Background Paper

The International Space Station: Canada's Involvement

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Jean Dupuis

Industry, Infrastructure and Resources Division
Parliamentary Information and Research Service

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(Background Paper)

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THE INTERNATIONAL SPACE STATION: CANADA'S INVOLVEMENT*

1 INTRODUCTION

The International Space Station (ISS) is a research facility being assembled in low Earth orbit by an international consortium of space agencies.[1] Construction of the facility began in 1998 and is scheduled for completion in 2011. Current plans provide for continued operation of the ISS until 2020 or beyond. This document presents background information about the space station and the contributions of the main participants in the project.

In 1984, former US president Ronald Reagan committed the United States to building a permanently manned space station and invited Canada, Japan and the European Space Agency (ESA) to join in this ambitious program. In 1986, Canada, Japan, and 11 member countries of the ESA agreed to participate.

The Canadian Space Agency was established by an Act of Parliament in March 1989. In January 1998, Canada and the other original participants signed a revised intergovernmental agreement establishing a new ISS partnership, which now included Russia and Brazil. The new agreements reflected changes to the space station program resulting from significant Russian participation and from design changes that had been introduced over the years.

The mission of the ISS is threefold:

- First, it provides an orbiting research base for the assessment of the effects of long stays in space on human physiology and well-being. This information is essential to the successful exploration and exploitation of the space environment.
- Second, it functions as an advanced research laboratory for the study of the unique features of space and their application (near-zero gravity, near-perfect vacuum and lack of atmospheric interference), as well as of new materials, medicines and technologies.
- Finally, the space station is an engineering test bed for the construction, operation and maintenance of complex systems in space.[2]

The Canadian government agreed to develop, build and operate one of the station's "mission-critical" elements, the Mobile Servicing System (MSS). (A mission-critical element is one that must operate on time and in the prescribed fashion in order for the mission to continue.) The MSS, which is used for assembly, maintenance and servicing tasks on the space station, consists of a Mobile Base System, two manipulators – the Space Station Remote Manipulator System (SSRMS), also called Canadarm2, and the Special Purpose Dextrous Manipulator (SPDM), otherwise known as Dextre – and the Canadian Space Vision System, which provide the mechanical arms with "synthetic visual cues" to allow them to "see" what they are doing. The total cost of building, testing and operating the MSS hardware is estimated at C$1.4 billion.[3] This amount does not include the annual operational cost of the CSA's involvement with the ISS program, which is estimated at C$40 million.

2 BACKGROUND AND ANALYSIS

2.1 THE SPACE STATION

The ISS is not the world's first space station. Beginning in 1971, the Soviet Union and later Russia launched three space station programs (Salyut, Almaz and Mir), which provided orbital platform facilities for a series of crews. In 1973–1974, the United States embarked on the Skylab program, which allowed three successive crews of American astronauts to stay in orbit for periods ranging from one to three months. Between that time and the 1984 decision to build the space station, the US manned space program was committed to the development of the Space Shuttle. Operating from 1986 to 2001, the Mir station provided valuable practical experience with long-duration human stays in space. In 1995, the United States began Shuttle missions to Mir as a phase-in to the Russian participation in the ISS program.

In 1990, budget restrictions – along with some misgivings about the design of the proposed station – led the US Congress to order NASA to review its design and adjust the program. As a result, a smaller version of the space station became the official proposal. Because this 1990 redesign did not affect the MSS design, Canada proceeded according to the original criteria set out by NASA.

2.1.1 ASSEMBLY OF THE ISS

NASA launched the first two elements of the space station in November and December 1998, while the third, supplied by NASA's Russian partners, suffered repeated delays until July 2000. After only six assembly flights, the station reached the status of "man-tended capability." The first three-person resident crew arrived at the ISS in November 2000. Since then, numerous manned and unmanned space flights for station assembly, maintenance and crew rotation, as well as three utilization flights, have been made each year.[4] During the utilization flights, the Shuttle, with its seven-person crew, docks with the station for about two weeks at a time; four of the shuttle's crew devote their time to carrying out experiments for space station users. The countries participating in the operation of the station share operating costs. These countries have access to time and space in the laboratories in proportion to their contribution. Other countries send experiments to the space station on a commercial basis, as time and facility space allow.

Initially, the ISS construction schedule called for a completion date of 2006; however, the loss of Space Shuttle *Columbia* (STS-107) and crew in February 2003 grounded the Shuttle fleet and postponed the construction of the ISS for over two years. In March 2006, a new assembly schedule provided for 16 Shuttle flights dedicated to the completion of the ISS before the scheduled retirement of the Space Shuttle in 2010.[5]

In February 2007, the ESA's laboratory module, Columbus, was delivered and assembled. Between March 2008 and July 2009, three separate Shuttle missions delivered components of the Japan Experimental Module (JEM). A new pressurized component from Russia, the Mini Research Module, which is to be attached to the earth-facing port of the Zarya module (the first component launched for the ISS), was scheduled for delivery and assembly in May 2010.

In late 2009, the ISS reached the advanced assembly phase. Although further delays in the assembly of the ISS are still possible, according to the Consolidated Launch Manifest the Station is now expected to be completed in December 2011, when the final component, the Multipurpose Laboratory Module, is due to be installed.[6] Once the assembly phase is completed, NASA plans to extend funding to support ISS operations to at least 2020.

The cost of the ISS project over its entire life cycle is difficult to establish. Because of poorly defined requirements, changes in program content and difficulties with oversight, the ISS program has been prone to delays, complex redesigns and cost overruns. The United States General Accounting Office (GAO) reported that NASA has struggled to contain costs and keep to the construction schedule throughout the ISS program.[7] According to recent NASA estimates, the cost to the United States of completing the station will total US$31 billion, and an additional US$11 billion will be required to keep it running until fiscal year 2016 (the planned decommissioning date at the time the GAO published its report).[8]

Depending on the information source used and the type of cost being considered, total ISS project cost estimates can be as low as US$35 billion or as high as US$100 billion (both figures exclude the financial participation of other nations involved). The lower estimate reflects NASA's practice of reporting only the direct costs related to the development, assembly and operation of the ISS. The higher figure includes Space Shuttle program costs incurred in support of the delivery of ISS components. The ESA provides a total cost estimate of the ISS program at around 100 billion Euros (about C$159 billion). This figure represents the shared cost of the primary participants (United States, Europe, Japan, Russia and Canada) over a period of 30 years (1985–2015).[9]

However, the cost of operating the ISS will rise, since the Obama administration announced in February 2010 that it supports extending the lifetime of the ISS from 2016 to at least 2020. The recently tabled fiscal 2011 NASA budget proposes to increase funding to the ISS by more than US$463 million over the previous year's proposed budgetary allocation, and by US$2 billion more over four years (2011–2014), relative to the 2010 budget.[10]

The relatively high costs associated with a project whose ultimate outcome remains uncertain have raised questions among some observers as to whether this initiative should have been undertaken at all. Given the many delays and cost overruns, the ISS will be more modest in its dimensions and will have a smaller crew and a lower capacity to carry out scientific activities than originally planned.[11] Some observers have suggested that the funds spent on an orbiting platform of limited scientific utility could have sustained a number of more scientifically and technically ambitious space projects, including sending unmanned probes to the planets or manned missions to the Moon and Mars.[12]

2.2 Canada's Space Station Program

2.2.1 Program Objectives: Why is Canada Participating?

The many reasons that have been put forward to justify Canadian participation in the ISS include achieving international prestige as a technologically advanced industrial economy; securing access to important new high-technology fields; generating technological spin-offs on Earth; buying long-term access to the space environment for Canadian researchers; and developing a highly qualified workforce in the fields of robotics and automation. In the short term, the technical and economic spin-offs on Earth are arguably the most significant goals, together with the creation of a pool of knowledgeable scientists and industrialists in several emerging technological fields. According to the CSA, Canada's participation in the ISS is expected to generate about C$6 billion in economic benefits and, as of 2008, has already resulted in C$919 million in contracts awarded to the Canadian aerospace industry.[13] According to CSA officials, the total cost of Canada's participation in the ISS is $1.4 billion for developing, designing and installing the MSS and $40 million in annual operating costs to maintain this participation.[14]

Many of the technologies developed for the space station, especially in the fields of robotics and automation, will have terrestrial applications, including work in "hostile" environments such as the nuclear industry, mining and offshore resource development. However, some observers question the value of Canada's participation. Given the high costs associated with this ambitious engineering project (relative to the CSA's budget) and the limited outlets for the robotic technology being developed, these observers question whether the accrued benefits of participation will outweigh the costs.[15]

2.2.2 The Mobile Servicing System (MSS)

In the past, Canada contributed to the US space program with the very successful Canadarm, which now flies on almost every Space Shuttle flight. When asked to join in the space station program, it was logical for Canada to build on this expertise. To ensure that its involvement would continue after the station became operational, Canada insisted that its participation should entail more than the provision of a piece of hardware. After the United States had agreed to this demand, Canada agreed to design, build and operate the MSS. It is worth noting that, until Russia became involved in the program, Canada was the only foreign country supplying a mission-critical element of the station.

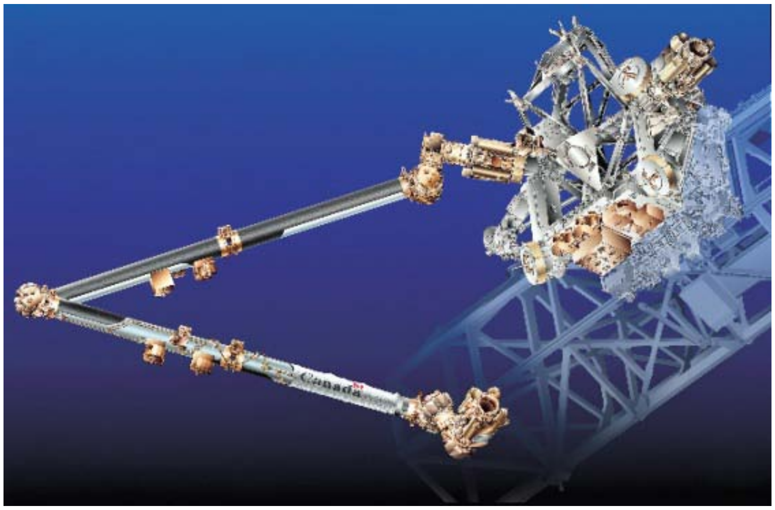
Figure 1 presents an artist's impression of the design of the MSS. This system plays the main role in the assembly and maintenance of the space station by: moving equipment and supplies around the station; supporting astronauts during extra-vehicular activities; and servicing instruments and other payloads attached to the station. In addition, the MSS is used for docking the visiting Space Shuttles and for loading and unloading the Shuttle cargo bay. Canada is responsible for the total design, development and long-term operation of the MSS.

As can be seen in Figure 1, the MSS consists of two main elements. The remotely controlled manipulator arm, Canadarm2, which has seven motor-driven, computer-controlled joints (rather than six, as in the first-generation Canadarm). The addition of the seventh joint enhances the arm's functionality, enabling the device to mimic most human arm movements. The arm is 17.6 metres long and has a payload capacity of 116,000 kilograms. Canadarm2 was delivered to NASA in February 1999 and sent into space in April 2001 aboard the Shuttle. The arm is attached to the Canadian-built mobile servicing base system. The base, in turn, is attached to the US-supplied mobile transporter system. The latter is like a small railway track running along the truss structure of the station.

Canadarm2 is also designed to accommodate Dextre, which has two seven-jointed arms, each about 2 metres long. Dextre's manipulability enables it to undertake more delicate tasks, such as working on electrical circuits, fuel lines and cooling systems. Advances in robotics, vision systems and artificial intelligence have provided Dextre with human-like senses. For example, it is equipped with cameras that allow it to "see" its way around the station. It can recognize targets and adjust its own position in response. Sophisticated software programs also prevent the two arms from colliding with one another, and automatically keep the elbow from hitting anything, or anyone, when the arms are reaching to grasp a target. In addition to "seeing" with the help of the space vision system, this robot can also "feel." It is equipped with force-sensing systems that detect how hard it is touching, pushing, pulling or twisting something. Given this ability, Dextre can be used to repair and/or replace delicate electronic parts or tighten bolts without risk of stripping them. These abilities relieve astronauts of the necessity to go out into space to undertake routine repairs.[16]

Figure 1

A. Space Station Mobile Servicing System (Canadarm2)



B. Special Purpose Dextrous Manipulator (Dextre)

Source: Canadian Space Agency website. Credit: MD Robotics Ltd.

Canadarm2 and Dextre are designed for a lifetime greater than 10 years, and must withstand the stresses of prolonged exposure in space with maximum reliability. The composition of the industrial team responsible for most of the Canadarm2 and Dextre components reflects the goal of spreading government space-related expenditures throughout the country. The team was headed by MD Robotics (Brampton, Ontario).

Other companies involved include IMP Group (Halifax), CAE Electronics (Montréal), FRE Composites (Saint-André, Quebec), CAL Corporation (Ottawa), SED Systems (Saskatoon) and MacDonald Dettwiler Associates (Richmond, BC).[17] Dextre was scheduled to be installed aboard the ISS during a mission in 2003. However, the *Columbia* accident and subsequent investigation interrupted the original schedule of Space Shuttle launches, which delayed the assembly timetable by at least two years. Dextre was finally delivered and installed in March 2008.[18]

Canada's Space Station Program also includes highly sophisticated ground facilities. The ground-based segment is known as the MSS Operations Complex (MOC) and is located at the CSA headquarters in Saint-Hubert, Quebec. It provides the infra-structure, resources, equipment and expertise for MSS space operations. The MOC is a state-of-the-art centre that houses a number of operations and training facilities, including the Space Station Operations Support Centre, MSS Simulation Facility, Operations Kinematic Simulator and the Canadian SSRMS Training Facility.

Canada's involvement in the ISS project is not limited to providing equipment and ground facilities to the ISS program but also involves supplying crews who participate in its assembly, scientific research and day-to-day operations. Since the ISS project started, six Canadian astronauts have visited the space station: Julie Payette (May–June 1999 and July 2009), Marc Garneau (November–December 2000), Chris Hadfield (April–May 2001), Steve MacLean (September 2006) and Dave Williams (August 2007), and Dr. Robert Thirsk, who in 2009 became the first Canadian astronaut to participate on a six-month (May to December 2009) mission on the ISS.[19]

In September 2009, Guy Laliberté, the founder of the circus arts company Cirque du Soleil, visited the ISS for 12 days as the first Canadian "space tourist." Mr. Laliberté is the seventh space tourist participating in a special program promoted by the Russian Space Agency to help finance its activities.[20]

2.3 Other International Contributions

2.3.1 Kibo – The Japanese Experimental Module (JEM)

Japan's contribution to the space station project, the Japanese Experimental Module (JEM), or "Kibo," accommodates general scientific and technology development research activities, including microgravity studies. This laboratory consists of a pressurized module (a tube 10 metres long and 4.2 metres in diameter), a smaller, exposed facility and an airlock joining the two elements, as well as a local remote manipulator and an Experiment Logistics Module (ELM). The ELM attaches to the laboratory and can be removed, returned to Earth to deliver experiments and products made in space, refilled with new materials and supplies, and returned to the station to be reattached to Kibo. JEM itself attaches to the basic truss framework of the station. Kibo's components were delivered and installed on the space station between March 2008 and July 2009.

Kibo's ELM is being made compatible with an automated orbital transfer vehicle developed by Japan to deliver supplies to the ISS: the H-II Transfer Vehicle, or HTV. A demonstration flight of the HTV was conducted in September 2009; currently, JAXA plans to conduct one or two HTV cargo supply missions per year to support ISS operations.[21]

2.3.2 Columbus – The European Space Agency Pressurized Module (ESA Module)

The ESA has developed a "multi-purpose" laboratory as part of its contribution to the space station. This facility, which is almost 12 metres long with a diameter of 4.5 metres, is permanently attached to the space station. It is designed for international use principally in the fields of fluid physics, life sciences research and materials research.

Like Japan's Kibo and the US laboratory and habitation modules, Columbus has "crew safe-haven capability." In other words, in the event of an emergency, the space station crew would have sufficient supplies and accommodation to await rescue. Columbus was initially scheduled for launch in 2004, but was delivered and installed in February 2008.

The ESA has also developed automated transfer vehicles (ATVs) to carry supplies to – and waste from – the ISS. The ESA plans to deliver about 8 tonnes of cargo to the ISS by this means approximately every 18 months. The first of these, the *Jules Verne,* was launched in April 2008 with a delivery of supplies and remained docked to the ISS until September 2008. Once each supply mission is completed, the ATV undertakes a "destructive re-entry" into the Earth's atmosphere during which it breaks up and burns, together with up to 6.5 tonnes of material that is no longer required on the Station.[22] The second ATV, the *Johannes Kepler,* is scheduled for launch in 2010.

2.3.3 Russia's Contribution

With the end of the Cold War, Russia and the United States began a number of joint scientific undertakings. Russia's experience with the Mir Space Station prompted the United States to invite Russian participation in the ISS. Russia agreed to allow US astronauts access to the Mir station to gain experience and also undertook to use its expertise to build several elements of the ISS. The United States provided the design and the financing for construction in Russia of the Zarya module, otherwise known as the Functional Cargo Block. Zarya is now used as a storage facility.

Russia is also contributing Soyuz spacecraft to ferry crews to the space station and, during emergencies, to act as escape vehicles. In addition, Russia agreed to the use of its Proton heavy-lift vehicle (rocket) to launch elements of the station. This contribution was welcomed by the United States, which would have been relieved of the need to develop its own heavy lift vehicle to supplement Space Shuttle flights during assembly of the ISS. However, the 1999 crash of two Proton rockets shortly after lift-off caused NASA a great deal of concern with respect to Russia's ability to meet this commitment. It also delayed the launch of the Russian-built Zvezda Service Module.

The Zvezda Service Module is the most complex Russian contribution. It served as the early living quarters for astronauts assembling the ISS and contains vital life-support and propulsion elements. Zvezda was originally scheduled for launch on a Proton rocket in November 1999; however, lack of financial resources and Proton rocket failures caused many delays, and the launch date was repeatedly pushed back. NASA eventually provided additional money to get the project on track, and Zvezda was finally launched in July 2000. Subsequently, Russian authorities announced that, because of financial constraints, all work had stopped on the remaining smaller space station elements that Russia had agreed to supply. In addition, it is likely that Russia will not be able to provide the ongoing Proton-rocket launch support it had promised. Continuing financial problems in Russia have raised serious concerns over the rising costs that would ensue if NASA ultimately has to supply the Russian elements. Already, a number of US and Russian modules planned for the ISS were cancelled in the face of budgetary pressures or ISS redesign following the *Columbia* accident. Some Russian modules that were originally planned for delivery by Russian launchers have been redesigned and are now to be delivered by the Space Shuttle (e.g., the Russian Mini-Research Module 1 is to be delivered by Space Shuttle *Atlantis* to the ISS in May 2010).[23]

The loss of the *Columbia* in February 2003 postponed any further Shuttle launches and delayed the construction of the ISS for more than two years. As a result, the *Soyuz* spacecraft became the principal crew transportation vehicle to the ISS. It was also decided to reduce the long-duration crew for the ISS from three to two persons to save on consumables (i.e., breathable air, water and food).[24] The unmanned Progress supply ships continued to provide the re-supply and logistical support to the ISS in the absence of the Space Shuttle.

After the investigation of the *Columbia* accident, the US government announced that it would be retiring the Space Shuttle program soon after the targeted completion of the assembly of the ISS in 2011.

In April 2007, NASA announced a US$719 million contract with Russia to expand crew rotation and cargo services through 2011. The new contract provided for rotations of 15 crew members over three years and for the delivery of cargo and removal of refuse. The modification will also enable delivery of the outfitting hardware that NASA is committed to provide for the Russian Multipurpose Laboratory Module in 2010, and provides a flight opportunity to allow an astronaut from one of the international ISS partners to spend approximately six months aboard the space station.[25] In December 2008, NASA signed a US$141 million modification to its ISS contract with Russia to cover comprehensive Soyuz support, including training and preparation for a long-duration mission for three station crew members. The crew members will launch on two Soyuz vehicles in the fall of 2011.[26] This mission, combined with flights to the Russian segment of the ISS, are expected to double Russian traffic during the 2009–2010 period.[27]

2.4 Further Developments

NASA funding of the ISS was expected to cease by 2015, with plans to take the station out of orbit by 2016. However, the Obama administration recently requested an increase to NASA's budget of $6 billion over the next five years and proposed significant changes in US space policy, including increasing the utilization of the ISS to 2020 or beyond. Other changes include increasing investments in exploration research and development and relying more on private commercial spaceflight technologies to ensure transportation of crews and cargo into space. One consequence of this new direction is the cancellation of the Constellation program for the return to the Moon and an extra $600 million in funding allocation for fiscal year 2011 to ensure the safe retirement of the Space Shuttle fleet after the completion of its current flight manifest.[28]

At an international conference held in Tokyo in March 2010, the heads of space agencies from Canada, Europe, Japan, Russia, and the United States met to discuss ISS cooperation within the context of the recent changes to US space policy. At the end of the conference, the agency heads issued a joint statement declaring that there were no technical constraints to continuing ISS operations beyond the current planning horizon of 2015 to at least 2020 and beyond, and that all had a strong interest in continuing ISS operations and utilization as long as the ISS exploitation continues to demonstrate benefits. All of the agency heads pledged that they would undertake the necessary steps with their respective governments to reach a consensus on the continuation of the ISS into the next decade.[29]

NOTES

* The original version of this paper was prepared by Lynne C. Myers, formerly of the Library of Parliament.

1. The consortium members are the United States (National Aeronautics and Space Agency – NASA), Russia (Russian Federal Space Agency – RKA), Japan (Japan Aerospace Exploration Agency – JAXA), Canada (Canadian Space Agency – CSA) and eleven European nations (through the European Space Agency – ESA): Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. See NASA, Space Station Assembly, Washington DC, updated 1 October 2008. Brazil is a bilateral partner of the United States in the ISS by means of a contract with NASA to supply hardware; in return, Brazil will have access to ISS facilities and a flight opportunity for one astronaut. Italy has a similar arrangement with the United States despite its membership in the ESA.

2. NASA, *The National Aeronautics and Space Administration (NASA) Research and Utilization Plan for the International Space Station (ISS)*, Washington, DC, June 2006.

3. CSA, "Status Report on Major Crown Projects (MCPs): Report 2004," Ottawa, 29 September 2005, p. 2. In addition, the CSA currently spends about C$40 million a year on ISS-related operational costs. (Capital and operational cost figures correct as of spring 2010, according to CSA officials.)

4. As of 7 February 2010, 52 manned flights and 39 unmanned supply missions had been made to the International Space Station: 32 Space Shuttle flights (NASA) and 20 Soyuz flights (RKA), 37 unmanned Progress flights (RKA), one automated transfer vehicle (ESA) and one H-II Transfer Vehicle (JAXA) supply mission to the ISS.
5. For a schedule of the remaining missions to the ISS, see NASA, "Consolidated Launch Manifest: Space Shuttle flights and ISS Assembly Sequence Schedule."
6. Ibid.
7. United States General Accountability Office, "NASA: Challenges in Completing and Sustaining the International Space Station," Testimony Before the Subcommittee on Space and Aeronautics, Committee on Science and Technology, House of Representatives, Washington, DC, 24 April 2008.
8. Joel Achenbach, "Space Station Is Near Completion, Maybe the End," *The Washington Post,* 13 July 2009.
9. ESA, "Human spaceflight: How much does it cost?"
10. NASA, "Fiscal Year 2011 Budget Estimates," Washington, DC, 1 February 2010.
11. Jim Wilson, "Scientists Believe ISS Is Waste of Money," *Popular Mechanics*, December 2002.
12. Denis Legacey, "Is the International Space Station Really Worth It?" *Policy Options*, March 2001.
13. CSA, "International Space Station."
14. Figures obtained from CSA officials.
15. Legacey (2001).
16. An animated representation of Canadarm2 working in conjunction with Dextre can be viewed on the CSA website.
17. CSA, "What is the Canadarm2?"
18. CSA, "Mission STS-123 Timeline."
19. CSA, "Space Missions."
20. Société Radio Canada, "Laliberté dans l'espace," 30 September 2009.
21. JAXA, "HTV: H-II Transfer Vehicle," Brochure, n.d.
22. European Space Agency, *Automated Transfer Vehicle*, "ATV Flight Phases."
23. RIA [Russian Information Agency] Novosti, "Russia Needs Billions More to Complete Its ISS Segment," Moscow, 14 April 2008.
24. NASA, "Space Station Assembly: Russian Soyuz TMA Spacecraft."
25. NASA, "NASA Extends Contract with Russia's Federal Space Agency," News release, Washington, DC, 9 April 2007.
26. NASA, "NASA Extends Contract with Russian Federal Space Agency," News release, Washington, DC, 2 December 2008.
27. The "Russian Segment" refers to the part of the International Space Station that is operated and controlled by the Russian Federation space agency, namely the Zarya and Zvezda modules, and provides Russia with the right to nearly one-half of the crew time for the ISS.
28. NASA (2010).
29. ESA, "Joint Statement: International Space Station Heads of Agency," News release, 11 March 2010.