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The International Space Station: Canada's Involvement

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The International Space Station: Canada's Involvement
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THE INTERNATIONAL SPACE STATION: CANADA'S INVOLVEMENT*

1 INTRODUCTION

The International Space Station (ISS) is a research facility operated in low-Earth orbit by an international consortium of space agencies.[1] Assembly of the facility began in 1998 and was completed in 2011. Current plans provide for operation of the ISS until at least 2020.[2] This document presents background information about the space station and the contributions of the main participants, particularly Canada, in the project.

In 1984, United States president Ronald Reagan committed the U.S. 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 ESA agreed to participate.

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 agreement 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, it is an engineering test bed for the construction, operation and maintenance of complex systems in space.[3]

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, also called Canadarm2, and the Special Purpose Dextrous Manipulator, otherwise known as "Dextre" – and the Canadian Space Vision System, which provides 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 was estimated at about C$1.3 billion as of 31 March 2003.[4] This amount does not include the annual assembly, maintenance and utilization costs related to the involvement of the Canadian Space Agency (CSA) with the ISS program, which is estimated at C$44.3 million in 2012–2013.[5]

2 THE INTERNATIONAL 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 U.S. 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 Russia's participation in the ISS program.

In 1990, budget restrictions – along with some misgivings about the design of the proposed station – led the U.S. Congress to order the National Aeronautics and Space Administration (NASA) to review its design of the ISS 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 Assembly of the International Space Station

The assembly of the ISS began in November 1998 with the launch of the *Zarya* module into orbit by the Russian Space Agency, and was followed soon after by the transport of the *Unity* module by space shuttle *Endeavour* (STS-88) in December 1998. The third module, Z*vezda*, supplied by NASA's Russian partners, was launched in July 2000.[6] 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.[7] 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, to be carried out as time and facility space allow.

Initially, the completion date in the ISS construction schedule was 2006; however, the loss of the space shuttle *Columbia* (STS-107) and its crew in February 2003 grounded the shuttle fleet and postponed the construction of the ISS for more than two-and-a-half years. ISS assembly activity resumed with the delivery of the multi-purpose logistics module *Raffaello* by the crew of space shuttle *Discovery* (STS-114) in July 2005.[8]

In February 2007, ESA's laboratory module was delivered and assembled. Between March 2008 and July 2009, three separate shuttle missions delivered components of the Japanese Experiment Module. A new pressurized component from Russia, the Mini Research Module (MRM-1 or *Rassvet*) was attached to the earth-facing docking port of the *Zarya* module in May 2010.[9] Space shuttle missions STS-133 and STS-

134 completed the ISS assembly in 2011.[10] In July 2011, on the final space shuttle mission (STS-135), the crew of *Atlantis* performed a number of tasks, including deploying instruments, conducting scientific experiments and transferring supplies and consumables to the ISS.[11] Even as the assembly phase was completed, NASA already had 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 Government Accountability Office (GAO) reported that NASA struggled to contain costs and keep to the construction schedule throughout the ISS program.[12]

According to newspaper reports that cite 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).[13]

Other information sources set total ISS project cost estimates 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.

In 2005, ESA estimated that the total cost of the ISS program would be around €100 billion (or about C$151 billion, based on the annual average of the exchange rate). 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).[14]

The cost of operating the ISS will continue to rise, since the administration of U.S. President Barack Obama announced in June 2010 that it supported extending the lifetime of the ISS from 2016 to 2020 or even longer.[15] According to the most recent presidential budget request for fiscal year 2013, NASA's annual budget for ISS operations and support activities is US$4.013 billion. NASA's annual budget related to ISS activities is notionally set at US$4.035 billion for the next four fiscal years.[16]

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. The ISS has had many delays and cost overruns, and it is more modest in its dimensions and has a smaller crew and a lower capacity to carry out scientific activities than originally planned.[17] 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.[18]

3 CANADA'S SPACE STATION PROGRAM

3.1 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, C$919 million in contracts had been awarded to the Canadian aerospace industry.[19] According to a 2012 CSA audit, the total cost of Canada's participation in the construction of the ISS was C$1.245 billion as of 31 March 2003 for developing, designing and installing the MSS and about C$40 million in annual operating expenditures to maintain this participation since that date.[20]

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 those at times experienced in the nuclear industry, in mining and in offshore resource development. However, some observers have questioned 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.[21]

3.2 THE MOBILE SERVICING SYSTEM

In the past, Canada contributed to the U.S. space program with the very successful Canadarm, which flew on almost every space shuttle flight. It was logical, when Canada was asked to join the space station program, for it 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 country outside the United States 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 can be used to grapple and dock visiting automated ferry vehicles and to load and unload them. Canada is responsible for the total design, development and long-term operation of the MSS.

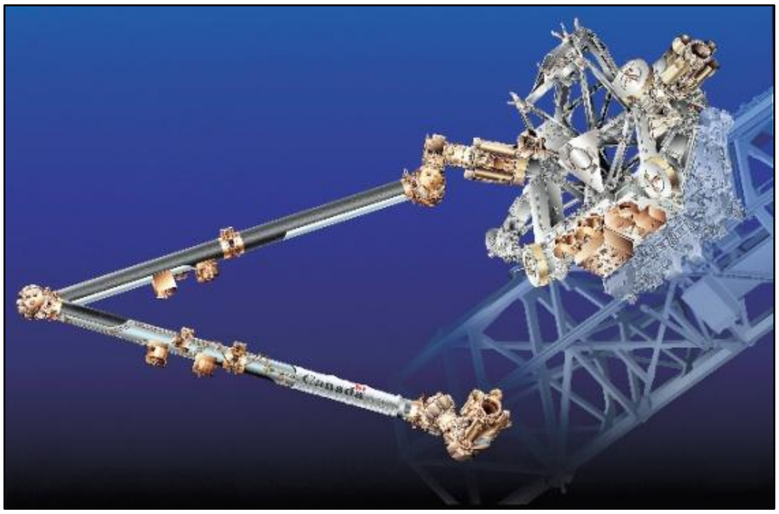
As can be seen in Figure 1, the MSS consists of two main elements: the Space Station Mobile Servicing System (Canadarm2) and the Special Purpose Dextrous Manipulator (Dextre). The remotely controlled manipulator arm, Canadarm2, has seven motor-driven, computer-controlled joints (rather than six, as in the first-generation Canadarm). The addition of the seventh joint enhances the arm's functionality, enabling the device to mimic most human arm movements.

Canadarm2 is 17.6 metres long and has a payload capacity of 116,000 kilograms. It was delivered to NASA in February 1999 and sent into space in April 2001 aboard the space shuttle *Endeavour*. The arm is attached to the Canadian-built mobile servicing base system. The base, in turn, is attached to the U.S.-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.[22]

Figure 1

A. Space Station Remote Manipulator 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 and Associates Ltd. (Richmond, British Columbia). 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.[23]

Canada's Space Station Program also includes highly sophisticated ground facilities. The ground-based segment is known as the MSS Operations Complex and is located at the CSA headquarters in Saint-Hubert, Quebec. It provides the infrastructure, resources, equipment and expertise for MSS space operations. The MSS Operations Complex 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 Space Station Remote Manipulator System Training Facility.

Canada's involvement in the ISS project is not limited to providing equipment and ground facilities to the ISS program; it also involves supplying crews who participate in 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 and December 2012–May 2013), Steve MacLean (September 2006), Dave Williams (August 2007), and Robert Thirsk, who in 2009 became the first Canadian astronaut to participate on a six-month mission on the ISS (May–December 2009).[24] Chris Hadfield will become the first Canadian commander of the ISS in March 2013.

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 was one of a number of space tourists participating in a special program promoted by the Russian Space Agency to help finance its activities.[25]

4 OTHER INTERNATIONAL CONTRIBUTIONS

4.1 *Kibo:* The Japanese Experiment Module

Japan's contribution to the space station project, the Japanese Experiment Module, 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*. The Japanese Experiment Module 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. The Japan Aerospace Exploration Agency plans to conduct one HTV cargo supply mission to the ISS per year from 2010 to 2017.[26]

4.2 *COLUMBUS*: THE EUROPEAN SPACE AGENCY PRESSURIZED MODULE

ESA developed a "multi-purpose" laboratory (*Columbus*) 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 U.S. 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 inside *Columbus*. *Columbus* was initially scheduled for launch in 2004, but was delivered and installed in February 2008.

ESA has also developed automated transfer vehicles (ATVs) to carry supplies to, and waste from, the ISS. ESA plans to deliver about 8 tonnes of cargo to the ISS by this means approximately every 18 months. The first ATV, 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.[27] To date, ESA has sent three ATVs to the ISS. A fourth ATV resupply mission is planned for early 2013.

4.3 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 U.S. 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. Initially, Russia had agreed to the use of its Proton heavy-lift vehicle (rocket) to launch other modules of the station.

The *Zvezda* Service Module is the most complex Russian contribution to the ISS. It served as the early living quarters for astronauts assembling the ISS and contains vital life-support and propulsion elements. It was originally scheduled to be launched in November 1999, but lack of financial resources and multiple rocket failures repeatedly postponed its delivery to the ISS. 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 initially agreed to supply. In addition, Russia was not able to provide the Proton-rocket launch support it had originally promised. Continuing financial problems in Russia raised serious concerns over the rising costs that would ensue if NASA ultimately had to supply the Russian elements. A number of U.S. and Russian modules planned for the ISS were cancelled in the face of budgetary pressures and ISS redesign following the *Columbia* accident. Some Russian modules were redesigned and eventually delivered by a space shuttle (e.g., the Russian Mini-Research Module 1 was delivered by space shuttle *Atlantis* to the ISS in May 2010).[28]

The loss of the *Columbia* in February 2003 postponed further shuttle launches and delayed the construction of the ISS for two-and-a-half years. As a result, the *Soyuz* spacecraft became the only means of transporting crews to the ISS. It was also decided, as a temporary measure, that the size of the long-duration crew for the ISS would be reduced from three to two persons to save on consumables (i.e., breathable air, water and food).[29] The unmanned Progress supply ships continue to provide resupply and logistical support to the ISS in the absence of the space shuttle. During the Expedition 20 mission (May–December 2009), the ISS long-duration (i.e., six months) crew complement returned to three crew members.

After the investigation of the *Columbia* accident, the U.S. government announced that it would be retiring the space shuttle program soon after ISS assembly was completed 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 the removal of refuse. The modification also provided an opportunity for an astronaut from one of the international ISS partners to spend approximately six months aboard the space station.[30]

Since 2007, NASA has renegotiated a number of contractual agreements with the Russian Federal Space Agency to provide for crew transportation services to the ISS. NASA signed the latest version in March 2011, agreeing to pay the Russian Space Agency US$753 million to ferry 12 crew members to the ISS. The fixed-price contract ends in June 2016 and provides for the launch of six crew members to the ISS in 2014 and six more in 2015, through to the return of the final group in spring 2016.[31]

In the meantime, NASA is extending funding to private partners to develop an American-made commercial crew and cargo transportation system to service the ISS by mid-decade.[32]

5 FURTHER DEVELOPMENTS

NASA funding of the ISS was originally expected to cease by 2015, with plans to take the station out of orbit by 2016. However, in 2010 the Obama administration proposed significant changes in U.S. space policy, including increasing use of the ISS to at least 2020.

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 U.S. 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 that all partners have a strong interest in continuing ISS operations as long as they continue 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.[33] In April 2011, NASA received a commitment from ESA to continue ISS operations to at least 2020.[34]

With the retirement of the space shuttle fleet, NASA is refocusing its priorities and resources to concentrate on:

- expanding exploration activities;
- conducting research and development;
- relying to a greater degree on private space flight technologies to transport crew and cargo to the ISS; and
- expanding its capabilities for human space exploration beyond low-Earth orbit by developing a successor space transportation system, which includes a new heavy-lift launch vehicle (the Space Launch System) and a crewed space capsule (the Orion Multi-Purpose Crew Vehicle).[35]

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 Administration – NASA), Russia (Russian Federal Space Agency – RKA), Japan (Japan Aerospace Exploration Agency – JAXA), Canada (Canadian Space Agency – CSA) and 11 European nations (through the European Space Agency – ESA): Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. (See NASA, "Space Station Assembly," *International Space Station*.) 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 has access to ISS facilities and a flight opportunity for one astronaut. Italy has a similar arrangement with the United States, despite its membership in ESA.

2. National Aeronautics and Space Administration [NASA], "International Cooperation at NASA," p. 25.

3. NASA, *The National Aeronautics and Space Administration (NASA) Research and Utilization Plan for the International Space Station (ISS): A Report to the Committee on Science of the United States House of Representatives and the Commitee on Commerce, Science, and Transportation of the United States Senate*, June 2006.

4. Canadian Space Agency [CSA], "International Space Station Assembly and Maintenance Operations Program Management Framework Audit (1.2.1.1)," September 2012, p. 6.

5. CSA, "Analysis of Program Activities by Strategic Outcome," Section 2 in *2012–2013 Estimates: Report on Plans and Priorities*, 2012, p. 21.

6. NASA, "Past Expeditions and Crews," *International Space Station Assembly*. See also RussianSpaceWeb.com, "A complete chronology of ISS missions."

7. As of 31 December 2012, and according to the U.S. and Russian space agencies' launch schedules, 71 crewed missions and 58 unmanned supply missions have been made to the International Space Station. These include:

   - 37 space shuttle flights (NASA);
   - 34 *Soyuz* flights (RKA);
   - 50 unmanned Progress resupply missions (RKA);
   - 3 European Automated Transfer Vehicles (ESA);
   - 3 Japanese H-II Transfer Vehicles (JAXA); and
   - 2 Dragon (U.S. private corporation Space-X) commercial resupply missions.

   These figures exclude the launch by Proton rocket of the first two major components of the ISS, that of the *Zarya* Functional Cargo Bloc in November 1998 and the Service Module *Zvezda* in July 2000.

8. NASA, "STS-114," *Mission Archives*.

9. NASA, "Final Planned Flight of Atlantis Delivers New 'Dawn,'" *Space Shuttle*.

10. NASA, "Shuttle Missions – 2011," *Space Shuttle*.

11. NASA, *STS-135: The Final Mission*, July 2011, p. 65. Soon after the STS-135 mission was completed, the space shuttle fleet was retired, and the entire 30-year-old shuttle program was wound down. NASA has delegated to the private sector the task of developing the next crewed vehicle to service the ISS. Meanwhile, NASA is developing its own successor vehicle to support manned exploration missions to the moon, near lunar space and Mars.

12. United States Government 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, 24 April 2008.

13. Joel Achenbach, "Space Station Is Near Completion, Maybe the End," *Washington Post,* 13 July 2009.

14. European Space Agency [ESA], "How much does it cost?," *International Space Station: Human Spaceflight and Exploration*.

15. Office of the President of the United States, *National Space Policy of the United States of America*, 28 June 2010.

16. NASA, "Space Operations," in *FY 2013 Budget Request*.

17. Mark K. Matthews, "International Space Station: Critics ask, where's the science?," *Los Angeles Times*, 10 May 2012.

18. Denis Legacey, "Is the International Space Station Really Worth It?," *Policy Options*, March 2001.

19. CSA, "International Space Station."

20. CSA (2012).

21. Legacey (2001).

22. An animated representation of Canadarm2 working in conjunction with Dextre can be viewed at CSA, "Canadarm2 and Dextre," Images and videos.

23. CSA, "2008: March," *Canadian Space Milestones*.

24. CSA, "Space Missions."

25. Société Radio-Canada, "Laliberté dans l'espace," 30 September 2009.

26. Japan Aerospace Exploration Agency, *H-IIB Launch Vehicle No. 3 (H-IIB F3): Overview*, p. 11.

27. ESA, "ATV Flight Phases," *Automated Transfer Vehicle*.

28. RIA [Russian Information Agency] Novosti, "Russia Needs Billions More To Complete Its ISS Segment," Moscow, 14 April 2008.

29. NASA, "Russian Soyuz TMA Spacecraft," *International Space Station*.

30. NASA, "NASA Extends Contract With Russia's Federal Space Agency," News release C07-18, 9 April 2007.

31. NASA, "NASA Extends Crew Flight Contract With Russian Space Agency Administrator; Bolden Repeats Call for American-Made Commercial Alternative," News release C11-013, 14 March 2011.

32. Ibid.

33. ESA, "Joint Statement: International Space Station Heads of Agency," News release, 11 March 2010.

34. NASA, "NASA Receives European Commitment To Continue Space Station," News release 11-125, 27 April 2011.

35. NASA, *NASA Exploration Destinations, Goals, and International Collaboration pursuant to the Conference Report (House Report 112-284) accompanying the FY 2012 Consolidated and Further Continuing Appropriations Act (P.L. 112-55)*, August 2012.