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Ares I and Orion Project Risks and Key Indicators to Measure Progress

Statement of Cristina T. Chaplain, Director
Acquisition and Sourcing Management

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Area I and Orion Project Risk and Key Indicators to Measure Progress

Why GAO Did This Study

The National Aeronautics and Space Administration (NASA) is in the midst of two new development efforts as part of the Constellation Program—the Ares I Crew Launch Vehicle and the Orion Crew Exploration Vehicle. These projects are critical to the success of the overall program, which will return humans to spaceflight after Space Shuttle retirement in 2010. To reduce the gap in human spaceflight, NASA plans to launch Ares I and Orion in 2015—5 years after the Shuttle's retirement.

GAO has issued a number of reports and testimonies that touch on various aspects of NASA's Constellation Program, particularly the development efforts underway for the Orion and Ares I projects. These reports and testimonies have questioned the affordability and overall acquisition strategy for each project. NASA has revised the Orion acquisition strategy and delayed the Ares I preliminary design review based on GAO's recommendations in these reports. In addition, GAO continues to monitor these projects on an ongoing basis at the request of members of Congress. Based on this work, GAO was asked to testify on the types of challenges that NASA faces in developing the Ares I and Orion vehicles and identify the key indicators that decision makers could use to assess risks associated with common trouble spots in development. The information in this testimony is based on work completed in accordance with generally accepted government auditing standards.

To view the full product, including the scope and methodology, click on GAO-08-186T. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

NASA is currently working toward preliminary design reviews for the Ares I and Orion vehicles. While this is a phase for discovery and risk reduction, there are considerable unknowns as to whether NASA's plans for these vehicles can be executed within schedule goals and what these efforts will ultimately cost. This is primarily because NASA is still in the process of defining many performance requirements. Such uncertainties could affect the mass, loads, and weight requirements for the vehicles. NASA is aiming to complete this process in 2008, but it will be challenged to do so given the level of knowledge that still needs to be attained. The challenges NASA is facing pose risks to the successful outcome of the projects. For example:

- Both vehicles have a history of weight issues;
- Excessive vibration during launch threatens system design;
- Uncertainty about how flight characteristics will be impacted by a fifth segment added to the Ares I launch vehicle;
- Ares I upper stage essentially requires development of a new engine;
- No industry capability currently exists for producing the kind of heat shields that the Orion will need for protecting the crew exploration vehicle when it reenters Earth's atmosphere; and
- Existing test facilities are insufficient for testing Ares I's new engine, for replicating the engine's vibration and acoustic environment, and for testing the thermal protection system for the Orion vehicle.

All these unknowns, as well as others, leave NASA in the position of being unable to provide firm cost estimates for the projects at this point. Meanwhile, tight deadlines are putting additional pressure on both the Ares I and Orion projects. Future requirements changes raise risks that both projects could experience cost and schedule problems.

GAO's past work on space systems acquisition and the practices of leading developers identifies best practices that can provide decision makers with insight into the progress of development at key junctures, facilitate Congressional oversight, and support informed decision making. This work has also identified common red flags throughout development, which decision makers need to keep in mind when assessing the projects. They include:

Key indicators: Weight growth is often among the highest drivers of cost growth. Unanticipated software complexity, often indicated by increases in the number of lines of code, can portend cost and schedule growth.

Key junctures: The preliminary design review, critical design review, and production review are key junctures that involve numerous steps and help focus the agency on realistic accomplishments within reachable goals. A disciplined approach aligned with key indicators can provide the knowledge needed to make informed investment decisions at each review.

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss challenges that the National Aeronautics and Space Administration (NASA) faces in developing the systems to achieve its goals for the President's Vision for Space Exploration.[1] We have been focusing our work primarily on the Ares I Crew Launch Vehicle and the Orion Crew Exploration Vehicle[2], as they are among the first major efforts conducted as part of NASA's Constellation Program to support implementation of the Vision and represent a substantial investment for NASA. Over $7 billion in contracts has already been awarded—and nearly $230 billion is estimated to be ultimately spent over the next two decades. Moreover, NASA is under pressure to develop the vehicles quickly, as the Space Shuttle's retirement in 2010 means that there could be at least a 5-year gap in our nation's ability to send humans to space.

In summary, NASA is currently working toward preliminary design reviews for the vehicles—a milestone that successful development organizations use to make hard decisions about whether a program should proceed with development. While this is a phase for discovery and risk reduction, there are considerable unknowns as to whether NASA's plans for the Ares I and Orion vehicles can be executed within schedule goals, as well as what these efforts will ultimately cost. In fact, we do not know yet whether the architecture and design solutions selected by NASA will work as intended. This is primarily because NASA is still in the process of defining both of the projects' performance requirements and some of these uncertainties could affect the mass, loads, and weight requirements for the vehicles. It is also working through significant technical risks, such as oscillation within the first stage of the Ares I vehicle, which computer modeling indicates could cause unacceptable structural vibrations.

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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 in preparation for future, more ambitious missions.

[2]GAO, *NASA: Agency Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps*, GAO-08-51 (Washington, D.C.: Oct. 31, 2007) and GAO, *NASA: Long-Term Commitment to and Investment in Space Exploration Program Requires More Knowledge*, GAO-06-817R (Washington, D.C.: July 17, 2006).

NASA is aiming to complete preliminary design reviews for the Ares I and Orion this year, scheduled for August 2008 Ares I and September 2008 respectively, but it will be challenged in doing so given the level of knowledge that still needs to be attained. In addition, to minimize the gap in human spaceflight caused by the shuttle's retirement, there is a high degree of concurrency within the projects. Our prior work has shown that concurrent development, especially when new technologies are involved, increases the risk that significant problems will be discovered as the systems' designs are integrated that could result in cost and schedule delays. NASA's schedule leaves little room for the unexpected. If something goes wrong with the development of the Ares I or the Orion, the entire Constellation Program could be thrown off course and the return to human spaceflight delayed.

NASA recognizes the risks involved with its approach and has taken steps to mitigate some of these risks. It is important that, in mitigating risks, NASA continually assess the viability of its plans for the Ares I and Orion. The current state of play requires that NASA remain open to the possibility that it may need to revisit decisions on its architecture and design as these vehicles are expected to be in use for decades to come and decisions made now will have long-term consequences.

Moreover, with additional significant investment decisions still ahead, it is important that agency decision makers and Congress maintain clear insight into the progress the projects are making as well as any potential problems. This type of oversight is important, not just for the Ares I and Orion vehicles, but for the entire future exploration effort—since resources available to fund the Vision are constrained, as competition for resources increases within the federal government over the next several decades. In this regard, our work has identified specific markers that can be used to (1) assess NASA's progress in closing critical knowledge gaps and (2) identify issues that could result in cost growth, schedule delays, or decreased performance. In other words, they can be used to assess whether there is a viable business case for pressing forward with the projects.

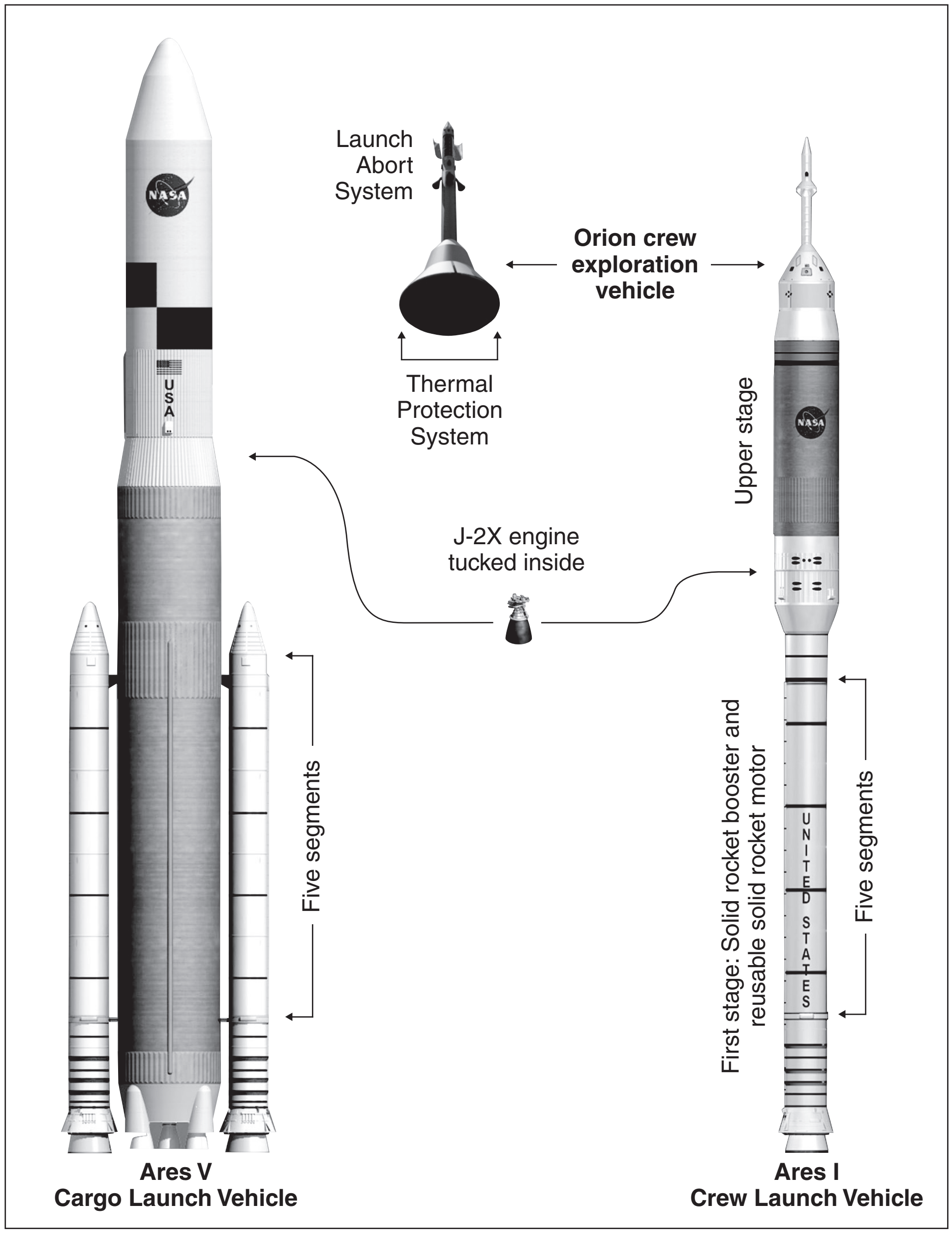
We have issued a number of reports and testimonies that touch on various aspects of NASA's Constellation Program and in particular the development efforts underway for the Orion and Ares I projects. These reports and testimonies have questioned the affordability and overall acquisition strategy for each project. In July 2006 we recommended that NASA modify the Orion Crew Vehicle acquisition strategy to ensure the agency did not commit itself to a long-term contractual obligation prior to establishing a sound business case. Although initially NASA disagreed with our recommendation, the agency subsequently revised its acquisition strategy to address some of the concerns we raised. In October 2007 we recommended that NASA 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. NASA concurred with this recommendation and subsequently slipped the Ares I preliminary design review from July 2008 to August 2008.

My statement today is based on these products, as well as updated information based on our continual monitoring of the projects at the request of members of Congress. To conduct these reviews, we analyzed relevant project documentation, prior GAO reports, NASA documents, and contractor information; interviewed program and project officials; and reviewed NASA's risk management system for the Constellation Program. Based on this work, my statement will specifically address the challenges that NASA faces developing the Ares I and Orion vehicles with regard to requirements definition, technology and hardware gaps, cost and schedule estimates, and facilities needs. Further, I will provide key indicators that decision makers could use to assess risks as the two development efforts move forward. We conducted this performance audit from October 2007 through April 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

In September 2005, NASA outlined an initial framework for implementing the President's Vision for Space Exploration in its Exploration Systems Architecture Study. NASA is now implementing the recommendations from this study within the Constellation Program, which includes three major development projects—the Ares I Crew Launch Vehicle, the Orion Crew Exploration Vehicle, and the Ares V Cargo Launch Vehicle as shown in figure 1.

Figure 1: Overview of Ares I and Orion Projects



Source: GAO analysis and presentation of NASA photos and data.

To reduce cost and minimize risk in developing these projects, NASA planned to maximize the use of heritage systems and technology. Since 2005, however, NASA has made changes to the basic architecture for the Ares I and Orion designs[3] that have resulted in the diminished use of heritage systems. This is due to the ability to achieve greater cost savings with alternate technology and the inability to recreate heritage technology. For example, the initial design was predicated on using the main engines and the solid rocket boosters from the Space Shuttle Program. However, NASA is no longer using the Space Shuttle Main Engines because greater long-term cost savings are anticipated through the use of the J-2X engine. In another example, NASA increased the number of segments on the Ares I first-stage reusable solid rocket booster from four to five to increase commonality between the Ares I and Ares V, and eliminate 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. Finally, according to the Orion program executive the Orion project originally intended to use the heat shield from the Apollo program as a fallback technology for the Orion thermal protection system, but was unable to recreate the Apollo material.

NASA has authorized the Ares I and Orion projects to proceed with awarding development contracts. In April 2006, NASA awarded a $1.8 billion contract for design, development, test, and evaluation of the Ares I first stage to Alliant Techsystems. NASA also awarded a $1.2 billion contract for design, development, test, and evaluation of the Ares I upper stage engine—the J-2X—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. However, NASA awarded a $514.7 million contract for design support and production of the Ares I upper stage to the Boeing Company in August 2007. In August 2006, NASA awarded Lockheed Martin a $3.9 billion contract to design, test, and build the Orion crew exploration vehicle.[4] According to NASA, the contract was modified in April 2007, namely by adding 2 years to the design phase and two test flights of Orion's launch abort system and by deleting the production of an cargo variant for the

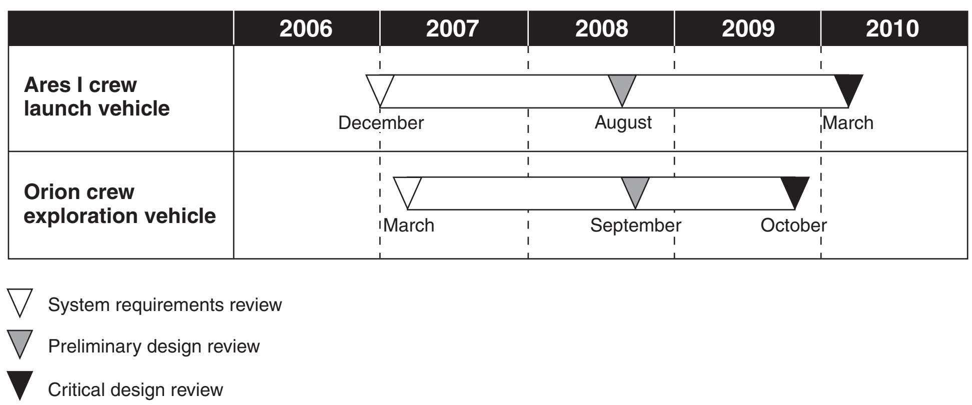
[3]Heritage systems are systems with characteristics similar to the one being developed. A heritage system is often the one the new program is replacing.

[4] The actual value of the contract could be greater than $3.9 billion if NASA exercises options on the contract for production and sustainment or issues orders against the indefinite delivery/indefinite quantity portion of the contract.

International Space Station. NASA indicates that these changes increased the contract value to $4.3 billion. Federal procurement data shows that an additional modification has been signed which increased the value of the contract by an additional $59 million.

NASA has completed or is in the process of completing key reviews on both the Ares I and Orion projects. NASA has completed the system requirements review for each project and is in the midst of finalizing the system definition reviews.[5] At the systems requirements review, NASA establishes a requirements baseline that serves as the basis for ongoing design analysis work and systems testing. Systems definition reviews focus on emerging designs for all transportation elements and compare the predicted performance of each element against the currently baselined requirements. Figure 2 shows the timeline for Ares I and Orion critical reviews.

Figure 2: Timeline for Ares I and Orion Critical Reviews (in fiscal years)



Source: GAO analysis of NASA data.

NASA is using its Web-based Integrated Risk Management Application to help monitor and mitigate the risks with the Ares I and Orion development efforts and for the overall Constellation Program. The risk management

[5]The system requirements review is intended to examine the function and performance requirements defined for the system and the preliminary project plan and ensure that the requirements and the selected concept will satisfy the mission. The system definition review examines the proposed system design and the flow-down of that design to all functional elements of the system. The system requirements review and system definition review process culminates with key decision point B wherein NASA determines the project's readiness to move forward.

application 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. For the Ares I project, the application is tracking 101 risks, 36 of which are considered high-risk areas.[6] For the Orion project, NASA is tracking 193 risks, including 71 high-risk areas.[7] NASA is developing and implementing plans to mitigate some of these risks.

Requirements Setting is a Primary Challenge for Both the Ares I and Orion Projects

Although project level requirements were baselined at both systems requirements reviews, continued uncertainty about the systems' requirements have led to considerable unknowns as to whether NASA's plans for the Ares I and Orion vehicles can be executed within schedule goals, as well as what these efforts will ultimately cost. Such uncertainty has created knowledge gaps that are affecting many aspects of both 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 I lift requirements. Likewise, the lift capacity of the Ares I drives the Orion design. 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. According to agency officials, continuing weight growth led NASA to rebaseline the Orion vehicle design in fall 2007. This process involved "scrubbing" the Orion Vehicle to establish a zero-based design capable of meeting minimal mission requirements but not safe for human flight. Beginning with the zero-based design NASA first added back the systems necessary to ensure crew safety and then conducted a series of engineering trade-offs to determine what other systems should be included to maximize the probability of mission success while minimizing the system's weight. As a result of these trade-offs, NASA modified the requirement for nominal landing on land to nominal landing in water, thereby gaining 1500 lbs of trade space in the Orion design.

NASA recognizes that continued weight growth and requirements instability are key risks facing the Orion project and that continued

[6] This is the total number of open risks for the Ares I project as of March 25, 2008. It does not include risks that have been closed or risks that NASA considers sensitive.

[7] This is the total number of open risks for the Orion project as of March 25, 2008. It does not include risks that have been closed or risks that NASA considers sensitive.

instability in the Orion design is a risk facing the Ares I project. The Ares I and Orion projects are working on these issues but have not yet finalized requirements or design. Our previous work on systems acquisition work shows that the preliminary design phase is an appropriate place to conduct systems engineering to support requirement and resource trade-off decisions. For the Ares I project, this phase is scheduled to be completed in August 2008, whereas for the Orion project, it is September 2008—leaving NASA only 4 and 5 months respectively to close gaps in requirements knowledge. NASA will be challenged to close such gaps, given that it is still defining requirements at a relatively high level and much work remains to be done at the lower levels. Moreover, given the complexity of the Orion and Ares I efforts and their interdependencies, as long as requirements are in flux, it will be extremely difficult to establish firm cost estimates and schedule baselines.

Technology and Hardware Gaps Along with Requirements Uncertainty are Increasing Risk

Currently, nearly every major segment of Ares I and Orion faces knowledge gaps in the development of required hardware and technology and many are being affected by uncertainty in requirements. For example, computer modeling is showing that thrust oscillation within the first stage of the Ares I could cause excessive vibration throughout the Ares I and Orion. Resolving this issue could require redesigns to both the Ares I and Orion vehicles that could ultimately impact cost, schedule, and performance. Furthermore, the addition of a fifth segment to the Ares I first stage has the potential to impact qualification efforts for the first stage and could result in costly requalification and redesign efforts. Additionally, the J-2X engine represents a new engine development effort that, both NASA and Pratt and Whitney Rocketdyne recognize, is likely to experience failures during development. Addressing these failures is likely to lead to design changes that could impact the project's cost and schedule. With regard to the Orion project, there is currently no industry capability for producing a thermal protection system of the size required by the Orion. NASA has yet to develop a solution for this gap, and given the size of the vehicle and the tight development schedule, a feasible thermal protection system may not be available for initial operational capability to the space station. The table 1 describes these and other examples of knowledge gaps in the development of the Ares I and Orion vehicles.

Table 1: Examples of Ares I and Orion Technology and Hardware Gaps

Ares I Crew Launch Vehicle	First stage	Current modeling indicates that thrust oscillation within the first stage causes unacceptable structural vibrations. There is a possibility that the thrust oscillation frequency and magnitude may be outside the design limits of the Ares design requirements. A NASA focus team studied this issue and has proposed options for mitigation including incorporating vibration absorbers into the design of the first stage and redesigning portions of the Orion Vehicle to isolate the crew from the vibration. Further, it is unknown how the addition of a fifth segment to the launch vehicle will affect flight characteristics. Failure to completely understand the flight characteristics of the modified booster could create a risk of hardware failure and loss of vehicle control. Ares I relies on hardware adapted from the Space Shuttle program that may not meet qualification requirements. Qualification requirements may be difficult to meet due to the new ascent loads (the physical strain on the spacecraft during launch) and vibration and acoustic environments associated with the Ares I. Resulting redesign and requalification efforts could affect cost and schedule. NASA is currently working to further define the vibration and acoustic environment.
	Upper stage	NASA redesigned the upper stage configuration from two completely separate propellant tanks to two tanks with one common bulkhead. The prior configuration employed a simpler design with a lower manufacturing cost but did not meet mass requirements. The current common bulkhead design involves a complex and problematic manufacturing process that challenged earlier development efforts on the Apollo program. In fact, NASA's Web-based Integrated Risk Management Application indicated that one of the lessons learned from the Apollo program was not to use common bulkheads because they are complex and difficult to manufacture.
	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 number of planned changes is such that, according to NASA review boards, the effort essentially represents a new engine development. NASA and Pratt and Whitney Rocketdyne recognize that some level of developmental problems are inherent in all new engine development programs. As such, the project has predicted that the J-2X development will require 29 rework cycles. In addition, the J-2X faces extensive redesign to incorporate modern controls, achieve increased performance requirements, and meet human rating standards. The J-2X developers also face significant schedule risks in developing and manufacturing a carbon composite nozzle extension needed to satisfy thrust requirements. According to contractor officials, the extension is more than 2 feet—i.e., about one-third—wider in diameter than existing nozzle extensions.
Orion Crew Exploration Vehicle	Launch abort system	Technology development of the launch abort system is being conducted concurrently with design of Orion. Ongoing requirements changes related to the Orion system and its subsystems or development setbacks could (1) prevent some test objectives from being adequately demonstrated during early launch abort system tests, (2) drive the need for additional testing of the abort system, or (3) lead to design revisions or changes to the required number of spares. Any of these possibilities could lead to increased program costs and delays to the flight test schedule. According to NASA officials, the agency is currently assessing alternative designs for the launch abort system to address weight and vibration concerns.

	Thermal protection system	The Orion requires the development of a large-scale ablative thermal protection system. Given the size of the vehicle and the tight development schedule, a feasible thermal protection system may not be available in time for the Orion initial operational capability to the space station. There is currently no industry capability for producing a thermal protection system of the size required by the Orion. Furthermore, heat shield design features required by the Orion, namely the size, have never been proven and must be developed. NASA is currently conducting an advanced development project to mature technologies necessary to meet thermal protection system requirements.

Source: GAO analysis of NASA data.

Constellation Cost Estimates Are Preliminary Due to Requirements Uncertainty

NASA's preliminary cost estimates for the Constellation Program are likely to change when requirements are better defined. NASA will establish a preliminary estimate of life cycle costs for the Ares I and Orion in support of each project's system definition review. A formal baseline of cost, however, is not expected until the projects' preliminary design reviews are completed. NASA is working under a self-imposed deadline to deliver the new launch vehicles no later than 2015 in order to minimize the gap in human spaceflight between the Space Shuttle's retirement in 2010 and the availability of new transportation vehicles. The Constellation Program's budget request maintains a confidence level of 65 percent (i.e., NASA is 65 percent certain that the actual cost of the program will either meet or be less than the estimate) for program estimates based upon a 2015 initial operational capability. Internally, however, the Ares I and Orion projects are working toward an earlier initial operational capability (2013), but at a reduced budget confidence level—33 percent. However, NASA cannot reliably estimate the money needed to complete technology development, design, and production for the Ares I and Orion projects until requirements are fully understood.

NASA has identified the potential for a life cycle cost increase as a risk for the Orion program. According to NASA's risk database, given the historical cost overruns of past NASA systems and the known level of uncertainty in the current Orion requirements, there is a possibility that Orion's life cycle cost estimate may increase over time. NASA acknowledges that such increases are often caused by the unknown impacts of decisions made during development. One factor currently contributing to cost increases is the addition of new requirements. NASA is working to formulate the best life cycle cost estimate possible during development, is identifying and monitoring costs threats, and is implementing management tools all aimed at addressing this risk.

Schedule Pressures Add Additional Risks for Ares I and Orion

There are considerable schedule pressures facing both the Ares I and Orion projects. These are largely rooted in NASA's desire to minimize the gap between the retirement of the space shuttle and availability of the new vehicles. Because of this scheduling goal, NASA is planning to conduct many interdependent development activities concurrently—meaning if one activity should slip in schedule, it could have cascading effects on other activities. Moreover, some aspects of the program are already experiencing scheduling delays due to the fact that high-level requirements are still being defined.

Ares I

The development schedule for the J-2X is aggressive, allowing less than 7 years from development start to first flight, and highly concurrent. 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 Ares I vehicle. This approach has introduced a high degree of concurrency between the setting of overall Ares I requirements and the development of the J-2X design and hardware. Consequently, the engine development is out of sync with the first stage and upper stage in the flow-down and decomposition of requirements, an approach our past work has shown to be fraught with risk. 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. 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 of cost and schedule impacts throughout the entire Ares I project.

The schedule for the first stage also presents a potential issue for the entire Ares I project. Specifically, the critical design review for the first stage 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 additional testing of developmental motors is conducted. By conducting the Ares I critical design review before the first stage project 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. If problems are found in the first stage design during the later testing, implementing solutions could result in costly rework and redesign and delay the overall project schedule.

Orion

Cost and schedule reporting on the Orion project indicates that the Orion project's efforts to mature requirements and design and to resolve weight issues is placing pressure on the Orion schedule. Specifically, activities aimed at assessing alternate designs to reduce overall vehicle mass, rework to tooling concepts, and late requirements definition have contributed to the project falling behind schedule. Further, the Orion risk system indicates that schedule delays associated with testing may occur. The current Orion design has high predicted vibration and acoustic levels. Historically, components designed and qualified for uncertain vibration and acoustic environments have resulted in some failures and required subsequent redesign and retest. Failures during qualification testing of Orion components may lead to schedule delays associated with redesigning components.

NASA's Administrator has publicly stated that if Congress provided the Agency an additional $2 billion that NASA could accelerate the Constellation program's initial operational capability date to 2013. We believe that this assessment is highly optimistic. The development schedule for the J-2X engine, the critical path for the Ares I development, is already recognized as aggressive, allowing less than 7 years for development. The development of the Space Shuttle Main engine by comparison took 9 years. Further, NASA anticipates that the J-2X engine is likely to require 29 rework cycles to correct problems identified during testing. Given the linear nature of a traditional test-analyze-fix-test cycle, even large funding increases offer no guarantee of program acceleration, particularly when the current schedule is already compressed and existing NASA test facilities are already maximized.

Test Facilities for Ares I and Orion Insufficient

According to NASA, at this time, existing test facilities are insufficient to adequately test the Ares I and Orion systems. Existing altitude test facilities are insufficient to test the J-2X engine in a relevant environment. To address this issue, NASA is in the process of constructing a new altitude test facility at Stennis Space Center for the J-2X. Also, current facilities are inadequate to replicate the Orion vibration and acoustic environment. Further, Pratt and Whitney Rocketdyne—the J-2 X upper stage engine contractor—indicated that existing test stands that could support J-2X testing will be tied up supporting the Space Shuttle program until 2010. NASA has taken steps to mitigate J-2X risks by increasing the amount of component-level testing, procuring additional development hardware and test facilities, and working to make a third test stand available to the contractor earlier than originally planned. NASA has compensated for this schedule pressure on the Ares I project by adding funds for testing and other critical activities. But it is not certain that added resources will enable NASA to deliver the Ares I when expected.

With respect to Orion's thermal protection system, facilities available from the Apollo era for testing large-scale heat shields no longer exist. Therefore, NASA must rely on two facilities that fall short in providing the necessary capability and scheduling to test ablative materials needed for Orion. Additionally, NASA has no scheduled test to demonstrate the thermal protection system needed for lunar missions. NASA is exploring other options, including adding a lunar return flight test and building a new improved test facility. Due to the scheduled first lunar flight, any issues identified during such testing would need to be addressed in the time between the flight test and the first flight.

Oversight Based on Best Practices and Key Indicators Important for Program Success

NASA is poised to invest a significant amount of resources to implement the Vision over the long term and specifically to develop the Ares I and Orion projects over the next several years. Accordingly, you asked us to articulate indicators that Congress could use to assess progress. Our prior work has shown that investment decisions of this magnitude need to be based on an established and executable business case and that there are several key indicators that Congress could be informed of to assess progress throughout development. These include areas commonly underestimated in space programs, such as weight growth and software complexity, as well as indicators used by best practice organizations to assess readiness to move forward in the development cycle. Space programs which we have studied in detail in the past have tended to underestimate cost in some of these areas.

Weight Growth

Our previous work on government-funded space systems has shown that weight growth is often not anticipated even though it is among the highest drivers of cost growth for space systems. Weight growth can affect the hardware needed to support a system, and, in the case of launch vehicles, the power or thrust required for the system. As the weight of a particular system increases, the power or thrust required for that system will also increase. This could result in the need to develop additional power or thrust capability to lift the system, leading to additional costs, or to stripping down the vehicle to accommodate current power or thrust capability. For example, NASA went through the process to zero-base the design for the Orion to address weight concerns. Continual monitoring of system weight and required power/thrust, as well as margins or reserves for additional growth, can provide decision makers with an indicator of whether cost increases can be anticipated.

Software Complexity

The complexity of software development on a system, often denoted by the number of lines of code on a system, can also be used as an indicator to monitor whether a program will meet cost and schedule goals. In our work on software development best practices, we have reported that the Department of Defense has attributed significant cost and schedule overruns on software-intensive systems to developing and delivering software. Generally, the greater the number of lines of code, the more complicated the system development. Changes to the amount of code needed to be produced can indicate potential cost and schedule problems. Decision makers can monitor this indicator by continually asking for information on the estimated amount of code needed on a system and inquiring about any increases in need and their impact on cost and schedule.

There are other areas, such as the use of heritage systems and industrial base capability that are commonly underestimated in space programs as well. However, weight increases and software growth are more quantifiable and thus useful for oversight purposes.

Indicators that Can be Used to Assess Knowledge Gap at Key Junctures

Additionally, since the mid-1990s, GAO has studied the best practices of leading commercial companies. On the basis of this information, and taking into account the differences between commercial product development and major federal acquisitions, we have outlined a best practices product development model—known as a knowledge-based approach to system development. This type of approach calls for investment decisions to be made on the basis of specific, measurable levels of knowledge at critical junctures before investing more money and proceeding with development.

Importantly, our work has shown the most leveraged decision point is matching the customer’s needs with the developer’s resources (time, dollars, technology, people, etc.) because it sets the stage for the eventual outcome—desirable or problematic. The match is ultimately achieved in every development program, but in successful development programs, it occurs before product development is formally initiated (usually the preliminary design review). If the knowledge attained at this and other critical junctures does not confirm the business case on which the acquisition was originally justified, the best practice organizations we have studied do not allow the program to go forward.

We have highlighted the three critical junctures at which developers must have knowledge to make large investment decisions—the preliminary design review, the critical design review, and the production review—and the numerous key indicators that can be used to increase the chances of successful outcomes.

In assessing the Orion and Ares programs, the Congress and NASA decision-makers can use these indicators in order to reliably gauge whether there is a sufficient business case for allowing the programs to proceed forward.

Preliminary design review: Before product development is started, a match must be made between the customers' needs and the available resources—technical and engineering knowledge, time, and funding. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following have indicators been met:

- All critical technologies are demonstrated to a high level of technology maturity, that is demonstrated that they can perform in a realistic or, more preferably, operational environment. A technology readiness level 6 or 7 would indicate that this has been achieved. One approach to ensure that technology readiness is reliably assessed is to use independent testing;
- Project requirements are defined and informed by the systems engineering process;
- Cost and schedule estimates established for the project are based on knowledge from the preliminary design using systems engineering tools;
- Additional resources are in place, including needed workforce, and a decision review is conducted following completion of the preliminary design review.

A critical enabler for success in this phase of development is performance and requirements flexibility. Customers and product developers both need to be open to reducing expectations, deferring them to future programs, or to investing more resources up front to eliminate gaps between resources and expectations. In successful programs we have studied, requirements were flexible until a decision was made to commit to product development because both customers and developers wanted to limit cycle time. This makes it acceptable to reduce, eliminate, or defer some customer wants so that the product's requirements could be matched with the resources available to deliver the product within the desired cycle time.

Critical design review: A product's design must demonstrate its ability to meet performance requirements and be stable about midway through development. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following indicators have been met:

- At least 90 percent of engineering drawings are complete;
- All subsystem and system design reviews have been completed;
- The design meets requirements demonstrated through modeling, simulation, or prototypes;
- Stakeholders' concurrence that drawings are complete and producible is obtained;
- Failure modes and effects analysis have been completed;
- Key system characteristics are identified;
- Critical manufacturing processes are identified;
- Reliability targets are established and a growth plan based on demonstrated reliability rates of components and subsystems is developed; and
- A decision review is conducted following the completion of the critical design review.

Production Review: The developer must show that the product can be manufactured within cost, schedule, and quality targets and is demonstrated to be reliable before production begins. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following indicators have been met:

- Manufacturing processes have been demonstrated;
- Production representative prototypes have been built;
- Production representative prototypes have been tested and have achieved reliability goals;
- Production representative prototypes have been demonstrated in an operational environment through testing;
- Statistical process control data have been collected;
- Critical processes have been demonstrated to be capable and that they are in statistical control;
- A decision review is conducted following completion of the production readiness review.

Over the past 2 years, we have recommended that NASA incorporate a knowledge-based approach in its policies and take steps to implement this type of approach in its programs and projects.[8] NASA has incorporated some knowledge-based concepts into its acquisition policies. For example, NASA now requires a decision review between each major phase of the acquisition life cycle and has established general entrance and success criteria for the decision reviews. In addition, we have reported that this type of approach is being embraced by the Ares I project.

Concluding Observations

In conclusion, the President's Vision for Space Exploration is an ambitious effort, not just because there will be technical and design challenges to building systems needed to achieve the Vision's goals, but because there are limited resources within which this can be accomplished. Moreover, the long-term nature of the Vision means that commitments for funding and to the goals of the Vision will need to be sustained across presidential administrations and changes in congressional leadership. For these reasons, it is exceedingly important that the right decisions are made early on and that decision-makers have the right knowledge going forward so that they can make informed investment decisions.

In looking at the first major investments, the Ares I and Orion projects, it is important to recognize that they are risky endeavors, largely due to their complexity, scope, and interdependencies. It is also important to recognize that the desire to minimize the gap in human space flight adds considerable risk, since it could limit NASA's ability to study emerging problems and pursue alternative ways of addressing them. For these reasons, as well as the magnitude of investment at stake, it is imperative that NASA be realistic and open about the progress it is making and to be willing to make changes to the architecture and design if technical problems can not be solved without overly compromising performance. Additionally, Congress needs to be well-informed about the extent to which knowledge gaps remain and what tradeoffs or additional resources are needed to close those gaps and to support changes if they are determined to be necessary. The upcoming preliminary design review

[8] GAO, *NASA: Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes*, GAO-06-218 (Washington, D.C.: Dec. 21, 2005); GAO, *NASA: Long-Term Commitment to and Investment in Space Exploration Program Requires More Knowledge*, GAO-06-817R (Washington, D.C.: July 17, 2006); and GAO, *NASA's James Webb Space Telescope: Knowledge-Based Acquisition Approach Key to Addressing Program Challenges*, GAO-06-634 (Washington, D.C.: July 14, 2006)..

milestones represent perhaps the most critical juncture where these assessments can take place and where hard decisions can be made as to whether the programs should proceed forward. It may well be the last opportunity to make significant adjustments before billions of dollars are spent and long term commitments become solidified.

Mr. Chairman, this concludes my prepared statement. I would be pleased to answer any questions that you may have at this time.

GAO Contacts and Staff Acknowledgements

For further questions about this statement, please contact Cristina T. Chaplain at (202) 512-4841. Individuals making key contributions to this statement include James L. Morrison, Meredith A. Kimmitt, Lily Chin, Neil Feldman, Rachel Girshick, Shelby S. Oakley, and John S. Warren, Jr.

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