

November 3, 2008

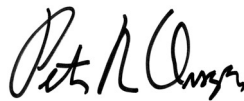
Honorable Dave Weldon, M.D.
U.S. House of Representatives
Washington, DC 20515

Dear Congressman:

In response to your request, the Congressional Budget Office (CBO) has analyzed the human spaceflight program of the National Aeronautics and Space Administration—and, in particular, its plans for development of the Ares 1 and Orion vehicles as part of its Constellation Program. The enclosed report addresses the likelihood of a delay in retiring the space shuttle and in attaining initial operating capability for the new vehicles; the potential impact of such delays on the gap in U.S. human spaceflight after the shuttle is retired; and the budgetary implications of various possible developments, in light of the lower-than-requested funding provided in the Revised Continuing Appropriations Resolution, 2007 (Public Law 110-5).

If you would like further details, we would be pleased to provide them. The analysis was prepared by Kevin Eveker, who can be reached at (202) 226-2973.

Sincerely,



Peter R. Orszag

Enclosure

Identical letter sent to the Honorable John Culberson and the Honorable Robert Aderholt

Honorable Dave Weldon, M.D.

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cc: Honorable Bart Gordon, Chairman
House Committee on Science and Technology

Honorable Ralph M. Hall, Ranking Member
House Committee on Science and Technology

Honorable Mark Udall, Chairman
Subcommittee on Space and Aeronautics
House Committee on Science and Technology

Honorable Tom Feeney, Ranking Member
Subcommittee on Space and Aeronautics
House Committee on Science and Technology

Honorable Daniel K. Inouye, Chairman
Senate Committee on Commerce, Science and Transportation

Honorable Kay Bailey Hutchison, Ranking Member
Senate Committee on Commerce, Science and Transportation

Honorable Bill Nelson, Chairman
Subcommittee on Space, Aeronautics, and Related Sciences
Senate Committee on Commerce, Science and Transportation

Honorable David Vitter, Ranking Member
Subcommittee on Space, Aeronautics, and Related Sciences
Senate Committee on Commerce, Science and Transportation

An Analysis of NASA's Plans for Continuing Human Spaceflight After Retiring the Space Shuttle

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An Analysis of NASA's Plans for Continuing Human Spaceflight After Retiring the Space Shuttle

Summary

In 2004, President Bush announced his “Vision for U.S. Space Exploration,” which called for the National Aeronautics and Space Administration (NASA) to complete construction of the International Space Station and retire the space shuttle fleet by 2010. The President also directed NASA to develop new vehicles for human spaceflight that would allow missions to the moon, Mars, and beyond. NASA was directed to complete that development as quickly as possible to minimize the gap in time, once the space shuttle fleet was retired, during which NASA would be unable to carry out human space missions.

The development of new vehicles for such missions—including the Ares 1 crew launch vehicle and the Orion crew exploration vehicle—is funded through NASA's Constellation Program. This Congressional Budget Office (CBO) report describes the status of the program and the prospects for accomplishing its goals over the planned timetable. NASA's current plans call for the Ares 1 and Orion vehicles to reach the milestone of initial operating capability (IOC) in March 2015. (At that point, the Ares 1 and Orion vehicles should be capable of carrying a crew of astronauts to the International Space Station.) NASA is also developing additional vehicles and systems—including the Ares 5 cargo launch vehicle—that are required to return humans to the moon by 2020.

NASA indicates that the probability of achieving the IOC milestone for the Ares 1 and Orion vehicles by March 2015 is 65 percent—that is, its level of confidence about meeting that date is 65 percent, which the agency considers to be a reasonable level for purposes of program planning. (NASA estimates the feasibility of meeting such milestones by using standard probability analyses of its plans for development programs.) NASA's 65 percent figure takes into account the reduction in its fiscal year 2007 budget (relative to the Administration's request) of \$577 million (in 2007 dollars), a change enacted in the Revised Continuing Appropriations Resolution, 2007 (Public Law 110-5). The agency has accommodated the cut in its 2007 funding by eliminating some future missions of its Lunar Precursor Robotic Program. (That program is designed to launch robotic spacecraft to the moon to collect data about the moon's surface to help plan future human lunar missions.)

CBO's analysis of NASA's Constellation Program points to several general conclusions:

- *The five-year gap in U.S. human spaceflight between the retirement of the space shuttle, in September 2010, and the achievement of initial operating capability for Ares 1 and Orion, in March 2015, might increase if NASA could not avoid the risks to the successful completion of those projects that it and others (in particular, the Government Accountability Office, or GAO) have identified in the Constellation Program.*¹ Those risks include an increase during development in the mass of the Orion vehicle that would exceed the capability of the Ares 1 to lift it into orbit; excessive thrust oscillation in the first stage of the Ares 1 and less-than-required performance during the rocket's launch; a longer-than-expected development period for the J-2X engine of the Ares 1's second, or upper, stage; and NASA's inability to develop and fabricate effective heat shields for the Orion within its current development schedule.

- *The potential problems that those risks represent could require additional time and money to resolve.* NASA's current plans include an allowance of almost \$7 billion to ensure that the Ares 1 and Orion achieve initial operating capability according to the current schedule. (Unless otherwise noted, dollar amounts are expressed as 2009 dollars of budget authority.) NASA staff indicate that those reserves imply a 65 percent level of confidence that the IOC milestone will be met as planned. However, CBO's 2004 analysis of the growth of costs in previous NASA programs indicates that the costs that the agency currently foresees for the Ares 1 and Orion programs could rise by 50 percent.² Accommodating that cost growth would require as much as \$7 billion more than NASA has budgeted, CBO estimates. Moreover, if NASA's total budget grew by no more than 2 percent annually, such cost increases, in CBO's estimation, would imply a delay of as much as 18 months beyond March 2015 for the vehicles to achieve the IOC milestone.

- *The five-year gap in U.S. human spaceflight could also increase if delays consistent with past space shuttle missions occurred in launching the remaining missions needed to complete construction of the International Space Station.* Such delays could postpone retirement of the shuttle, thereby increasing the funding needed for its operations and, under a constrained total NASA budget, decreasing the funding available to the Constellation Program. A one-year delay in retiring the space shuttle, CBO estimates, would result in a corresponding one-year delay in achieving initial operating capability for Ares 1 and Orion. NASA officials estimate that the probability that the shuttle can complete its 10 remaining missions by September 2010 is between 40 percent and 69 percent; CBO estimates that a delay is more likely and that the probability of carrying out those missions on that timetable is between

1. See Government Accountability Office, *NASA: Ares 1 and Orion Project Risks and Key Indicators to Measure Progress*, GAO-08-186T (April 3, 2008).

2. See Congressional Budget Office, *A Budgetary Analysis of NASA's New Vision for Space Exploration* (September 2004).

20 percent and 60 percent.³ NASA has also stated that if delays occurred that required missions to be flown after September 2010, it might cancel those missions so as not to use funding that would otherwise have been reallocated to the Ares 1 and Orion programs.

- *NASA's decision to accommodate the \$577 million reduction in its 2007 funding by forgoing robotic surface exploration of the moon has the potential to delay the launch of the Constellation Program's first human lunar missions beyond 2020.*

The Constellation Program and NASA's Budget

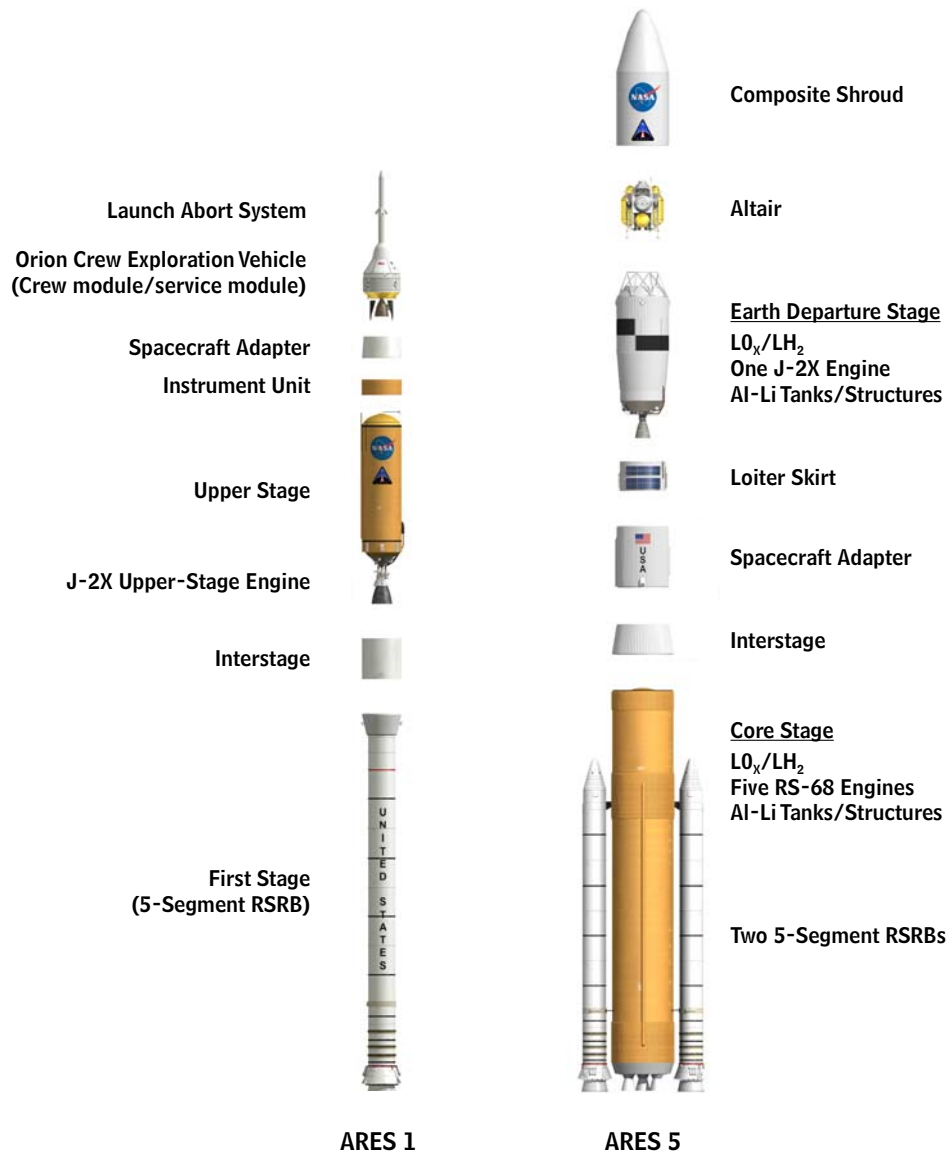
NASA's current plans for human spaceflight call for retiring the space shuttle fleet in 2010, after construction of the International Space Station is complete, and achieving an initial operating capability in March 2015 for two of the new spacecraft being developed to return humans to the moon: the Ares 1 crew launch vehicle and the Orion crew exploration vehicle. During the gap between the shuttle fleet's retirement and the start of flights using the Ares 1 and the Orion, NASA plans to use commercial transportation services and the Russian-operated Soyuz spacecraft to transport cargo and crew members to the space station.

The designs for the new vehicles were initially formulated in NASA's 2005 Exploration Systems Architecture Study (ESAS) and have since been refined as development progressed.⁴ Under NASA's plan for the Constellation Program, which is drawn from the results of the ESAS, the space agency will first develop the Ares 1 and Orion vehicles.

- The two-stage Ares 1 launch vehicle is based in part on hardware used in the shuttle—specifically, for the Ares 1's first stage, hardware derived from the shuttle's reusable solid rocket motor/booster (see Figure 1). The second stage of the Ares 1 is a new design, and it is now under development. The Ares 1 will deliver the Orion crew exploration vehicle into low Earth orbit for human missions to the space station and later to the moon.⁵

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3. Those confidence levels have been adjusted to take into account the postponement of the servicing mission to repair a malfunction on the Hubble Space Telescope. The levels incorporate the assumption that NASA's new 10-mission manifest will require the same amount of time to achieve as the manifest in place prior to the postponement, with the first of 10 launches occurring one month later (on November 14 instead of October 14). The effect (if any) on the Ares 1 development program from postponing the Hubble servicing mission currently is not known. (Such an effect would arise from a delay in the availability of launch pad 39B at Kennedy Space Center.)
 4. See National Aeronautics and Space Administration, *NASA's Exploration Systems Architecture Study*, NASA-TM-2005-214062 (November 2005).
 5. A low Earth orbit has an altitude of no more than 800 kilometers above the Earth's surface.

Figure 1.
The Ares 1 and Ares 5 Vehicles



Source: National Aeronautics and Space Administration.

Notes: The architecture for the vehicles is as of February 2008.

Al-Li = aluminum-lithium; LO_x = liquid oxygen; LH₂ = liquid hydrogen; RSRB = reusable solid rocket booster.

- The Orion is made up of a crew module to carry astronauts, a service module containing propulsion and power systems, and a launch abort system that allows the crew to escape unharmed if a launch fails. The Orion's crew module resembles a larger version of the Apollo spacecraft used in the original U.S. lunar landing program of the 1960s and 1970s.

NASA's plans to return humans to the moon also require development of the Ares 5 cargo launch vehicle and the Altair lunar lander. The Ares 5, which comprises a core stage and an Earth-departure stage, will also be based in part on hardware from the shuttle. The core stage of the Ares 5 is intended to deliver the Earth-departure stage and the Altair into orbit to rendezvous with the Orion. The Earth-departure stage of the vehicle is designed to propel the Altair and the Orion to the moon.

NASA has altered its original plans for the Constellation Program several times since it completed the ESAS. Those changes include the following:

- The date of the United States' return to human spaceflight following retirement of the space shuttle has been moved from 2011 to 2015 to ensure sufficient time and budgetary resources for developing the Ares 1 and Orion vehicles.
- NASA has decreased the diameter of the Orion crew module from 5.5 meters (about 18 feet) to 5.0 meters to reduce the module's weight but still maintain sufficient room for up to six crew members.
- The first stage of the Ares 1 will use a five-segment solid rocket motor instead of the four-segment motor used on the space shuttle. That change allows the first stage to carry more propellant and provides more thrust during the launch.
- The Ares 1 will use a new J-2X engine for its second stage rather than a modified version of the space shuttle's main engine.⁶ That change, which addresses technical and cost issues associated with use of the shuttle engine, also increases the number of elements that the Ares 1 and Ares 5 have in common, thereby reducing development and procurement costs for both programs. (The Ares 5 will also use the J-2X engine in its Earth-departure stage.)
- NASA will use a common wall between the two tanks of the Ares 1's upper stage instead of using two independent tanks. That change will reduce the inert weight of the second stage, thereby improving the Ares 1's performance during launch.

6. Using the shuttle's main engine for the Ares 1 would have required changes in design to allow for ignition at high altitudes instead of at sea level, which is where the engine on the space shuttle is started. Furthermore, NASA anticipated that it would have to change the engine's design to make it more cost-effective as a disposable engine for the Ares 1 instead of the reusable version in place on the shuttle.

- NASA has decided that its primary recovery approach for the Orion will be on water rather than on land, as originally planned, a change that will permit a reduction in the Orion's weight. However, NASA will also maintain an emergency backup capability to recover the Orion on land.

Public Law 110-5, the Revised Continuing Appropriations Resolution, 2007, provided funding for NASA's Constellation Program for that year that was \$577 million (in 2007 dollars) less than the Administration had requested. Initially, NASA indicated that the reduction in funding would cause the program's total costs to increase and significant delays to occur in the first launches of the Ares 1 and the Orion.⁷ Subsequently, NASA chose to accommodate the reduction and avoid those delays by downsizing its Lunar Precursor Robotic Program (a series of robotic missions to the moon designed to help prepare for future human lunar missions). Cuts to the Lunar Precursor Robotic Program, however, could risk delaying those future human lunar missions, which are currently scheduled by NASA to begin no later than 2020.

The Gap in U.S. Human Spaceflight

Members of the space community have expressed concerns regarding the five-year gap in the United States' ability to carry out human spaceflight missions between the time of the shuttle's retirement and NASA's achievement of initial operating capability for the Ares 1 and Orion systems. Until August 2008, NASA had assessed a 30 percent probability that the Ares 1 and the Orion would achieve initial operating capability in September 2013 if no additional problems were encountered. If, however, \$1 billion was added to the agency's proposed budget for both fiscal year 2009 and 2010, the agency assessed a higher probability—65 percent—of the vehicles' achieving the IOC milestone in September 2013.⁸

Now, however, NASA states that initial operating capability for Ares 1 and Orion cannot be achieved by September 2013. However, there is a 50 percent chance that, if no additional problems are encountered, the Ares 1 and Orion vehicles will achieve the IOC milestone in September 2014 and a 65 percent chance of achieving the milestone in March 2015. NASA has also stated that at this point in the development process for the two vehicles, additional funding can no longer significantly change either the estimated date for or NASA's level of confidence about its achievement of the IOC milestone.

The Constellation Program Within NASA's Budget

NASA provided actual and planned funding for its programs for the years 2007 to 2013 in its 2009 budget request, and CBO used those data (together with information about NASA's plans beyond 2013) to project budgets for the agency through

7. See the statement of Michael Griffin, NASA Administrator, before the House Committee on Science and Technology, March 15, 2007.

8. See F. Moring Jr., "Bipartisan Blueprint: Congress Sending a Message to Next President on Space," *Aviation Week and Space Technology* (May 26, 2008).

2020. CBO assumes, as does NASA, that in general the agency's overall funding will experience no real growth (that is, no growth after accounting for inflation) beyond 2013—an assumption that also applies to funding for the majority of the components of NASA's budget. However, CBO's projection of funding for the Constellation Program beyond 2013 shows real increases—a view consistent with NASA's plans—as development and operation of the Ares and Orion vehicles proceed.

Within NASA's planned total budget request of about \$18 billion annually (in 2009 dollars) between 2007 and 2013, the Constellation Program's budget ranges from about \$3 billion in 2007 to more than \$3.5 billion in 2010 and then, in a sharp increase, to roughly \$6.5 billion in 2011. By 2013, according to NASA's plans, the total annual budget for the Constellation Program will be about \$7 billion. Beyond 2013, the budget for the program will reach \$8 billion in 2016, CBO projects, with additional increases through 2020. The jump in funding between 2010 and 2011 is due to the retirement of the space shuttle fleet and the transfer of that funding to the Constellation Program. (Because of that linkage, a delay in retiring the space shuttle would result in a delay of additional funding to support the Constellation Program, which would affect the timing of development of the Ares 1 and the Orion.) Beyond 2016, according to NASA's current budget plan, the agency will not support the operations of the International Space Station, and the funds previously allocated for that purpose will be redirected to the Constellation Program. However, NASA thus far has taken no action that would preclude its support of the space station's operations beyond 2016.

Through 2015, projected funding for the Constellation Program will primarily pay for the development of Ares 1 and Orion. As that development nears completion and the vehicles begin operations, funding to develop the Ares 5 cargo launch vehicle and the Altair lunar lander and to support other activities associated with future human lunar missions is projected to increase (see Figure 2).

Risks to the Timely Completion of Ares 1 and Orion

In its budget justification materials for fiscal year 2009, NASA lists several potential problems that could increase the costs and time needed to develop the Ares 1 and the Orion spacecraft. (GAO has identified several similar risks to the successful outcome of the two development programs.)⁹ Those factors include the following:

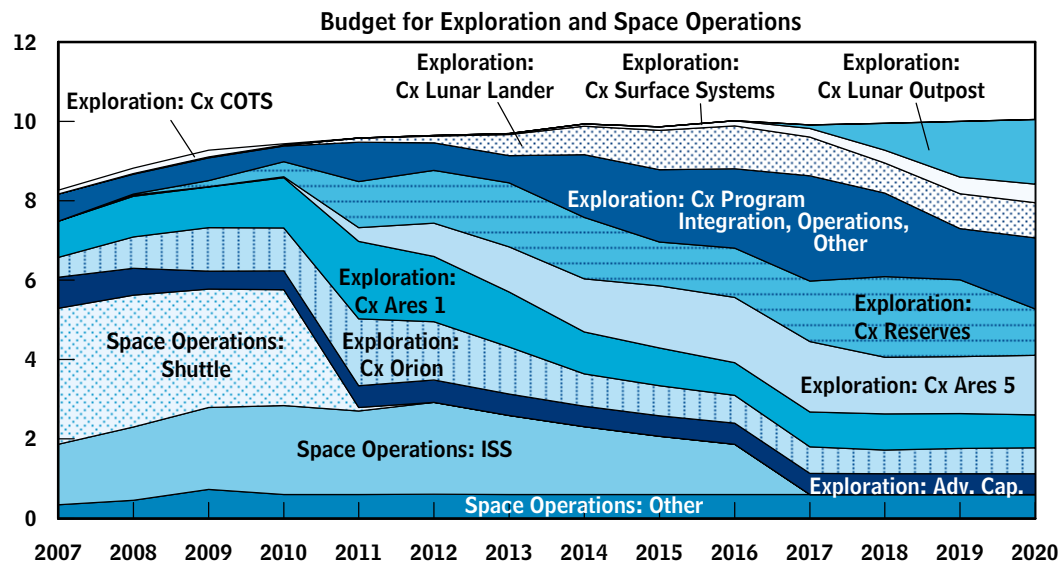
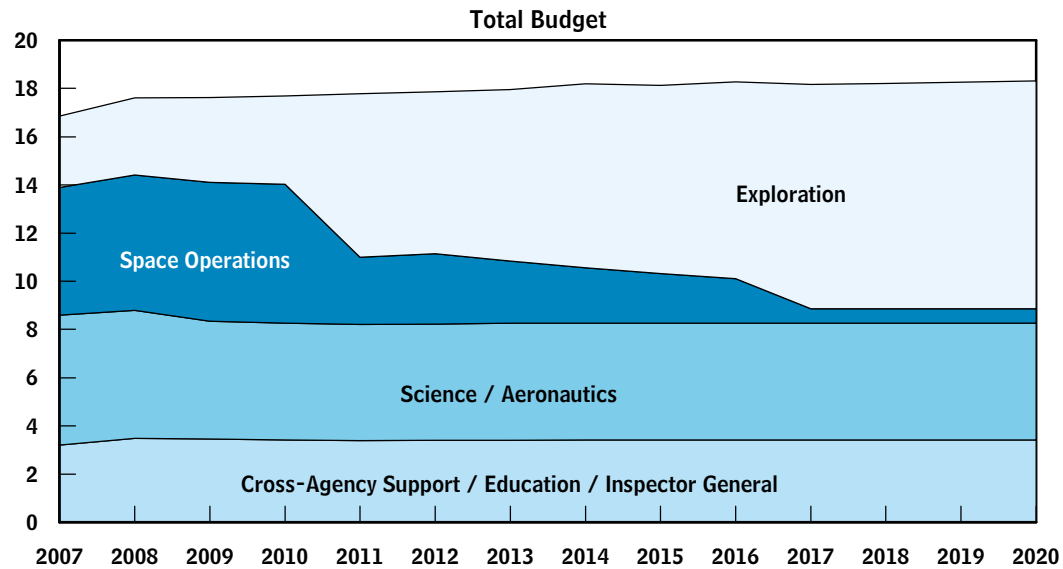
- An increase during the development process in the mass of the Orion crew exploration vehicle that would exceed the Ares 1's capability to lift the Orion into low Earth orbit;

9. See Government Accountability Office, *NASA: Ares 1 and Orion Project Risks*.

Figure 2.

Budget of the National Aeronautics and Space Administration, 2007 to 2020

(Billions of 2009 dollars)



Source: Congressional Budget Office based on the President's budget for fiscal year 2009 and data provided by the National Aeronautics and Space Administration.

Notes: Cx = Constellation theme; ISS = International Space Station; COTS = commercial orbital transportation services; Adv. Cap. = Advanced Capabilities.

- Excessive thrust oscillations during the burn of the first stage of the Ares 1 that result in excessive vibrations in the Orion crew module;
- Performance of the Ares 1 that is less than that required to lift the Orion into low Earth orbit;¹⁰
- A longer time than planned to develop the J-2X engine needed for the Ares 1's second stage, which would delay the vehicle's completion;¹¹ and
- The inability to develop and fabricate heat shields for the Orion within NASA's current schedule.

NASA has plans to mitigate those risks. For example, it has established a mass properties group to study the potential problem with the Orion's mass and lessen the risk that an excessive increase in its mass poses. However, should NASA's planned efforts fail to address the potential problems that those risks represent, additional time and funding would be required to develop vehicles that could satisfy NASA's requirements. In that case, the timing gap between the space shuttle's retirement and the achievement of initial operating capability for the Ares 1 and Orion would widen.

CBO cannot estimate the specific costs and delays that the risks listed above would entail. However, using data on the cost growth associated with past NASA programs, CBO calculated the potential increase in the overall costs to develop the Ares 1 and Orion vehicles. Those historical data indicate that when problems such as those identified by NASA and GAO occur during the development of systems like the Ares 1 and Orion, solving such problems has required additional time and money. NASA's plans for the two vehicles include allowances of 6 months and almost \$7 billion to help ensure—with a probability of 65 percent—that the Ares 1 and the Orion can achieve the IOC milestone by March 2015. (NASA has said that if no additional problems arise, the programs could achieve initial operating capability by September 2014, but its confidence level regarding that date is a lower 50 percent.)

CBO expects, on the basis of its analysis of 72 past NASA programs, that cost growth in the Ares 1 and Orion programs will be about 50 percent and that NASA will require as much as \$7 billion more than it has budgeted.¹² If no real growth occurred in NASA's overall annual budget, the increase in costs that CBO has projected would also imply as much as an 18-month delay beyond March 2015 in achieving initial operating capability for Ares 1 and Orion. Moreover, under a fixed overall budget for

10. To date, the Ares 1 program has met the targets set for the vehicle's performance. But the Ares 1 has only a limited potential for expansion and risks being unable to provide the greater lift capability that could be required as designs for it and the Orion evolve and become final.

11. The design of the new J-2X engine is based on the J-2 and J-2S engines used on the Saturn V launch vehicle developed during the original U.S. lunar landing program of the 1960s and 1970s.

12. See Congressional Budget Office, *A Budgetary Analysis of NASA's New Vision for Space Exploration*.

the agency, increases in costs and delays in development schedules for the two vehicles would also hold up funds that NASA plans to use to support lunar exploration, which would in turn interfere with the agency's goal of returning humans to the moon by 2020. Details of several of the potential problems in the Ares 1 and Orion development programs are described below.

The Margin for Increases in Orion's Mass

An excessive increase in the mass of the Orion vehicle as development proceeds could affect both the costs and the schedule for completing it and the Ares 1. If the Orion is too large, the Ares 1 launch vehicle will be unable to lift it into orbit; in that case, NASA would probably have to redesign both vehicles. Under the ground rules and assumptions laid out in its Exploration Systems Architecture Study, NASA set maximum margins for increases in mass during development: 15 percent for any launch vehicle (such as the Ares 1) and 20 percent for any in-space element (such as the Orion).

Data from earlier NASA programs indicate that increases in the mass of systems in such projects during the development stage have ranged from about 8 percent to nearly 55 percent, with a mean across 70 programs of 28.5 percent—a figure greater than NASA's assumptions about maximum margins in the ESAS.¹³ Statistical analysis of those data on mass growth in the agency's programs indicates that NASA should have initially used a mass margin of 32 percent for Orion (a margin associated with a 65 percent level of confidence); it should also have had 21 percent of that margin left at the time of the preliminary design review (PDR)—that is, before the start of detailed design work. However, the remaining mass margin dropped to below 2 percent, in CBO's estimation, during the preliminary design stage, notwithstanding the reductions in Orion's mass that NASA had made since the completion of the ESAS. So, in August 2007, NASA began a complete overhaul of the design for the Orion vehicle to bring the spacecraft's mass within bounds, and the agency now estimates that mass margins for Orion are greater than 20 percent. However, NASA has delayed its planned achievement of the PDR milestone, shifting it from September 2008 to November 2008. If the agency requires additional changes to reduce the Orion's mass, they could further affect development costs as well as NASA's current schedule for both the Ares 1 and the Orion.

Development Risks for the Ares 1

NASA has identified several problems associated with the Ares 1 that could delay successful development of the vehicle beyond March 2015. Those problems include thrust oscillations during the firing of the first stage that could cause unacceptable structural vibration, the risk that the vehicle will not perform as required, and the possibility that the development schedule for the second-stage J-2X engine will not be met.

13. See A.W. Wilhite and others, "Evaluating the Impacts of Mass Uncertainty on Future Exploration Architectures," in *Space 2006 Conference Proceedings*, 4 vols., AIAA 2006-7250 (Reston, Va.: American Institute of Aeronautics and Astronautics, September 2006).

Thrust Oscillations. The agency's guideline for vibrational loads on the crew of astronauts in the Orion module is 0.25 g.¹⁴ NASA estimates that the effects on the crew of the structural vibration caused by thrust oscillations during the Ares 1's first stage are, at worst, plus or minus 5 g. The agency is currently working on changes in the design of the vehicle that will add a system at its aft skirt to actively control the oscillations and reduce the vibrational loads on the crew to meet the agency's guideline. (The aft skirt is on the very bottom of the Ares 1.) However, the modification will reduce the weight of the Ares 1's payload (that is, the weight of the object or objects it can lift into orbit) by 1,200 to 1,400 pounds.

Performance Shortfall. NASA has also identified a risk that the Ares 1 vehicle will not be capable of lifting the Orion into low Earth orbit—specifically, if the Orion's mass increases so much that it cannot be accommodated by changes in the Ares 1. The agency is currently conducting detailed design analyses of the Ares 1 to mitigate that risk. For example, to save weight in the vehicle's second stage and increase the mass of the payload that the Ares 1 can lift into low Earth orbit, NASA has changed the design of the fuel tanks in the second stage, shifting from two tanks that are completely separate to two tanks that share a common bulkhead. However, the latter design is more difficult to produce and thus could increase the costs and time required to develop the Ares 1.

Schedule for Development of the J-2X Engine. As the ESAS indicates, NASA had planned to use the space shuttle's main engine in the second stage of the Ares 1 launch vehicle. It now intends to use the J-2X engine—originally planned only for the Ares 5—on both Ares vehicles to increase the number of common components and reduce life-cycle costs (for development, manufacturing, and operations) for both programs. According to NASA's current plans, development of the J-2X engine will take seven years versus the nine years it took to develop the space shuttle's main engine. Any delay in developing the J-2X would postpone NASA's achievement of initial operating capability for both the Ares 1 and the Orion.

Potential Delays in Completing the Space Station and Retiring the Space Shuttle

NASA's current plans call for retiring the space shuttle in 2010 after the assembly of the International Space Station is completed. NASA's launch manifest for the space shuttle contains 10 remaining missions (including two "contingency" flights that would transport critical spare parts and supplies to the space station for use in

14. One g equals approximately 9.8 meters per second squared acceleration—or roughly the gravitational acceleration that an object would experience at the Earth's surface.

emergency or other situations arising after the shuttle's retirement).¹⁵ After 2010, NASA plans to reallocate funding that had previously been budgeted for the space shuttle's operations and use it for development of the Ares 1 and Orion vehicles. Thus, in the context of a fixed overall budget for the agency, a delay in retiring the space shuttle would mean a delay in developing the Ares 1 and the Orion. NASA officials estimate (at confidence levels ranging from 40 percent to 69 percent) that the shuttle can complete its 10 remaining missions by September 2010. Those levels were calculated by using NASA's Manifest Assessment Simulation Tool; CBO's corresponding estimate shows confidence levels ranging from about 20 percent to about 60 percent, depending on the assumed frequency of minor delays (see Figure 3). Thus, there is a substantial probability, in CBO's view, that the September 2010 target date will not be met. NASA has also stated that if delays occurred that required missions to be flown beyond September 2010, the agency might decide to cancel any remaining missions so as not to use funding that would otherwise have been reallocated to the Ares 1 and Orion programs.

To estimate potential delays during the 10 upcoming missions, CBO used the manifest of remaining launches and data on the delays that had occurred during past shuttle missions. The analysis considered both minor delays (those attributable to known but unpredictable causes, such as bad weather) and major delays (those attributable to unforeseen problems that are identified during a mission—such as the foam that was shed from the shuttle *Columbia's* external tank and caused the loss of the shuttle). In the case of problems that cause major delays, subsequent missions are postponed until the problem causing the delay is resolved.

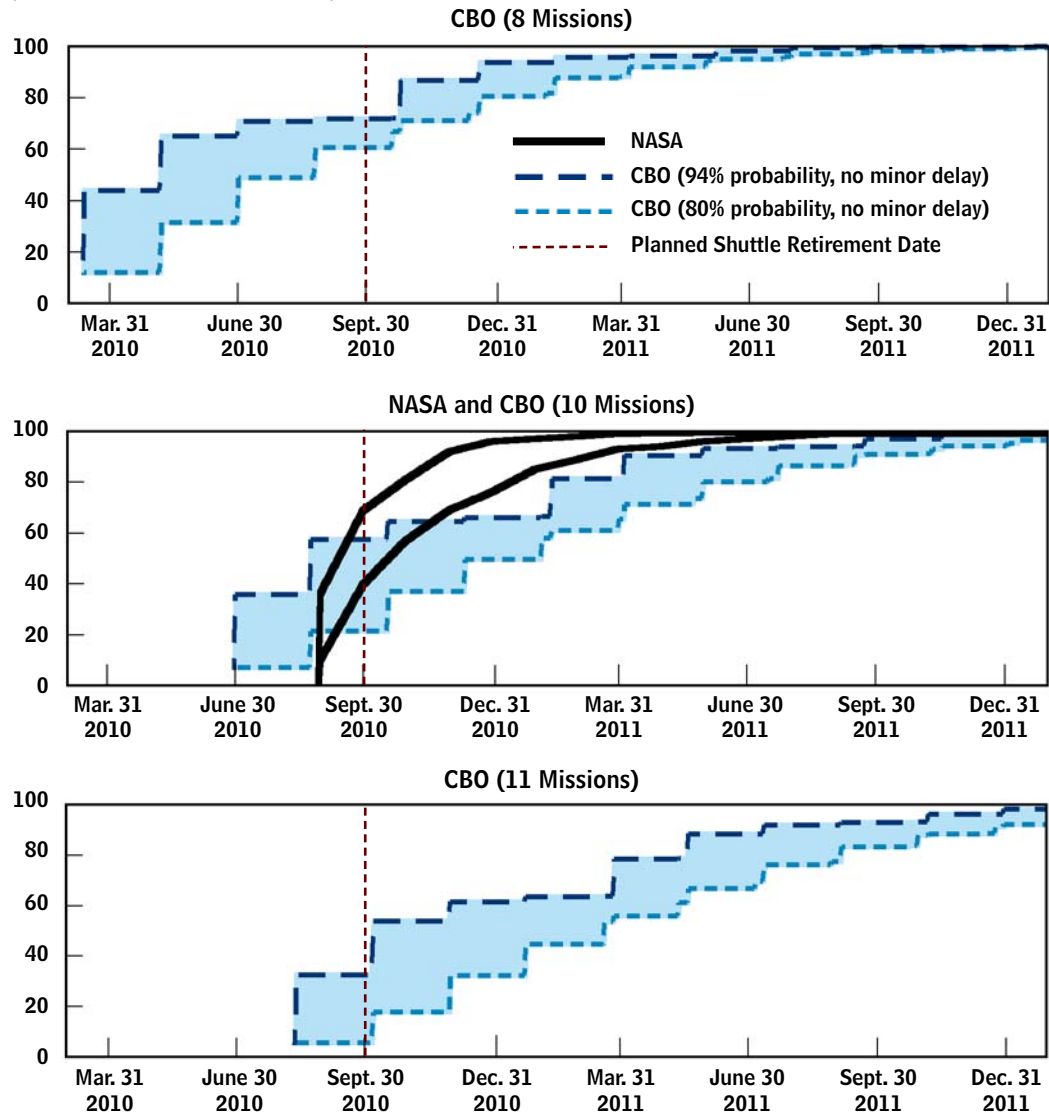
NASA schedules shuttle launches at a minimum interval of five weeks. For its analysis, CBO used data from previous launches to identify delays that resulted in postponements of more than five weeks. In the history of the shuttle program, the probability of a successful launch without a minor delay has been about 94 percent, and the duration of the average delay has been about seven weeks. For missions since the *Columbia* disaster, the probability of a shuttle launch without a minor delay has been 80 percent (8 out of 10 launches). CBO's assessment of five major delays (including those following the loss of the *Challenger* and the *Columbia*) indicates that the launch schedule for subsequent missions was typically postponed by more than seven months. On the basis of data from the entire shuttle program to date, CBO estimates the probability of a successful launch without a major delay to be 96 percent.

15. Until the loss of the shuttle *Columbia*, NASA had planned more missions before retiring the space shuttle fleet, but after that disaster, the number of shuttle missions was reduced. (Included among the missions that were cut was transport of the Alpha Magnetic Spectrometer—a space-borne particle physics experiment designed to search for and measure unusual types of matter—to the International Space Station.)

Figure 3.

Confidence Estimates for Space Station Completion and Shuttle Fleet Retirement Under Various Mission Manifests

(Confidence level in percent)



Sources: Congressional Budget Office; National Aeronautics and Space Administration.

Note: The figure compares estimated levels of confidence about the date for retirement of the space shuttle fleet, as calculated by CBO and NASA using various assumptions about the probability of delays in scheduled shuttle missions. The top line of the stair-step structure shows CBO's estimated levels of confidence about the retirement date for the shuttle when the probability of launching a mission without a minor delay is 94 percent; the lower line represents estimates that assume an 80 percent probability of no minor delay. For NASA's estimates, the top line represents confidence levels derived by using likely-case assumptions from the agency's Manifest Assessment Simulation Tool; the lower line represents the use of conservative assumptions. Thus, in the case of the 10-mission manifest, the probability that NASA can retire the space shuttle fleet by September 2010 is shown at the dashed vertical line: The probability is between about 20 percent and 60 percent in CBO's estimation, and between roughly 40 percent and 70 percent in NASA's estimation.

To compute the delays that would be expected in completing the shuttle's remaining missions, CBO simulated the schedule of remaining launches by using a Monte Carlo analysis. For each case in the analysis (each simulation considered a million such cases), randomly drawn numbers determined whether each launch on the manifest was postponed for one or more minor delays. Once each launch occurred in the simulation (except for the final scheduled launch), randomly drawn numbers determined whether the subsequent launch would be postponed seven months because of a major delay.

The delay in the space shuttle's retirement that CBO projected through the simulation is greater when more missions are flown—because there are more opportunities for launches to be delayed (see Figure 3). CBO simulated NASA's planned launch manifest of 10 missions, a manifest of 8 missions (under which the final two contingency missions are not flown), and an 11-mission manifest that adds a mission to transport the Alpha Magnetic Spectrometer project to the space station. Analysts used two different probabilities for a successful launch without a minor delay: 94 percent (based on the history of the entire shuttle program) and 80 percent (based on the missions flown since the loss of the *Columbia*).

For the 10-mission manifest, the probability that NASA can retire the space shuttle fleet by September 2010, in CBO's estimation, is between 20 percent and 60 percent. (The lower boundary of that confidence interval results from using the assumption that the probability of launching the shuttle without a minor delay is 80 percent; the higher end of the range derives from the assumption of a 94 percent probability of a minor delay.) CBO estimates confidence intervals in the 60 percent to 70 percent range for the 8-mission manifest and between about 5 percent and 30 percent for the 11-mission manifest.