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June 2009

NASA

Commercial Partners Are Making Progress, but Face Aggressive Schedules to Demonstrate Critical Space Station Cargo Transport Capabilities

GAO-09-618

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Highlights

Highlights of GAO-09-618, a report to congressional addressees

NASA

Commercial Partners Are Making Progress, but Face Aggressive Schedules to Demonstrate Critical Space Station Cargo Transport Capabilities

Why GAO Did This Study

After the planned retirement of the space shuttle in 2010, the National Aeronautics and Space Administration (NASA) will face a cargo resupply shortfall for the International Space Station of approximately 40 metric tons between 2010 and 2015. NASA budgeted $500 million in seed money to commercial partners to develop new cargo transport capabilities through its Commercial Orbital Transportation Services (COTS) project. NASA used its other transaction authority to award agreements to commercial partners. These agreements are not federal government contracts, and are therefore generally not subject to federal laws and regulations that apply to federal government contracts.

GAO previously reported concerns about whether COTS vehicles would be developed in time to meet the shortfall. Subsequently, GAO was directed by the explanatory statement accompanying the Consolidated Appropriations Act, 2008, to examine NASA's management of the COTS project and its expenditures. In addition, GAO was asked to examine (1) NASA's reliance on commercial partners to meet the space station's cargo resupply needs; and (2) progress or challenges in developing commercial space transport capabilities.

GAO analyzed NASA reports, briefings, and other information and held interviews with NASA and commercial partner officials. NASA concurred with GAO's findings.

View GAO-09-618 or key components.
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What GAO Found

During the course of our review, we found NASA's management of the COTS project has generally adhered to critical project management tools and activities and the vast majority of project expenditures were for milestone payments to COTS partners. NASA has established fixed-price, performance-based milestones in its agreements with commercial partners and partners are only paid once the milestone has been successfully completed. NASA has also taken several steps since the beginning of the COTS project to ensure that risks were identified, assessed, and documented, and that mitigation plans were in place to reduce these risks. NASA has communicated regularly with its partners through quarterly and milestone reviews and provided them with technical expertise to assist in their development efforts and to facilitate integration with the space station. As of the end of fiscal year 2008, NASA has spent $290.1 million, with 95 percent of project funding spent on milestone payments to COTS partners.

The vehicles being developed by commercial partners Space Exploration Technologies Corporation (SpaceX) and Orbital Sciences Corporation (Orbital) through the COTS project have become essential to NASA's ability to fully utilize the space station after its assembly is completed and the space shuttle is retired in 2010. NASA estimates that it will need a total of 82.7 metric tons of dry cargo delivered to the space station between 2010 and 2015 to meet crew needs and to support maintenance and scientific experiments. Commercial partners' vehicles will transport almost half of this cargo and are scheduled to fly more cargo delivery missions than the space shuttle and international partners' vehicles combined—including 14 of the last 19 missions. Delays in the availability of commercial partners' vehicles to fill the cargo resupply gap would result in diminished usage of the space station.

While SpaceX and Orbital have completed most of the development milestones required thus far on time, both companies are working under aggressive schedules and have recently experienced schedule slips that have delayed upcoming demonstration launch dates by several months. SpaceX successfully completed its first 14 development milestones on time and is in the process of testing, fabricating, and assembling key components. However, a schedule slip in the development of its launch vehicle has contributed to anticipated delays of 2 to 4 months in most of its remaining milestones, including upcoming demonstration missions. Its first demonstration mission has been delayed from June 2009 to no earlier than September 2009, and its third demonstration mission has been delayed from March 2010 to no earlier than May 2010. NASA is currently evaluating the effect of potential further delays. Orbital has successfully completed 7 of 19 development milestones thus far, but has experienced delays in the development of its launch vehicle. Orbital and NASA have recently amended their agreement to demonstrate a different cargo transport capability than had been originally planned, delaying its demonstration mission date from December 2010 until March 2011.

Contents

Abbreviations

ATK	Alliant Techsystems, Inc.
CDR	critical design review
COTS	Commercial Orbital Transportation Services
CRS	Commercial Resupply Services
DOD	Department of Defense
FAA	Federal Aviation Administration
NASA	National Aeronautics and Space Administration
Orbital	Orbital Sciences Corporation
PDR	preliminary design review
RpK	Rocketplane Kistler
SLC-40	Space Launch Complex 40
SpaceX	Space Exploration Technologies Corporation
USAF	U.S. Air Force

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United States Government Accountability Office
Washington, DC 20548

June 16, 2009

Congressional Addressees

After the planned retirement of the space shuttle in 2010, the United States will lack a domestic capability to send crew and cargo to the International Space Station. As a consequence, the National Aeronautics and Space Administration (NASA) faces a cargo resupply shortfall of 40 metric tons (approximately 88,000 pounds) between 2010 and 2015 that cannot be met by international partners' space vehicles.[1] To fill the gap, NASA plans to rely on vehicles being developed by the private sector through NASA's Commercial Orbital Transportation Services (COTS) project. However, we previously reported concerns about whether these vehicles will be developed in time to address the shortfall.[2]

GAO was directed through the explanatory statement accompanying the Consolidated Appropriations Act, 2008 to review NASA's management of the COTS project and its expenditures, the first objective of this report.[3] Subsequently, you asked us to cover two additional objectives: examine the extent to which (1) NASA is reliant on commercial partners to meet the space station's cargo resupply needs, and (2) commercial partners have made progress or experienced challenges in developing cargo transport capabilities.

To examine NASA's management of the COTS project and its expenditures, we interviewed NASA and company officials and analyzed project documentation, including agreements between NASA and its commercial partners, NASA's guidance for implementing these agreements, development milestone and quarterly reviews and other briefings, and project funding and expenditures data. We also evaluated NASA's management of the COTS project by comparing COTS management activities with critical project management tools and

[1]The 40 metric ton shortfall refers to usable cargo, which does not include the mass of any required packing materials and/or flight support equipment. Usable cargo combined with packing materials and/or flight support equipment is referred to as customer cargo.

[2]GAO, *NASA: Challenges in Completing and Sustaining the International Space Station*, GAO-08-581T (Washington, D.C.: April 24, 2008).

[3]See Explanatory Statement, Cong. Rec. H 15471, 15821 (daily ed. Dec. 17, 2007) and the Consolidated Appropriations Act, 2008, Pub. L. No. 110-161, § 4 (2007).

activities identified in NASA guidance and in prior GAO work on NASA projects with similarities to COTS.

To determine the extent to which NASA is reliant on commercial partners to meet the space station's cargo resupply needs, we interviewed NASA officials and reviewed International Space Station program office documentation on the space station's cargo resupply needs and risks, NASA's plans to meet its cargo resupply needs between 2010 and 2015, and international and commercial partners' vehicle capabilities. We also reviewed NASA studies that assessed the impact of the COTS project on NASA's cargo resupply strategy.

To determine the extent to which commercial partners have made progress or experienced challenges in developing cargo transport capabilities, we reviewed each partner's agreement with NASA, commercial partners' supporting documentation submitted for each milestone, partners' development schedules and technical risks, NASA's requirements for integrating with the space station, commercial transportation space regulations, launch safety requirements, and prior GAO work. We also conducted field visits and interviewed commercial partners to determine partners' progress against performance milestones and to identify development challenges.

We conducted this performance audit from July 2008 to June 2009 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

Since the 1980s, U.S. law and policy have directed NASA to encourage growth and promote opportunities within the commercial space industry.[4] NASA's Authorization Act of 2005 directed NASA to work closely with the private sector to encourage entrepreneurs to develop new means to launch satellites, crew, or cargo, and to contract for crew and cargo transport services to the space station.[5] In accordance with its long-term goals, NASA plans to retire the space shuttle upon completing assembly of the space station in 2010. NASA plans on using a mixed fleet of vehicles, including those developed by international partners, to service the space station.[6] However, international partners' vehicles alone cannot fully satisfy the space station's cargo resupply needs. Without a domestic cargo resupply capability to augment this mixed fleet approach, NASA faces a 40 metric ton (approximately 88,000 pounds) usable cargo resupply shortfall between 2010 and 2015.[7]

In November 2005, NASA established the Commercial Crew and Cargo program office at Johnson Space Center to challenge the commercial space industry to establish capabilities and services that can open new space markets and support the space station's crew and cargo transportation needs. NASA directed the program office to establish the COTS project and budgeted $500 million for fiscal years 2006 through 2010 for the development and demonstration of cargo transport capabilities.

[4]National Aeronautics and Space Administration Authorization Act of 1985, Pub. L. No. 98-361, § 110 (c), (1984) (codified as amended at 42 U.S.C. § 2451) declared that the general welfare of the United States requires that NASA seek and encourage, to the maximum extent possible, the fullest commercial use of space. The Commercial Space Act of 1998, Pub. L. No. 105-303, § 101, directed NASA to identify opportunities for the private sector to play a role in servicing the International Space Station. Following the Space Shuttle Columbia disaster in 2003, President George W. Bush's *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration* called for the shuttle's retirement in 2010 upon completing space station assembly, and for pursuit of commercial opportunities for providing transportation and other services. The August 2006 U.S. National Space Policy also directed departments and agencies to encourage innovation in the commercial space sector.

[5]National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No. 109-155, § 101.

[6]International partners' vehicles include the Russian Federal Space Agency's Progress (cargo) and Soyuz (crew), the European Space Agency's Automated Transfer Vehicle (cargo), and the Japan Aerospace Exploration Agency's H-II Transfer Vehicle (cargo), which is currently in development.

[7]The 40 metric ton shortfall includes 36.9 metric tons of dry usable cargo and 3.1 metric tons for water, propellant, and atmospheric gases. Dry usable cargo includes food, spare parts, and materials to support scientific experiments.

NASA structured the COTS project as a partnership with the commercial space industry, sharing the risks, costs, and rewards of developing new space transportation capabilities. NASA expected commercial partners participating in the project to develop their own technology solutions to meet NASA's crew and cargo needs and raise additional funding to demonstrate their solutions. Once the capabilities have been demonstrated, NASA and other customers would be able to purchase space transportation services directly from commercial partners.

The COTS project was originally intended to be executed in two sequential phases: (1) private industry development and demonstration of cargo and crew transport capabilities in coordination with NASA and (2) procurement of commercial resupply services to the space station once cargo transport capabilities had been successfully demonstrated. NASA asked commercial partners to meet the following cargo transport capabilities: capability A—external cargo delivery (unpressurized) and disposal; capability B—internal cargo delivery (pressurized) and disposal; capability C—internal cargo delivery and return to Earth; and capability D—crew transportation. The COTS project is initially focused on developing cargo transport capabilities because NASA has identified cargo transport as a more pressing need and incremental step toward crew transport. Furthermore, the Commercial Crew and Cargo program office reported that it has not yet received funding for crew transport capability development.[8]

NASA designed the COTS project to be a technology development and demonstration effort. To implement the COTS project, NASA issued Space Act agreements utilizing its "other transaction authority" under the National Aeronautics and Space Act of 1958.[9] Generally speaking, other transaction authority enhances the government's ability to acquire cutting-edge science and technology, in part through attracting companies that typically have not pursued government contracts because of the cost and impact of complying with government procurement requirements. These types of agreements are not federal government contracts, and are

[8]The National Aeronautics and Space Administration Authorization Act of 2008, Pub. L. No. 110-422, § 101 authorized $100 million for COTS demonstration of a crew transport capability, but the COTS program office has not yet received any funding for this capability.

[9]Pub. L. No. 85-568, § 203 (1958). This act is commonly referred to as the Space Act and agreements signed utilizing NASA's other transaction authority are known as Space Act agreements.

therefore generally not subject to those federal laws and regulations that apply to federal government contracts. Consequently, agreements formed using other transaction authority permit considerable latitude by agencies and companies in negotiating agreement terms. NASA has established guidance on how to implement agreements under this authority.

In August 2006, NASA competitively awarded Space Act agreements to two commercial partners, Space Exploration Technologies Corporation (SpaceX) and Rocketplane Kistler (RpK), to develop and demonstrate end-to-end transportation systems, including the development of launch and space vehicles, ground and mission operations, and berthing with the space station. SpaceX was awarded a $278 million agreement to develop and demonstrate the three COTS cargo capabilities. The agreement was amended in February 2008 to reschedule milestones, including the three demonstration flights to occur from June 2009 through March 2010.[10] NASA's agreement with SpaceX includes an option for SpaceX to demonstrate crew transport capabilities. RpK was awarded a $207 million agreement, but the agreement was terminated in October 2007 after RpK had missed financial and technical milestones. NASA held a second competition and awarded Orbital Sciences Corporation (Orbital) a $170 million agreement in February 2008 to develop two of the COTS cargo capabilities (unpressurized and pressurized cargo delivery and disposal), culminating in an unpressurized demonstration flight scheduled for December 2010. In March 2009, Orbital and NASA amended this agreement, removing its unpressurized cargo demonstration and replacing it with a pressurized demonstration, scheduled for March 2011.[11] Each partner proposed its own development milestone schedule in their respective agreements, which were then negotiated and agreed to by NASA. NASA conducts milestone reviews to determine whether the milestone has been met and payment only occurs if the partner has successfully completed the milestone. Five additional companies signed nonreimbursable agreements with NASA, but these partners have either

[10]SpaceX officials reported to NASA in January 2009 that they expected a 2- to 4-month delay for most of the remaining milestones, including the first and third demonstration flights.

[11]This amendment was made because NASA awarded a commercial resupply services contract to Orbital in December 2008 in which NASA ordered pressurized cargo delivery and disposal services rather than unpressurized cargo delivery and disposal services. The commercial resupply services contract was a separate procurement from NASA's February 2008 Space Act agreement with Orbital.

terminated their agreements or made limited progress due in part to difficulty attracting external investment.

In order to demonstrate cargo transport capabilities, commercial partners must comply with NASA and the Federal Aviation Administration (FAA) requirements or regulations, and SpaceX must satisfy U.S. Air Force (USAF) requirements since it is launching from Cape Canaveral Air Force Station.

- **Space Station Integration.** The International Space Station program office manages the process of integrating COTS vehicles with the space station. Before COTS partners' vehicles may approach and berth with the space station, they must provide verification that all of the technical requirements described in NASA's International Space Station to Commercial Orbital Transportation Services Interface Requirements Document have been met and NASA must approve each requirement's closure.[12] The partners must also pass three rounds of review by the International Space Station program office's Safety Review Panel.[13]

- **Launch Range Safety.** The USAF 45th Space Wing manages, monitors, and enforces launch range safety requirements for users, including SpaceX, at Cape Canaveral Air Force Station. SpaceX must demonstrate that its operations meet the 45th Space Wing's launch range safety requirements or that it can provide an equivalent level of safety.[14] USAF launch range safety requirements may be modified by users to meet the specifications of a given launch, with the USAF's approval of the changes. Orbital's demonstration launch is planned to take place at Wallops Flight

[12]NASA's International Space Station to Commercial Orbital Transportation Services Interface Requirements Document defines the applicable physical and functional interface requirements between COTS partners' visiting vehicles and space station systems.

[13]The purpose of the International Space Station Safety Review Panel is to independently identify and track all critical hazards that visiting space vehicles may pose to the space station and its crew and to evaluate plans to mitigate these hazards. The Safety Review Panel is comprised of NASA and contractor personnel from across the agency. The panel holds three reviews that generally correspond with COTS partners' preliminary design review, critical design review, and fabrication and testing activities. COTS partners must complete all three phases of the Safety Review Panel process before they are allowed to berth with the space station.

[14]The USAF 45th Space Wing's Range Safety Office is responsible for ensuring the public's safety both within and beyond the launch range user's complex and the safety of nearby range sites. The launch range safety requirements are published in U.S. Air Force Space Command Manual 91-710.

Facility, Virginia, where launch range safety requirements are overseen by NASA.[15]

- **Launch Licensing.** The FAA's Office of Commercial Space Transportation has the authority to issue licenses for commercial launches and reentries and launch and reentry site operations.[16] The FAA reviews and makes a decision on an application within 180 days of receiving a complete application.[17] Prior to accepting the application, the FAA can review draft applications and provide feedback to the applicant.

Prior to the successful demonstration of COTS cargo transport capabilities, NASA put the International Space Station program office in charge of procuring commercial resupply services to the space station rather than the Commercial Crew and Cargo program office. The International Space Station program office awarded, under a separately competed procurement from COTS, two commercial resupply services contracts in December 2008 to SpaceX and Orbital to deliver at least 40 metric tons (approximately 88,000 pounds) to the space station between 2010 and 2015.[18] NASA's current plan estimates that commercial partners will transport 36.9 metric tons (approximately 81,400 pounds) of usable dry cargo and 3.1 metric tons (approximately 6,800 pounds) of water,

[15]NASA's top-level launch range safety requirements are set by NASA Procedural Requirements, NPR 8715.5, under the responsibility of NASA's Office of Safety and Mission Assurance. Vehicles launched from NASA's Wallops Flight Facility must also comply with the Range Safety Manual for Goddard Space Flight Center / Wallops Flight Facility (RSM-2002 Rev. B).

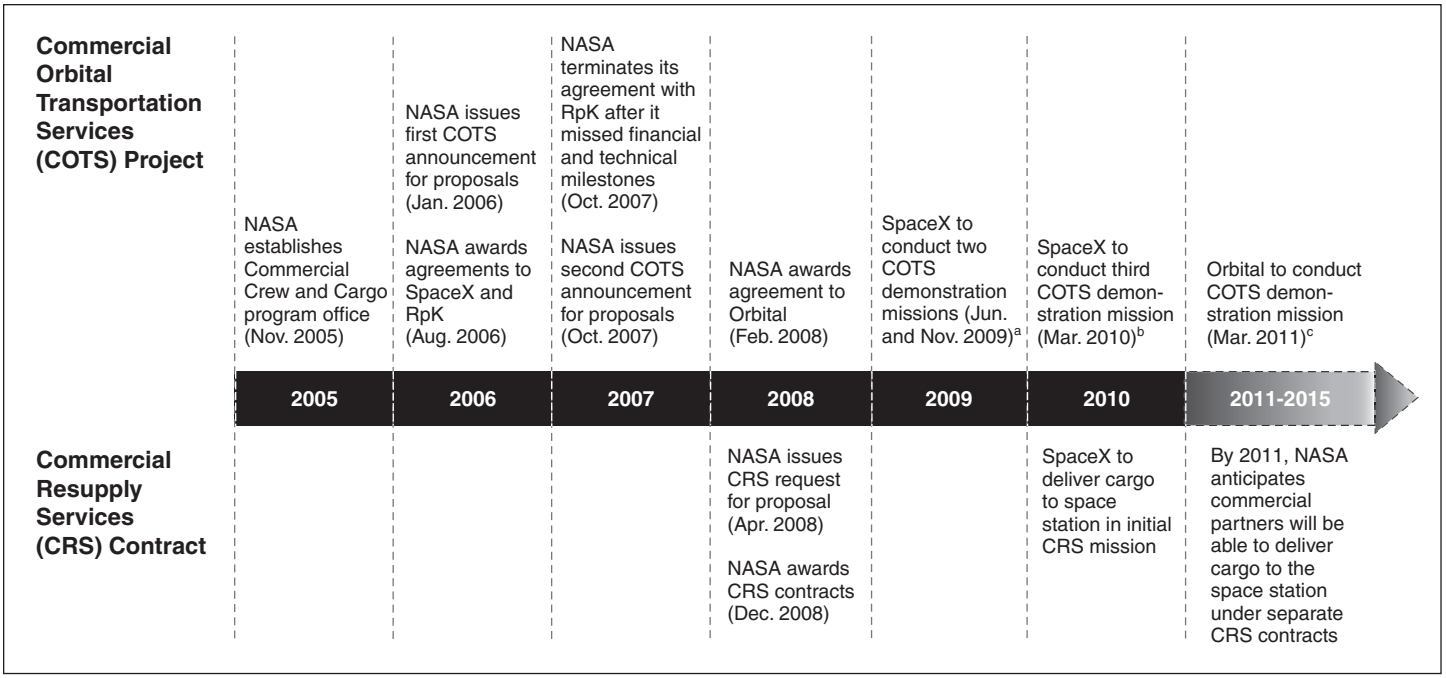
[16]FAA issues several commercial space licenses, including (1) launch license (for expendable launch vehicles), (2) a reusable launch vehicle mission license, (3) a re-entry license, and (4) a launch or re-entry site operator license. FAA requires a launch license for SpaceX's Falcon 9 launch vehicle and a re-entry license for its Dragon space vehicle. Orbital must obtain a launch license for its Taurus II launch vehicle and a re-entry license for its Cygnus space vehicle.

[17]Commercial Space Launch Act, Pub. L. No. 98-575, § 9 (1984) (as amended), codified at 49 U.S.C. § 70105.

[18]These contracts also include a clause guaranteeing a minimum of 3 metric tons in return cargo downmass.

propellant, and atmospheric gas.[19] SpaceX was awarded 12 cargo resupply missions for approximately $1.6 billion and Orbital was awarded eight cargo resupply missions for approximately $1.9 billion. Figure 1 provides a timeline of key events in the COTS project.

Figure 1: Key Events in the Commercial Orbital Transportation Services Project



Source: GAO analysis of NASA data.

[a]NASA reported in February 2009 that SpaceX plans to delay its first demonstration flight from June 2009 to no earlier than September 2009.

[b]NASA also reported in February 2009 that SpaceX plans to delay its third demonstration flight from March 2010 to no earlier than May 2010.

[c]NASA and Orbital amended the original agreement to replace Orbital's unpressurized cargo capability demonstration milestones with pressurized ones and changed the date of the demonstration mission from December 2010 to March 2011.

[19]NASA awarded SpaceX and Orbital indefinite-delivery / indefinite-quantity contracts, which provide for an indefinite quantity, within stated limits, of supplies or services during a fixed period. The contracts contain firm-fixed-price contract line items, where a specified price is paid regardless of the contractor's costs, thereby minimizing the financial risk to the government. NASA issues orders under these contracts for cargo resupply missions. Each mission is divided into a series of performance milestones with set payments. NASA may withhold milestone payments due to non performance. To earn the full amount for each mission, a partner must complete all milestones, including the successful delivery of cargo to the space station.

NASA Has Adhered to Critical Project Management Tools and Project Expenditures Track Closely with Achieved Milestones

During the course of our review, we found NASA's management of the COTS project has generally adhered to critical project management tools and activities and the vast majority of project expenditures were for milestone payments to COTS partners. Because the COTS project utilized NASA's other transaction authority to enter into agreements, NASA was not required to follow its program management requirements. However, it used them as a guide to ensure that it had the proper planning documentation in place. NASA has established fixed-price, performance-based milestones in its agreements with commercial partners and only pays them once the milestone has been successfully completed. NASA has also taken several steps since the beginning of the COTS project to ensure that risks were identified, assessed, and documented, and that mitigation plans were in place to reduce these risks. NASA has communicated regularly with its partners through quarterly and milestone reviews and provided them with technical expertise to assist in their development efforts and to facilitate integration with the space station. For example, NASA created the Transportation Integration Office to streamline the requirements for integrating with the space station and provided access to critical space station integration technologies. As of the end of fiscal year 2008, 95 percent of project funding had been spent on milestone payments, 3 percent on project operations, and the remaining 2 percent had been obligated, but not yet expended.

NASA's Use of Critical Project Management Tools Has Enabled It to Monitor Partners' Development Efforts

Undertaking ambitious, technically challenging efforts like the COTS project—which involves multiple contractors and technologies that have yet to be fully developed and proven—requires careful oversight and management. Due to the COTS project's emphasis on partnering with the private sector, NASA served in a supervisory or advisory role rather than being in charge of developing the COTS project's space and launch vehicles. In this capacity, for example, NASA was responsible for reviewing milestone documentation, including risk assessments, making associated milestone payments, and sharing technical expertise. NASA's Space Act Agreements Guide and prior GAO work have identified several critical project management tools and activities which NASA generally followed, including (1) developing program planning documentation; (2) establishing performance-based, fixed-price milestones; (3) developing risk management plans; and (4) facilitating communication and coordination between NASA and its partners. Our prior work on NASA development programs with similarities to COTS, such as the X-33

program, has shown that not carefully implementing such project management tools and activities is a recipe for failure.[20]

Program Planning Documentation

Due to NASA's use of its other transaction authority for the COTS project and because it did not intend to take ownership of any flight or ground systems, it was not required to follow its program management requirements, which included developing program authorization and planning documentation. Nonetheless, NASA used these management requirements as a guide to ensure that it had the proper program authorization and planning documentation in place for the COTS project. Such plans help define realistic time frames, identify responsibility for key tasks and deliverables, and provide a yardstick by which to measure the progress of the effort. NASA developed a program authorization document that outlined NASA's management structure, project objectives, acquisition strategy, project scope, funding profile, and planned program reviews. In addition, the first performance milestone in NASA's agreements with its commercial partners required the partners to develop a program or project management plan that included the overall project schedule with milestones and described how the partner would manage the development process and identify and mitigate risks. Each commercial partner successfully passed this milestone.

Performance-Based Milestones

NASA has established fixed-price, performance-based milestones in its agreements with commercial partners that include entrance and success criteria, payment amounts, and specific due dates. NASA reviews the documentation submitted for each milestone—which includes design documentation, risk identification and mitigation strategies, development schedules, and test plans and results—and only pays its partners once it has determined the milestone has been successfully completed. Our prior work has emphasized the importance of developing performance-based milestones with fixed payments in order to minimize financial and

[20]GAO, *Space Transportation: Critical Areas NASA Needs to Address in Managing Its Reusable Launch Vehicle Program*, GAO-01-826T (Washington, D.C.: June 20, 2001). The X-33 program was part of an effort to build a full-scale, commercially developed, reusable launch vehicle reaching orbit in one stage. NASA's goal was to reduce payload launch costs from $10,000 per pound on the space shuttle to $1,000 per pound by using innovative design methods, streamlined acquisition procedures, and creating industry-led partnerships with cost sharing to manage the development of advanced technology demonstration vehicles. The program did not adhere to critical project management tools and activities and was terminated due to significant cost increases.

performance risks.[21] NASA's use of performance-based milestones has enabled it to minimize these risks. For example, NASA modified its agreement with SpaceX in February 2008 to include several milestones that were focused on conducting tests of critical hardware, such as the space vehicle's thrusters and the launch vehicle's first-stage engines. SpaceX passed these milestones on time, successfully demonstrating the maturation of key technologies. In another instance, NASA terminated an agreement with RpK when it failed to meet financial and technical milestones. NASA paid RpK only for the milestones that it completed ($32.1 million) and was able to award the remaining funding—$170 million—to Orbital approximately 4 months later.

Risk Management Plans

Although NASA has held partners responsible for their own risk management planning, it has taken several steps since the inception of the COTS project to ensure that risks were identified, assessed, and documented, and that mitigation plans were in place to reduce these risks. Our prior work has highlighted the importance of risk management plans, which identify, assess, and document risks associated with cost, schedule, and technical aspects of a project and determine the procedures that will be used to manage those risks.[22] These plans help ensure that a system will meet performance requirements and be delivered on schedule and within budget. In our prior work, we found that NASA did not prepare risk management plans for both the X-33 and X-34 programs until several years after they were initiated. Both programs were subsequently terminated because of significant cost increases caused by problems developing the necessary technologies and flight demonstration vehicles. Through the COTS announcement for proposal process, NASA required companies to identify programmatic and technical risks and strategies for mitigating each risk. After each partner had been awarded an agreement, NASA required them to develop program or project management plans that outlined each partner's risk management approach and identified key project risks and mitigation efforts. Furthermore, the Commercial Crew and Cargo program office has continued to monitor these risks through quarterly and milestone design reviews with its partners. The program office has also ensured that these project and program office-specific risks

[21]GAO, *Department of Homeland Security: Improvements Could Further Enhance Ability to Acquire Innovative Technologies Using Other Transaction Authority*, GAO-08-1088 (Washington, D.C.: Sept. 23, 2008).

[22]GAO-01-826T.

and mitigations have been reported to senior NASA management through program management reviews.

Facilitating Communication and Coordination

NASA and its partners have successfully fulfilled their respective responsibilities as outlined in the agreements, which has helped to facilitate communication and coordination between the parties. Our prior work has found that ambitious, technically challenging efforts require a high level of communication and coordination.[23] For example, in the case of the X-33 program, ineffective communication between NASA and its contractor regarding concerns about the X-33's fuel tank design contributed to its failure. The COTS partners' agreements outline several responsibilities that are directly related to fostering communication and coordination, such as holding quarterly and milestone reviews and providing partners with technical expertise to assist with their development efforts and to facilitate integration with the space station. In addition, NASA and SpaceX have amended their agreement to define how they will collaborate to integrate critical communications hardware into the space station and to test a relative navigation sensor. NASA has worked closely with SpaceX, as these items will be flown on an upcoming space shuttle flight. Another example of NASA's efforts to facilitate communication and coordination with its partners is through the creation of the Transportation Integration Office within the International Space Station program office. This office has streamlined the requirements for integrating with the space station and provided access to critical space station integration technologies, such as the grapple fixtures, Common Berthing Mechanism design, and Japan Aerospace Exploration Agency's proximity operations communications system.[24] NASA has also assigned a project executive for each partner to provide day-to-day oversight of the partners' development efforts and to coordinate technical assistance.

[23]GAO-01-826T.

[24]Proximity operations refer to maneuvers by vehicles visiting the space station that are conducted in close proximity to the space station. These operations include maneuvers to properly position the space vehicle in relation to the space station so that it can be captured by the space station's robotic arm prior to berthing.

Vast Majority of Project Expenditures Are for Milestone Payments to COTS Partners

As of the end of fiscal year 2008, 95 percent of project funding had been spent on milestone payments, 3 percent on project operations, and the remaining 2 percent had been obligated, but not yet expended.[25] NASA's Administrator budgeted $500 million in 2005 for the development and demonstration of cargo transport capabilities between fiscal years 2006 and 2010.[26] For fiscal year 2009, NASA requested $173 million in funding for the COTS project and plans to request $31.3 million for fiscal year 2010. See table 1 below for COTS project funding, obligations, and expenditures through fiscal year 2008.

Table 1: COTS Project Funding, Obligations, and Expenditures through Fiscal Year 2008

Dollars in millions

Fiscal year	Project funding	Obligations	Expenditures
2005	$22.8	N/A[a]	N/A
2006	51.3	63.6	39.1
2007	91.1	99.0	93.7
2008	130.5	133.1	157.3
Total	**$295.7**	**$295.7**	**$290.1**

Source: NASA.

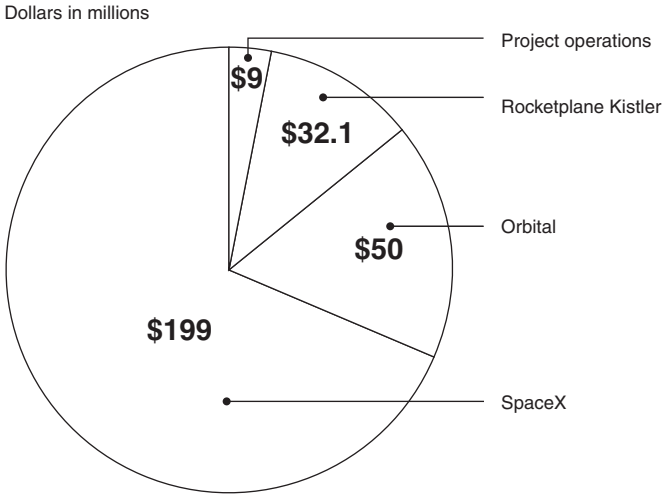
[a]NASA did not obligate fiscal year 2005 funding until fiscal year 2006. Therefore, fiscal year 2005 funding was included in all fiscal year 2006 calculations.

Figure 2 illustrates how the $290.1 million in project expenditures have been divided between COTS partners' milestone payments and project operations from fiscal years 2006 to 2008.

[25]COTS project operations expenditures include funding for civil service labor; civil service travel; technical assistance provided to COTS partners; and procurement activities, which consist of technical and business support, information technology, and safety and mission assurance.

[26]The International Space Station program office's Transportation Integration Office has estimated that it will spend an additional $56 million to support COTS partners' space station integration efforts.

Figure 2: COTS Project Expenditures to Partners and Project Operations through Fiscal Year 2008



Source: NASA.

In fiscal year 2009, SpaceX has received an additional $35 million for completing two milestones, bringing its total milestone payments to date to $234 million.[27] SpaceX could potentially earn an additional $44 million in future milestone payments. Orbital has been paid $30 million for completing three milestones in fiscal year 2009, increasing its total milestone payments to date to $80 million.[28] Orbital has $90 million remaining in potential milestone payments.

[27]SpaceX completed milestone 13, Demo 2 / Demo 3 System Critical Design Review, in December 2008 ($25 million) and milestone 14, its third and final financial milestone, in March 2009 ($10 million).

[28]NASA paid Orbital for milestone 6, Pressurized Cargo Module Preliminary Design Review, in November 2008 ($10 million); milestone 8, Instrumentation Program and Command List, in March 2009 ($10 million); and milestone 9, Completion of International Space Station Phase 1 Safety Review, in March 2009 ($10 million).

NASA Will Rely on Commercial Partners to Meet Much of the Space Station Cargo Resupply Needs

The vehicles being developed by commercial partners have become essential to NASA's ability to fully utilize the space station after the retirement of the space shuttle in 2010. NASA's 2006 Strategic Plan established a goal of supporting a crew of six astronauts on the space station by the end of 2009 in order to fully utilize the space station's research capabilities. NASA is in the process of installing the necessary equipment to support a six-person crew, and has estimated that the space station's final construction cost will be $31 billion.[29] NASA estimates that it will need 82.7 metric tons (approximately 182,000 pounds) of usable dry cargo delivered to the space station between 2010 and 2015 to meet crew needs and to support maintenance and scientific experiments. NASA plans to transport this cargo using several vehicles, including the space shuttle and commercial and international partners' vehicles.[30] Between 2010 and 2015, commercial partners' vehicles will transport almost half of this cargo and are scheduled to fly more cargo delivery missions than the space shuttle and international partners' vehicles combined—including 14 of the last 19 missions. Furthermore, after the retirement of the space shuttle, SpaceX's space vehicle will be the only vehicle capable of safely returning significant amounts of cargo to Earth—which is an essential capability to accomplish NASA's scientific research program.[31] Figure 3 outlines NASA's strategy for meeting the space station's usable dry cargo resupply needs between 2010 and 2015, identifies which vehicles are capable of returning cargo to Earth, and highlights NASA's increasing reliance on U.S. commercial partners' vehicles. Figure 3 does not include the amount of propellant, water, and atmospheric gas to be delivered to the space station between 2010 and 2015 nor does it depict the maximum cargo mass delivery capacities of each vehicle, which range from more than 17 metric

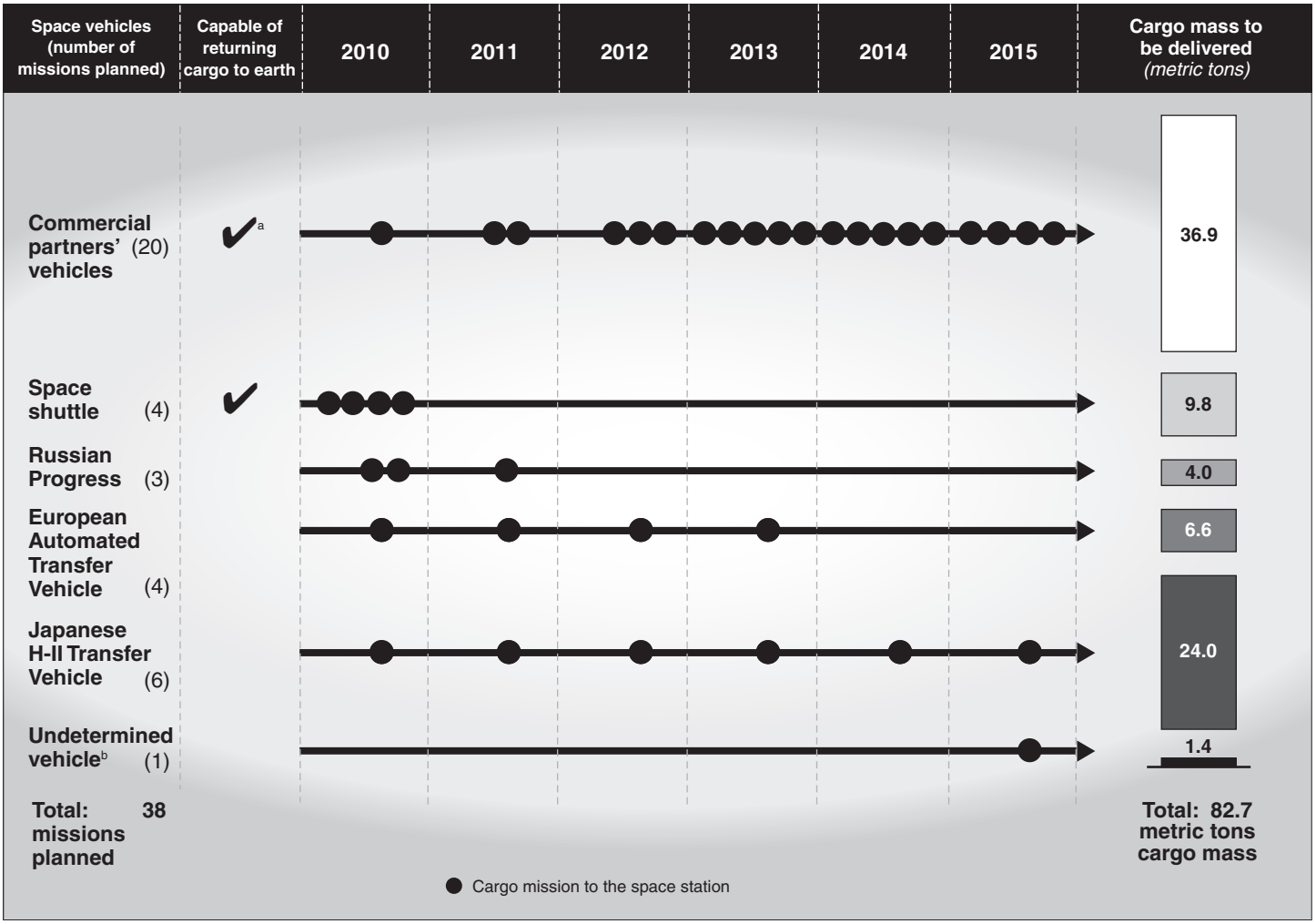
[29]Equipment necessary to support a six-person crew includes systems for oxygen recycling, removal of carbon dioxide, and transforming urine into water. NASA plans to install a new module, known as Tranquility (formerly Node 3), in February 2010 and it will hold some of this equipment. In addition to the $31 billion for the space station's construction, NASA expects sustainment costs through the space station's planned retirement in fiscal year 2016 to total $11 billion.

[30]The European Space Agency's Automated Transfer Vehicle successfully completed its first demonstration mission to dock with the space station in April 2008. The Japan Aerospace Exploration Agency has yet to attempt a demonstration mission for its H-II Transfer Vehicle. The first demonstration mission is planned for September 2009.

[31]SpaceX's Dragon is designed to return up to 2.5 metric tons (approximately 5,500 pounds) to Earth, but will likely be limited by volume constraints to about 1.7 metric tons (3,748 pounds). The international partners' vehicles and Orbital's Cygnus do not provide this capability. NASA could use the Russian crew transport vehicle to carry a small amount of cargo (50 kg) to Earth, but this vehicle cannot bring experiments to Earth for assessment.

tons for the space shuttle to as little as 2 metric tons for Orbital's space vehicle in its standard configuration.

Figure 3: NASA's Strategy for Meeting Space Station Usable Dry Cargo Needs—2010 to 2015



Source: GAO analysis of NASA data.

Note: This figure reflects NASA's November 2008 estimate of the space station's projected usable dry cargo needs and identifies which vehicles are capable of returning cargo to Earth. Propellant, water, and atmospheric gas are not included in these figures. The exact cargo mix for a particular mission is not determined until several months prior to launch and the cargo mass to be delivered for a particular mission may therefore be subject to change.

[a]Of the two commercial providers, only SpaceX's Dragon space vehicle is designed to return cargo to Earth.

[b]The International Space Station program office has reported that the vehicle that will be used for this 2015 mission has not been determined, and it will depend on what is needed to decommission the space station in late 2015 or early 2016.

Other options for transporting cargo to the space station are limited. NASA has purchased the equivalent of three Russian Progress vehicles for use in 2010 and 2011, but it has no plans to purchase any additional vehicles beyond 2011.[32] According to NASA officials, there is a 24- to 30-month lead time to manufacture the Progress should NASA decide to procure additional vehicles. NASA plans to use six Japanese H-II Transfer Vehicles for missions between 2010 and 2015 and four European Automated Transfer Vehicles between 2010 and 2013. NASA officials told us that the Japanese and European space agencies have no plans to manufacture additional vehicles beyond their current commitments. In addition, NASA's new crew exploration and launch vehicles, Orion and Ares I, designed to replace the space shuttle, are not expected to be available until 2015.[33]

Delays in the availability of commercial vehicles to fill the cargo resupply gap would result in diminished usage of the space station. The International Space Station program office has identified the 40 metric ton (approximately 88,000 pound) cargo resupply shortfall as a top program risk, and its risk summary report states that a delay in 2010 in the availability of commercial partners' vehicles would lead to a significant scaling back of NASA's use of the space station for scientific research. If there were a delay in 2011, NASA could no longer maintain a space station crew of six astronauts and its ability to conduct scientific research would be compromised.

[32]Space Station program officials told us that they expect Russia to launch six Progress flights each year between 2009 and 2011. They stated the NASA cargo will be spread across four Progress flights in 2009 and will represent the equivalent cargo capacity of a single Progress (1.4 metric tons). NASA will be procuring the equivalent of two Progress vehicles in 2010 and one Progress vehicle in 2011.

[33]These vehicles were designed to implement President George W. Bush's *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration*, which included a return to the moon and future exploration of Mars. NASA had also planned to utilize these vehicles to transport cargo to the space station as early as 2011. However, schedule and technical setbacks have delayed the anticipated availability of these vehicles until 2015.

Commercial Partners Are Making Progress, but Face Challenges Meeting Aggressive Development Schedules

While SpaceX and Orbital have completed most of the development milestones required thus far on time, both companies are working under aggressive schedules and have recently experienced schedule slips which have delayed upcoming demonstration launch dates by several months. SpaceX successfully completed its first 14 development milestones on time and is in the process of testing, fabricating, and assembling key components. However, a schedule slip in the development of its launch vehicle's second-stage engine components has contributed to anticipated delays of 2 to 4 months in most of its remaining milestones, including upcoming demonstration missions. NASA is currently evaluating the effect of potential further delays. Orbital has successfully completed 7 of 19 development milestones thus far, including several preliminary design reviews (PDR), but has experienced delays in the development of its launch vehicle's first-stage engine components. Orbital and NASA recently amended their Space Act agreement to conduct a pressurized cargo delivery and disposal demonstration mission instead of an unpressurized mission, delaying its demonstration mission date by 3 months, from December 2010 until March 2011.

Space development programs are by nature complex and rife with technical obstacles that can easily result in development delays. In our recent report on selected large-scale NASA projects, we found that 10 of the 13 projects that we reviewed had experienced significant cost and/or schedule growth from their project baselines.[34] Commercial partners must develop and demonstrate new launch and space vehicles, launch and mission operations capabilities, and achieve integration with the space station in a 3- to 4-year period.

SpaceX Has Made Progress Completing Milestones as Scheduled, but Challenges Are Likely to Delay Demonstration Missions

SpaceX completed its first 14 development milestones on time, and has made progress developing its space transport capabilities; however, several schedule and regulatory challenges are likely to delay upcoming demonstration missions by at least 2 to 4 months. SpaceX's agreement with NASA established 22 development milestones that SpaceX must complete in order to successfully demonstrate COTS cargo capabilities. Although it completed its first 14 COTS development milestones on

[34]GAO, *NASA: Assessments of Selected Large-Scale Projects*, GAO-09-306SP (Washington, D.C.: Mar. 2, 2009). For purposes of our analysis, significant cost and schedule growth occurs when a project's cost and/or its schedule growth exceeds the thresholds established for Congressional reporting. *See* 42 U.S.C. § 16613. Of the projects that we reviewed with launch delays, delays ranged from 5 months to as many as 26 months.

schedule, SpaceX experienced a delay completing the fabrication, assembly, and integration of its launch vehicle's second-stage components, and delayed its first demonstration mission readiness review (milestone 15) from March 2009 until no earlier than June 2009. In addition, SpaceX has a significant amount of work remaining to complete technical requirements for integrating its space vehicle with the space station. SpaceX must also obtain required licenses and approvals from the FAA and the USAF before its scheduled demonstration mission launch dates. SpaceX has informed NASA that its first demonstration mission will be delayed from June 2009 until no earlier than September 2009, and its third demonstration mission is likely to be delayed from March 2010 to no earlier than May 2010.[35] NASA reported it has yet to modify SpaceX's agreement to reflect these changes, but it is closely monitoring SpaceX's activity and is consulting with SpaceX to ascertain the cause of SpaceX's failure to meet milestone 15 in the timeframe identified in the current agreement.[36] SpaceX has received $234 million in milestone payments thus far, with $44 million yet to be paid. Table 2 describes SpaceX's progress meeting the COTS milestones in its agreement with NASA.

Table 2: SpaceX's Progress Completing COTS Development Milestones

Milestone number	Milestone description	Scheduled completion date	Completed on time	Payment amount (millions)
1	Project Management Plan Review	Sept. 2006	✓	$23.1
2	Demo 1 System Requirements Review	Nov. 2006	✓	5
3	Demo 1 Preliminary Design Review	Feb. 2007	✓	18.1
4	Financing Round 1	Mar. 2007	✓	10
5	Demo 2 System Requirements Review	Mar. 2007	✓	31.1
6	Demo 1 System Critical Design Review	Aug. 2007	✓	8.1
7	Demo 3 System Requirements Review	Oct. 2007	✓	22.3
8	Demo 2 Preliminary Design Review	Dec. 2007	✓	21.1
9	Draco Initial Hot-Fire	Mar. 2008	✓	6

[35]SpaceX has not announced plans to delay to its second demonstration mission, scheduled for November 2009.

[36]According to NASA's agreements with the partners, should either partner fail to meet milestones, NASA and the partner must meet to determine why the failure occurred and whether it is in the best interests of the parties to continue the agreement. NASA may terminate the agreement 30 days after providing written notification to the partner that it has failed to perform.

Milestone number	Milestone description	Scheduled completion date	Completed on time	Payment amount (millions)
10	Financing Round 2	Mar. 2008	✓	10
11	Demo 3 Preliminary Design Review	Jun. 2008	✓	22
12	Multi-engine Test	Sept. 2008	✓	22
13	Demo 2/Demo 3 System Critical Design Review	Dec. 2008	✓	25
14	Financing Round 3	Mar. 2009	✓	10
15	Demo 1 Readiness Review	Mar. 2009		5
16	Communications Unit Flight Unit Design, Accept, Delivery	May 2009		9
17	Demo 1 Mission	Jun. 2009		5
18	Demo 2 Readiness Review	Sept. 2009		5
19	Demo 2 Mission	Nov. 2009		5
20	Cargo Integration Demonstration	Jan. 2010		5
21	Demo 3 Readiness Review	Jan. 2010		5
22	Demo 3 Mission	Mar. 2010		5
			Total:	$278 million for the completion of all milestones
				$234 million paid to date

Source: NASA and SpaceX.

Note: SpaceX did not complete milestone 15 in March 2009 as scheduled. NASA reported that SpaceX has delayed delivery of milestone 15 from March 2009 until no earlier than June 2009. In addition, SpaceX has informed NASA that it anticipates a 2 to 4 month delay in most of its remaining milestones; including a delay in its first demonstration mission (milestone 17) from June 2009 until no earlier than September 2009, and a delay in its third demonstration milestone (milestone 22) from March 2010 until no earlier than May 2010.

SpaceX's Technical Approach and Development Status

To accomplish its COTS objectives, SpaceX is developing a medium-class launch vehicle (Falcon 9) and a space vehicle (Dragon), which is designed to ferry crew and cargo to and from the space station.[37] The Falcon 9 launch vehicle is a two-stage rocket that uses nine liquid-fueled engines for

[37]SpaceX's technical approach is intended to meet each of the four COTS capabilities: capability A—unpressurized cargo delivery and disposal, capability B—pressurized cargo delivery and disposal, capability C—pressurized cargo delivery and return to Earth, and capability D—crew transportation. SpaceX's Space Act agreement includes an option to demonstrate crew transportation. COTS project officials told us that they have not yet received funding for crew transport capability development.

its first-stage booster and one similar engine for its second-stage booster.[38] The Falcon 9 is designed to lift payloads, such as the Dragon spacecraft, into various orbits—including low-Earth orbit where the space station is located. On a single mission, the Dragon spacecraft is designed to deliver and dispose of 3 metric tons (approximately 6,600 pounds) of cargo distributed between its pressurized and unpressurized cargo carriers. Dragon is designed to return up to 2.5 metric tons (approximately 5,500 pounds) of pressurized cargo mass to Earth, but will likely be limited by volume constraints to about 1.7 metric tons (3,748 pounds).[39] SpaceX reported that it is developing and manufacturing almost all of the components for the Falcon 9 and Dragon in-house to keep development costs low and to remove dependencies on external suppliers. For example, SpaceX is developing a thermal protection system to enable the Dragon to safely re-enter the Earth's atmosphere, and its own hardware and software components to enable the Dragon to integrate with the space station. A summary of SpaceX's progress developing its COTS system is provided below.

Launch vehicle. SpaceX has made progress developing and testing the first-stage engines on its Falcon 9 launch vehicle; however, it has experienced a schedule slip in the development, assembly, and integration of the Falcon 9's second-stage engine components. From the beginning of the COTS project, SpaceX has tracked the development of its nine first-stage engines as a significant technological risk and has conducted several multi-engine tests at the company's Texas testing facility to reduce this risk. SpaceX reported that it successfully completed a 178-second test of

[38]The Falcon 9's first- and second-stage engines are derived from engines used in SpaceX's Falcon 1 launch vehicle, which had its first successful orbital launch in September 2008. The Falcon 1 uses one Merlin 1C engine for its first-stage booster, while the Falcon 9 uses nine similar engines for its first-stage and a single engine modified to operate in a space environment for its second-stage booster. The Merlin engines are fueled by liquid oxygen and rocket propellant grade kerosene. SpaceX plans to retrieve its first- and second-stage engines after launch and refurbish them for use in other missions.

[39]The Dragon will be propelled by 18 "Draco" thruster engines which are fueled by nitrogen tetroxide and monomethylhydrazine hypergolic fuels. Because the Dragon is yet to be fully qualified and flown, the ultimate cargo capacity of this vehicle is yet to be known. SpaceX estimates the upmass cargo capacity of the vehicle may be as high as 3.3 metric tons (approximately 7,300 pounds). The Dragon's cargo capacity for a given mission will also vary depending on the density and volume of the cargo and how it is packed. SpaceX estimates that the Dragon is likely to carry about 2.55 metric tons (approximately 5,620 pounds) of cargo on a typical mission. To demonstrate this capability, SpaceX plans to carry 1.7 metric tons (3,748 pounds) of pressurized and 0.85 metric tons (1,874 pounds) of unpressurized simulated cargo on its third demonstration mission.

its nine engines intended to simulate operations during a typical COTS launch. SpaceX also reported that it completed qualification testing of these engines in December 2008; however, NASA's Commercial Crew and Cargo program manager reported that NASA has yet to review the documentation for these and other qualification tests conducted by SpaceX, but plans on doing so during milestone 15, SpaceX's first demonstration mission readiness review. This review has been delayed from March 2009 until no earlier than June 2009, in part to provide SpaceX with more time to address issues with the fabrication, assembly, and integration of the Falcon 9's second stage components. For example, SpaceX experienced a 3-month delay in the delivery of the domes that go on top of its second-stage booster, which delayed its ability to integrate these components as scheduled. Although SpaceX recently reported that it completed a 6-minute firing of its second-stage engine, additional testing remains before the Falcon 9 second-stage engine components can be qualified for flight and integrated with the corresponding tanks and structures.

Space vehicle. SpaceX has made progress developing key components for its Dragon space vehicle; however it faces an aggressive schedule completing technical requirements to integrate the Dragon with the space station. SpaceX reported that it has completed 120 hot-fire tests of the Dragon's engines—including a 15-minute firing in a vacuum chamber designed to simulate orbital firing operations. According to NASA, SpaceX considers these engines sufficiently qualified for SpaceX's first demonstration mission, which does not include integration with the space station. However, NASA reported that SpaceX must modify the design of its thruster valves and will need to requalify these engines before it can attempt its third demonstration mission, when it will first attempt to integrate with the space station. SpaceX is also manufacturing its own heat-shield tiles for the Dragon's thermal protection system, and reported that it has completed qualification testing and analyses of its material at NASA's Ames Research Center.

Before SpaceX can attempt its third demonstration mission, it must demonstrate that it has met all of the technical requirements in NASA's International Space Station to COTS Interface Requirements Document. For example, SpaceX must develop and test new hardware and software components designed to enable the Dragon to share positioning data and

communicate with the space station.[40] SpaceX and NASA have made arrangements to fly the two components on separate space shuttle missions scheduled this summer in order to conduct development tests on them prior to SpaceX's second demonstration mission, scheduled for November 2009. SpaceX and NASA have set a goal for SpaceX to demonstrate compliance with 75 percent of NASA's space station interface requirements by the second demonstration mission, with the remaining 25 percent to be completed before the third demonstration mission. NASA officials reported that SpaceX's schedule to complete its space station integration activities is aggressive and that all aspects of integrating a new space vehicle with the space station are technically challenging.

Launch readiness. Before SpaceX may launch its first demonstration mission from the USAF's Space Launch Complex 40 (SLC-40), it must receive the approval of the 45th Space Wing Commander that its launch infrastructure and operations meet the USAF's launch range safety requirements. SpaceX has cited the range safety approval process as a significant risk that could result in schedule slips. SpaceX has made progress addressing many of the USAF's requirements, and it has installed launch infrastructure at SLC-40—including components of the Falcon 9 fueling system and the hangar structure where the Falcon 9 stages will be integrated and mated with the Dragon space vehicle.[41] However, officials from the 45th Space Wing expressed concerns that SpaceX's aggressive schedule may not give SpaceX sufficient time to submit its requests to modify USAF range safety requirements or give the USAF sufficient time to review, validate, and approve SpaceX's facilities and launch operations before upcoming demonstrations. USAF officials reported that SpaceX has yet to submit its requests to modify Dragon fueling requirements, which

[40]The two components in development by SpaceX to enable these operations are its relative navigation sensor, known as DragonEye, and its COTS ultra high frequency communications unit. SpaceX is equipping its Dragon with three DragonEye units to create a redundant system for the Dragon to share positioning data with the space station during proximity operations. The ultra high frequency communications units will be installed in both the Dragon and the space station to transmit telemetry data during proximity operations.

[41]The Falcon 9 fueling system includes tanks and distribution systems for liquid oxygen and rocket propellant grade kerosene, helium, and nitrogen. SpaceX reported that the hangar is operational for the integration of its launch and space vehicles; however, the hangar has yet to be approved for Dragon fueling. SpaceX reported that it has also fabricated, assembled, and successfully completed a dry-run test of its transporter erector system, which will be used to transport the integrated Falcon 9 and Dragon from the hangar and erect it for launch.

the USAF considers to be a potential public safety hazard, and subject to its review and approval. SpaceX reported that it intends to submit its requests to modify these requirements in the summer of 2009. SpaceX plans to conduct independent tests to demonstrate that its launch facilities meet USAF requirements for a launch safety critical design review (CDR) that will also be held in the summer of 2009.

Prior to its first demonstration mission, SpaceX must also receive from the FAA a launch license for the Falcon 9 and a re-entry license for the Dragon space vehicle. FAA reported that SpaceX has yet to submit a sufficiently complete launch license application for the Falcon 9 for SpaceX's first COTS demonstration mission.[42] However, in April 2009 FAA accepted a sufficiently complete re-entry license application from SpaceX for the Dragon space vehicle. FAA must decide within 180 days after accepting a license application whether to approve it. FAA officials reported that they do not anticipate making a determination much sooner than 180 days after acceptance of SpaceX's applications. Although it remains to be seen when SpaceX will deliver and the FAA will accept its Falcon 9 launch license application for the first COTS demonstration, there appears to be little margin for SpaceX to obtain its FAA-required licenses in time for its September 2009 COTS demonstration mission.

Orbital Has Completed Several Preliminary Design Reviews, but Faces Challenges Completing Development in Time for Its Demonstration Mission

Orbital—which entered the COTS project about 18 months after SpaceX—has successfully completed 7 of 19 required milestones thus far, including several preliminary design reviews for its systems, but challenges lie ahead in its efforts to complete its recently revised milestone schedule. Orbital's February 2008 agreement with NASA required it to conduct a single mission demonstrating the capability to deliver unpressurized cargo to the space station. Although Orbital was preparing a preliminary design of a pressurized cargo module, it was not required in its agreement with NASA to demonstrate this capability. However, in December 2008 NASA awarded Orbital a commercial resupply services contract calling for eight pressurized cargo missions, but no unpressurized missions. Subsequently, in March 2009, Orbital and NASA amended their COTS demonstration

[42]FAA reported that SpaceX has submitted and FAA has accepted a sufficiently complete launch license for a separate, non-COTS Falcon 9 mission. SpaceX intends to attempt an inaugural Falcon 9 demonstration mission prior to attempting its first COTS demonstration mission. NASA officials reported that they did not have a firm launch date for this inaugural Falcon 9 mission, but said that SpaceX is working toward a launch in late summer or early fall 2009.

agreement and replaced the unpressurized demonstration with a pressurized one. This required adding several new milestones to demonstrate this capability and delaying existing milestones, including Orbital's single demonstration mission from December 2010 until March 2011. Orbital has completed a PDR for its pressurized cargo capability and other development milestones for its Taurus II launch vehicle.[43] However, Orbital reported that it has experienced delays completing design reviews for the first-stage engine components for its launch vehicle, which have resulted in further compressing its already aggressive development schedule. In addition, NASA reported that Orbital faces an aggressive schedule to complete the technical requirements to integrate its space vehicle with the space station. Orbital has received $80 million in milestone payments thus far, with $90 million yet to be paid (see table 3).

Table 3: Orbital's Progress Completing COTS Development Milestones

Milestone number	Milestone description	Scheduled completion date	Completed on time	Payment amount (millions)
1	Program Plan Review	Mar. 2008	✓	$10
2	Demo Mission System Requirements Review	Jun. 2008	✓[a]	20
3	Unpressurized Cargo Module Preliminary Design Review	Jul. 2008	✓	10
4	COTS System Preliminary Design Review was milestone 4, but it has been renumbered as milestone 10	No longer applicable	No longer applicable	No longer applicable
5	COTS Integration/Operations Facility Review	Sept. 2008[b]	✓	10
6	Pressurized Cargo Module Preliminary Design Review	Oct. 2008	✓	10
7	DELETED: Unpressurized Cargo Module Critical Design Review	No longer applicable	No longer applicable	No longer applicable
8	Instrumentation Program and Command List	Feb. 2009	✓	10
9	Completion of ISS Phase 1 Safety Review	Mar. 2009	✓	10
10	COTS System Preliminary Design Review	Apr. 2009		20
11	DELETED: Unpressurized Cargo Module Fabrication Started	No longer applicable	No longer applicable	No longer applicable
11	Pressurized Cargo Module Critical Design Review	Jul. 2009		10
12	Cygnus Avionics Test	Aug. 2009		10
13	Completion of ISS Phase 2 Safety Review	Aug. 2009		10
14	COTS System Critical Design Review	Sept. 2009		10

[43]Generally speaking, most of the Taurus II development milestones are not included in Orbital's agreement with NASA. However, Orbital has invited NASA officials to participate in several Taurus II design reviews. Orbital has completed several other development milestones for its Taurus II launch vehicle.

Milestone number	Milestone description	Scheduled completion date	Completed on time	Payment amount (millions)
15	Service Module Core Assembly Completed	Dec. 2009		7.5
16	Service Module Test Readiness Review	Apr. 2010		7.5
17	Service Module Initial Comprehensive Performance Test	Jul. 2010		5
18	Launch Vehicle Stage 1 Assembly Complete	Oct. 2010		2.5
19	Cargo Integration Demonstration	Dec. 2010		2.5
20	Mission Readiness Review	Feb. 2011		2.5
21	System Demonstration Flight	Mar. 2011		2.5
			Total:	$170 million for completion of all milestones
				$80 million paid to date

Source: NASA and Orbital.

Note: When Orbital amended its agreement with NASA in March 2009, it deleted milestones 7 and 11, and moved milestone 4 to become milestone 10. These changes are indicated in this revised schedule.

[a]Orbital submitted its milestone documentation for milestones 2 and 3 about 2 weeks later than originally planned; however, NASA approved both milestones. Orbital's demo mission system requirements review (milestone 2) was completed in July 2008 and its unpressurized cargo module preliminary design review (milestone 3) was completed in August 2008.

[b]Milestone 5 (COTS integration/operations facility review) was originally scheduled for October 2008, but was accelerated to September 2008 as requested by Orbital. Milestone 6 (pressurized cargo module preliminary design review) was also accelerated 1 month at Orbital's request from November 2008 to October 2008.

Orbital's Technical Approach and Development Status

Orbital is developing a new, medium-class launch vehicle (Taurus II) and a modular visiting vehicle (Cygnus), which is designed to transport pressurized cargo to and dispose of trash from the space station.[44] Orbital has teamed with several external space companies to develop the Taurus II and serves as its prime integrator.[45] The first-stage engines, known as AJ26-62s, are being developed by Orbital and Aerojet and are derived from Russian NK-33 engines. Orbital's Ukrainian subcontractor Yuzhnoye/ Yuzmash is responsible for the development of the first-stage fuel tanks. The Taurus II's second-stage motor, known as the Castor-30, is being

[44]Orbital's amended technical approach is designed to meet one of the four COTS capabilities, pressurized cargo delivery and disposal (capability B).

[45]The Taurus II is a two-stage rocket with two liquid-fueled engines for its first stage and a single solid rocket motor for its upper stage. The first stage engines are fueled by rocket propellant grade kerosene and liquid oxygen. Orbital reported that it is also developing an optional liquid-fueled third stage engine that will not be used for COTS and commercial resupply services missions.

developed by Alliant Techsystems, Inc. (ATK), which has developed solid rocket motors used by the space shuttle and Japan's H-IIA launch vehicle. The Cygnus space vehicle uses a service module to provide propulsion and power to deliver a pressurized cargo module to the space station.[46] The service module draws from the avionics systems of NASA's Dawn spacecraft, developed by Orbital, and propulsion and power systems from its flight-proven STAR GEO communications satellites.[47] To develop its pressurized cargo module, Orbital has teamed with Thales-Alenia Space—which was the prime contractor of several pressurized logistics modules currently used by the space shuttle to transport cargo to the space station.[48] A summary of the progress made by Orbital in developing its COTS system follows.

Launch vehicle. Orbital has completed several early design reviews of its Taurus II launch vehicle; however, delays in the development of first-stage tanks and ongoing development tests of first-stage engine components have compressed Orbital's already aggressive development schedule. Orbital began Taurus II development as an independent research and development project in 2007 and completed a Taurus II system requirements review and PDR in July 2007 and February 2008, respectively. Orbital officials reported that since joining the COTS project, it has completed separate subsystem design reviews with its partners: in October 2008, Orbital completed a CDR of the first-stage engine assembly with Aerojet, a PDR of the first-stage tanks with Yuzhnoye, and a CDR of

[46]Orbital's Cygnus visiting vehicle is not designed to return cargo to Earth, although it can dispose of trash from the space station. Orbital estimates that Cygnus will be able to deliver or dispose of about 2 metric tons (approximately 4,400 pounds) of pressurized cargo on a single mission. Because the Cygnus is yet to be qualified and flown, the final cargo capacity of the Cygnus is yet to be known. Once development is completed, Orbital estimates that in an enhanced configuration, its pressurized cargo module could provide as much as 2.7 metric tons (approximately 5,950 pounds) of cargo delivery and disposal in a given mission. The Cygnus's cargo capacity for a given mission will vary depending on the density of the cargo and how it is packed.

[47]Orbital is working with Draper Laboratory to develop guidance, navigation, and fault tolerant computer support, and plans to use hardware and software developed by Japan Aerospace Exploration Agency for the H-II Transfer Vehicle to facilitate proximity and berthing operations with the space station.

[48]Thales-Alenia Space was the prime contractor to NASA and the Italian Space Agency in the development of the three multipurpose pressurized logistics modules used by the space shuttle to ferry pressurized cargo to and from the space station. Thales-Alenia Space was also the prime contractor to the European and Italian Space Agencies for the development of Nodes 2 and 3 of the space station. COTS vehicles are intended to berth with the space station at Node 2 during their COTS demonstrations.

the second-stage motor with ATK in March 2008. However, Orbital reported that it has experienced schedule slips for other Taurus II development milestones. Orbital's joint CDR with Aerojet and Yuzhnoye for the first-stage engine and tanks slipped 4 months from November 2008 until March 2009.[49] Orbital also delayed a separate CDR with Yuzhnoye for the first-stage tanks 6 months from February 2009 to August 2009 to address issues with the engine feed lines and fuel tank mass.

Although Orbital has moved its COTS demonstration date 3 months, from December 2010 until March 2011, Orbital's schedule to complete Taurus II first-stage development appears to provide little margin to respond to future technical issues, should they arise. Orbital is tracking the delivery of its first-stage engine components as a significant Taurus II risk. Its Taurus II risk summary report indicates that given the compressed schedule for developing these components, there is a possibility that the Taurus II program schedule for its COTS demonstration mission may not be met. In addition, Orbital and Aerojet are in the process of conducting development tests of components from heritage NK-33 rocket engines that will be used to produce the Taurus II first-stage engines. Orbital reported that the NK-33 engines have been in storage since 1972 and tests are being done to ensure that components have not degraded over time.

Space vehicle. Orbital has completed several early design reviews of key components for its Cygnus space vehicle; however, technical and schedule obstacles must be overcome before Orbital may attempt its COTS demonstration. Orbital completed a system requirements review for its demonstration mission in July 2008, a PDR for its pressurized cargo module in October 2008, and the first of three space station Safety Review Panel reviews in March 2009. Orbital also reported that procurement of long-lead systems for the Cygnus has begun, with production scheduled to begin before the end of 2009 and integration tests scheduled to begin in February 2010. However, NASA officials reported that Orbital had a late start in developing its capabilities to integrate its space vehicle with the space station. According to NASA officials, this is due, in part, to Orbital's late entry to the COTS project and because there was some question over whether Orbital would demonstrate a pressurized or unpressurized cargo delivery capability in its COTS demonstration mission.

[49]This slip was due, in part, to difficulties establishing and negotiating testing and delivery requirements with Yuzhnoye for the development of the first-stage tanks.

Orbital's aggressive schedule could present challenges with completing requirements in NASA's International Space Station to COTS Interface Requirements Document in time for its March 2011 demonstration mission launch date.[50] To help address the technical challenges of integrating with the space station, Orbital plans to use hardware and software developed by Japan Aerospace Exploration Agency for the H-II Transfer Vehicle to facilitate proximity and berthing operations. NASA officials reported that Orbital may benefit from its partnerships with experienced subcontractors, such as Japan Aerospace Exploration Agency and Thales-Alenia Space, but a significant amount of work remains to be done under a compressed development schedule before Orbital can be certified to integrate with the space station.

Launch readiness. Orbital has begun the development of its COTS launch site at the Mid-Atlantic Regional Spaceport in Wallops Island, Virginia, but more work remains to be done to complete NASA's launch safety requirements and acquire FAA launch licenses. As required by its agreement, Orbital completed an initial review of the launch site facilities to be developed and prepared a concept of operations for its launch activities. To support its COTS demonstration mission, Orbital and the Mid-Atlantic Regional Spaceport intend to construct several new facilities, including a horizontal integration facility (to integrate the Taurus II with the Cygnus); a launch pad, mount, and ramp; and separate fueling facilities for the Taurus II and the Cygnus. Orbital's construction schedule indicates that its launch pad, mount, and ramp will be completed by the end of 2009. Orbital reported that construction of the horizontal integration facility is planned for completion in May 2010, and the Cygnus space vehicle fueling facility is planned to be completed by October 2010. Before it may attempt its demonstration mission, Orbital must receive NASA's approval that its new launch site facilities in development meet NASA's range safety requirements, which apply at the Mid-Atlantic Regional Spaceport. These requirements are scheduled for completion by Orbital's demonstration mission readiness review, scheduled for February 2011. Orbital must also submit applications to the FAA for a launch license for the Taurus II and a re-entry license for the Cygnus space vehicle. A draft of its launch license

[50]NASA's International Space Station to COTS Interface Requirements Document requires COTS vehicles to have two-fault tolerant systems to mitigate against catastrophic hazards that could occur during integrated operations with the space station. Orbital reported that it typically builds its components with one-fault tolerance and has cited the development and verification of hardware and software needed for space station rendezvous and proximity operations as a high risk.

application is required as part of its COTS System CDR, scheduled for September 2009.

Concluding Observations

With the approaching retirement of the space shuttle in 2010, NASA faces the difficult challenge of securing sufficient and reliable cargo transportation capabilities to the space station from 2010 to 2015. NASA has taken several steps recently to finish its $31 billion investment in the construction of the space station, which include installing the necessary equipment to support a crew of six astronauts and to fully utilize the space station's research capabilities. While commercial partners have made progress in developing cargo transportation capabilities, they have recently fallen behind their development schedules. Furthermore, the most critical steps lie ahead, including successfully launching new vehicles and completing integration with the space station. The impending retirement of the space shuttle leaves NASA with little margin to address future COTS development delays. Should commercial partners suffer future delays or be unable to provide cargo resupply services when anticipated, NASA will be unable to fully utilize the space station as intended.

Agency Comments and Our Evaluation

We provided a copy of the draft report to the Department of Defense (DOD), FAA, and NASA for comment. We also gave SpaceX and Orbital an opportunity to comment on the findings related to their development efforts. DOD and FAA did not submit comments. In commenting on a draft of our report, NASA found it to be "thorough, objective, and helpful in addressing commercial crew and cargo demonstration efforts." NASA's written comments appear in appendix II. NASA, SpaceX, and Orbital also provided technical comments which we have incorporated as appropriate.

We will send copies of the report to NASA's Administrator and interested congressional committees. The report will be available at no charge on the GAO Web site at http://www.gao.gov.

Should you or your staffs have any questions on matters discussed in this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix III.

Cristina Chaplain
Director, Acquisition and Sourcing Management

List of Congressional Addressees

The Honorable Barbara A. Mikulski
Chairman
The Honorable Richard C. Shelby
Ranking Member
Subcommittee on Commerce, Justice, Science,
and Related Agencies
Committee on Appropriations
United States Senate

The Honorable Alan B. Mollohan
Chairman
The Honorable Frank R. Wolf
Ranking Member
Subcommittee on Commerce, Justice, Science,
and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Gabrielle Giffords
Chairwoman
Subcommittee on Space and Aeronautics
Committee on Science and Technology
House of Representatives

The Honorable Mark Udall
United States Senate

Appendix I: Scope and Methodology

To examine the National Aeronautics and Space Administration's (NASA) management of the Commercial Orbital Transportation Services (COTS) project and its expenditures, we analyzed project documentation, including the Space Act agreements NASA entered into with its commercial partners, NASA's guidance for implementing these agreements,[51] development milestone and quarterly reviews and other briefings, and project funding and expenditures. We evaluated NASA's management of the COTS project by comparing COTS management activities with critical project management tools and activities identified in NASA's Space Act Agreements Guide and in prior GAO work on NASA projects with similarities to COTS.[52] We also analyzed NASA budget and funding documentation, confirmed this data with relevant milestone payment documentation, and evaluated the processes used for validating expenditures. In addition, we interviewed NASA and company officials to assess NASA's management of the project and to verify project funding and expenditures.

To determine the extent to which NASA is reliant on commercial partners to meet the space station's cargo resupply needs, we reviewed International Space Station program office documentation on the space station's cargo resupply needs and risks, NASA's plans to meet its cargo resupply needs between 2010 and 2015, and international and commercial partners' vehicle capabilities. We interviewed officials at NASA's Commercial Crew and Cargo and International Space Station program offices to confirm NASA's cargo resupply plans and to verify cargo resupply needs and risks and vehicle capabilities. We also reviewed NASA studies that assessed the impact of the COTS project on NASA's cargo resupply strategy.

To determine the extent to which commercial partners have made progress or experienced challenges in developing cargo transport capabilities, we reviewed each partner's agreement with NASA, supporting documentation submitted by commercial partners to NASA for each milestone, partners' development schedules and technical risks, NASA's

[51]NASA Advisory Implementing Instruction (NAII) 1050-1A is also known as NASA's Space Act Agreements Guide.

[52]GAO, *Space Transportation: Critical Areas NASA Needs to Address in Managing Its Reusable Launch Vehicle Program*, GAO-01-826T (Washington, D.C.: June 20, 2001).

requirements for integrating with the space station,[53] and prior GAO reports. We also reviewed the commercial transportation space regulations of the Federal Aviation Administration's Office of Commercial Space Transportation[54] and U.S. Air Force Space Command's range safety requirements[55] to evaluate commercial partners' progress in obtaining required licenses and in developing their launch sites and operations procedures. We conducted field visits and interviewed commercial partners to determine partners' development progress against performance milestones and to identify technical and schedule challenges. In addition, we interviewed officials at NASA's Headquarters, Johnson Space Center, and Wallops Flight Facility; the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation; Patrick Air Force Base and Cape Canaveral Air Force Station; and Mid-Atlantic Regional Spaceport. Our review did not attempt to independently identify risks and challenges or assess whether a partner successfully accomplished a particular milestone. We relied on the commercial partners' assessments of the technical challenges they faced and NASA's determination that a milestone had been successfully completed.

[53]The International Space Station to Commercial Orbital Transportation Services Interface Requirements Document (SSP 50808) provides interface and performance requirements between the space station and COTS partners, performance and design requirements for the COTS ground systems supporting COTS vehicle flights to space station, and design requirements on the COTS vehicle to ensure safe integration with the space station.

[54]The commercial space licensing regulations are outlined at 14 C.F.R. §§ 413-437 (2009).

[55]The range safety requirements are published in U.S. Air Force Space Command Manual 91-710, which is divided into seven volumes.

Appendix II: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

June 05, 2009

Reply to Attn of: Exploration Systems Mission Directorate

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

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to comment on your draft report entitled, "Commercial Partners Are Making Progress, but Face Aggressive Schedules to Demonstrate Critical Space Station Cargo Transport Capabilities," GAO-09-618.

Overall, NASA finds the draft report to be thorough, objective, and helpful in addressing commercial crew and cargo demonstration efforts. We are pleased with your recognition of our positive steps and progress in this area and generally agree and support the conclusions you have reached.

There are a few recommended technical changes that we believe will help clarify some details in the report. Those technical comments have been sent to your staff via e-mail.

If you have any questions or require additional information, please contact Mr. Marc Timm at (202) 358-0373.

Sincerely,

Douglas R. Cooke

Douglas R. Cooke
Associate Administrator for
Exploration Systems Mission Directorate

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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

Acknowledgments

In addition to the individual named above, Jim Morrison, Assistant Director; Matt Barranca; Greg Campbell; Brian Hartman; Jeff Hartnett; Arturo Holguin; Kenneth E. Patton; Tim Persons; and Alyssa Weir made contributions to this report.

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