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NASA

Challenges in Completing and Sustaining the International Space Station

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GAO-08-581T

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Highlights

Highlights of GAO-08-581T, a testimony before the Subcommittee on Space and Aeronautics, Committee on Science and Technology, House of Representatives

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NASA

Challenges in Completing and Sustaining the International Space Station

Why GAO Did This Study

The International Space Station (ISS), the most complex scientific space project ever attempted, remains incomplete. NASA expects the station's final construction cost will be $31 billion and expects sustainment costs through the station's planned retirement in fiscal year 2016 to total $11 billion. The space shuttle, the only vehicle capable of transporting large segments of the station into orbit, is critical to its completion. NASA plans to complete ISS assembly and retire the shuttle in 2010 in order to pursue a new generation of space flight vehicles, which will not begin to be available until 2015. To provide crew rotation and logistical support during this 5-year gap, NASA plans to rely on spacecraft developed by the commercial sector and other countries.

In light of these circumstances, GAO examined the risks and challenges NASA faces in (1) completing assembly of the ISS by 2010 and (2) providing logistics and maintenance to the ISS after 2010.

GAO's work to accomplish this included reviewing budget, planning, and other documents from NASA; reviewing NASA officials' testimonies; and interviewing NASA and foreign space program officials.

To view the full product, including the scope and methodology, click on GAO-08-581T. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

NASA faces significant challenges in its plans to complete assembly of the International Space Station (ISS) prior to the scheduled retirement of the space shuttle in 2010. Since GAO testified on this issue in July 2007, the shuttle flight schedule has remained aggressive—slating the same number of launches in a shorter period. While NASA thinks the proposed schedule is still achievable, the schedule

- is only slightly less demanding than it was prior to the Columbia disaster when the agency launched a shuttle every other month with a larger shuttle fleet and
- leaves little room for the kinds of weather-related, technical, and logistical problems that have delayed flights in the past.

Unanticipated delays could result in changes to the station's configuration, that is, some components may not be delivered. We have previously testified that such changes could limit the extent of scientific research that can be conducted on board the ISS.

After assembly is completed and the shuttle retires, NASA's ability to rotate crew and supply the ISS will be impaired because of the absence of a vehicle capable of carrying the 114,199 pounds of additional supplies and spares needed to sustain the station until its planned retirement in 2016. For crew rotation and logistics, NASA plans to rely on:

- *Russian, European and Japanese vehicles.* These vehicles were designed to augment the capabilities of the shuttle, not replace them, and have far less capacity to haul cargo. Furthermore, aside from a single Russian vehicle that can bring back 132 pounds of cargo, no vehicle can return cargo from the ISS after the shuttle is retired.
- *Commercially developed vehicles.* NASA has pledged approximately $500 million for the development of commercial vehicles. NASA expects these vehicles will be ready for cargo use in 2010 and crew use in 2012, even though none of the vehicles currently under development has been launched into orbit yet and their aggressive development schedule leaves little room for the unexpected. If one of these vehicles cannot be delivered according to NASA's current expectations, NASA will have to rely on Russian vehicles to maintain U.S. crew presence on the ISS until the new generation of U.S. spacecraft becomes available.

We are not making recommendations as a result of our review as NASA is well aware of the predicament it faces with the station and has weighed options and trade-offs for the remainder of the schedule manifest. However, it is important that flexibility continue to be maintained as events impacting schedule occur and that decisions be made with the goal of maximizing safety and results.

Mr. Chairman and Members of the Committee:

I am pleased to be here to discuss challenges that the National Aeronautics and Space Administration (NASA) faces in completing and sustaining the International Space Station (ISS). After delays and redesigns, efforts are under way for a long-envisioned expansion of the station so it can support a larger crew and more scientific research. NASA officials estimate the entire cost to complete the station will total $31 billion, and another $11 billion will be needed to sustain it through its planned decommissioning in fiscal year 2016.

The space shuttle has been and is critical to completion of the space station and re-supplying the station. The shuttle remains the only vehicle capable of transporting large segments of the station into orbit for assembly. NASA plans to complete ISS assembly duties and retire the shuttle fleet in 2010 in order to pursue a new generation of space flight vehicles for exploration. To that end, NASA has begun the process of making key decisions on suppliers that will no longer be needed. NASA officials told us that in many cases, restarting suppliers after these decisions are made would be cost prohibitive and time consuming. However, a new NASA vehicle will not be available until 2015 at the earliest, when the Crew Launch Vehicle (Ares I) and Crew Exploration Vehicle (Orion) are expected to fly. To fill the gap following retirement of the shuttle and provide crew rotation and logistical support, NASA plans to rely on a variety of spacecraft developed by the commercial sector and other countries.

In July 2007, we testified on a number of challenges NASA was facing with regard to completing the ISS within the time constraints created by the shuttle's retirement. Those challenges are still relevant. In light of these issues, we examined the risks and challenges NASA faces in (1) completing assembly of the ISS by 2010, and (2) providing logistics and maintenance support to the ISS after 2010.

In short, our work continued to find that NASA's plans to complete assembly of the International Space Station prior to the scheduled retirement of the space shuttle at end of fiscal year 2010 require much to happen and very little to go wrong. While NASA believes the schedule is still achievable, the flight rate that NASA is projecting is only slightly less aggressive than it was prior to the Columbia disaster[1] when, from 1992 to 2003, the agency launched a shuttle every other month. At that time, NASA used four vehicles to maintain its flight schedule. To complete the station by 2010, NASA will need to maintain a similar flight rate with fewer shuttles and with a shuttle fleet that is aging and continuing to face fuel sensor challenges. NASA remains confident that the current manifest can be accomplished within the given time, and in fact, it has several months of reserve time in its manifest. However, agency officials readily admit that the schedule is aggressive. If delays continue, NASA may need to reduce the number of flights to the station, which could prevent delivery of items currently scheduled for assembly and the pre-positioning of critical spares. Further, while NASA still expects to be able to increase crew capacity from three to six persons, changes it may need to make to the space station's configuration could limit the extent of scientific research that can be conducted onboard the ISS or quality of life for the crew.

After assembly is completed and the shuttle is retired, NASA's ability to rotate crew and supply the ISS will be impaired because of the absence of a vehicle capable of carrying the 114,199 pounds (or 51.8 metric tons) of additional supplies needed to sustain the station until its planned retirement in fiscal year 2016. NASA plans to rely on Russian, European and Japanese vehicles to service the station. Even with these vehicles, this shortfall remains. While the Russian vehicles are already in service, the European vehicle just completed its first operational test flight, and development efforts are still under way on the Japanese vehicle. In addition, these vehicles were designed to augment the capabilities of the shuttle, not replace them. Both the European and Japanese vehicles were designed to deliver supplies to the station but their capacities are not equal to the shuttle's 37,864 pounds of capacity. Furthermore, aside from a single Russian vehicle that can bring back 132 pounds of cargo and rotate crew, no vehicle can return cargo from the International Space Station after the shuttle is retired. NASA plans to rely on commercially developed vehicles to address some of these shortfalls and has pledged approximately $500 million for their development. NASA expects one of these vehicles will be ready for cargo use in 2010 and crew use in 2012. However, no vehicle has successfully been launched into orbit and their development schedules may leave little room for the unexpected. If these

[1] In 2003, the space shuttle Columbia broke up as it returned to Earth after 16 days in orbit. After the accident of Columbia, the shuttle fleet was grounded for approximately 2 ½ years. During that the time, U.S. crew and supplies were launched in the Russian Soyuz and Progress.

vehicles cannot be delivered according to NASA's current expectations, NASA will have to rely on Russian vehicles to maintain U.S. crew on the International Space Station until the new generation of U.S. spacecraft becomes available.

To conduct our work, we reviewed documents and testimonies by NASA officials relating to the challenges associated with ISS completion, the delivery schedule for ISS assembly and replacement units, and the space shuttle manifest. We reviewed key ISS budget and strategic maintenance plans, the ISS Independent Safety Task Force Report, and previous GAO reports relating to the ISS. We visited and interviewed officials responsible for ISS operations at NASA Headquarters, Washington, D.C., and the Johnson Space Center in Houston, Texas. At NASA Headquarters, we met with officials from the Exploration Systems Mission Directorate and the Space Operations Mission Directorate, including representatives from the International Space Station and space shuttle programs. We met with ISS and space shuttle officials at the Johnson Space Center. We also talked to a commercial developer of space vehicles and met with representatives of foreign space efforts. Complete details of our scope and methodology can be found in appendix I. We conducted this performance audit from July 2007 to 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.

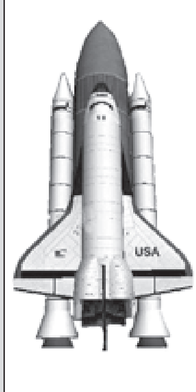
Background

The International Space Station program began in 1993 with several partner countries: Canada, the 11 member nations of the European Space Agency (ESA), Japan, and Russia. The ISS has served and is intended to expand its service as a laboratory for exploring basic questions in a variety of fields, including commercial, scientific, and engineering research. The first assembly flight of the station, in which the space shuttle Endeavor attached the U.S. laboratory module to the Russian laboratory module, occurred in early December of 1998. However, since the program's inception, NASA has struggled with cost growth, schedule delays and re-designs of the station. As we reported in the past, these challenges were largely due to poorly defined requirements, changes in program content and inadequate program oversight. Due to these challenges, the configuration of the station has devolved over time. In the spring of 2001, NASA announced that it would make major changes in the final configuration of the ISS to address cost overruns. In 2003, the National Academies reported that this reconfiguration greatly affected the overall ability of the ISS to support science. NASA estimates that assembly and operating costs of the ISS will be between $2.1 billion to $2.4 billion annually for FY2009-FY2012. The ISS as of February 19, 2008, is approximately 65 percent complete.

The shuttle program and the ISS program are inherently intertwined. The shuttle has unique capabilities in that it can lift and return more cargo to and from orbit than any other current or planned space vehicle. Figure 1 shows the capabilities of the shuttle in various configurations. Most segments of ISS cannot be delivered by any other vehicle. For example, the Columbia disaster in 2003 put ISS assembly on hiatus as NASA ceased shuttle launches for 2½ years while it investigated the safety of the fleet. During this period, the Russian Soyuz became the means of transportation for crewmembers traveling to and returning from the ISS.

Figure 1: Cargo Capabilities of the Shuttle

The shuttle's different capabilities



Mixed Flight Capability: 16,480 lbs./7,475 mass kg.
Consisting of internal cargo (8,818 lbs./4,000 kg.), external (2,205 lbs./1,000 kg.), water (882 lbs./400 kg.), nitrogen (55 lbs./25 kg.), oxygen (110 lbs./50 kg.) and propellants which are fuel and oxidizer (4,409 lbs./2,000 kg.). The majority of internal cargo is packaged in cargo transfer bags and then flown in either a rack or middeck locker.

External Capability: 14,716 lbs./6,675 mass kg.
Consisting of internal cargo (441 lbs./200 kg.), external (8,818 lbs./4,000 kg.), water (882 lbs./400 kg.), nitrogen (55 lbs./25 kg.), oxygen (110 lbs./50 kg.) and propellant (4,409 lbs./2,000 kg.). Two Express Logistics Carriers (ELC) can be loaded on the Shuttle payload bay. The ELC's can be left on the ISS for stowage of science payloads and maintenance of spares—each holding up to 10 orbital replacement units (ORU), and each has the ability to deliver up to two science payloads.

Assembly Capability: 37,864 lbs./17,175 mass kg.
Consisting of internal cargo (441 lbs./200 kg.), external (31,967 lbs./14,500 kg.), water (882 lbs./400 kg.), nitrogen (55 lbs./25 kg.), oxygen (110 lbs./50 kg.) and propellant (4,409 lbs./2,000 kg.). The assembly configuration enables the delivery of assembly hardware, such as the ESA's Columbus module.

Source: GAO analysis of NASA data.

In a major space policy address on January 14, 2004, President Bush announced his "Vision for U.S. Space Exploration" (Vision) and directed NASA to focus its future human space exploration activities on a return to the Moon as prelude to future human missions to Mars and beyond. As part of the Vision, NASA is developing new crew and cargo vehicles, with the first crew vehicle currently scheduled to be available in 2015. The President also directed NASA to retire the space shuttle after completion of the ISS, which is planned for the end of the decade. Based on that directive, NASA officials told us that they developed a manifest consisting of 17 shuttle launches to support ISS assembly and supply between 2005 and 2010.[2] Nine of these have taken place. In response to the President's Vision, NASA formally set September 30, 2010, as the date that the shuttle program will cease because agency officials believe that continuing the program beyond that date will slow development of the agency's new vehicles—specifically, the agency budget cannot support both programs at costs of $2.5 billion to $4 billion above current budget. As shown in Table 1, the shuttle program costs NASA several billion dollars annually and projected funding is phased out in fiscal year 2011. NASA officials stated that the majority of shuttle program cost is fixed at roughly $3 billion a year whether it flies or not. NASA officials stated that the average cost per flight is $150 million to $200 million.[3]

Table 1: Space Shuttle Program Costs

Dollars in millions

Funding Year	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
space shuttle program	3,315.3	3,266.7	2,981.7	2,983.7	95.7	—	—

Source: President's FY 2009 Budget Request.

The 2005 NASA Authorization Act designated the U.S segment of the ISS as a national laboratory and directed NASA to develop a plan to increase the utilization of the ISS by other federal entities and the private sector. In response, NASA has been pursuing relationships with these entities. NASA expects that as the nation's newest national laboratory, the ISS will strengthen NASA's relationships with other federal entities and private sector leaders in the pursuit of national priorities for the advancement of science, technology, engineering, and mathematics. The ISS National

[2] The manifest includes 18 total flights, but one of the launches is reserved for repairs to the Hubble Space Telescope.

[3] This cost is based on hardware, such as the booster rocket, used for the shuttles.

Laboratory is also intended to open new paths for the exploration and economic development of space.

The Retirement of the Shuttle Poses Challenges to NASA's Ability to Complete the International Space Station

It will be a challenge for NASA to complete the space station by 2010 given the compressed nature of the schedule, maintenance and safety concerns, as well as events beyond its control such as weather. Any of these factors can cause delays that may require NASA to re-evaluate and reconstitute the assembly sequence. NASA remains confident that the current manifest can be accomplished within the given time and there are tradeoffs NASA can make in terms of what it can take up to support and sustain the station should unanticipated delays occur. However, failure to complete assembly as currently planned would further reduce the station's ability to fulfill its research objectives and short the station of critical spare parts that only the shuttle can currently deliver.

Shuttle Flight Schedule Is Aggressive

In our July 2007 testimony, we reported that NASA planned to launch a shuttle once every 2.7 months. The plan for launches remains aggressive, partly because NASA plans on completing the ISS with the last assembly mission in April 2010, with two contingency flights in February and July 2010 to deliver key replacement units. The 5 months between the last assembly launch and shuttle retirement in September 2010 act as a schedule reserve, which can be used to address delays. There are 8 shuttle flights left to complete the station and two contingency flights left to deliver key components necessary to sustain the ISS after the retirement of the shuttle. There is an average of 2 ½ months between each shuttle launch.[4] Table 2 shows the current shuttle manifest.

Table 2: Remaining Flights of the Space Shuttles

Space shuttles	Expected launch dates
Discovery	May 31, 2008
Atlantis[a]	August 28, 2008
Endeavor	October 16, 2008
Discovery	December 4, 2008
Endeavor	March 2009

[4] This includes one mission to repair the Hubble Space Telescope and two contingency flights.

Space shuttles	Expected launch dates
Discovery	April 2009
Endeavor	August 2009
Discovery	October 2009
Endeavor[b]	February 2010
Discovery	April 2010
Endeavor[b]	July 2010

Source: GAO analysis of NASA's shuttle manifest.

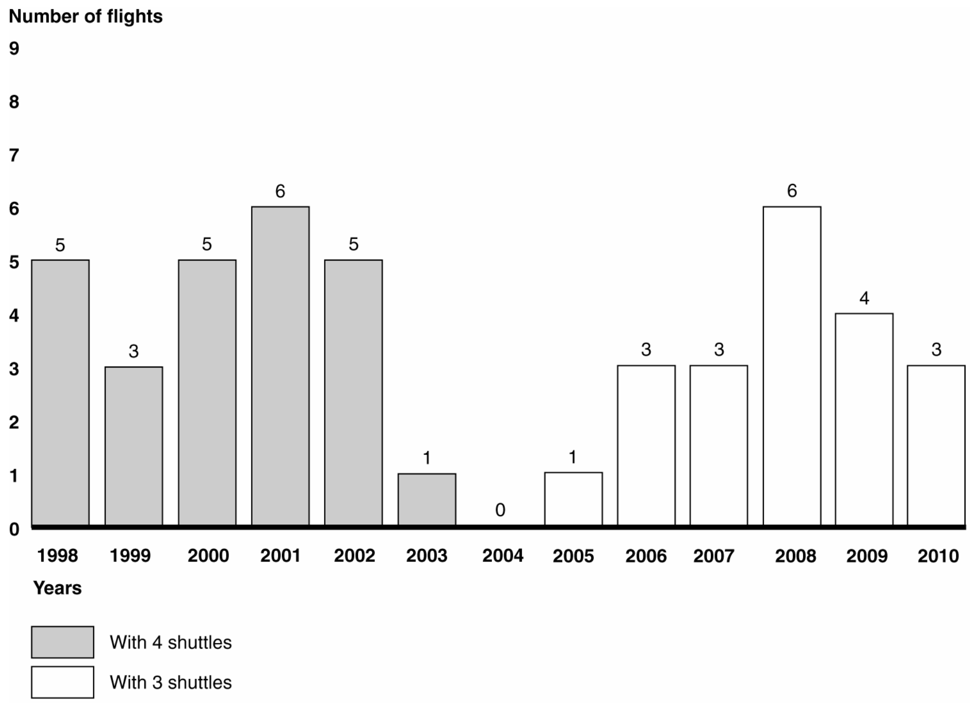
[a]Mission to repair the Hubble Space Telescope

[b]Contingency flights

NASA has launched shuttles at this rate in the past. In fact, the agency launched a shuttle, on average, every two months from 1992 through the Columbia disaster in 2003. However, at that time the agency was launching a fleet of four shuttles.[5] The shuttles require maintenance and refurbishing that can last four to five months before they can be re-launched. Launching at such a rate means that the rotation schedule can handle few significant delays, such as those previously experienced due to weather and fuel sensor difficulties. Lastly, NASA officials said that Shuttle Atlantis, which was to go out of service after the Hubble mission, will return to servicing the ISS for two more flights, which NASA believes will add more schedule flexibility.

[5] The remaining three shuttles are the Atlantis, Discovery, and Endeavor.

Figure 2: Completed and Projected Space Shuttle Flights Needed for ISS Assembly



Source: GAO analysis of NASA data.

Potential Launch Delays Remain

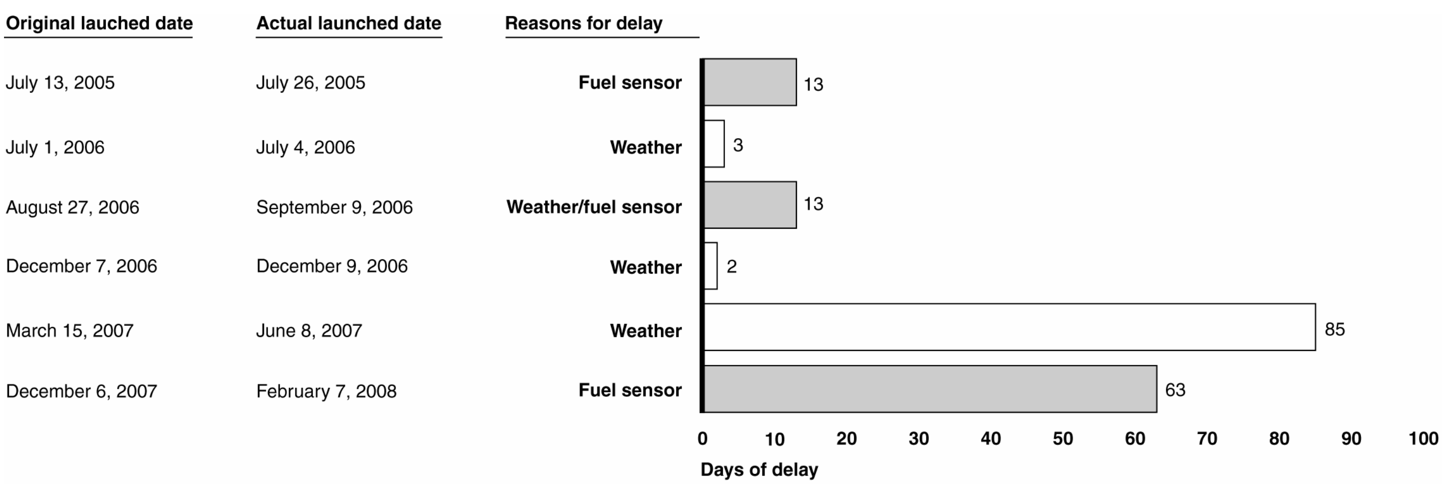
NASA officials stated repeatedly that NASA is committed to safely flying the shuttle until its retirement and will not succumb to schedule pressure. However, the compressed nature of the manifest will continue to test that commitment. Fuel sensor challenges continue to surface in the shuttle fleet. For example, the recent shuttle Atlantis launch was delayed two months while NASA addressed a fuel sensor problem associated with the shuttle's liquid hydrogen tank. This is the same system that caused a 2-week delay in the launch of the shuttle Discovery in 2005.

There are also challenges associated with the shuttle launch window. NASA officials told us that the duration of that window is dependent on a number of factors, which include changes in the position of the earth and spacecraft traffic restrictions. NASA must consider its traffic model constraints for vehicles docking at the space station. According to the traffic model for ISS, no other vehicle can dock while the shuttle is docked, and each vehicle has constraints on how long it can stay docked. For example, the shuttle can dock for a maximum of 10 days, while the

Soyuz can dock a maximum of 200 days. The docking of these two vehicles must be coordinated and meet other technical restrictions.

In addition, the shuttle has experienced delays due to severe weather, such as when Atlantis's external tank was damaged by a hailstorm in 2007. In this case the delay was about three months. Figure 3 shows the delays in recent shuttle launches related to weather and other causes.

Figure 3: Causes of Recent Space Shuttle Flight Delays



Source: GAO analysis of NASA data.

Completion of ISS Needed to Expand Scientific Research

The ISS is scheduled to support a six-person crew as early as 2009 and maintain that capability through 2016. NASA officials said that equipment essential to support a six-person crew, such as systems for oxygen recycling, removal of carbon dioxide and transforming urine into water as well as an exercise machine will be delivered to the station this fall. In addition, there are two components that have been planned to hold this and other equipment needed for the six-person crew, which are scheduled to go up in April 2010. If unanticipated delays occur, NASA may need to hold back these two components—known as the Node 3 and the Cupola—which could constrain the ability to conduct research and the quality of life on the station for the crew.

NASA officials emphasized that NASA's intent was to have most science conducted on ISS only after the assembly of the ISS was completed. The ISS currently supports three crewmembers. NASA stated that the majority of the crew's time is spent maintaining the station, rather than conducting scientific study. According to NASA, the crew spends no more than 3 hours per week on science. Completion of the ISS would allow NASA to expand to a six-person crew who could conduct more research.

Since the ISS is designated as a national laboratory, the expectation is that it will support scientific experimentation. NASA is in the process of negotiating agreements with scientific organizations to support scientific research on the ISS. NASA officials told us that they are negotiating a Memorandum of Understanding with the National Institutes of Health to explore the possibility of scientific experimentation onboard the ISS. These officials also told us that NASA is in the process of negotiating with at least two other agencies.

The Need to Pre-Position Replacement Units to Sustain the ISS May Also Affect Assembly

NASA's efforts to complete the ISS are further complicated by the need to put replacement units—the spare parts that are essential to sustaining the ISS—into position before the shuttle retires. The two contingency flights of the shuttle have been designated to deliver these key replacement units, which only the shuttle is capable of carrying. According to NASA, the original approach to deal with these key components (also known as orbital replacement units—ORU[6]) was to take the ones that failed or reached the end of their lifetime back to Earth on the shuttle, refurbish them and launch them back to ISS for use. As a result of the shuttle retirement, NASA will no longer be bringing down ORUs to fix. Instead, NASA officials stated they have adopted a "build and burn" philosophy, which means that after the shuttle retires, instead of being brought down to be refurbished, ORUs will be discarded and disintegrate upon re-entry into the atmosphere. To determine how many replacement units need to be positioned at the station, NASA officials told us they are using data modeling that has been very effective in determining how long ORUs will last. Table 3 illustrates the shuttle manifest. This includes elements needed for the planned configuration to complete the station and delivery of critical spares.

[6] Orbital Replacement Units (ORU), according to NASA officials, are critical spares are necessary to sustain the ISS.

Table 3: Manifest of Remaining Space Shuttle Flights

Dates	Space shuttle	Element being delivered
May 31, 2008	Discovery	Kibo Japanese Experiment Module Pressurized Module (JEM-PM), one of two Japanese's research facilities. Japanese Remote Manipulator System (JEM RMS) are two robotic arms that support operations on the outside of Kibo.
Aug. 28, 2008	Atlantis	Final shuttle Mission to Hubble Space Station.
Oct. 16, 2008	Endeavor	Multi-Purpose Logistics Module (MPLM) are a reusable "moving van" carrying equipments, experiments, and supplies to and from the ISS.
Dec. 4, 2008	Discovery	Fourth starboard truss segment (ITS S6), power element. Fourth set of solar arrays and batteries-power element.
March 2009	Endeavor	Kibo Japanese Experiment Module Exposed Facility (JEM EF), the second Japanese research facility. Logistics Module Exposed Section (ELM-ES) is a pallet that can hold three experiment payloads. Spacelab Pallet Deployable 2 (SLP-D2) is a platform for mounting instruments.
April 2009	Discovery	MPLM Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC) is the carrier to carry experiments to the ISS. Galley-multi-purpose facility to handle meal preparations. Second treadmill Crew Health Care System 2 (CHeCS 2) are a suite of hardware on the ISS that provides the medical and environmental capabilities to ensure the health and safety of crewmembers during long-duration missions.
Aug. 2009	Endeavor	EXPRESS Logistics Carrier 1 (ELC1) and 2 (ELC2) are designed to carry external payloads and Orbital Replacement Units (ORUs).
Oct. 2009	Discovery	MPLM LMC
Feb. 2010 Contingency Flight	Endeavor	ELC3 and ELC4 are designed to carry external payloads and ORUs.
April 2010	Discovery	Node 3 is a habitation system with the Cupola observatory.

Dates	Space shuttle	Element being delivered
July 2010 Contingency Flight	Endeavor	ELC5 and ELC1 are designed to carry external payloads and ORUs.

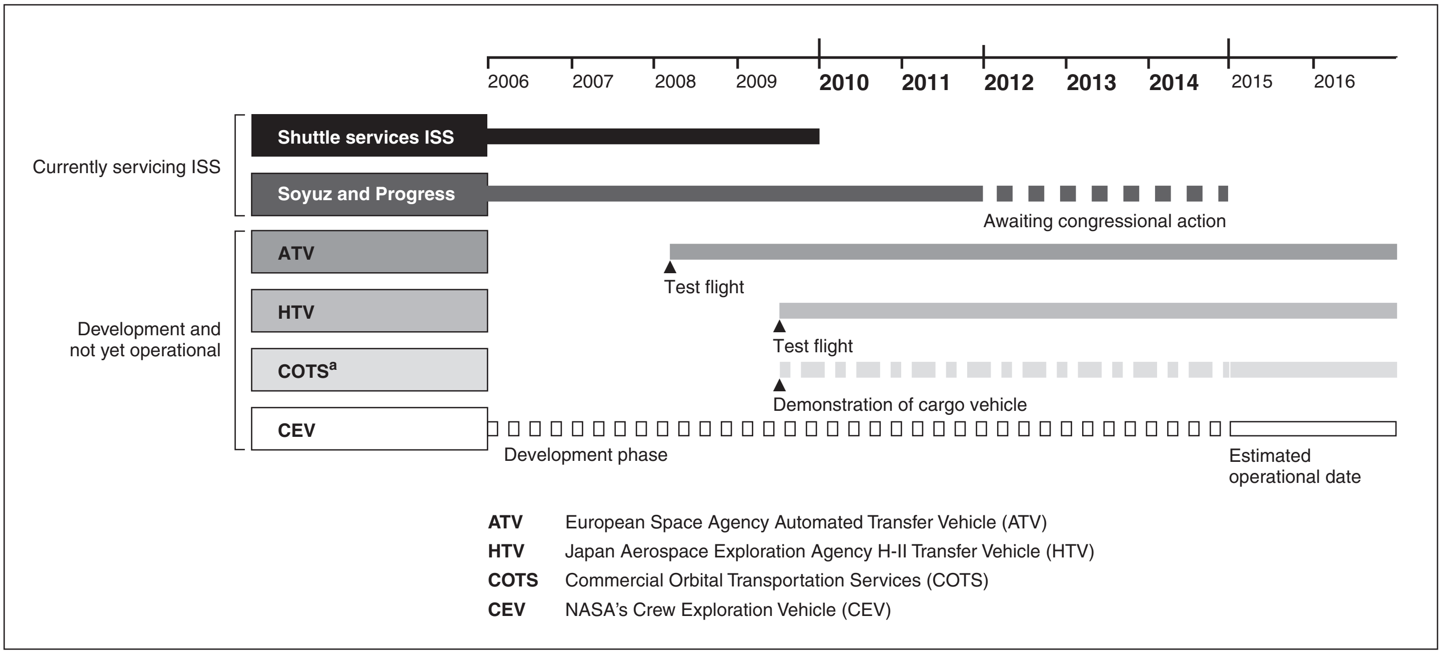
Source: GAO analysis of NASA's shuttle manifest.

NASA currently plans to use two contingency flights for these replacements because all other flights are planned with assembly cargo. Recently, the NASA Administrator publicly stated that these flights are considered necessary to sustain the ISS and have been scheduled to carry key spare units.

Alternative Vehicle Options to Service the International Space Station Pose Challenges

In the event that NASA completes assembly of the ISS on schedule and prepositions an adequate number of critical spares, the agency still faces a myriad of challenges in sustaining the research facility until its retirement, currently planned for fiscal year 2016. Without the shuttle, NASA officials told us that they face a significant cargo supply shortfall and very limited crew rotation capabilities. NASA will rely on an assortment of vehicles in order to provide the necessary logistical support and crew rotation capabilities required by the station. Some of these vehicles are already supporting the station. Others are being developed by international partners, the commercial sector, and NASA. (See Figure 4) Furthermore, some of these transportation services may face legal restrictions, and still others face cost, schedule, and performance issues that raise serious questions about their development and utilization. These issues will challenge NASA's ability to close the sustainment gap between the retirement of the shuttle in 2010 and the availability of the Crew Exploration Vehicle (CEV) in 2015. Failure of any or some of these efforts would also seriously restrict NASA's options to sustain and maintain a viable space station.

Figure 4: Availability of Vehicles Serving the International Space Station



Source: GAO analysis of NASA data.

[a]Represents space exploration technologies only

Russian Vehicles

With the exception of the Shuttle and the recently completed demonstration flight of the ATV, the only vehicles currently capable of supporting the space station are the Russian Progress and Soyuz vehicles. NASA officials stated that both of these vehicles have provided reliable service to the ISS. From the Columbia disaster in 2003 until return to flight in 2005, the Russian vehicles were the sole source of logistical support and crew rotation capability for the station. The Progress provides atmospheric gas, propellant, water, and pressurized cargo. It also has the capability to use its thrusters to change the Station's altitude and orientation. The Soyuz provides crew delivery and rescue capability for three crew members. Progress vehicles are expendable and offer no recoverable return capability, but provide important trash removal capabilities. Soyuz vehicles have a limited recoverable cargo capacity. However, some NASA officials have suggested that their limited capabilities restrict the capacity of the station to move to a six-member crew and significantly limit the scientific research because the vehicles cannot bring experiments to earth for assessment.

NASA currently purchases crew and cargo transport services from Russia through a contract with the Russian Federal Space Agency (Roscosmos).

NASA officials told us that after the initial ISS contract between Roscosmos and NASA expired, NASA entered into another contract that runs through 2011. However, according to NASA, the Iran Nonproliferation Act of 2000 restricted certain payments in connection to the ISS that may be made to the Russian government. In 2005, NASA requested relief from the restrictions of the Act, and Congress amended the Act.[7] Through this amendment, NASA and Roscosmos have negotiated quantities and prices for services through January 1, 2012.

NASA officials anticipate the use of 4 Soyuz flights per year and approximately 6 Progress flights beginning in approximately 2010. While NASA officials stated that they are making every effort to limit amount of fees they pay for usage of Russian vehicles, to date, NASA officials told us that they anticipate that from fiscal year 2009 to fiscal year 2012, NASA will spend $589 million on cargo and crew services from the Russians.[8] NASA officials also told us that the Roscosmos has suggested that it will charge NASA higher fees for usage of its vehicles.

European and Japanese Vehicles

NASA has stated it will use its international partners' vehicles to conduct some supply activities. Specifically, Japan's Aerospace Exploration Agency (JAXA) H-II Transfer Vehicle (HTV) and the European Space Agency's (ESA) Automated Transfer Vehicle (ATV) vehicles will be used for bringing up cargo. NASA's reliance on the ATV and HTV assumes that these vehicles will be ready to service the ISS by the time the shuttle stops flying in 2010.

The new vehicles being developed by the European and Japanese space agencies are very complex. The ATV had a development timeline of 20 years. Its first operational test flight to the ISS was in March 2008. NASA has stated that both the European and Japanese vehicle development programs experienced technical hurdles and budgetary constraints, but are committed to fulfilling their roles as partners in the ISS program. NASA officials told us they have confidence the European vehicle will be

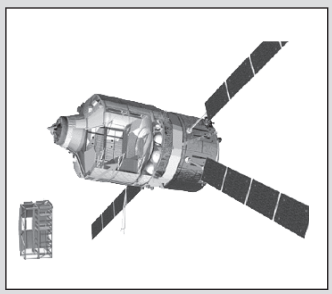
[7] The 2005 Amendment to the Iran Nonproliferation Act of 2000 altered the Acts definition of "extraordinary payments in connection with the International Space Station." NASA refers to this amendment as its "exemption."

[8] NASA and Roscosmos have negotiated quantities and prices for services through calendar year 2011. According to NASA it will require additional relief from the restrictions of the Act, currently entitled the Iran, North Korea and Syria Nonproliferation Act.

available for ISS operations before retirement of the shuttle, but they are not as confident about the Japanese vehicle's being ready by that time. The Japanese vehicle is still under development and has faced some setbacks. NASA officials told us that the HTV's first test launch is planned for July 2009.

Figure 5: The European Automated Transfer Vehicle (ATV)

The European Automated Transfer Vehicle (ATV) **capability**

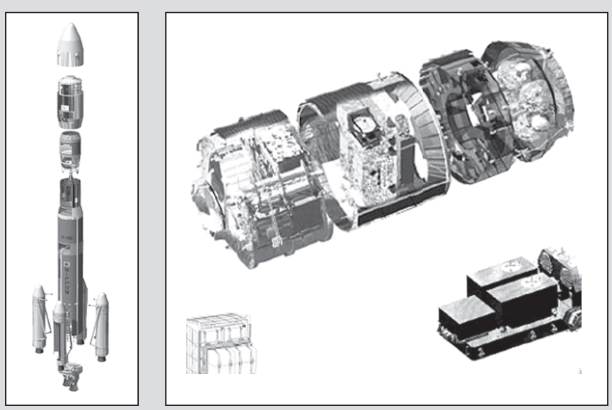


Maximum capability:
16,535 lbs./7,500 mass kg. The ATV is capable of performing many ISS reboost and altitude burns and resupplying ISS with water and atmospheric gas. The ATV has no external capability and is expendable and offers no recoverable return capability.

Source: GAO analysis of NASA data.

Figure 6: The Japanese H-II Transfer Vehicle (HTV)

The Japanese H-II Transfer Vehicle (HTV) capability



Maximum capability:
13,228 lbs./6,000 mass kg. The HTV can provide atmospheric gas and water re-supply to the ISS. The HTV can also deliver limited unpressurized external cargo. The HTV has no re-boost capability and is an expendable vehicle like the ATV.

Source: GAO analysis of NASA data.

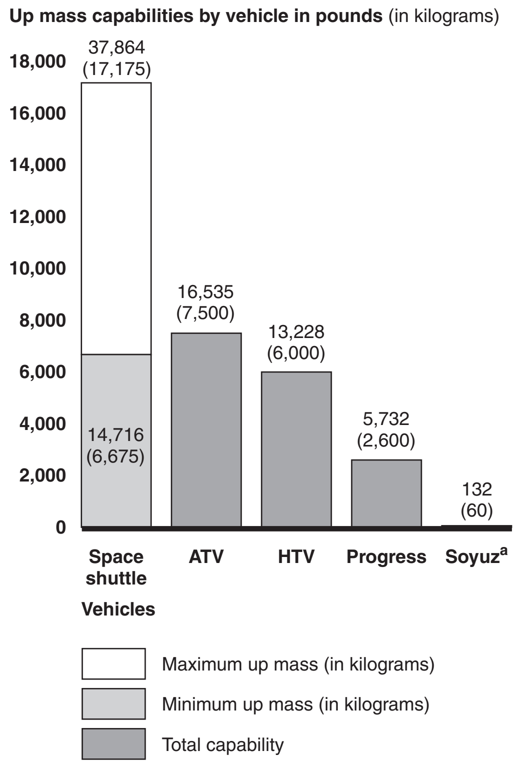
International Partner Vehicles Have Constraints in Ability to Ferry Crew and Cargo to and from the ISS in Comparison to the Shuttle

In addition to potential development challenges, the international partner vehicles have constraints in terms of what they can take to and from the ISS in comparison to the shuttle. NASA's current plans to manage the gap after the shuttle retirement do not take into account the possibility of delays in the development of these vehicles, and even if they do come on line on time, NASA officials estimate that there will be a significant shortfall to the ISS of at least 114,199 pounds (or 51.8 metric tons) in cargo re-supply capability. These vehicles were designed to augment the capabilities of the shuttle and have significantly less capability to deliver cargo to the ISS. The shuttle can carry a maximum cargo of close to 38,000 pounds (17,175 kg.). In comparison, the European ATV's maximum capability is 16,535 pounds (7,500 kg.) and the Japanese HTV's average capability is 13,228 pounds (6,000 kg.). The HTV and ATV are expendable vehicles. NASA can use them for trash removal, but cannot carry cargo or scientific experiments back to earth because the vehicles disintegrate when re-entering the atmosphere.

The Russian Progress and Soyuz vehicles also have very limited cargo capacity. For example, the Progress has an average capability of 5,732 pounds (2,600 kg.)—roughly one-seventh the shuttle's capability. The Progress, like the ATV and HTV, is an expendable vehicle. The Soyuz can transport three crew persons to the ISS and can serve as a rescue vehicle capable of taking three crew members back to earth. Unlike the ATV and HTV, the Soyuz does have the capacity to bring down cargo—roughly 132 pounds (60 kg.). NASA officials have stated that until NASA deploys its new crew exploration vehicles or commercial vehicles become available, NASA will be dependent on the Russian vehicles for crew transportation services and on the Japanese and European vehicles for limited cargo services whenever they become available.

Figure 7 compares the up mass capabilities of the various vehicles.

Figure 7: Upmass capability by vehicle



Source: GAO analysis of NASA data.

[a]The Soyuz has the capability to bring down from the ISS up to 132 pounds of cargo.

Commercial Vehicles

NASA is working with the commercial space sector through its Commercial Orbital Transportation Services (COTS) program to develop and produce vehicles that can take equipment and crew to and from the space station. NASA expects that these vehicles will be ready for cargo use in 2010 and crew use in 2012. However, these vehicles have yet to be successfully launched into orbit, and some NASA officials have acknowledged that their development schedules leave little room for the unexpected.

Under the COTS program, NASA has pledged $500 million to promote commercial opportunities for space transportation vehicles. Using Space

Act agreements[9] instead of traditional contracting mechanisms, NASA will make payments to companies based on the achievement of key milestones during the development of their vehicles. These agreements are both funded and unfunded. For the two funded agreements that have been reached, NASA stated that the commercial suppliers for space transportation services will have customers outside of ISS, including NASA's Constellation program, which plans to send humans back to the moon and eventually Mars. The COTS program will occur in phases. In the first phase companies will demonstrate the vehicle launch and docking capabilities with the ISS. The second phase is the procurement of services for transportation of cargo and crew to the ISS, which is scheduled to begin sometime in the 2010 timeframe.

NASA had seven COTS agreements through the Space Act. NASA signed five unfunded Space Act agreements, which facilitate the sharing of technical and ISS integration information between commercial companies and NASA. NASA has funded two companies, Rocketplane Kistler (RpK) and Space Exploration Technologies (SpaceX). NASA officials stated that through the funded Space Act agreements, SpaceX has received $139 million for its project and is still working on successfully launching a vehicle that can reach low-Earth orbit. The company successfully completed a critical design review in August 2007 and told us that it is planning its first orbital demonstration test flight for June 2009. NASA officials told us that RpK received $37 million in funding, but then forfeited the remainder of its share because it did not meet certain financial development milestones. When NASA began to redistribute these forfeited funds, RpK filed a bid protest with GAO, which GAO denied. NASA officials then moved forward and awarded $170 million to Orbital Sciences Corporation in February 2008.

NASA officials acted quickly to award the forfeited money and expect that SpaceX will have cargo capability available in 2010 (by the time the shuttle is retired) and crew capability in 2012. While Space X has been meeting key milestones in the development of its vehicle, some officials at the

[9] COTS agreements are Space Act agreements issued pursuant to NASA's other transactions authority. These types of agreements are not contracts, and are therefore generally not subject to those federal laws and regulations that apply to government contracts. NASA has budgeted $500 million in fiscal year 2006 to fiscal year 2010 as an investment for the demonstration of commercial orbital capabilities and will be executed in two phases. The first phase consists of technical development/demonstration funded by the Space Act agreements. The second phase may include the competitive procurement of orbital transportation services.

Johnson Space Center were skeptical that COTS would be available on the current projected schedule. Additionally, the International Space Station Independent Safety Task Force (IISTF) reported that design, development and certification of the new COTS program was just beginning and that "if similar to other new program development activities, it most likely will take much longer than expected and will cost more than anticipated." In our opinion, the schedule is optimistic when compared to other government and commercial space programs we have studied. We will be studying the COTS program and schedules in more detail in response to a request of members of congress.

Ares I and Orion

NASA is under pressure to develop its own 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. Among the first major items of NASA's development efforts to implement the Vision program are the development of new space flight systems—including the Ares I Crew Launch Vehicle and the Orion Crew Exploration Vehicle. Ares I and Orion are currently targeted for operation no later than 2015. NASA plans to use these vehicles as they become available to service the space station.

However, we recently testified that 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. This is primarily because NASA is still in the process of defining many of the project's performance requirements and some of these uncertainties could affect the mass, loads, and weight requirements for the vehicles. Such uncertainty has created knowledge gaps that are affecting many aspects of both projects. 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.

NASA recognizes the risks involved with its approach and it is taking steps to mitigate those risks. However, given the complexity of the Orion and Ares I efforts and their interdependencies, any significant requirements changes can have reverberating effects and make it extremely difficult to establish firm cost estimates and schedule baselines. If knowledge gaps persist, programs will cost more, fail to meet their schedules, or deliver less than originally envisioned. Ultimately, NASA's aggressive schedule leaves little room for the unexpected. If something goes wrong with the development of the Crew Launch Vehicle or the Crew Exploration Vehicle, the entire Constellation Program could be thrown off course and the return to human spaceflight further delayed.

Concluding Observations

The decision to retire the space shuttle in 2010 has had profound effects on the ISS program. It leaves little flexibility in the shuttle schedule. Any delays could require NASA to choose between completing the station as planned and the pre-positioning of needed critical spares. The decision also leaves NASA dependent on Russia for crew rotation services until other vehicles are developed and demonstrated. And even with the development of these vehicles, NASA still faces a significant capacity shortfall in its ability to provide logistical support to the station. The shortfall may well impact support for a six person crew and the quality of research that can be conducted on the ISS. At the same time, it also provides opportunities to commercial suppliers to demonstrate capabilities that could have long-term benefits for future U.S. space exploration and development. We are not making recommendations as a result of our review as NASA is well aware of the predicament it faces with the station and has weighed options and trade-offs for the remainder of the schedule manifest. However, it is important that flexibility continue to be maintained as events impacting schedule occur and that decisions be made with the goal of maximizing safety and results.

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

GAO Contacts and Staff Acknowledgments

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, Greg Campbell, Brendan S. Culley, Masha P. Pastuhov-Purdie, Keo Vongvanith, and Alyssa B. Weir.

Appendix I: Scope and Methodology

To identify the risks and challenges NASA faces in completing assembly of the International Space Station by 2010, we

- analyzed key documents and testimonies by NASA officials relating to the challenges associated with ISS completion. This included: the delivery schedule for ISS parts for assembly and the delivery schedule for replacement units, the space shuttle manifest, budget documents and the strategic maintenance plan, the ISS Independent Safety Task Force Report, and previous GAO reports relating to the ISS.
- interviewed NASA mission officials to obtain information on the status of the ISS. We also discussed these issues with the International Partners (Canadian Space Agency, European Space Agency and Japan Aerospace Exploration Agency) to get their perspectives.

To determine the risks and challenges NASA faces in providing logistics and maintenance support to the International Space Station after 2010, we

- analyzed documents related to the up-mass and down-mass capabilities of the International Partners and SpaceX vehicles, the shortfall in ISS up-mass for re-supply and sustainment, the new vehicles that will support ISS NASA's plans for using Russian vehicles to support ISS through what NASA refers to as its "exemption," and the impacts to the utilization of the ISS.
- We interviewed key NASA officials from NASA Headquarters, the Space Operations Mission Directorate, NASA's Commercial Orbital Transportation Services program, and the ISS program officials, and interviewed officials representing the International Partners

To accomplish our work, we visited and interviewed officials responsible for the ISS operations at NASA Headquarters, Washington, D.C., and the Johnson Space Center in Houston, Texas. At NASA Headquarters, we met with officials from the Exploration Systems Mission Directorate and the Space Operations Mission Directorate, including representatives from the International Space Station and space shuttle programs. We also met with ISS and space shuttle mission officials at the Johnson Space Center.

We conducted this performance audit from July 2007 to 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.

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