

GAO

Report to the Chairman, Committee on
Science and Technology, House of
Representatives

October 2007

NASA

Agency Has Taken
Steps Toward Making
Sound Investment
Decisions for Ares I
but Still Faces
Challenging
Knowledge Gaps



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Highlights

Highlights of [GAO-08-51](#), a report to the Chairman, Committee on Science and Technology, House of Representatives

Why GAO Did This Study

One of the first steps in the National Aeronautics and Space Administration's (NASA) efforts to implement the President's plan to return humans to the moon and prepare for eventual human space flight to Mars is the development of the Ares I Crew Launch Vehicle. In 2005, NASA outlined a framework for implementing the President's plan and has awarded contracts for Ares I and the Orion Crew Exploration Vehicle it is designed to send into space. It plans to conduct the first human space flight in 2015. However, the agency is seeking to speed development efforts in order to reduce the gap in our nation's ability to provide human access to space caused by the Space Shuttle's retirement in 2010. GAO was asked to assess NASA's progress in developing the knowledge needed to make sound investment decisions for the Ares I project. GAO's work included analyzing Ares I plans, contracts, schedules, and risk assessments.

What GAO Recommends

GAO recommends NASA establish a sound business case for Ares I before proceeding beyond preliminary design review (now set for July 2008), and if necessary, delay the preliminary design review until the project's readiness to move forward is demonstrated.

To view the full product, including the scope and methodology, click on [GAO-08-51](#). For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

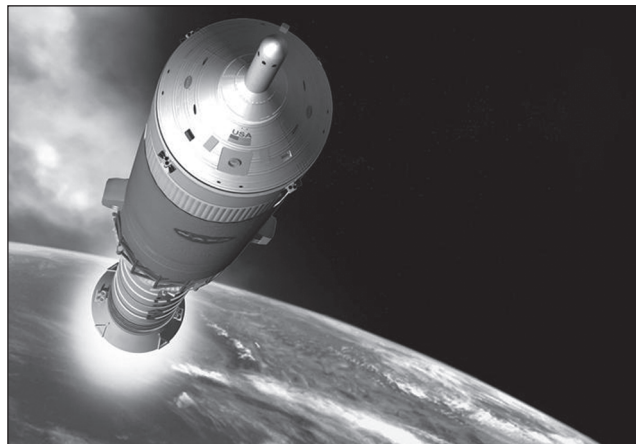
NASA

Agency Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps

What GAO Found

NASA has been taking steps to build a business case—demonstrating the project is achievable within the constraints of time and money and other resources NASA has available—for Ares I. This has included relying on established technology and adopting an acquisition strategy that emphasizes attaining knowledge on cost, schedule, and technical and development feasibility before commitments are made to long-term investments. The project also acknowledges that many risks are present and is undertaking an array of activities to track and mitigate those risks. However, NASA has not yet developed the knowledge needed to make sound investment decisions for the Ares I project. Principally, there are gaps in knowledge about requirements, costs, schedule, technology, design, and production feasibility. Our work shows that successful program execution is dependent on having these elements in place at the time long-term investment commitments are made. While NASA still has 10 months under its own schedule to close gaps in knowledge about requirements, technologies, costs, and time and other elements needed to develop the Ares I system, the gaps we identified are fairly significant and challenging given the complexity and interdependencies in the program. For example, continued instability in the design of the Orion Crew Exploration Vehicle is hampering the Ares I project's efforts to establish firm requirements, the aggressive J-2X upper stage engine development schedule is not synchronized with the rest of the project, and it is unclear if NASA has allocated sufficient funding to the project.

Artist's rendition of Ares I



Source: NASA.

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Abbreviations

DDT&E	design, development, test, and evaluation
ESAS	Exploration Systems Architecture Study
IRMA	Integrated Risk Management Application

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United States Government Accountability Office
Washington, DC 20548

October 31, 2007

The Honorable Bart Gordon
Chairman
Committee on Science and Technology
House of Representatives

Dear Mr. Chairman:

The National Aeronautics and Space Administration (NASA) plans to spend nearly \$230 billion over the next 2 decades to implement the President's Vision for Space Exploration (Vision), which calls for a return of humans to the moon and eventual human spaceflight to Mars. NASA is implementing the Vision under the Constellation program.¹ Among the first major efforts of this program are the development of new space flight systems—including the Ares I Crew Launch Vehicle and the Orion Crew Exploration Vehicle—to tackle the mission. NASA has awarded contracts related to each effort and plans to conduct the first human spaceflight launch in 2015. However, the agency is seeking to speed development efforts in order to reduce the gap in our nation's ability to provide human access to space caused by the Space Shuttle retirement in 2010.

In September 2005, NASA outlined an initial framework for implementing the Vision in its Exploration Systems Architecture Study (ESAS). NASA indicated it would maximize the use of heritage hardware and established technology in order to reduce cost and minimize risk. It proposed using the same engines and reusable solid rocket boosters that now launch the Space Shuttle as the basis for the Ares I Crew Launch Vehicle. Since then, however, NASA has undertaken a number of additional reviews to further refine the project requirements which resulted in changes to the Ares I design.

You asked us to assess NASA's progress in developing the knowledge needed to make sound investment decisions for the Ares I project. To

¹Within NASA, a program is defined as a strategic direction that the agency has identified as needed to implement agency goals and objectives. A project is a specific investment within a program having defined requirements, a life-cycle cost, a beginning, and an end that yields new or revised products that directly address NASA's strategic needs. Ares I is a project within the Constellation program.

address this objective, we obtained and reviewed Ares I plans, contracts, schedules, risk assessments, budget documentation, and technology maturity assessments. We conducted further qualitative and quantitative analyses of these documents and compared them to criteria established in NASA directives governing development projects and in GAO's best practices body of work. Our work was conducted between March 2007 and September 2007 in accordance with generally accepted government auditing standards.

Results in Brief

NASA has been taking steps to build a business case for Ares I, including relying on established technology and adopting an acquisition strategy that emphasizes attaining knowledge on cost, schedule, and technical and development feasibility before commitments are made to long-term investments. The program also acknowledges that many risks are present and is undertaking an array of activities to track and mitigate those risks. However, NASA has not yet developed the knowledge needed to make sound investment decisions for the Ares I project. Principally, there are gaps in knowledge about requirements, costs, schedule, technology, design, and production feasibility. Our work shows that successful program execution is dependent on having these elements in place at the time long-term investment commitments are made. While NASA still has 10 months under its own schedule to close gaps in knowledge about requirements, technologies, costs, and time and other elements needed to develop the Ares I system, the gaps we identified are significant and challenging given the complexity and interdependencies in the program. More specifically, the challenges NASA faces are the following:

- *Requirements knowledge gaps:* Ares I requirements are not yet stable, namely because requirements are not yet stable for the Orion Crew Exploration Vehicle—which Ares I will be launching. NASA recognizes the need to synchronize Ares I and Orion requirements as the top risk facing the Ares I project. According to NASA, at least 14 of the 57 risks in the Ares project—as tracked by the Constellation program's integrated risk management system—are explicitly tied to requirements instability. When requirements are in flux and development efforts are contingent upon the flow-down of stable requirements, it can create a ripple effect of unknowns and be extremely difficult to establish firm cost and schedule baselines. In fact, NASA was not able to definitize, that is, reach agreement on the terms and conditions of its development contracts for the first stage and upper stage engine until very recently because requirements were in flux.

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- *Technology and hardware development knowledge gaps:* Three major elements of the Ares I system—first stage, upper stage, and the upper stage engine—pose significant development challenges. Although the first stage draws heavily from existing Space Shuttle systems, incorporating a fifth segment is likely to affect the flight characteristics of the existing reusable solid rocket booster. These flight characteristics would need to be demonstrated and understood prior to the production effort. Also, the upper stage is including a shared or “common” bulkhead between its two fuel tanks. Experience from the Apollo program indicates that common bulkheads are complex, difficult to manufacture, and should be avoided. Further, the J-2X upper stage engine represents a new engine development effort that is likely to encounter problems during development. NASA estimates that J-2X will require 29 rework cycles to address problems.
 - *Aggressive schedule:* The J-2X upper stage engine, the critical path for the Ares I development, is on an aggressive development schedule wherein the J-2X engine design cycle is ahead of the Ares I vehicle design cycle. Delays in the J-2X schedule for design, development, test, and evaluation would have a ripple effect throughout the entire Ares I project. In addition, the critical design review for the first stage is currently scheduled after the Ares I project-level critical design review. This places the project at risk of prematurely beginning full-scale test and integration activities.
 - *Projected funding shortfalls:* NASA’s funding strategy for the Constellation program relies on accumulating funds in fiscal years 2006 and 2007 for work planned in fiscal years 2008, 2009, and 2010. NASA estimates its total budget will be insufficient to fund all Constellation activities during these years. These funding shortfalls could result in planned work not being completed to support schedules and milestones.

NASA acknowledges these risks and has mitigation plans in place for most of them. For example, NASA is mitigating J-2X schedule risk by acquiring additional test resources in order to relieve pressure on the test schedule. We are making recommendations to the NASA Administrator to direct the Ares I project to develop a sound business case before beginning product development.

Background

Ares I and Orion are currently targeted for operation no later than 2015 (see fig. 1). However, NASA is seeking to accelerate this schedule to

minimize the gap in the nation’s ability to launch humans into space.² Following the initial phase, Constellation will develop crew and cargo capabilities for missions to the lunar surface, no later than 2020. As currently planned, this system will include the Ares V Cargo Launch Vehicle, Earth Departure Stage, Lunar Surface Access Module, and associated support capabilities. Further development will provide crew, cargo, and infrastructure to support human exploration of Mars and beyond.

Figure 1: Constellation Program Schedule, by Fiscal Year

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Ares I crew launch vehicle		▽ December	▽ July		▼ March					Initial operating capability for both projects: March
Orion crew exploration vehicle		▽ March	▽ August		▼ September					

- ▽ System requirements review
- ▽ Preliminary design review
- ▼ Critical design review

Source: GAO analysis of NASA data.

In September 2005, NASA authorized the Ares I project to proceed with the development of a new human-rated crew launch vehicle with a 24.5-metric ton lift capability and a total budget of \$14.4 billion for design, development, test, and evaluation (DDT&E), and production.³ In April 2006, NASA awarded a \$1.8 billion contract for DDT&E of the first stage to Alliant Techsystems followed by a \$1.2 billion contract for DDT&E of the J-2X upper stage engine to Pratt and Whitney Rocketdyne in June 2006. NASA is developing the upper stage and the upper stage instrument unit, which contains the control systems and avionics for the Ares I, in-house.

² The Constellation program is maintaining a 2015 date for first human spaceflight launch at a 65 percent confidence level based on current funding. The program is also working internally toward achieving a first human spaceflight by 2013 at a confidence level of less than 40 percent based on current funding.

³ Human rated space systems incorporate those design features, operational procedures, and requirements necessary to accommodate human passengers and crew.

Recent Changes to Ares I Architecture

As initially conceived in the ESAS—NASA’s effort to identify the best architecture and strategy to implement the President’s 2004 *Vision for Space Exploration*—the Ares I design was predicated on using existing Shuttle components including the four-segment reusable solid rocket booster as the first stage and the Space Shuttle main engine as the upper stage engine. According to agency officials, after standing up the Ares I project office, NASA began to examine the ESAS architecture from a more programmatic perspective. At this point NASA began to consider alternatives that would streamline the development path for the Ares family of launch vehicles and save development and operations costs in the long run.

Implementing the ESAS architecture for the Ares launch vehicle family would have entailed five new efforts to develop and/or modify propulsion hardware including

- modifying and certifying the Space Shuttle’s four-segment reusable solid rocket booster for the Ares I first stage;
- modifying and certifying, a five-segment reusable solid rocket booster for the Ares V, based on the Space Shuttle’s four-segment reusable solid rocket booster;
- modifying and certifying an expendable Space Shuttle main engine for the Ares I upper stage;
- modifying and certifying a different expendable Space Shuttle main engine for the Ares V; and
- developing and certifying, based on the Apollo era J-2 engine, an engine for the Ares V.

This approach would have also required NASA to manage multiple booster configurations and multiple Space Shuttle main engine versions during the lunar mission time frame.

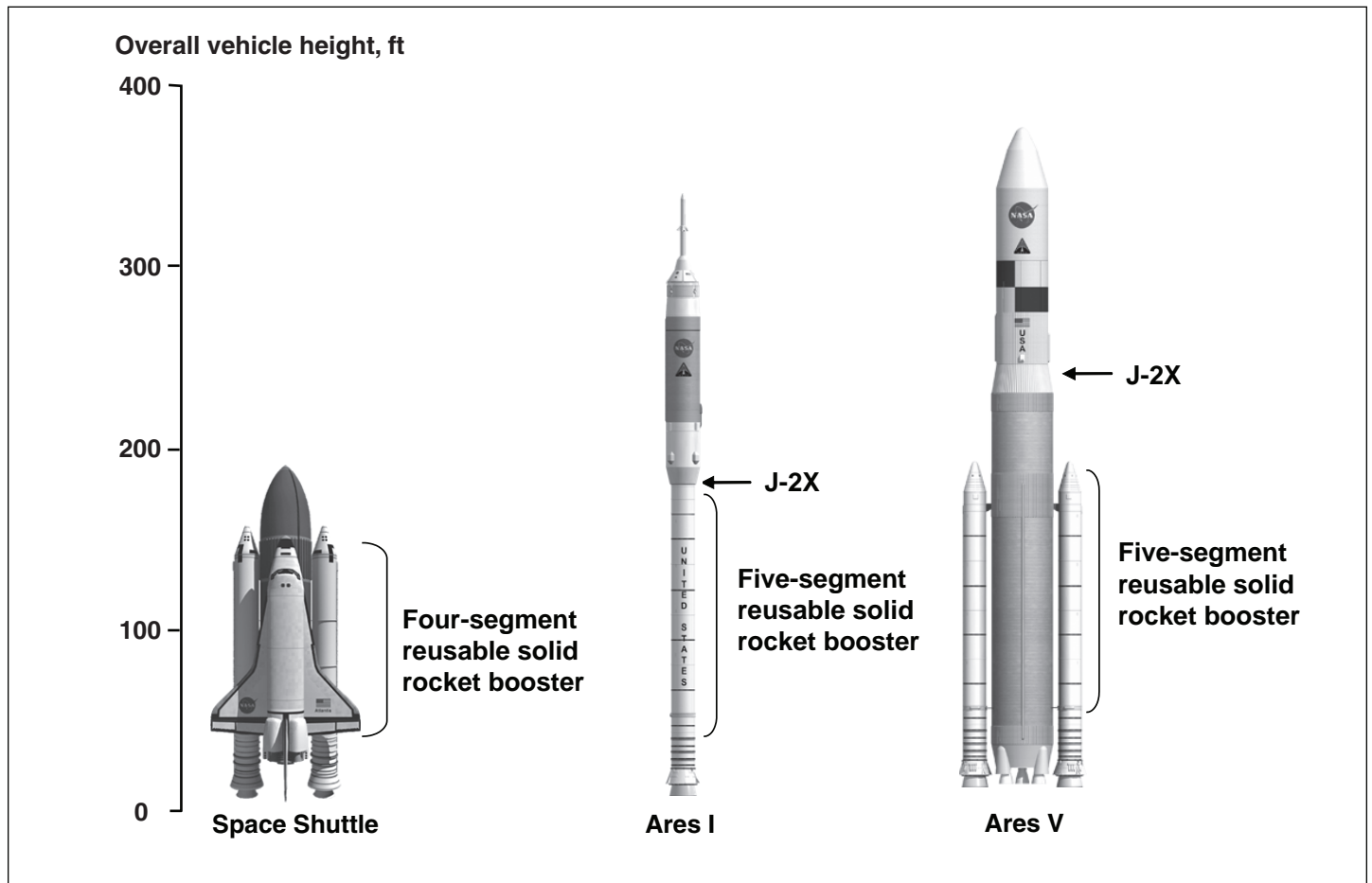
After completing additional systems engineering and analysis of life-cycle costs, in January 2006 NASA made changes to the Ares I design to reduce the total number of development efforts required to enable the Ares launch vehicle family.⁴ The Ares I design (see fig. 2) now includes the five-segment reusable solid rocket booster for its first stage and the J-2X—an

⁴As a result of this analysis, NASA also modified the Ares V design to replace the Space Shuttle main engine with an improved version of the RS-68 engine used on the Air Force’s Delta IV heavy launch vehicle. NASA estimates that using the RS-68 will save approximately \$4.25 billion in life-cycle costs through 2020.

engine based on the J-2 and J-2S engines used on the 1960s era Saturn V—as the upper stage engine.⁵ The current design increases commonality between the Ares I and Ares V, and eliminates the need to develop, modify, and certify both a four-segment reusable solid rocket booster and an expendable Space Shuttle main engine for the Ares I. NASA also expects the J-2X to be less expensive and easier to manufacture than the Space Shuttle main engine. According to NASA, by developing the J-2X and resolving risks associated with incorporating a fifth segment into the reusable solid rocket booster earlier, the new Ares I design now represents a significant and direct down payment on the Ares V. Furthermore, NASA believes this approach can enable an earlier Ares V availability date, since the risks associated with incorporating the fifth segment into the reusable solid rocket booster will have been resolved.

⁵A five-segment reusable solid rocket booster-based Ares I was the initial solution during the early phase of the ESAS study; existing four-segment hardware was eventually selected during ESAS due to anticipated schedule and start-up cost savings based on using existing inventories and production lines.

Figure 2: Space Shuttle, Ares I, and Ares V Comparison



Source: NASA and GAO presentation.

NASA estimates that incorporating the J-2X and five-segment reusable solid rocket booster in the Ares I design will result in long-term cost savings. According to NASA officials, the savings can be realized by minimizing the number of development efforts—eliminating the cost of modifying and certifying the Space Shuttle main engine and four-segment reusable solid rocket booster for use on the Ares I—and increasing commonality between the Ares I and the Ares V. While achieving these savings involves increasing the Constellation budget by \$730 million through 2010, NASA estimates that these changes will result in net long term savings of \$1.2 billion. Our past work on total ownership costs indicates that making design trades early in development is a best practice

among leading commercial developers that can reduce long-term operating and support costs.⁶

NASA Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Knowledge Gaps

NASA has taken steps toward making sound investment decisions for Ares I. For instance, it is relying on established technology to support the program, and it is adopting an acquisition strategy that emphasizes attaining knowledge on cost, schedule, and technical and development feasibility before commitments are made to long-term investments. NASA also recognizes that the program is still facing many technical, programmatic, and funding risks and has undertaken measures to track and mitigate those risks. However, NASA still must develop the knowledge needed to make sound investment decisions for the Ares I project. Principally, there are gaps in knowledge about requirements, costs, schedule, technology, design, and production feasibility.

Knowledge about Requirements and Resources Is Critical to Making Sound Investment Decisions

GAO's work on best practices over the past decade has shown that success in large-scale, expensive development efforts like Ares I depends on establishing an executable business case before committing resources to a new product development effort. The business case in its simplest form is demonstrated evidence that (1) the customer's needs are valid and can best be met with the chosen concept, and (2) the chosen concept can be developed and produced within existing resources—that is, proven technologies, design knowledge, existing funding, and adequate time to deliver the product when it is needed. A program should not go forward into product development unless a sound business case can be made. For a program to deliver a successful product within available resources, managers should demonstrate high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time.

Having adequate knowledge about requirements and resources is particularly important for a project like Ares I. Human spaceflight development programs are complex and difficult by nature, and the Ares I project faces daunting challenges in terms of design, testing, and manufacturing regardless of the systems and technologies underpinning the system's design. There are also considerable external pressures being placed on the program. For example, the program is being asked to deliver

⁶GAO, *Best Practices: Setting Requirements Differently Could Reduce Weapon Systems' Total Ownership Costs*, [GAO-03-57](#) (Washington, D.C.: Feb. 11, 2003).

capability by 2015 in order to minimize the gap between the Space Shuttle's retirement and deployment of new transportation vehicles. In addition, there are funding constraints due to the need to fund other programs in NASA's portfolio. Moreover, over the past decade, there have been a number of instances where NASA pursued costly efforts to build a second generation of reusable human spaceflight vehicles without attaining critical knowledge about requirements and resources and, in turn, experienced significant problems—including cost and schedule delays. These include the National Aero-Space Plane, the X-33 and X-34, and the Space Launch Initiative, which were eventually canceled. While these endeavors have helped to advance scientific and technical knowledge, none of these projects accomplished NASA's objective of fielding a new reusable space vehicle. We estimate that these unsuccessful development efforts have cost approximately \$4.8 billion since the 1980s.

NASA Is Attempting to Follow a Knowledge-Based Approach to Building a Business Case for the Ares I Project

The current Ares I acquisition strategy does include some knowledge-based concepts. The Ares I first stage design draws heavily from existing Space Shuttle systems. Our work has shown that design solutions based on modifying and/or improving existing technologies and systems are less risky than design solutions based on new technologies and new inventions. Furthermore, NASA's decision to include the J-2X engine and five-segment booster in the Ares I design in order to reduce long-term operations and support cost is in line with the practices of leading commercial developers that give long-term savings priority over short-term gains.

The Ares I project was also proactive in ensuring that the ongoing project was in compliance with NASA's new directives, which include elements of a knowledge-based approach. NASA's new acquisition directives require a series of key reviews and decision points between each life-cycle phase of the Ares I project that serve as gates through which the project must pass before moving forward.⁷ The directives also recommend, but do not require, specific entrance and success criteria for each technical review. We found that the Ares I project had implemented the use of key decision points and adopted the recommended entrance and exit criteria for the December 2006 Systems Requirements Review and the upcoming October

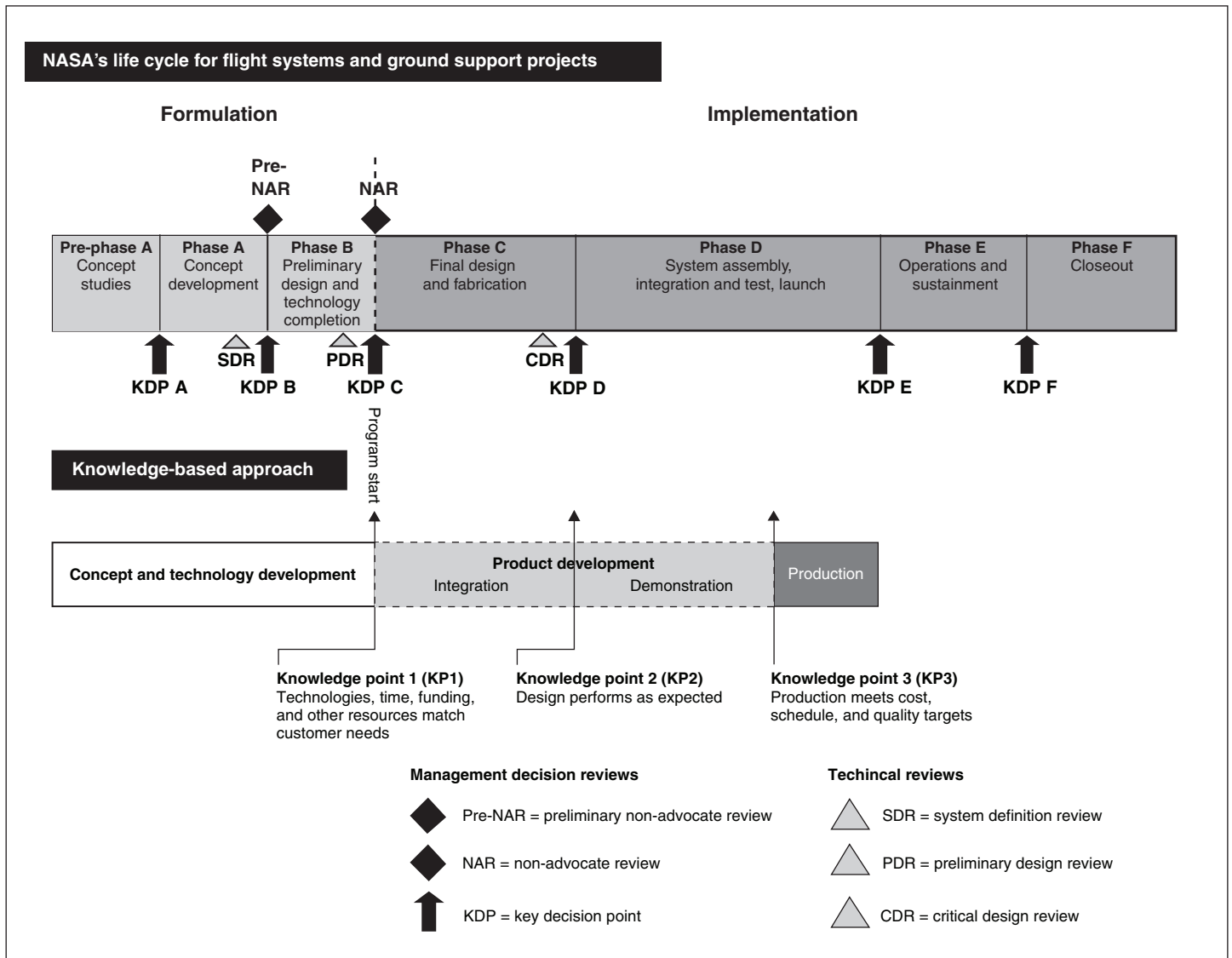
⁷NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, March 6, 2007. NASA Procedural Requirements 7123.1A, *NASA Systems Engineering Processes and Requirements*, March 26, 2007.

2007 Systems Definition Review. According to NASA officials, the Constellation program made a conscious decision to require all of its projects to use the criteria recommended in the new directives for all reviews. We also found that the Ares I project has established specific knowledge-based goals—such as demonstrating maturity of key technologies by the preliminary design review and requiring a threshold 90 percent of engineering drawings be complete by the critical design review.

Figure 3 illustrates how NASA’s current acquisition directives for spaceflight programs and projects have incorporated some knowledge-based concepts into NASA’s approach to acquisitions. For example, NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, requires decision reviews between each major phase of the acquisition life cycle. Further, NASA Procedural Requirements 7123.1A, *NASA Systems Engineering Processes and Requirements*, recommends general entrance and success criteria for the decision reviews. While the directives include multiple decision points at which progress in development can be measured, they also allow the centers and individual projects to establish the specific criteria used to define success for these reviews. NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, also requires that at the end of the formulation phase, projects demonstrate some elements of a sound business case, to include firm requirements, mature technologies, a preliminary design, and realistic cost and schedule estimates before proceeding into implementation.⁸

⁸The purpose of the formulation phase is to establish a cost-effective program that is demonstrably capable of meeting agency objectives.

Figure 3: Comparison of NASA's Life Cycle with a Knowledge-Based Acquisition Life Cycle



Source: NASA data and GAO analysis.

NASA Is also Taking Measures to Mitigate Risks

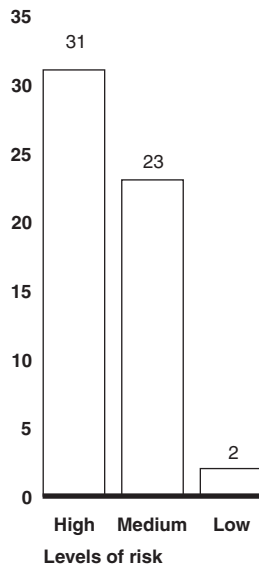
In accordance with a knowledge-based approach, NASA's acquisition directives also require all space flight programs and projects, including the Ares I project, to maintain a continuous risk management system.⁹ NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, defines risk management as an organized, systematic decision-making process that efficiently identifies, analyzes, and plans for the handling of risks, and tracks, controls, communicates, and documents risk in order to increase the likelihood of achieving project goals.

NASA is currently using the Web-based Integrated Risk Management Application (IRMA) as a tool for implementing continuous risk management within the Ares I project. IRMA identifies and documents risks, categorizes risks—as high, medium, and low based on both the likelihood of an undesirable event as well as the consequences of that event to the project—and tracks performance against mitigation plans. In the case of the Ares I project, as illustrated by figure 4, IRMA is tracking 57 Ares I risks including 31 high-risk areas.¹⁰

⁹NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, March 6, 2007. NASA Procedural Requirements 8000.4, *Risk Management Procedural Requirements*, February 1, 2007.

¹⁰ This is the total number of open risks as of September 17, 2007. It does not include risks that have been closed or risks that NASA considers sensitive.

Figure 4: Ares I Risks as Tracked by IRMA



Source: NASA data and GAO analysis.

Note: Risks in this figure total only 56 because 1 of the risks has not been categorized as high, medium, or low.

Critical Knowledge Needed for Investment Decision Making for Ares I Has Not Yet Been Attained

NASA has not yet established firm requirements or developed mature technologies, a preliminary design, or realistic cost estimates, or determined the ultimate time and money needed to complete the program and so is not in a position to make informed investment decisions. Our work and NASA's own directives have shown that a successful knowledge-based acquisition strategy is dependent on having these elements in place at the time long-term investment commitments are made. For NASA, this milestone is currently scheduled for July 2008. While NASA still has 10 months to close gaps in knowledge, it will be challenged to do so.

Gaps in Knowledge about Ares I Requirements

In following a knowledge-based approach to development, successful organizations extensively research and define requirements before program start to ensure that they are achievable, given available resources. In successful programs, negotiations and trade-offs occur before product development is started to ensure that a match exists between customer expectations and developer resources. By contrast, previous NASA programs have continued to define requirements after product development was started—which in turn created unknowns about costs

and schedule as well as the need for rework late in development to address changes in performance parameters.

For the Ares I program, 14 of the project's self-identified risk factors are tied to unstable requirements—many of which are interrelated between Ares I and Orion projects. Because the Orion vehicle is the payload that the Ares I must deliver to orbit, changes in the Orion design, especially those that affect weight, directly affect Ares lift requirements. Both the Orion and Ares I vehicles have a history of weight and mass growth, and NASA is still defining the mass, loads, and weight requirements for both vehicles. For example, a design analysis cycle completed in May 2007 revealed an unexpected increase in ascent loads (the physical strain on the spacecraft during launch) that could result in increases to the weight of the Orion vehicle and both stages of the Ares I. While our work shows that the preliminary design phase is an appropriate place to conduct systems engineering to support requirement trade-off decisions, when requirements are in flux and development efforts are contingent upon the flow-down of stable requirements, it can create a ripple effect of unknowns and make it extremely difficult to establish firm cost estimates and schedule baselines. NASA recognizes that the need to synchronize Ares I and Orion requirements is the top risk facing the Ares I project and that continued instability in the Orion design is increasing risk to the Ares I project. The Ares I and Orion projects are working on this issue but don't expect to finalize new mass, loads, and weight allocations until after the October 2007 Systems Definition Review. Until these top-level requirements are finalized, lower-level requirements will also remain in flux.

Requirements instability is also increasing risk for the individual elements of the Ares I. The J-2X engine design cycle is ahead of the Ares I vehicle design cycle. Consequently, there is a possibility that new and/or late developing requirements for the Ares I could lead to costly changes being required for the engine design. In addition, until the Ares I requirements are finalized, NASA will not know whether the existing hardware—such as the first stage reusable solid rocket boosters—will need modifications to satisfy requirements. Furthermore, NASA has not yet matured guidance, navigation, and control requirements for the upper stage subsystems. According to an agency official, these requirements cannot be finalized until mass, loads and weight requirements are finalized. Since these requirements are not expected to be provided until just 2 ½ months prior to the upper stage preliminary design review process start, there is a possibility that the system requirements review design concepts will be highly affected once requirements are received.

Requirements instability also contributed to NASA's inability to definitize design, development, and test and evaluation contracts for both the first stage and upper stage engine until August and July 2007 respectively—more than a year after the contracts were awarded. The NASA Federal Acquisitions Regulation Supplement establishes a goal of definitizing undefinitized contracts¹¹ within 6 months of issuance.¹² NASA awarded sole-source, cost-reimbursable contracts for all of design, development, and test and evaluation of the first stage and upper stage engine in April 2006 and June 2006 respectively. Our past work indicates that while it is appropriate for developmental contracts for government specific items to be cost-reimbursable in nature, it is a poor practice to allow these types of contracts to remain undefinitized for extended periods. In fact, both GAO and NASA inspector general reports have identified risks in NASA programs in the past, including the International Space Station and the Space Shuttle due to heavy reliance on undefinitized contract actions. According to agency officials, these contracts remained undefinitized over 1 year because of the difficulty associated with establishing requirements for the complex Ares I development effort. According to agency officials, however, NASA mitigated the risk of the contracts remaining undefinitized by capping the value of the undefinitized work and by closely monitoring the contractor's progress.

Gaps in Knowledge about Resources

In following a knowledge-based approach, successful organizations also ensure that resources—primarily funding, time, and other resources—can be matched to requirements before program start. For example, they ensure that technologies can work as intended, funding will be available, costs are accurately estimated, and that the project schedule provides the time required to complete critical technology development, design, and production activities. Although NASA is relying on the use of existing systems and low-risk technology, there are still gaps in knowledge about resources—including money, time, and availability of technologies and hardware.

¹¹NFS 1843.7001 defines an undefinitized contract action as a unilateral or bilateral modification or delivery/task order in which the final price or estimated cost and fee have not been negotiated and mutually agreed to by NASA and the contractor.

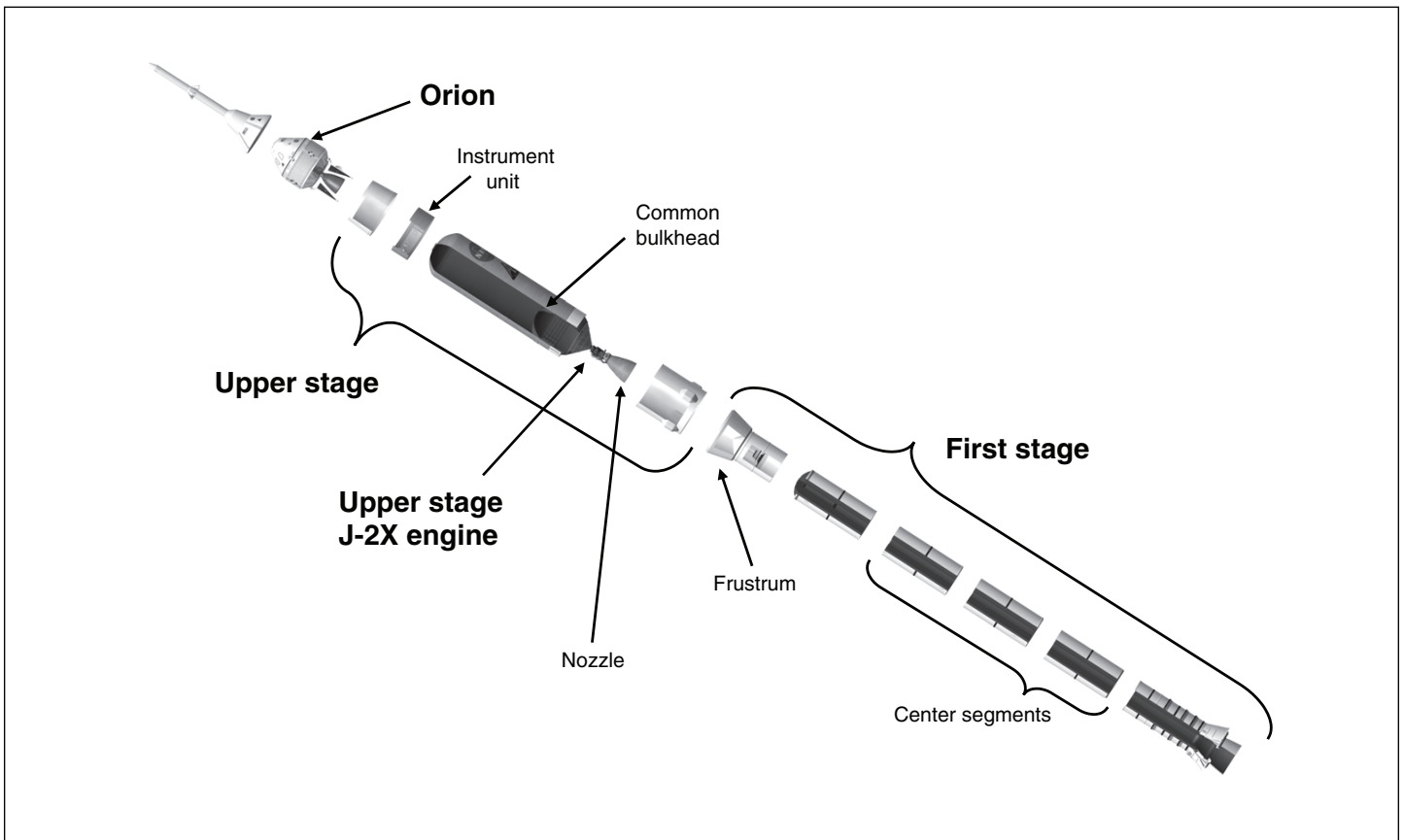
¹²NASA FAR Supplement 1843.7005(a).

Ares I First Stage

NASA is incorporating a fifth segment into the existing four-segment Space Shuttle reusable solid rocket booster by adding a third center segment—the two center segments of the four-segment reusable solid rocket booster are identical. NASA is also adding a frustum—an inverted cone-shaped connector—to mate the reusable solid rocket booster to the larger-diameter upper stage (see fig. 5). Adding the fifth segment and the frustum has increased the length and flexibility of the reusable solid rocket booster. It is currently unclear how the modification will affect the flight characteristics of the reusable solid rocket booster. Failure to completely understand the flight characteristic of the modified booster could create a risk of hardware failure and loss of vehicle control. In addition, there is also a possibility that the reusable solid rocket booster heritage hardware may not meet qualification requirements given the new ascent and re-entry loads and vibration and acoustic environments associated with the Ares I. This could result in cost and schedule impacts due to redesign and requalification efforts. NASA is currently working to define this risk. Furthermore, the added weight of the fifth segment to the boosters is forcing the contractor to push the state of the art in developing a parachute recovery system.

In January 2007, an independent review of the first stage development questioned the cost-effectiveness of continuing with a reusable booster design. According to NASA and contractor officials, the primary benefit of recovering the reusable solid rocket boosters is not financial in nature but is the knowledge gained through analysis of the recovered flight hardware. However, NASA may need to consider expendable first stage options given the weight issues associated with both the Ares I and Orion vehicles. If NASA opts to pursue an expendable solution for the first stage, the overall Ares I design and requirements could change dramatically.

Figure 5: Illustration of Ares I Common Bulkhead and Frustrum



Source: NASA.

Ares I Upper Stage

NASA's development effort for the Ares I upper stage has resulted in the redesign of its propellant tanks from two completely separate tanks to two tanks with one shared, or common, bulkhead. While the prior two-tank configuration was a simpler design with a lower manufacturing cost, it did not meet mass requirements. The current common bulkhead design involves a complex and problematic manufacturing process that plagued earlier development efforts on the Apollo program. In fact, IRMA indicates that one of the lessons learned from the Apollo program was to not use common bulkheads because they are complex and difficult to manufacture. In addition, there is a possibility that upper stage subsystems will not meet the Constellation program's requirements for human rating unless the Constellation program grants waivers to failure tolerance

requirements. NASA's human rating directive generally requires that human spaceflight hardware be "two-failure tolerant," that is, the system should be designed to tolerate two component failures or inadvertent actions without resulting in permanent disability or loss of life.¹³ According to Ares I project officials, NASA's directive allows the use of ascent abort in response to a second failure during launch; however, Constellation program requirements do not allow abort and require Ares I to reach orbit even if there are two failures.

In August 2007, NASA awarded a cost-plus-award-fee contract for production of the upper stage. The basic contract calls for developmental hardware and test articles, the production of at least six operational flight units, and engineering support to the NASA in-house upper stage design team. The contract also included indefinite delivery/indefinite quantity tasks for additional support and quantity options for additional operational flight units. According to NASA officials, they needed to select the production contractor early to obtain the engineering support to ensure that the NASA design team develops a producible and cost-effective design and to enable the production contractor to maximize its ability to meet the production schedule.

J-2X Upper Stage Engine

Although the J-2X is based on the J-2 and J-2S engines used on the Saturn V, and leverages knowledge from the X-33 and RS-68, the extent of planned changes is such that both the ESAS and Ares I standing review boards reported that the effort essentially represents a new engine development. The scope of required changes is so broad, the contractor estimates that it will need nearly 5 million hours to complete design, development, test, and evaluation activities for the J-2X upper stage engine. In comparison, adding a fifth segment to the reusable solid rocket boosters requires less than one-third the amount of hours. According to Pratt and Whitney Rocketdyne representatives, these design changes will result in the replacement and/or modification of virtually every part derived from the J-2 or J-2S designs. NASA and Pratt and Whitney Rocketdyne recognize that some level of development anomaly and/or test failures are inherent in all new engine development programs, and the project has predicted that the J-2X development will require 29 rework

¹³NASA Procedural Requirements 8705.2A, *Human-Rating Requirements for Space Systems*, February 7, 2005.

cycles. In addition, the J-2X element faces extensive redesign in order to incorporate modern controls, achieve the increased performance requirements, and meet human rating standards. Pratt and Whitney Rocketdyne plans to replace the obsolete electromechanical controls used in the J-2 design with software-driven digital controls based on the controls used on the Delta IV's RS-68 engine. Pratt and Whitney Rocketdyne is also redesigning turbo-pumps from the X-33 program that feed fuel and oxidizer into a newly configured main combustion chamber, to increase engine thrust to 294,000 pounds—the J-2S had 265,000 pounds of thrust. The element also faces significant schedule risks in developing and manufacturing a carbon composite nozzle extension in order to satisfy these thrust requirements. According to contractor officials, the extension is more than 2 feet—i.e., about one-third—wider in diameter than existing nozzles.

Unknowns in Overall Project Schedule

As noted earlier, the Ares project cannot reliably estimate time needed to complete technology development, design, and production until requirements are fully understood. In addition, NASA is working under a self-imposed deadline to deliver the new launch vehicles no later than 2015 in order to minimize the gap between the Space Shuttle's retirement in 2010 and new transportation vehicles. NASA has compensated for this schedule pressure by adding funds for testing and other critical activities. But it is not certain that added resources will enable NASA to deliver when expected.

More specifically, the J-2X development effort is accorded less than 7 years from development start to first flight. In comparison, the Space Shuttle main engine, the only other human-rated liquid-fuel engine NASA has successfully flown since the Apollo program, development required 9 years. Due to the tight schedule and long-lead nature of engine development, the J-2X project was required to start out earlier in its development than the other elements on the vehicle. This has caused the engine development to be out of sync with the first stage and upper stage in the flow-down and decomposition of requirements. Although the only true mitigation to the technical and schedule risks for the element is a slowdown of the engine development to allow the requirements to catch up, this is unacceptable to the project because of the need to minimize the gap between the Space Shuttle's retirement in 2010 and the planned availability of the Ares I no later than 2015. NASA acknowledges that the engine development is proceeding with an accepted risk that future requirements changes may affect the engine design and that the engine may not complete development as scheduled in December 2012. If the engine does not complete development as scheduled, subsequent flight

testing might be delayed. The J-2X development effort represents a critical path for the Ares I project. Subsequently, delays in the J-2X schedule for design, development, test, and evaluation would have a ripple effect throughout the entire Ares I project.

NASA has taken steps to mitigate J-2X risks by increasing the amount of component-level testing, procuring additional development hardware, and working to make a third test stand available to the contractor earlier than originally planned. The project has secured funding to build a new \$180 million altitude test facility needed to test the engine in a relevant environment. However the project is still seeking early access to a third test stand to perform J-2X engine testing in early 2010. According to the contractor, the project is currently working with the Space Shuttle program to free up a third test stand, but the Space Shuttle program needs the stand to be available for Space Shuttle testing until 2010. According to NASA, earlier access to a third stand could provide mitigation of the nozzle extension development effort, relieve test rate anxieties, and enable test schedule confidence. Without the ability to perform this testing, the J-2X critical path test schedule could be affected.

In addition, as shown in figure 6, the first stage critical design review is out of sync with the Ares I project-level critical design review. NASA has scheduled two critical design reviews for the first stage. The first critical design review is scheduled for November 2009, 5 months before the Ares I project critical design review. At this point, however, the project will not have fully tested the first stage development motors. The second critical design review, in December 2010, occurs after static testing of additional developmental motors is conducted. According to the NASA Procedural Requirements 7120.5D, *NASA Space Flight Program and Project Management Requirements*, at the critical design review the Ares I project should demonstrate that the maturity of the project's design is appropriate to support proceeding into full-scale fabrication, assembly, integration, and test. It should also demonstrate that the technical effort is on track to complete the flight and ground system development and mission operations in order to meet overall performance requirements within the identified cost and schedule constraints. By conducting the Ares I critical design review before the first stage critical design review, the project could prematurely begin full-scale test and integration activities a full 9 months before the first stage design has demonstrated maturity.

Figure 6: Ares I Project Schedule Timelines, by Fiscal Year

Name	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
Ares I Project		SRR ▼ Dec		PDR ▼ July		CDR ▼ Mar				IOC ▲ Mar
Upper Stage J-2X Engine		SRR ▼ Nov	PDR ▼ Aug	CDR ▼ Aug						
Upper Stage		SRR ▼ Apr	PDR ▼ May		CDR ▼ Nov					
First Stage		SRR ▼ Dec	PDR ▼ Apr			CDR ▼ Dec				

SRR – System Requirements Review

PDR – Preliminary Design Review

CDR – Critical Design Review

IOC – Initial Operational Capability

Source: NASA and GAO analysis.

Constellation Funding Uncertain

NASA’s approach to funding is risky, and the current approved budget profile is insufficient to meet Constellation’s estimated needs. The Constellation program’s integrated risk management system indicates there is a high risk that funding shortfalls could occur in fiscal years 2009 through 2012, resulting in planned work not being completed to support schedules and milestones. As we reported in 2006, NASA’s basic approach for funding all of the Constellation program, including Ares I, depends on a “go as you can afford to pay” concept, wherein lower-priority efforts will be deferred, descoped, or discontinued to allow NASA to stay within its available budget profile.¹⁴ This approach relies on the accumulation of a large rolling budget reserve in fiscal years 2006 and 2007 to fund Constellation activities in fiscal years 2008, 2009, and 2010, when NASA estimates its total budget authority will be insufficient to fund all necessary Constellation activities.

¹⁴GAO, *NASA: Long-Term Commitment to and Investment in Space Exploration Program Requires More Knowledge*, [GAO-06-817R](#) (Washington, D.C.: July 17, 2006).

Risk Mitigation Activities Are Behind Schedule

Many of the risks NASA is tracking in IRMA correlate with the elements of a sound business case. For example, IRMA is tracking risks related to stabilizing requirements, finalizing a preliminary design, establishing realistic project schedules, and acquiring adequate funding. NASA has risk mitigation plans in place for most of these risks, and in most instances NASA is completing mitigation tasks on schedule. As of September 17, 2007, the project is behind schedule in completing mitigation tasks on four risks. While some of these tasks are just a few weeks late, there is one instance where the project has not completed mitigation tasks that were scheduled for completion in January and April 2007. In this instance, the Ares I project office is late completing mitigation tasks aimed at maturing Ares I requirements for the first stage. If mitigation does not proceed as planned on Ares I risks, NASA may be unable to establish a sound business case at the July 2008 preliminary design review.

Conclusions

NASA has been in a discovery and exploration phase for its Ares I project for nearly 2 years, and it expects to remain in this phase until July 2008. During this period, it is critical for programs to work toward closing knowledge gaps about requirements, technologies, funding, time, and other resources so that they can be positioned to succeed when decisions are made to commit to making significant, long-term investments. This is especially important for NASA given the cost of the program and past experiences with efforts to move beyond the current space transportation architecture.

NASA is taking positive steps toward this end, particularly by adopting some knowledge-based acquisition concepts, relying on established technologies and hardware, and proactively identifying and mitigating risk. Nevertheless, there are still considerable unknowns—principally, in terms of what requirements the program will be seeking to achieve, how much it will cost to do so, how long it will take, and whether certain development and production challenges inherent in the design and architecture can even be overcome. At a minimum, critical unknowns need to be addressed in the near future so that decision makers have a sound basis for moving forward. If they are not, NASA should delay making a long-term commitment to the program and reexamine external constraints, including time and money.

Recommendations for Executive Action

We recommend that the NASA Administrator direct the Ares I project manager to develop a sound business case—supported by firm requirements, mature technologies, a preliminary design, a realistic cost estimate, and sufficient funding and time—before proceeding beyond preliminary design review (currently planned for July 2008) and, if necessary, delay the preliminary design review until a sound business case demonstrating the project's readiness to move forward into product development is in hand.

Agency Comments and Our Evaluation

In written comments on a draft of this report (see app. II), NASA concurred with our recommendation. NASA acknowledged that the Ares I project faces knowledge gaps concerning requirements, technologies, funding, time and other resources and that the agency must close these gaps to be positioned for success when the project enters the implementation phase. NASA stated that the Ares I project manager will be required to demonstrate that the project meets all system requirements with acceptable risk and within the cost and schedule constraints, and that it has established a sound business case before the project is allowed to proceed into the implementation phase. NASA also stated that the NASA Agency Program Management Council and NASA Associate Administrator will review the Ares I project at the preliminary design review and determine the projects' readiness to proceed into the implementation phase and begin detailed design. Separately, NASA provided technical comments, which have been addressed in the report, as appropriate.

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

Should you or your staff have any questions on matters discussed in this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact

points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix III.

Sincerely yours,

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

Cristina Chaplain, Director
Acquisition and Sourcing Management

Appendix I: Scope and Methodology

To assess NASA's progress in developing the knowledge needed to make sound investment decisions for the Ares I project, we reviewed and analyzed NASA's acquisition strategy for the Ares I project including program and project plans, contracts, schedules, risk assessments, technology maturity assessments, budget documentation, and the results of independent assessments of the program. We interviewed and received briefings from officials within the Ares I project office at Marshall Space Flight Center in Huntsville, Alabama, regarding the project's risk areas, the status of requirements and the project's process in definitizing contracts and developing life-cycle cost estimates. We also interviewed contractor officials on location at Pratt and Whitney Rocketdyne in Canoga Park, California, and Alliant Techsystems in Brigham City, Utah, regarding the J-2X engine and first stage heritage hardware and design changes. We analyzed risk documented through the Constellation Program's Integrated Risk Management Application and followed up with project officials for clarification and updates to these risks. In addition, we interviewed Constellation program officials from Johnson Space Center regarding program risks, requirements, and the impact of budget reductions. We also spoke with NASA Headquarters officials from the Exploration Systems Mission Directorate's Resources Management Office in Washington, D.C., to gain insight into the basis for fiscal year 2006 through fiscal year 2010 budget requests as well as the funding strategy employed by the Constellation Program. Furthermore, we reviewed NASA, Marshall Space Flight Center, and Johnson Space Center program and project management directives and systems engineering directives. Our review and analysis of these documents focused on requirements and goals set for spaceflight systems. We compared examples of the centers' implementation of the directives and specific criteria included in these directives with our best practices work on system acquisition.

Our work was conducted between March 2007 and September 2007 in accordance with generally accepted government auditing standards.

Appendix II: Comments from the National Aeronautics and Space Administration

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



October 19, 2007

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

Dear Ms. Chaplain:

NASA appreciates the opportunity to comment on your draft Government Accountability Office (GAO) report, GAO-08-51, entitled "NASA: Agency Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps" which pertains to the Ares project within the Constellation Systems program.

In the draft report, GAO recommends that NASA develop the knowledge needed to make sound investment decisions for the acquisition of Ares I.

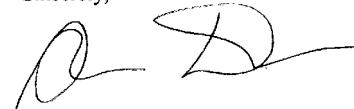
Recommendation: We recommend that the NASA Administrator direct the Ares I project manager to develop a sound business case—supported by firm requirements, mature technologies, a preliminary design, a realistic cost estimate, and sufficient funding and time—before proceeding beyond preliminary design review (currently planned for July 2008) and, if necessary, delay the preliminary design review until a sound business case demonstrating the project's readiness to move forward into product development is in hand.

Response: NASA concurs with this recommendation. The Agency is working toward closing knowledge gaps about requirements, technologies, funding, time, and other resources so that it can be positioned to succeed when decisions are made to commit to significant, long-term investments in the Ares I project. Substantial work defining the Ares I requirements, cost, and schedule estimates has been completed, and this work will continue to mature through the formulation phase of the project. The Ares I project manager will be required to demonstrate that the project meets all system requirements with acceptable risk and within the cost and schedule constraints, and that it has established a sound business case to proceed with the detailed design. The NASA

Agency Program Management Council and NASA Associate Administrator will review the Ares I project at this key juncture and determine readiness for the project to proceed into the implementation phase and detailed design.

Thank you for the opportunity to review this draft report.

Sincerely,

A handwritten signature in black ink, appearing to read 'Shana Dale', with a long horizontal flourish extending to the right.

Shana Dale
Deputy Administrator

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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

Acknowledgments

In addition to the contact named above, Jim Morrison, Assistant Director; Meredith M. Allen; Greg Campbell; Sylvia Schatz; and John S. Warren made key contributions to this report.

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