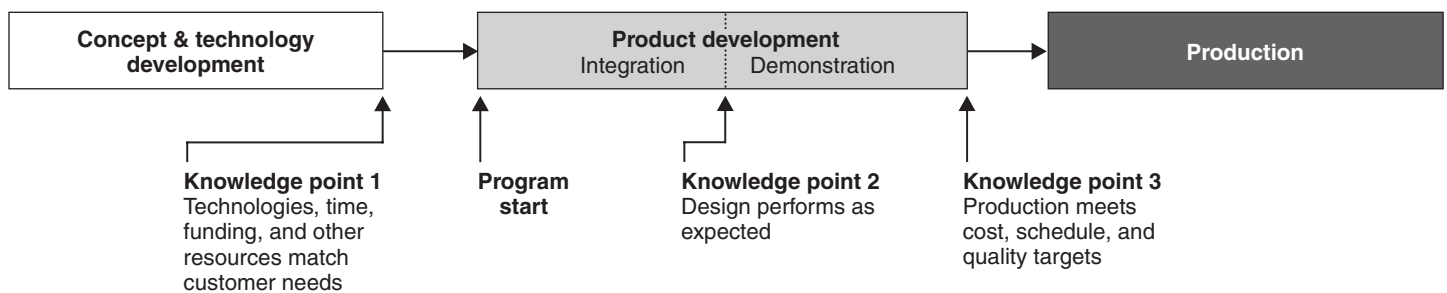
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[9] As defined by NPR 7120.5C, a CADRe is a formal document to understand the cost and cost risk of space flight projects. The policy defines EVM as a tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution of the project. As defined in NPR 7120.5C, all projects over $20 million must apply EVM.

[10] National Aeronautics and Space Administration, *NASA Systems Engineering Handbook*, SP-6105, (Washington, D.C.: June 1995).

[11] Our best practice reviews are identified in the "Related GAO Products" section at the end of this report.

points" in the acquisition life cycle, that their products are more likely to meet established cost, schedule, and performance baselines and, therefore provides them with information needed to make sound investment decisions. See figure 3 for a depiction of a knowledge-based acquisition life cycle.

Figure 3: Knowledge-Based Acquisition Life Cycle

Source: GAO.

- **Knowledge point 1 (KP1)**: Resources and needs match. Knowledge point 1 occurs when a sound business case is made for the product— that is, a match is made between the customer's requirements and the product developer's available resources in terms of knowledge, time, workforce, and money. To determine available resources, successful developers rely on current and valid information from predecessor projects, new technologies that have demonstrated a high level of maturity, system engineering data, and experienced people. Successful developers also communicate extensively with customers to match their wants and needs with available resources and with the developers ability to manufacture an appropriate product.

- **Knowledge point 2 (KP2)**: Product design is stable. Knowledge point 2 occurs when a developer determines that a product's design is stable—that is, it will meet customer requirements and cost and schedule targets. A best practice is to achieve design stability at the product's critical design review (CDR), usually held midway through development. Completion of at least 90 percent of engineering drawings at the CDR provides tangible evidence to decision makers that the design is stable.

- **Knowledge point 3 (KP3)**: Production processes are mature. This level of knowledge is achieved when it has been demonstrated that the product can be manufactured within cost, schedule, and quality targets.

A best practice is to ensure that all key manufacturing processes are in statistical control— that is, they are repeatable, sustainable, and capable of consistently producing parts within the product's quality tolerances and standards—at the start of production. It is important that the product's reliability be demonstrated before production begins, as investments can increase significantly if defective parts need to be repaired or reworked.

If the knowledge attained at each juncture does not confirm the business case on which the initial investment was originally justified, the project should not go forward and additional resources should not be committed. Product development efforts that do not follow a knowledge-based approach can be frequently characterized by poor cost, schedule, and performance outcomes.

NASA's Revised Policy Does Not Fully Support a Knowledge-Based Approach to Acquisitions

NASA's revised acquisition policy for developing flight and ground support systems incorporates some of the elements of a knowledge-based acquisition approach. However, it lacks specific key criteria and decision reviews necessary to fully support such an approach. NASA's policy defines a phased life cycle approach and requires a major decision review to move from project formulation to implementation. The policy requirements for this review address many of the key elements necessary to match needs to resources, such as requirements to establish project baselines. However, the policy does not require that projects demonstrate technologies at high levels of maturity before launching a project and investing a large amount of resources. In addition, NASA's policy does not require any further major decision reviews following the formulation phase of the project. Major decision reviews in the implementation phase based on specific evaluation criteria at the final design and fabrication, assembly, and testing milestones—critical decision points in any product development—could help NASA ensure that sufficient knowledge has been gained to warrant moving forward in the development process.

NASA's Policy Establishes a Phased Life Cycle

The life cycle for all NASA projects is divided into two major phases—formulation and implementation. Because flight systems and ground support projects are particularly complex and have long life cycles, NASA has further divided the formulation and implementation phases for these projects to allow managers to assess management and engineering progress (see fig. 4).
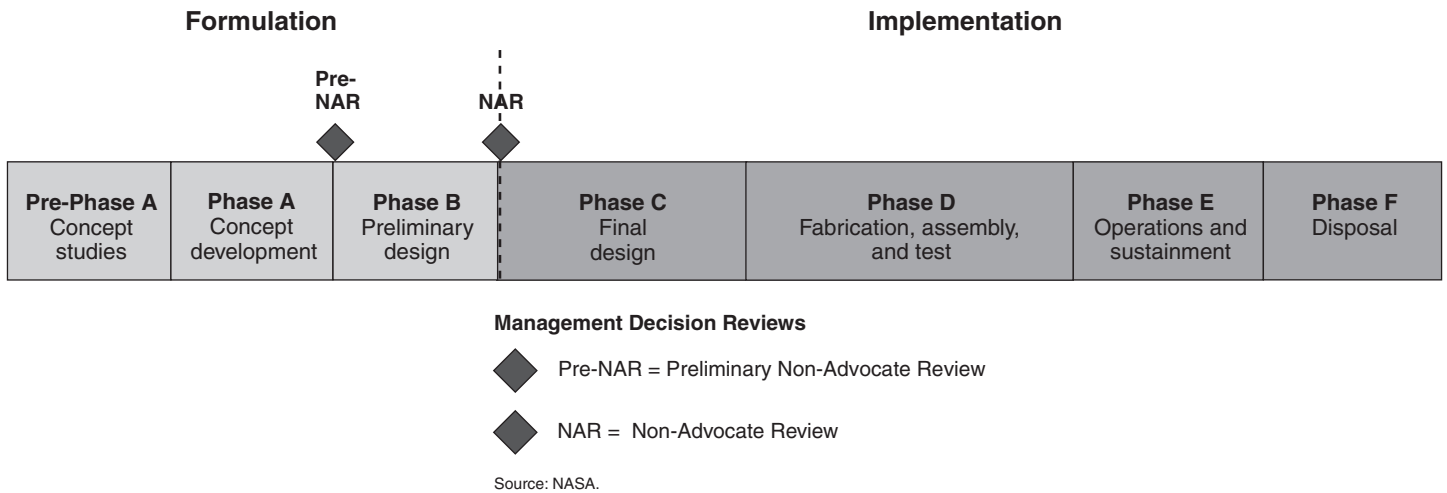
Flight systems and ground support projects must successfully complete two major decision reviews: a Preliminary-Non Advocate Review (Pre-NAR) between Phases A and B and a Non-Advocate Review (NAR) between Phases B and C. At these reviews, the Governing Program Management Committee (GPMC) evaluates the cost, schedule, safety, and technical content of the project to ensure that the project is meeting commitments specified in key management documents.[12] Following each of these reviews, the GPMC recommends to the appropriate decision authority[13] whether the project should be authorized to proceed.[14]

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[12] The key management documents for flight system and ground support projects are the *Project Formulation Authorization Document* (FAD), or equivalent, and the *Project Plan*. The FAD authorizes a Project Manager to initiate the formulation phase of a new project. Because a new project represents a major commitment of resources, the FAD requires approval of the project decision authority before the project enters Phase A of the life cycle. The *Project Plan* is an agreement between the Mission Directorate Associate Administrator, the Center Director, Program Manager, and Project Manager, as applicable. It defines, at a high level, the scope of the project, the implementation approach, the environment within which the project operates, and the commitments of the project. The *Project Plan* also establishes the cost, schedule, and technical baselines for the implementation phase and is used by the GPMC in the review process to determine if the project is fulfilling its agreements. A preliminary *Project Plan* is due at the Pre-NAR, and an updated or final version is due at the NAR.

[13] The decision authority for Category I projects is the Deputy Administrator; for Category II projects, the Mission Directorate Associate Administrator; and for Category III projects, the Center Director (of the executing center).

[14] A positive recommendation may be unconditional, or conditional on the Project Manager completing assigned action items. A negative recommendation could result in the decision authority either directing the Project Manager to address the deficiencies, or in the authorization of a termination review.

Figure 4: Life Cycle Phases for NASA's Flight Systems and Ground Support Projects

	Formulation		Implementation			
		Pre-NAR	NAR			
Pre-Phase A Concept studies	**Phase A** Concept development	**Phase B** Preliminary design	**Phase C** Final design	**Phase D** Fabrication, assembly, and test	**Phase E** Operations and sustainment	**Phase F** Disposal

Management Decision Reviews

◆ Pre-NAR = Preliminary Non-Advocate Review

◆ NAR = Non-Advocate Review

Source: NASA.

As with KP1 in a knowledge-based acquisition life cycle, the NAR marks the official project approval point in the life cycle. After approval at the NAR, projects are included as part of implementation reviews of their parent program. These implementation reviews are conducted biennially and are not tied to any design or production milestones. After entering the implementation phase, the GPMC is notified if cost or schedule performance exceeds the baselines established at the NAR by 10 percent or when key performance criteria are not met. Exceeding the NAR baselines can result in the GPMC conducting a termination review to determine whether or not to continue the project.

NASA's Policy Lacks Requirements for Maturing Technologies

To help ensure project requirements do not outstrip resources, leading developers obtain the right knowledge about a new product's technology, design, and production at the right time. NASA's policy emphasizes many elements needed at the NAR (or KP1) to match needs to resources, such as validating requirements, developing realistic cost and schedule estimates and human capital plans, and establishing a preliminary design. The policy does not, however, require projects to demonstrate technologies at high levels of maturity before launching a project. Table 2 compares KP1 criteria and NASA's policy criteria.

Table 2: KP1 Criteria Compared to NASA Policy Criteria

KP1 Criteria (resources and needs match)	NPR 7120.5C NAR requirements
High level of technology maturity	A technology plan describing the technology needed for the project, including plans for technology maturation, validation, and insertion, and quantifiable milestones, decision gates, and resources required.
Informed requirements	A set of requirements that are well formed (clear and unambiguous), complete (agrees with customer and stakeholder expectations), and consistent (conflict free); and each requirement is verifiable and traceable to higher level requirements.
Realistic cost and schedule estimates	A cost analysis data requirement (CADRe)[a] documents the programmatic, technical, and life cycle cost information. The CADRe includes a life cycle cost estimate, integrated master project schedule, and a work breakdown structure (WBS).[b]
Human capital in place	Plans to staff the project with personnel with the appropriate skills, abilities, and experience, and provide integrated team training to successfully execute the project. The project manager is required to negotiate to obtain the needed resources identified in the plan.
Preliminary system design	A preliminary system design is required and is reviewed at the NAR.
Conduct a decision review before project launch	The GPMC determines the project's readiness to proceed to implementation and recommends a course of action to the appropriate decision authority.

Source: NASA and GAO.

[a]A CADRe is required for Category I and Category II flight system and ground support projects.

[b]A WBS 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.
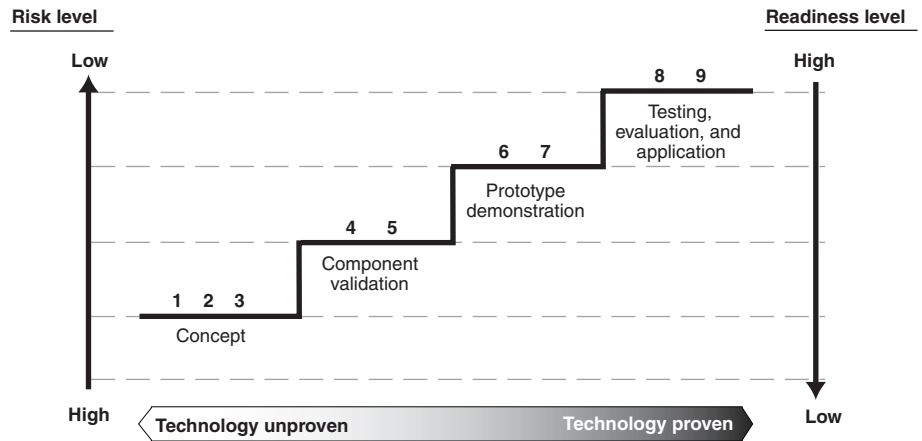
While NASA requires projects to develop plans that describe how technologies will be matured and to provide alternative development strategies for technologies that do not mature as expected, it does not establish a minimum threshold for technology maturity. Consequently, projects can enter the implementation phase with immature technologies and embark on a risky path of having to build technology, design, and production knowledge concurrently. Our best practices work has shown that maturing technologies during the preliminary design phase and before entering product development is a key element of matching needs to resources and that there is a direct relationship between the maturity of

technologies and the risk of cost and schedule growth.[15] Allowing technology development to carry over into the product development phase increases the risk that significant problems will be discovered late in development. Addressing such problems at this stage may require extensive retrofitting and redesign as well as retesting, which can jeopardize performance and result in more time and money to fix. This approach also makes it more difficult for projects to demonstrate the same level of design stability in later phases of implementation since technology and design activities will be done concurrently.

Technology readiness levels (TRL)—a concept developed by NASA—can be used to gauge the maturity of individual technologies. The higher the TRL, the more the technology has been proven and the lower the risk of performance problems and cost and schedule overruns (see fig. 5). TRL 7—demonstrating a technology as a fully integrated prototype in an operational environment—is the level of maturity preferred by product developers to minimize risks when entering product development.

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[15] GAO's 2005 assessment of 54 systems within the Department of Defense showed that development costs for programs that started development with mature technology increased by an average of 9 percent over the first full estimate, whereas the development costs for the programs that started development with immature technologies increased an average of 41 percent over the first full estimate. Likewise, program acquisition unit costs for the programs with mature technology increased by less than 1 percent, whereas the programs that started development with immature technologies experienced an average program acquisition unit cost increase of nearly 21 percent over the first full estimate. Programs with mature technology experienced an average schedule delay of 7 months—a 9 percent increase—whereas the schedule for the programs that started development with immature technology increased an average of 13 months—a 13 percent increase. GAO, *Defense Acquisitions: Assessments of Selected Major Weapon* Programs, GAO-05-301 (Washington, D.C.: Mar. 31, 2005).

Figure 5: Technology Maturity Levels for Product Development

Source: GAO.

Successful developers will not commit to undertaking product development, and more importantly investing resources, unless they have high confidence that they have achieved a match between what the customer wants and what the project can deliver. Technologies that are not mature continue to be developed in an environment that is focused solely on technology development. Once matured, these technologies can be transitioned to projects. This puts developers in a better position to succeed because they can focus on integrating the technologies and testing and proving the product design.

NASA's Policy Does Not Support Informed Design and Production Decisions

Our prior work has shown that successful developers establish specific criteria to ensure that requisite knowledge has been attained before moving forward from final design into the latter stages of development.[16] Before making significant increases in investments to fabricate, assemble, and test the product, these developers conduct a decision review to determine if the design is stable and performs as expected and the project is ready to enter the next phase. To make this determination and reach KP2, successful developers use specific, knowledge-based standards and criteria. (See app. II for more information on the specific knowledge-based standards and criteria successful developers use to judge readiness to proceed beyond detailed design activities.)

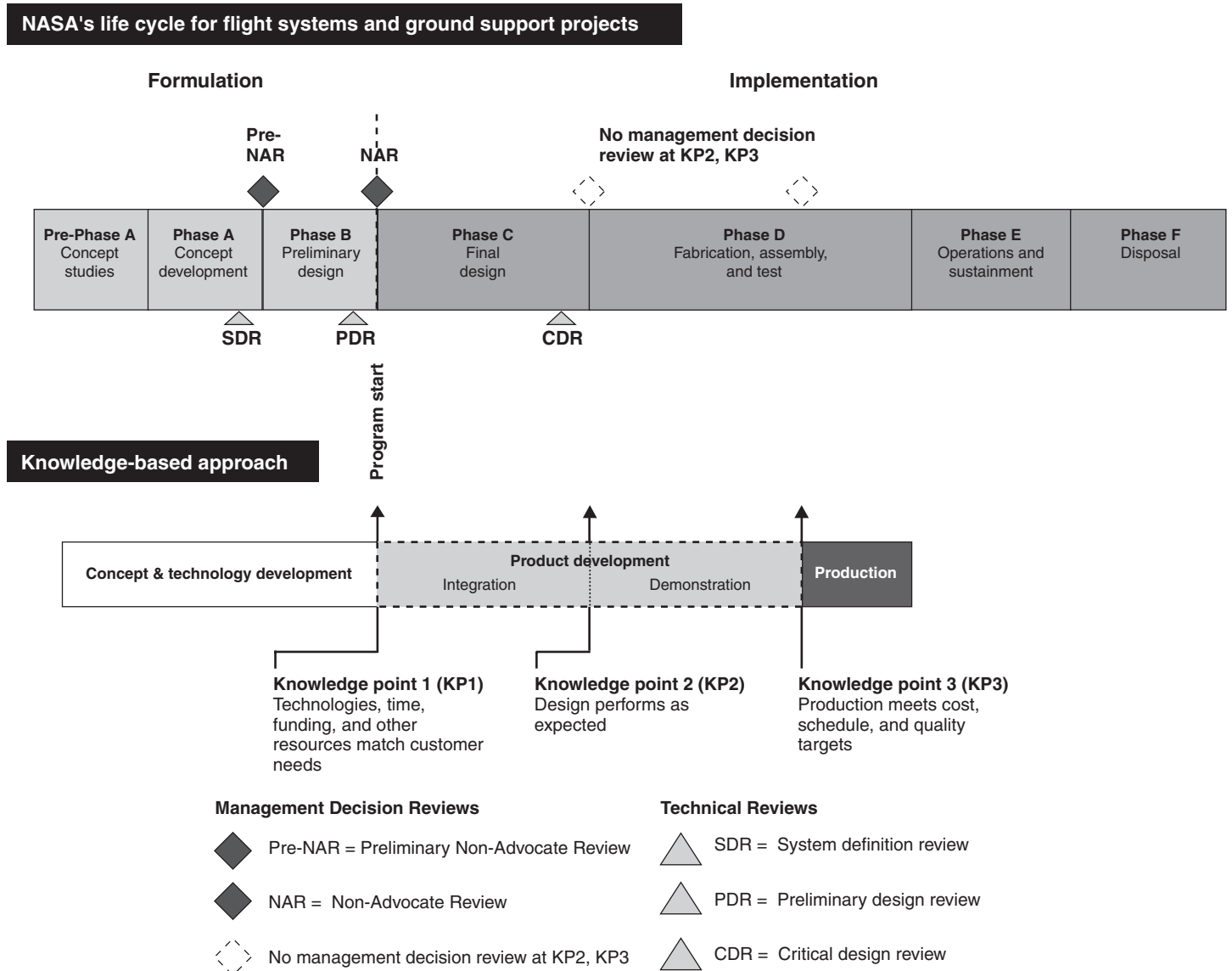[16] In NASA this is "Phase D—Fabrication, Assembly and Test."

Successful developers also demand proof that manufacturing processes are in control and product reliability goals are attained before committing to production. To determine whether they have achieved this knowledge point, KP3, successful developers conduct another mandatory decision review in which they use specific, knowledge-based standards and criteria to determine if the product can be produced within cost, schedule, and quality targets. (See app. II for more information on specific knowledge-based standards and criteria used by successful developers to judge readiness to enter into production.)

Contrary to these best practices, the NAR at the end of the preliminary design phase—KP1—is the last major decision review in the NASA project life cycle. (See fig. 6.) Although NPR 7120.5C requires that projects document in the project plan a continuum of technical and management reviews, such as a PDR and CDR, it does not require any specific reviews.[17] In addition, NASA's March 2005 policy does not require a NAR-type decision review to ensure a project has obtained the knowledge needed to proceed beyond the final design phase into the fabrication, assembly, and test phase, which serves as both the demonstration and production phase of the NASA life cycle.[18] According to NASA officials, projects conduct a CDR at the end of the final design phase to ensure adequate information is available about product design and producibility before entering the fabrication, assembly, and test phase. The CDR, however, is a technical review—not a major decision review like the NAR. Furthermore, the policy does not establish criteria as to what constitutes successful completion of a CDR.

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[17] Projects may also be required to complete specific technical and management reviews per individual center policy.

[18] According to NASA officials, some NASA centers require projects to provide status updates to the center PMC after the NAR, for example through monthly or quarterly status reports.

GAO-06-218 NASA Acquisition Policies

Figure 6: Comparison of NASA's Life Cycle with a Knowledge-Based Acquisition Life Cycle

NASA's life cycle for flight systems and ground support projects

Formulation

Implementation

Pre-NAR

NAR

No management decision review at KP2, KP3

| Pre-Phase A Concept studies | Phase A Concept development | Phase B Preliminary design | Phase C Final design | Phase D Fabrication, assembly, and test | Phase E Operations and sustainment | Phase F Disposal |

SDR

PDR

CDR

Program start

Knowledge-based approach

| Concept & technology development | Product development | | Production |
| | Integration | Demonstration | |

Knowledge point 1 (KP1)
Technologies, time, funding, and other resources match customer needs

Knowledge point 2 (KP2)
Design performs as expected

Knowledge point 3 (KP3)
Production meets cost, schedule, and quality targets

Management Decision Reviews

Pre-NAR = Preliminary Non-Advocate Review

NAR = Non-Advocate Review

No management decision review at KP2, KP3

Technical Reviews

SDR = System definition review

PDR = Preliminary design review

CDR = Critical design review

Sources: NASA and GAO analysis.

NASA's policy also does not require a major decision review before beginning manufacturing. (See fig. 6 above.) Therefore, the transition from final design to fabrication, assembly, and test often marks a *de facto* production decision. According to NASA officials, the agency rarely enters

a formal production phase due to the small quantities of space systems that they build. However, due to the high cost of failure associated with NASA projects and the costs and risks involved in repairing a system in-orbit, a major decision review at production that assesses product reliability is essential even for these limited production systems. In addition, although NASA's production quantities are typically low, in some instances NASA does produce larger quantities of a system or subsystem, such as the external tanks for the Space Shuttle. Furthermore, NASA's plans indicate that the agency may be increasing production for elements of their future systems. For example, NASA's *Exploration Systems Architecture Study* indicates that NASA plans to build several new crew exploration vehicles, with disposable elements, such as the lunar lander, solid rocket boosters, and space shuttle main engines that will require higher numbers of production runs.

Rather than establish specific criteria by which all projects are judged, NASA's policy requires that projects manage to baselines and plans established in key management documents and approved at the project NAR. The baselines and plans serve as their primary tools for measuring project progress and as the primary basis for judgment at project reviews. While the plans may include some information that addresses knowledge-based criteria for design and production, the instructions for preparing them leaves the establishment of thresholds and success criteria to the discretion of the project manager. For example, NASA policy requires that projects include, as part of the project plan, a *Verification and Validation Sub Plan* that describes the project's approach to verifying and validating hardware and software as part of the project plan. The policy, however, includes no instruction as to what constitutes a sufficient approach to testing. In other words, there are no requirements concerning the fidelity of test articles or the realism of the test environment. Similarly, NASA's policy requires that projects include, as part of the project plan, a *Systems Engineering Sub Plan* that describes the project's approach to systems engineering and the technical standards that are applicable, including metrics that verify the processes. The policy, however, does not identify the types of metrics appropriate to verify the process or establish any threshold criteria.

The absence of major decision reviews, along with specific criteria in the fabrication, assembly, and test phase, could result in concurrent design and manufacturing activities, a practice our past work has found increases

risk in acquisition programs.[19] Furthermore, lacking a major decision review to ensure that projects have gained the appropriate levels of knowledge at KP2 and KP3, NASA decision makers cannot be provided a high level of certainty that the project will meet cost, schedule, and performance requirements and have no assurance that the provisions of the key management documents required by NPR 7120.5C are being executed after the NAR.

Lack of NASA-Wide Project Management Criteria May Result in Investment Decisions Based on Inconsistent Information

NASA centers have varying approaches to implementing project management policies and systems engineering guidance for flight systems and ground support projects. Some centers use criteria at key decision points that are similar to the criteria required to ensure a knowledge-based approach is followed, while others lack such criteria. As a result, each center reports a different level and type of knowledge about a project at key decision points. Centers also rely on project managers and systems engineers to employ good project management and systems engineering practices. However, given the loss of experienced project managers and the decline of in-house systems engineering and technical capabilities agencywide, that reliance could be problematic. These situations make it difficult for NASA decision makers to evaluate center projects on a common foundation of knowledge and make sound investment decisions and tradeoffs based on those evaluations. A standardized, knowledge-based approach would prepare NASA to face competing budgetary priorities and make difficult decisions regarding the investment in and termination of projects.

Individual Centers Tailor Implementation of Agencywide Project Management Policies and Systems Engineering Guidance

While NASA centers are given discretion about how they implement agencywide policies, they are expected to have procedures and guidelines in place for implementing those policies. Some centers have developed center-specific policies and criteria for implementing NASA's project management policies and system engineering guidance, while others have not. Centers also rely on project managers and systems engineers to implement the requirements of NPR 7120.5C and to use NASA's *Systems Engineering Handbook* as guidance for good systems engineering

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[19] GAO, *Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C., July 30, 1999) and GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C., July 15, 2002).

practices.[20] Some NASA centers have also developed criteria in their policies that are similar to the criteria used to ensure a knowledge-based approach is followed; other centers lack such criteria.

Because of their varying policies and criteria, each center requires a different level of knowledge at the same point in a project's development cycle. For example, GSFC requires its projects to mature technologies to TRL 6 by the preliminary design review—before entering the implementation phase. On the other hand, JPL, MSFC, and JSC policies do not require projects to mature technology to a particular level before entering implementation, leaving the determination of needed technology maturity up to the project manager.

Requirements for assessing design maturity also vary across the centers. While most of the center policies require a CDR to enter "Phase D— Fabrication, Assembly, and Test"—the criteria used to assess projects at this point vary. For example, both GSFC and MSFC require projects to have completed a percentage of design drawings at this review. MSFC requires that 90 percent of design drawings to be complete by CDR, which is consistent with best practices. While GSFC establishes a minimum threshold of drawings to be complete by CDR—greater than 80 percent— neither JSC nor JPL establish a minimum percentage drawing requirement. Instead, JSC requires the design be complete and drawings ready to begin production, and JPL requires that the design be mature and provide confidence in the integrity of the flight system design.

Almost none of the center policies include a requirement to assess the maturity of production processes. According to NASA officials, due to the low quantities of systems generally produced by the agency, most of the center policies do not require a review before beginning manufacturing. Only JSC requires a Production Readiness Review to ensure that production plans, facilities, and personnel are in place and ready to begin production. However, the criteria do not specify quantifiable thresholds to measure production readiness at the review. JPL, MSFC, and GSFC do not have policies that outline requirements for such a review.

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[20] NASA's *Systems Engineering Handbook* provides systems engineers and project managers with a generic description of NASA systems engineering and a common language and perspective of the systems engineering process. See National Aeronautics and Space Administration, *NASA Systems Engineering Handbook*, *SP-6105*. (Washington, D.C.: June 1995).

In addition to individual policy requirements, centers may rely on project managers and systems engineers to employ good project management and systems engineering practices. For example, an experienced project manager at JPL told us that although JPL policy does not require a particular TRL at PDR to enter implementation, he required that all technologies for his project be around a TRL 6 in order to separate technology development from systems development. Reliance on project managers to implement good practices, however, could be problematic given the diminishing number of experienced project managers available to lead projects and the decline of in-house systems engineering and technical capabilities agencywide caused by increasing retirements and outsourcing.

Informed Investment Decisions Require Consistent Knowledge

In a knowledge-based process, the achievement of each successive knowledge point builds on the preceding one, giving decision makers the information they need, when they need it, to make decisions about whether to invest significant additional funds to move forward with product development. Our work has shown that successful product development efforts are marked by adherence to a disciplined process that establishes and uses common and consistent criteria for decision making at these key points. With varying project management and systems engineering criteria, NASA centers' technical reviews, such as PDR, provide different levels of knowledge to support NASA's major decision reviews, such as the NAR, which NASA uses to support its major investment decisions for flight systems and ground support projects.

In the near future, NASA will need to determine the resources necessary to develop the systems and supporting technologies to achieve the President's *Vision for Space Exploration* and structure its investment strategy accordingly. Initial implementation of the *Vision* as explained in NASA's *Exploration Systems Architecture Study* calls for completing the International Space Station, developing a new crew exploration vehicle, and returning to the moon no later than 2020. NASA estimates that it will cost approximately $104 billion over the next 13 years to accomplish these initial goals. These priorities, along with NASA's other missions, will be competing within NASA for funding. It will likely be difficult for NASA managers to agree on which projects to invest in and which projects to terminate. The NASA Administrator has acknowledged that NASA faces difficult choices about its missions in the future—for example, between human space flight, science, and aeronautics missions.

Using consistent criteria to evaluate all NASA projects would help ensure that the same level and type of knowledge is available about individual projects at key decision points. Analogous information about all flight systems and ground support projects would allow decision makers to make apples-to-apples comparisons across projects and make investment decisions, and trade-offs, based upon these comparisons. Further, policies with consistent criteria can provide inexperienced project managers and systems engineers with the necessary guidance to implement good project management and systems engineering practices and ensure that the right knowledge is available for decision makers.

NASA officials within the Chief Engineer's Office acknowledged the need for more consistency in criteria across the various NASA centers in order to successfully achieve NASA's *Vision for Space Exploration*. Some NASA centers, however, are resistant to standardized criteria because they feel it could be overly prescriptive. These centers indicated that because of the unique nature of the work done at each of the 10 NASA centers, it would be unrealistic to hold every project to the same criteria. Nonetheless, our work has shown that the process used by successful product developers to develop leading-edge technology and products does not differ based upon the type of product being developed. Further, these developers adhere to a disciplined process that establishes and uses common and consistent criteria for decision making—regardless of the type of product or technology being developed. Using consistent criteria can allow NASA decision makers to assess the likely return on competing investment priorities and to reevaluate alternatives and make investment decisions across projects to increase the likelihood of attaining the strategic goals of the agency.

Conclusions

Several of NASA's major acquisitions have been marked by cost, schedule, and performance problems. Yet the challenges NASA faces in the future are likely to far exceed those it has faced in the past. The complex technical requirements associated with fulfilling the President's *Vision*, the fiscal constraints under which NASA will be required to operate, the diminished number of experienced project managers and systems engineers, and the potential for increased production make following a knowledge-based approach for flight systems and ground support projects all the more critical. While NASA has made improvements to its policies governing project management, the lack of major decision reviews beyond the initial project approval gate leaves decision makers with little knowledge about the progress of the agency's projects. Further, without a standard set of criteria to measure projects at crucial phases in the

development life cycle, NASA cannot be assured that its decisions will result in the best possible return on its investments. Since NASA is currently in the process of revising its program and project management policies and developing an agencywide systems engineering policy, we believe this presents a unique opportunity for the agency to correct some of the problems identified during our review.

Recommendations for Executive Action

In order to close the gaps between NASA's current acquisition environment and best practices on knowledge-based acquisition, we recommend that NASA take steps to ensure NASA projects follow a knowledge-based approach for product development. Specifically, we recommend that the NASA Administrator direct the Office of the Chief Engineer to take the following two actions:

- In drafting its systems engineering policy, incorporate requirements in the policy for flight systems and ground support projects to capture specific product knowledge by key junctures in project development. The demonstration of this knowledge should be used as exit criteria for decision making at the following key junctures:

  - Before projects are approved to transition from formulation to implementation, the policy should require that projects demonstrate that key technologies have reached a high maturity level.
  - Before projects are approved to transition from final design to fabrication, assembly, and test, the policy should require that projects demonstrate that the design is stable.
  - Before projects are approved to transition into production, the policy should require projects to demonstrate that the design can be manufactured within cost, schedule, and quality targets.

- Revise NPR 7120.5C to institute additional major decision reviews following the NAR for flight systems and ground support projects, which result in recommendations to the appropriate decision authority. These reviews should be tied to the key junctures during project development mentioned above in order to increase the likelihood that cost, schedule, and performance requirements of the project will be met.

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for review and comment. In written comments, NASA indicated that it agreed with our recommendations and outlined specific actions that the agency plans to take to address them.

The actions that NASA plans to take to address our recommendations are a positive step toward achieving successful project outcomes and ensuring that decision makers are appropriately investing the agency's resources. We are pleased to hear that many knowledge-based practices identified in our report are currently being practiced agencywide in the management and development NASA systems. The addition of such practices to NASA's policies will only strengthen their use agencywide and ensure that these practices continue to be utilized by less experienced project managers and systems engineers as the more experienced workforce retires. The effectiveness of such practices, however, will be limited if project officials are not held accountable for demonstrating a high level of knowledge, consistent with the success criteria that NASA plans to require in its policies, at key junctures in development. It is critical that project officials not only have a high level of knowledge about a project at key junctures, but also that this information is used by decision makers to make decisions on whether to invest additional resources and allow a project to proceed through the development life cycle.

NASA's comments are reprinted in appendix III. NASA also provided technical comments, which we addressed throughout the report as appropriate.

As agreed with your offices, unless you announce its contents earlier, we will not distribute this report further until 30 days from its date. At that time, we will send copies to NASA's 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 your or your staff have any questions concerning this report, please contact me at (202) 512-4841 or lia@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are acknowledged in appendix IV.

Allen Li
Director
Acquisition and Sourcing Management

Appendix I: Scope and Methodology

To determine the extent to which NASA's current policies support an acquisition approach consistent with best practices identified in GAO's work on system acquisitions, we reviewed and analyzed NASA-wide program and project management policies and systems engineering guidance. Our review and analysis of the policy focused on requirements for flight systems and ground support projects. We interviewed NASA Headquarters officials from the Office of the Chief Engineer who are responsible for the policy and guidance. We compared NASA's policy on program and project management with criteria contained in GAO best practices work on systems acquisition and space system acquisitions. We concentrated on whether the policy provides a framework for a knowledge-based process and the criteria necessary to carry out this intent.

To determine how NASA-wide acquisition policies are implemented across the various NASA centers, we reviewed NASA center-specific program and project management policies and systems engineering policies and interviewed officials responsible for implementing those policies. While we interviewed officials from all centers, we focused on the centers that manage the majority of NASA's flight systems and ground support projects—GSFC, JPL, JSC, and MSFC. This approach included site visits with GSFC, JPL, JSC, and MSFC and teleconferences with the remaining centers. We compared examples of the centers' implementation of the policies and specific criteria included in these policies with our best practices work on systems acquisition.

We performed our work from May 2005 to November 2005 in accordance with generally accepted government auditing standards.

Appendix II: Activities That Enable the Capture of Design and Manufacturing Knowledge

Table 3: Activities to Capture Design Knowledge and Make Decisions

Knowledge: Design is stable and performs as expected (knowledge point 2)

Decision: Product is ready for initial manufacturing and system demonstration phase.

Key indicator: 90 percent of engineering drawings completed.

Activities to achieve stable design knowledge

- **Limit design challenge**—The initial design challenge is limited to a product that can be developed and delivered quickly and provide the user with an improved capability. A time-phased plan is used to develop improved products—future generations—in increments as technologies and other resources become available.
- **Demonstrate design meets requirements**—The product's design is demonstrated to meet the user's requirements. For a new product that is not based on an existing product, prototypes are built and tested. If the product is a variant of an existing product, companies often used modeling and simulation or prototypes at the component or subsystem level to demonstrate the new product's design.
- **Complete critical design reviews**—Critical design reviews are used to assess whether a product's design meets requirements and is ready to start initial manufacturing. Reviews are conducted for the system, subsystems, and components to assess design maturity and technical risk.
- **Stakeholders agree drawings complete and producible**—The agreement by stakeholders (engineers, manufacturers, and other organizations) is used to signify confidence that the design will work and the product can be built.
- **Executive level review to begin initial manufacturing**—Corporate stakeholders meet and review relevant product knowledge, including design stability, to determine whether a product is ready to initiate manufacturing of production representative prototypes used during system demonstrations. The decision is tied to the capture of knowledge.

Source: GAO.

Table 4: Activities to Capture Manufacturing Knowledge and Make Decisions

Knowledge: Product can be produced within cost, schedule, and quality targets (knowledge point 3)

Decision: Product is ready for production and will be reliable.

Key indicator: Critical processes in statistical control and product reliability demonstrated.

Activities to Achieve Manufacturing Knowledge

- **Identify key system characteristics and critical manufacturing processes**—Key product characteristics and critical manufacturing processes are identified. Because there can be thousands of manufacturing processes required to build a product, companies focus on the critical processes—those that build parts that influence the product's key characteristics such as performance, service life, or manufacturability.

- **Determine processes in control and capable**—Statistical process control is used to determine if the processes are consistently producing parts. Once control is established, an assessment is made to measure the process's ability to build a part within specification limits as well as how close the part is to that specification. A process is considered capable when it has a defect rate of less than 1 out of every 15,152 parts produced.

- **Conduct failure modes and effects analysis**—Bottom-up analysis is done to identify potential failures for product reliability. It begins at the lowest level of the product design and continues to each higher tier of the product until the entire product has been analyzed. It allows early design changes to correct potential problems before fabricating hardware.

- **Set reliability growth plan and goals**—A product's reliability is its ability to perform over an expected period of time without failure, degradation, or need of repair. A growth plan is developed to mature the product's reliability over time through reliability growth testing so that it has been demonstrated by the time production begins.

- **Conduct reliability growth testing**—Reliability growth is the result of an iterative design, build, test, analyze, and fix process for a product's design with the aim of improving the product's reliability over time. Design flaws are uncovered and the design of the product is matured.

- **Conduct executive level review to begin production**—Corporate stakeholders meet and review relevant product knowledge, including manufacturing and reliability knowledge, to determine whether a product is ready to begin production. The decision is tied to the capture of knowledge.

Source: GAO.

Appendix III: Comments from the National Aeronautics and Space Administration

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

December 15, 2005

Mr. Allen Li
Director, Acquisition and Sourcing Management
United States Government Accountability Office
Washington, DC 20548

Dear Mr. Li:

NASA appreciates the opportunity to comment on your draft report (General Accountability Office (GAO) 06-218) entitled "Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes."

Per the National Aeronautics and Space Act (Pub. L. No 85-568), NASA's charter is "to provide for research into problems of flight within and outside the Earth's atmosphere, and for other purposes." NASA is a research and development organization, and its projects face greater uncertainty further into the life cycle than traditional high-volume acquisitions. Most NASA missions fabricate one-of-a-kind spacecraft using a proto-flight or very small quantity approach.

Projects are primarily governed by two NASA Procedural Requirements (NPRs). NPR 7120.5C, *NASA Program and Project Management Processes and Requirements*, establishes the management system which governs the formulation, approval, implementation, and evaluation of NASA programs and projects. Requirements for performing, supporting, and evaluating a systems approach applied to all elements and levels of a system over the complete project life cycle are established for the implementing organizations in NPR 7123, *NASA Systems Engineering Processes and Requirements*. NPR 7123 is in the final approval cycle.

Many of the best practices you recommend are currently being practiced Agencywide but may not be apparent in our current policy. Issuance of NPR 7123 will establish a consistent minimum set of project reviews that are already practiced within NASA (i.e., Systems Requirement Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR)). While NPR 7120.5C does not depict decision reviews at key junctures beyond the Non-Advocate Review (NAR), NASA gains continuous knowledge throughout the implementation phase. Monthly or quarterly status reviews are typically held utilizing the hierarchy of governing program management councils. This process provides for decision points throughout the life cycle.

The following paragraphs provide the GAO recommendations and the NASA response addressing these recommendations:

2

First GAO Recommendation

In order to close the gaps between NASA's current acquisition environment and best practices on knowledge-based acquisition, we recommend that NASA take steps to ensure NASA projects follow a knowledge-based approach for product development. Specifically, we recommend that the NASA Administrator direct the Office of the Chief Engineer to take the following two actions:

- **In drafting its systems engineering policy, incorporate requirements in the policy for flight systems and ground support projects to capture specific product knowledge by key junctures in project development. The demonstration of this knowledge should be used as exit criteria for decision making at the following key junctures:**
    - o **Before projects are approved to transition from formulation to implementation, the policy should require that projects demonstrate that key technologies have reached a high maturity level.**
    - o **Before projects are approved to transition from final design to fabrication, assembly, and test, the policy should require that projects demonstrate that the design is stable.**
    - o **Before projects are approved to transition into production, the policy should require projects to demonstrate that the design can be manufactured within cost, schedule and quality targets.**

NASA agrees, with the following comments:

NASA takes a risk-based approach to technology readiness. NASA will define the applicable technology readiness level for each phase of the life cycle and include these definitions in NPR 7123. NASA will also strengthen the current wording in NPR 7120.5C to ensure that a design solution incorporating sufficiently mature technology will be available at PDR. This does not preclude the program/project manager from pursuing a parallel design approach utilizing a higher performance but less mature solution as long as the mature technology remains available and appropriate risk mitigation processes are employed. However, exceptions should be made in the cases where the primary mission objective is to mature and demonstrate technologies to reduce risk on future missions (i.e., New Millennium Program).

NASA implements a review process that includes peer reviews both within NASA and at the supplier. Per NPR 7123, CDRs are one of a minimum set of flight systems and ground support technical reviews held for the purpose of demonstrating "that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test, and that the technical effort is on track to complete the flight and ground system development and mission operations in order to meet mission performance requirements within the identified cost and schedule constraints." NASA will establish requirements

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for the CDR success criteria in NPR 7123 to ensure that the design is stable and that the system can be fabricated within cost, schedule, and performance specifications. In addition, NASA will establish requirements for the success criteria in NPR 7123 for other required technical reviews in the life cycle.

Very few NASA projects enter into a traditional production process. Most NASA missions fabricate one-of-a-kind spacecraft. For this class of mission, the CDR will thoroughly review the readiness to proceed to fabrication of the flight system. CDR success criteria will be reviewed and updated to include any additional fabrication information required to enable a knowledge-based decision (see above paragraph). In the event that systems or elements are intended for large scale production, including major components of unique systems, NASA will conduct a Production Readiness Review (PRR) that will meet required success criteria. This review and its success criteria will be added to NPR 7123.

Second GAO Recommendation

- **Revise NPR 7120.5C to institute additional major decision reviews following the NAR for flight systems and ground support projects, which result in recommendations to the appropriate decision authority. These reviews should be tied to the key junctures during project development mentioned above in order to increase the likelihood that cost, schedule, and performance requirements of the project will be met.**

NASA agrees, with the following comments:

The CDR results will provide the information needed for the decision authority. NASA will revise NPR 7120.5C to require the results of the CDR to be out-briefed to the appropriate decision authority in a timely manner for a decision to proceed. An additional decision point will be added, as applicable, to out-brief the results of a PRR in the case of large scale production lots to the appropriate decision authority for a decision to proceed.

Thank you for the opportunity to comment on this draft report.

Sincerely,

Shana Dale
Deputy Administrator

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Allen Li (202) 512-4841

Staff Acknowledgments

In addition to the individual named above, James L. Morrison, Assistant Director; Valerie Colaiaco, Tom Gordon, Alison Heafitz, Shelby S. Oakley, Ron Schwenn, Karen Sloan, and John S. Warren, Jr., made key contributions to this report.

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