All About International Space Station (Structures & Programs)

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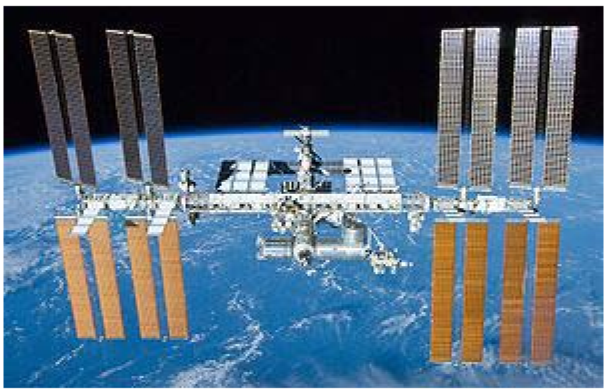
International Space Station

International Space Station



The International Space Station on 23 May 2010 as seen from the departing Space Shuttle *Atlantis* during STS-132.

ISS Insignia

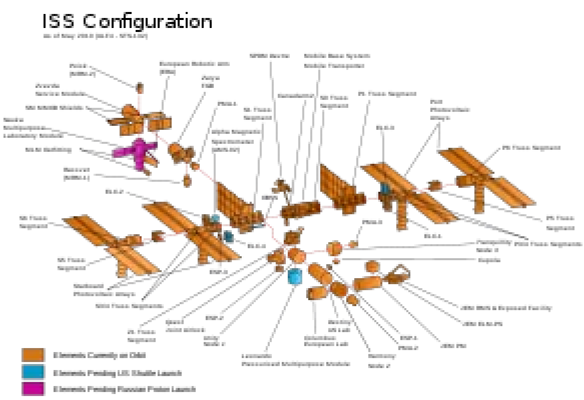
Station statistics

COSPAR ID	1998-067A
Call sign	*Alpha*
Crew	6
Launch	1998–2011
Launch pad	KSC LC-39, Baikonur LC-1/5 & LC-81/23

Mass	375,727 kg (828,340 lb)
Length	51 m (167.3 ft) from PMA-2 to *Zvezda*
Width	109 m (357.5 ft) along truss, arrays extended
Height	c. 20 m (c. 66 ft) nadir–zenith, arrays forward–aft (27 November 2009)
Pressurised volume	837 m^3 (29,561 cu ft)
Atmospheric pressure	101.3 kPa (29.91 inHg, 1 atm)
Perigee	347 km (187 nmi) AMSL (18 June 2010)
Apogee	360 km (194 nmi) AMSL (18 June 2010)
Orbital inclination	51.6 degrees
Average speed	7,706.6 m/s (27,743.8 km/h, 17,239.2 mph)
Orbital period	91 minutes
Days in orbit	4479 (24 February 2011)
Days occupied	3766 (24 February 2011)
Number of orbits	70305 (24 February 2011)
Orbital decay	2 km/month

Statistics as of 23 May 2010
(unless noted otherwise)

Configuration



Station elements as of 18 May 2010

The **International Space Station** (**ISS**) is an internationally developed research facility that is being assembled in low Earth orbit. On-orbit construction of the station began in 1998 and is scheduled for completion by late 2011. The station is expected to remain in operation until at least 2015, and likely 2020. With a greater cross-sectional area than that of any previous space station, the ISS can be seen from Earth with the naked eye, and is by far the largest artificial satellite that has ever orbited Earth. The ISS serves as a research laboratory that has a microgravity environment in which crews conduct experiments in biology, chemistry, medicine, physiology and physics, as well as astronomical and meteorological observations. The station provides a unique environment for the testing of the spacecraft systems that will be required for missions to the Moon and Mars. The ISS is operated by Expedition crews of six astronauts and cosmonauts, with the station programme maintaining an uninterrupted human presence in space since the launch of Expedition 1 on 31 October 2000, a total of 10 years and 116 days. The programme thus holds the current record for the longest uninterrupted human presence in space, surpassing the previous record of 3,644 days, set aboard *Mir*. As of 25 November 2010, the crew of Expedition 26 is aboard.

The ISS is a synthesis of several space station projects that include the American *Freedom*, the Soviet/Russian *Mir*-2, the European *Columbus* and the Japanese *Kibō*. Budget constraints led to the merger of these projects into a single multi-national programme. The ISS project began in 1994 with the Shuttle-*Mir* programme, and the first module of the station, *Zarya*, was launched in 1998 by Russia. Assembly continues, as pressurised modules, external trusses, and other components are launched by American space shuttles, Russian Proton rockets and Russian Soyuz rockets. As of May 2010, the station consists of fourteen pressurised modules and an extensive integrated truss structure (ITS). Power is provided by sixteen solar arrays mounted on the external truss, in addition to four smaller arrays on the Russian modules. The station is maintained at an orbit between 278 km (173 mi) and 460 km (286 mi) altitude, and travels at an average speed of 27,743.8 km/h (17,239.2 mph), completing 15.7 orbits per day.

Operated as a joint project between the five participant space agencies, the station's sections are controlled by mission control centres on the ground operated by the American National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), the Russian Federal Space Agency (ROSCOSMOS), the Japan Aerospace Exploration Agency (JAXA) and the Canadian Space Agency (CSA). The ownership and use of the space station is established in intergovernmental treaties and agreements that allow the Russian Federation to retain full ownership of its own modules in the Russian Orbital Segment, with the US Orbital Segment, the remainder of the station, allocated between the other international partners. The cost of the station has been estimated by ESA as €100 billion over 30 years, and, although estimates range from 35 to 160 billion US dollars, the ISS is believed to be the most expensive object ever constructed. The financing, research capabilities and technical design of the ISS programme have been criticised because of the high cost. The station is serviced by Soyuz spacecraft, Progress spacecraft, space shuttles, the Automated Transfer Vehicle and the H-II Transfer Vehicle, and has been visited by astronauts and cosmonauts from 15 different nations.

Purpose

The International Space Station (ISS) is an internationally developed habitable satellite currently being assembled in Low Earth Orbit. Primarily a research laboratory, the ISS offers an advantage over spacecraft such as NASA's Space Shuttle because it is a long-term platform in the space environment, where extended studies are conducted. The presence of a permanent crew affords the ability to monitor, replenish, repair, and replace experiments and components of the spacecraft itself. Scientists on Earth have swift access to the crew's data and can modify experiments or launch new ones, benefits generally unavailable on unmanned spacecraft.

Crews, who fly expeditions of several months duration, conduct scientific experiments each day (approximately 160 man-hours a week). As of the conclusion of Expedition 15, 138 major science investigations had been conducted on the ISS. Scientific findings, in fields from basic science to exploration research, are published every month.

The ISS provides a location in the relative safety of Low Earth Orbit to test spacecraft systems that will be required for long-duration missions to the Moon and Mars. This provides experience in the maintenance, repair, and replacement of systems on-orbit, which will be essential in operating spacecraft further from Earth. Mission risks are reduced, and the capabilities of interplanetary spacecraft are advanced.

Part of the crew's mission is educational outreach and international cooperation. The crew of the ISS provide opportunities for students on Earth by running student-developed experiments, making educational demonstrations, and allowing for student participation in classroom versions of ISS experiments, NASA investigator experiments, and ISS engineering activities. The ISS programme itself, with the international cooperation that it represents, allows 14 nations to live and work together in space, providing lessons for future multi-national missions.

Scientific research

Expedition 8 Commander and Science Officer Michael Foale conducts an inspection of the Microgravity Science Glovebox.

The ISS provides a platform to conduct experiments that require one or more of the unusual conditions present on the station. The primary fields of research include human research, space medicine, life sciences, physical sciences, astronomy and meteorology. The 2005 NASA Authorization Act designated the American segment of the International Space Station as a national laboratory with the goal of increasing the use of the ISS by other federal agencies and the private sector.

Research on the ISS improves knowledge about the effects of long-term space exposure on the human body. Subjects currently under study include muscle atrophy, bone loss, and fluid shift. The data will be used to determine whether space colonization and lengthy human spaceflight are feasible. As of 2006, data on bone loss and muscular atrophy suggest that there would be a significant risk of fractures and movement problems if astronauts landed on a planet after a lengthy interplanetary cruise (such as the six-month journey time required to fly to Mars). Large scale medical studies are conducted aboard the ISS via the National Space and Biomedical Research Institute (NSBRI). Prominent among these is the Advanced Diagnostic Ultrasound in Microgravity study in which astronauts (including former ISS Commanders Leroy Chiao and Gennady Padalka) perform ultrasound scans under the guidance of remote experts. The study considers the diagnosis and treatment of medical conditions in space. Usually, there is no physician onboard the ISS and diagnosis of medical conditions is a challenge.

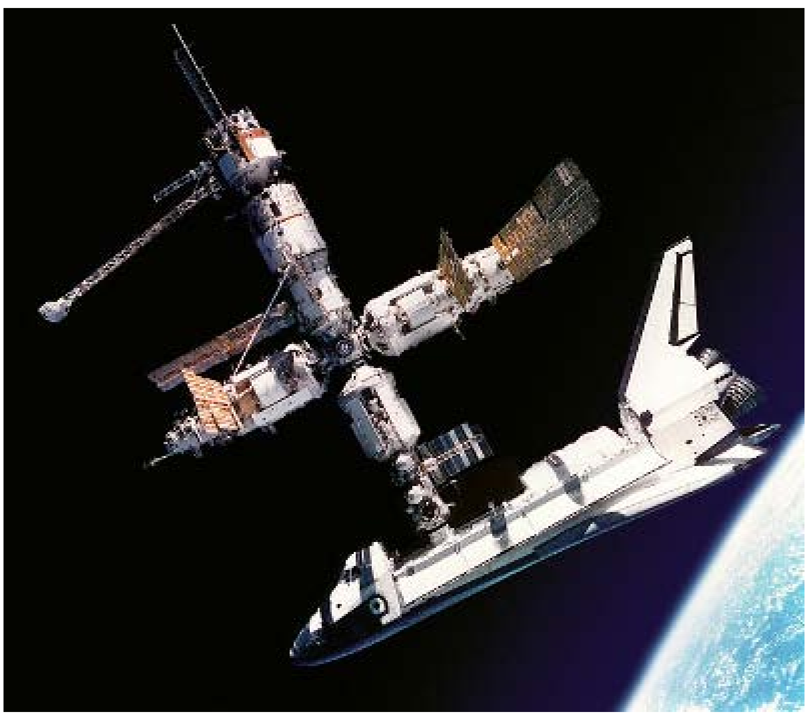
It is anticipated that remotely guided ultrasound scans will have application on Earth in emergency and rural care situations where access to a trained physician is difficult.

Researchers are investigating the effect of the station's near-weightless environment on the evolution, development, growth and internal processes of plants and animals. In response to some of this data, NASA wants to investigate microgravity's effects on the growth of three-dimensional, human-like tissues, and the unusual protein crystals that can be formed in space.

The investigation of the physics of fluids in microgravity will allow researchers to model the behaviour of fluids better. Because fluids can be almost completely combined in microgravity, physicists investigate fluids that do not mix well on Earth. In addition, an examination of reactions that are slowed by low gravity and temperatures will give scientists a deeper understanding of superconductivity.

The study of materials science is an important ISS research activity, with the objective of reaping economic benefits through the improvement of techniques used on the ground. Other areas of interest include the effect of the low gravity environment on combustion, through the study of the efficiency of burning and control of emissions and pollutants. These findings may improve our knowledge about energy production, and lead to economic and environmental benefits. Future plans are for the researchers aboard the ISS to examine aerosols, ozone, water vapour, and oxides in Earth's atmosphere, as well as cosmic rays, cosmic dust, antimatter, and dark matter in the universe.

Origins



Space Shuttle *Atlantis* docked to *Mir* on STS-71, during the Shuttle-Mir Program

The International Space Station represents a union of several national space station projects that originated during the Cold War. In the early 1980s, NASA planned to launch a modular space station called *Freedom* as a counterpart to the Soviet *Salyut* and *Mir* space stations, while the Soviets were planning to construct *Mir*-2 in the 1990s as a replacement for *Mir*. Because of budget and design constraints, *Freedom* never progressed past mock-ups and minor component tests.

With the fall of the Soviet Union and the end of the Space Race, *Freedom* was nearly cancelled by the United States House of Representatives. The post-Soviet economic chaos in Russia led to the cancellation of *Mir*-2, though only after its base block, DOS-8, had been constructed. Similar budgetary difficulties were faced by other nations with space station projects, which prompted the American government to negotiate with European states, Russia, Japan, and Canada in the early 1990s to begin a collaborative project.

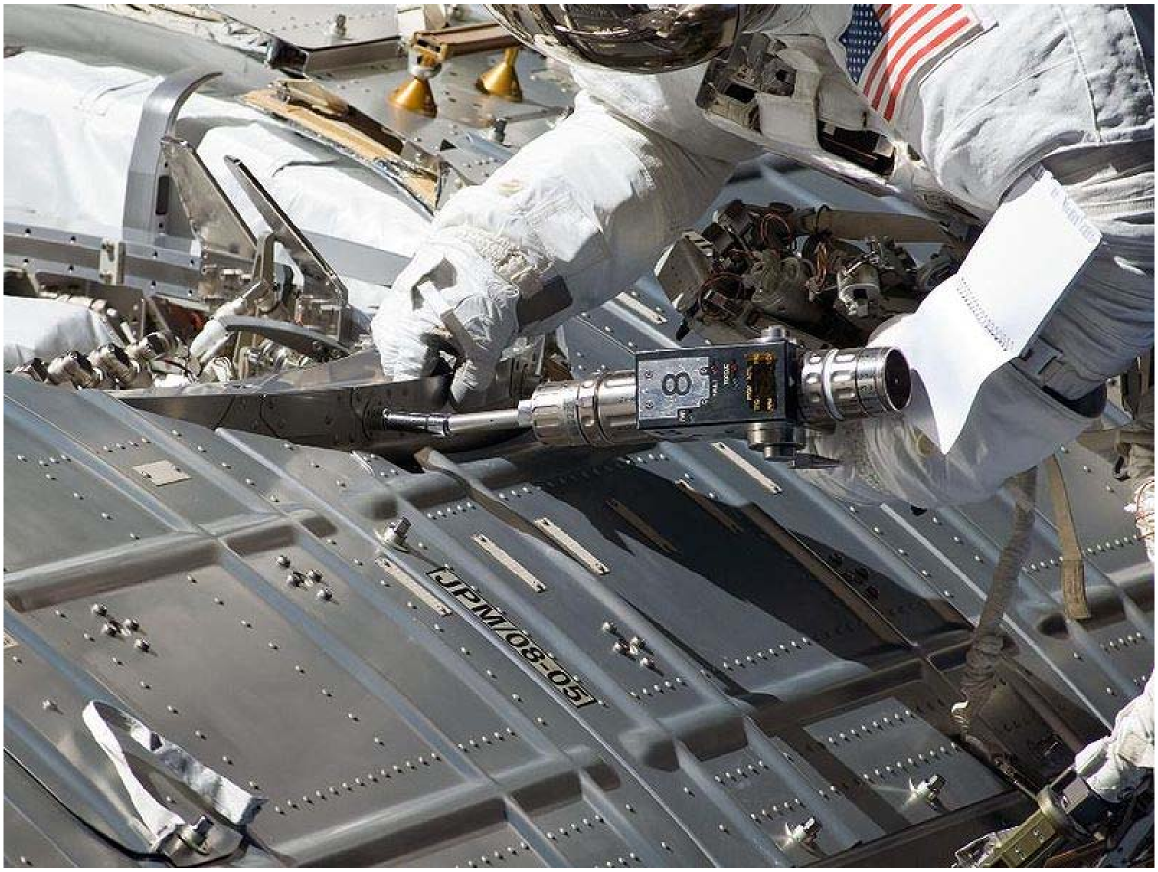
In June 1992 American president George H. W. Bush and Russian president Boris Yeltsin agreed to cooperate on space exploration. The resulting *Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes* called for a short, joint space programme, with one American astronaut deployed to the Russian space station *Mir* and two Russian cosmonauts deployed to a Space Shuttle.

In September 1993, American Vice-President Al Gore, Jr., and Russian Prime Minister Viktor Chernomyrdin announced plans for a new space station, which eventually became the International Space Station. They also agreed, in preparation for this new project, that the United States would be heavily involved in the *Mir* programme as part of an agreement that later included Space Shuttle orbiters docking with *Mir*.

According to the plan, the International Space Station programme would combine the proposed space stations of all participant agencies: NASA's *Freedom*, the RSA's *Mir*-2 (with DOS-8 later becoming *Zvezda*), ESA's *Columbus*, and the Japanese *Kibō* laboratory. When the first module, *Zarya*, was launched in 1998, the station was expected to be completed by 2003. Delays have led to a revised estimated completion date of 2011.

Station structure

Assembly



Astronaut Ron Garan during an STS-124 ISS assembly spacewalk

The assembly of the International Space Station, a major endeavour in space architecture, began in November 1998. Astronauts install each element using spacewalks. By 15

September 2010, they had completed 150, totalling 944 hours of extra-vehicular activity (EVA), all devoted to assembly and maintenance of the station. Twenty-eight of these spacewalks originated from the airlocks of docked Space Shuttles; the remaining 122 were launched from the station.

The first segment of the ISS, *Zarya*, was launched on 20 November 1998 on a Russian Proton rocket, followed two weeks later by *Unity*—the first of three node modules—which was launched aboard Space Shuttle flight STS-88. This bare two-module core of the ISS remained unmanned for the next one-and-a-half years. In July 2000 the Russian module *Zvezda* was added, allowing a maximum crew of three to occupy the ISS continuously. The first resident crew, Expedition 1, arrived in November 2000 on Soyuz TM-31, midway between the flights of STS-92 and STS-97. These two Space Shuttle flights each added segments of the station's Integrated Truss Structure, which provided the embryonic station with communications, guidance, electrical grounding (on Z1), and power via solar arrays located on the P6 truss.

Over the next two years the station continued to expand. A Soyuz-U rocket delivered the *Pirs* docking compartment. The Space Shuttles *Discovery*, *Atlantis*, and *Endeavour* delivered the *Destiny* laboratory and *Quest* airlock, in addition to the station's main robot arm, the *Canadarm2*, and several more segments of the Integrated Truss Structure.

The expansion schedule was interrupted by the destruction of the Space Shuttle *Columbia* on STS-107 in 2003, with the resulting hiatus in the Space Shuttle programme halting station assembly until the launch of *Discovery* on STS-114 in 2005.

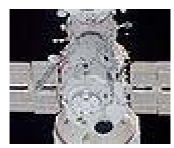
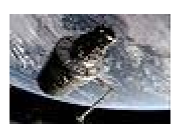
The official resumption of assembly was marked by the arrival of *Atlantis*, flying STS-115, which delivered the station's second set of solar arrays. Several more truss segments and a third set of arrays were delivered on STS-116, STS-117, and STS-118. As a result of the major expansion of the station's power-generating capabilities, more pressurised modules could be accommodated, and the *Harmony* node and *Columbus* European laboratory were added. These were followed shortly after by the first two components of *Kibō*. In March 2009, STS-119 completed the Integrated Truss Structure with the installation of the fourth and final set of solar arrays. The final section of *Kibō* was delivered in July 2009 on STS-127, followed by the Russian *Poisk* module. The third node, *Tranquility*, was delivered in February 2010 during STS-130 by the Space Shuttle *Endeavour*, alongside the Cupola, closely followed in May 2010 by the penultimate Russian module, *Rassvet*, delivered by Space Shuttle *Atlantis* on STS-132.

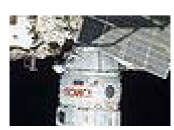
As of May 2010, the station consisted of fourteen pressurised modules and the complete Integrated Truss Structure. Still to be launched is the Permanent Multipurpose Module *Leonardo*, the Russian Multipurpose Laboratory Module *Nauka* and a number of external components, including the European Robotic Arm and Alpha Magnetic Spectrometer (AMS-02). Assembly is expected to be completed by 2011, by which point the station will have a mass in excess of 400 metric tons (440 short tons).

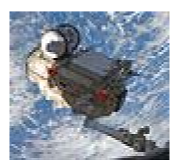
Pressurised modules

When completed, the ISS will consist of sixteen pressurised modules with a combined volume of around 1,000 cubic metres (35,000 cu ft). These modules include laboratories, docking compartments, airlocks, nodes and living quarters. Fourteen of these components are already in orbit, with the remaining two awaiting launch. Each module was or will be launched either by the Space Shuttle, Proton rocket or Soyuz rocket.

Module	Assembly mission	Launch date	Launch system	Nation	Isolated view	Notes
Zarya (lit. *dawn*) (FGB)	1A/R	20 November 1998	Proton-K	Russia (builder) USA (financier)		
	The first component of the ISS to be launched, *Zarya* provided electrical power, storage, propulsion, and guidance during initial assembly. The module now serves as a storage compartment, both inside the pressurised section and in the externally mounted fuel tanks.					
Unity (Node 1)	2A	4 December 1998	Space Shuttle *Endeavour*, STS-88	USA		
	The first node module, connecting the American section of the station to the Russian section (via PMA-1), and providing berthing locations for the Z1 truss, *Quest* airlock, *Destiny* laboratory and *Tranquility* node.					
Zvezda (lit. *star*) (service module)	1R	12 July 2000	Proton-K	Russia		
	The station's service module, which provides the main living quarters for resident crews, environmental systems and attitude & orbit control. The module also provides docking locations for Soyuz spacecraft, Progress spacecraft and the Automated Transfer Vehicle, and its addition rendered the ISS permanently habitable for the first time.					
Destiny (US laboratory)	5A	7 February 2001	Space Shuttle *Atlantis*, STS-98	USA		
	The primary research facility for US payloads aboard					

	the ISS, *Destiny* is intended for general experiments. The module houses 24 International Standard Payload Racks, some of which are used for environmental systems and crew daily living equipment, and features a 51-centimetre (20 in) optically perfect window, the largest such window ever produced for use in space. *Destiny* also serves as the mounting point for most of the station's Integrated Truss Structure.				
Quest (joint airlock)	7A	12 July 2001	Space Shuttle *Atlantis*, STS-104	USA	
	The primary airlock for the ISS, *Quest* hosts spacewalks with both US EMU and Russian Orlan spacesuits. *Quest* consists of two segments; the equipment lock, that stores spacesuits and equipment, and the crew lock, from which astronauts can exit into space.				
Pirs (lit. *pier*) (docking compartment)	4R	14 September 2001	Soyuz-U, Progress M-SO1	Russia	
	Pirs provides the ISS with additional docking ports for Soyuz and Progress spacecraft, and allows egress and ingress for spacewalks by cosmonauts using Russian Orlan spacesuits, in addition to providing storage space for these spacesuits.				
Harmony (node 2)	10A	23 October 2007	Space Shuttle *Discovery*, STS-120	Europe (builder) USA (operator)	
	The second of the station's node modules, *Harmony* is the utility hub of the ISS. The module contains four racks that provide electrical power, bus electronic data, and acts as a central connecting point for several other components via its six Common Berthing Mechanisms (CBMs). The European *Columbus* and Japanese *Kibō* laboratories are permanently berthed to the module, and American Space Shuttle Orbiters dock with the ISS via PMA-2, attached to *Harmony*'s forward port. In addition, the module serves as a berthing port for the Italian Multi-Purpose Logistics Modules during shuttle logistics flights.				
Columbus	1E	7	Space	Europe	

(European laboratory)		February 2008	Shuttle *Atlantis*, STS-122		
	The primary research facility for European payloads aboard the ISS, *Columbus* provides a generic laboratory as well as facilities specifically designed for biology, biomedical research and fluid physics. Several mounting locations are affixed to the exterior of the module, which provide power and data to external experiments such as the European Technology Exposure Facility (EuTEF), Solar Monitoring Observatory, Materials International Space Station Experiment, and Atomic Clock Ensemble in Space. A number of expansions are planned for the module to study quantum physics and cosmology.				
Kibō Experiment Logistics Module (lit. *hope* and *wish* JEM–ELM)	1J/A	11 March 2008	Space Shuttle *Endeavour*, STS-123	Japan	
	Part of the *Kibō* Japanese Experiment Module laboratory, the ELM provides storage and transportation facilities to the laboratory with a pressurised section to serve internal payloads.				
Kibō Pressurised Module (JEM–PM)	1J	31 May 2008	Space Shuttle *Discovery*, STS-124	Japan	
	Part of the *Kibō* Japanese Experiment Module laboratory, the PM is the core module of *Kibō* to which the ELM and Exposed Facility are berthed. The laboratory is the largest single ISS module and contains a total of 23 racks, including 10 experiment racks. The module is used to carry out research in space medicine, biology, Earth observations, materials production, biotechnology, and communications research. The PM also serves as the mounting location for an external platform, the Exposed Facility (EF), that allows payloads to be directly exposed to the harsh space environment. The EF is serviced by the module's own robotic arm, the JEM–RMS, which is mounted on the PM.				
Poisk (lit. 'search') (mini-	5R	10 November 2009	Soyuz-U, Progress M-MIM2	Russia	

research module 2)	One of the Russian ISS components, *Poisk* is used for docking of Soyuz and Progress ships, as an airlock for spacewalks and as an interface for scientific experiments.				
Tranquility (node 3)	20A	8 February 2010	Space Shuttle *Endeavour*, STS-130	Europe (builder) USA (operator)	
	The third and last of the station's US nodes, *Tranquility* contains an advanced life support system to recycle waste water for crew use and generate oxygen for the crew to breathe. The node also provides four berthing locations for more attached pressurised modules or crew transportation vehicles, in addition to the permanent berthing location for the station's Cupola.				
Cupola	20A	8 February 2010	Space Shuttle *Endeavour*, STS-130	Europe (builder) USA (operator)	
	The Cupola is an observatory module that provides ISS crew members with a direct view of robotic operations and docked spacecraft, as well as an observation point for watching the Earth. The module comes equipped with robotic workstations for operating the SSRMS and shutters to protect its windows from damage caused by micrometeorites.				
Rassvet (lit. *dawn*) (mini-research module 1)	ULF4	14 May 2010	Space Shuttle *Atlantis*, STS-132	Russia	
	Rassvet is being used for docking and cargo storage aboard the station.				

Scheduled to be launched

Module	Assembly mission	Launch date	Launch system	Nation	Isolated view	Notes
	ULF5	24 February 2011	Space Shuttle *Discovery*, STS-133	Italy (Builder) USA (Operator)		
Leonardo (Permanent Multipurpose Module)	The *Leonardo* PMM will house spare parts and supplies, allowing longer times between resupply missions and freeing space in other modules, particularly *Columbus*. The PMM was created by converting the Italian *Leonardo* Multi-Purpose Logistics Module into a module that could be permanently attached to the station. The arrival of the module will mark the completion of the US Orbital Segment.					
	3R	c. December 2011	Proton-M	Russia		
Nauka (lit. 'science') (Multipurpose Laboratory Module)	The MLM will be Russia's primary research module as part of the ISS and will be used for general microgravity experiments, docking, and cargo logistics. The module provides a crew work and rest area, and will be equipped with a backup attitude control system that can be used to control the station's attitude. Based on the current assembly schedule, the arrival of *Nauka* will complete construction of the Russian Orbital Segment and it will be the last major component added to the station.					

Cancelled modules

The prototype X-38 lifting body, the cancelled ISS Crew Return Vehicle

Several modules planned for the station have been cancelled over the course of the ISS programme, whether for budgetary reasons, because the modules became unnecessary, or following a redesign of the station after the 2003 *Columbia* disaster. The cancelled modules include:

- The US Centrifuge Accommodations Module for experiments in varying levels of artificial gravity.
- The US Habitation Module, which would have served as the station's living quarters. The sleep stations are now spread throughout the station.
- The US Crew Return Vehicle would have served as the station's lifeboat; a service now provided by one Soyuz spacecraft for every three crew members aboard.
- The US Interim Control Module and ISS Propulsion Module were intended to replace functions of *Zvezda* in case of a launch failure.
- The Russian Universal Docking Module, to which the cancelled Russian Research modules and spacecraft would have docked.
- The Russian Science Power Platform would have provided the Russian Orbital Segment with a power supply independent of the ITS solar arrays.
- Two Russian Research Modules that were planned to be used for scientific research.

Unpressurised elements

Astronaut Stephen K. Robinson anchored to the end of Canadarm2 during STS-114

In addition to the pressurised modules, the ISS features a large number of external components. The largest component is the Integrated Truss Structure (ITS), to which the station's main solar arrays and thermal radiators are mounted. The ITS consists of ten separate segments forming a structure 108.5 m (356 ft) long.

The Alpha Magnetic Spectrometer (AMS), a particle physics experiment, is scheduled to be launched on STS-134 in 2011, and will be mounted externally on the ITS. The AMS will measure cosmic rays and look for evidence of dark matter and antimatter.

The ITS serves as a base for the main remote manipulator system called the Mobile Servicing System (MSS). This consists of the Mobile Base System (MBS), the Canadarm2, and the Special Purpose Dexterous Manipulator. The MBS rolls along rails built into some of the ITS segments to allow the arm to reach all parts of the US segment of the station. The MSS is due to have its reach increased by an Orbiter Boom Sensor System, scheduled for installation during the STS-133 mission.

Two other remote manipulator systems are present in the station's final configuration. The European Robotic Arm, which will service the Russian Orbital Segment, will be launched alongside the Multipurpose Laboratory Module. The JEM RMS, which services the JEM Exposed Facility, was launched on STS-124 and is attached to the JEM Pressurised Module. In addition to these robotic arms, there are two Russian *Strela* cargo cranes used for moving spacewalking cosmonauts and parts around the exterior of the Russian Orbital Segment.

The station in its complete form will have several smaller external components, such as the three External Stowage Platforms (ESPs), launched on STS-102, STS-114 and STS-118, which are used to store spare parts. Four ExPRESS Logistics Carriers (ELCs) will allow experiments to be deployed and conducted in the vacuum of space, and will provide the necessary electricity and computing to process experimental data locally. ELCs 1 and 2 were delivered on STS-129 in November 2009, and ELCs 3 and 4 are scheduled for delivery on STS-134 in November 2010 and STS-133 in September 2010. There are two exposure facilities mounted directly to laboratory modules: the JEM Exposed Facility serves as an external 'porch' for the Japanese Experiment Module complex, and a facility on the European *Columbus* laboratory provides power and data connections for experiments such as the European Technology Exposure Facility and the Atomic Clock Ensemble in Space.

Power supply

The ISS in 2001, showing the solar arrays on *Zarya* and *Zvezda*, in addition to the US P6 solar arrays

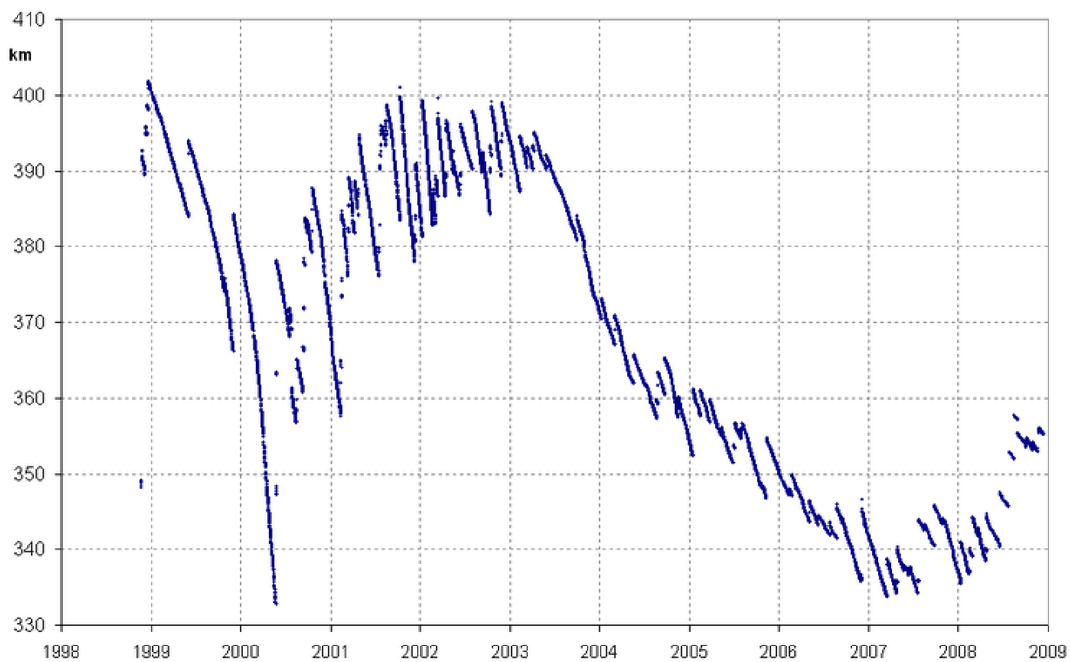
Photovoltaic (PV) arrays power the ISS. The Russian segment of the station, like the space shuttle and most aircraft, uses 28 volt DC partly provided by four solar arrays mounted directly to *Zarya* and *Zvezda*. The rest of the station uses 130–180 V DC from the US PV array arranged as four wing pairs. Each wing produces nearly 32.8 kW.

Power is stabilised and distributed at 160 V DC and converted to the user-required 124 V DC. The higher distribution voltage allows smaller, lighter conductors. The two station segments share power with converters, essential since the cancellation of the Russian Science Power Platform made the Russian Orbital Segment dependent on the US arrays.

The station uses rechargeable nickel-hydrogen batteries for continuous power during the 35 minutes of every 90 minute orbit that it is eclipsed by the Earth. The batteries are recharged on the day side of the earth. They have a 6.5 year lifetime (over 37,000 charge/discharge cycles) and will be regularly replaced over the anticipated 20-year life of the station.

The US solar arrays normally track the sun to maximise power generation. Each array is about 375 m^2 (450 yd^2) in area and 58 metres (63 yd) long. In the complete configuration, the solar arrays track the sun by rotating the *alpha gimbal* once per orbit while the *beta gimbal* follows slower changes in the angle of the sun to the orbital plane. The Night Glider mode aligns the solar arrays parallel to the velocity vector at night to reduce the significant aerodynamic drag at the station's relatively low orbital altitude.

Orbit control



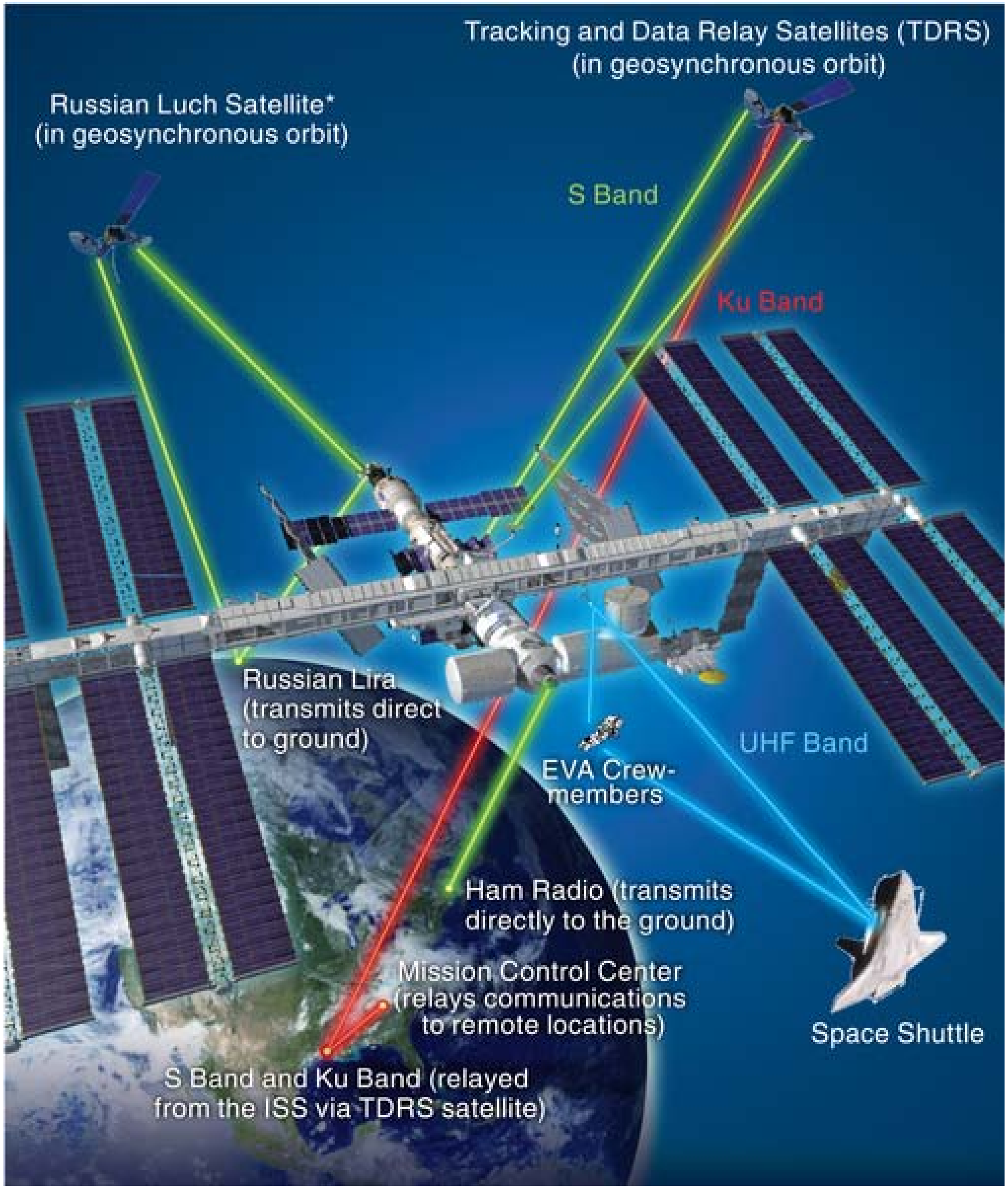
Graph showing the changing altitude of the ISS from November 1998 until January 2009

The ISS is maintained in a nearly circular orbit with a minimum mean altitude of 278 km (173 mi) and a maximum of 460 km (286 mi). It travels at an average speed of 27,724 kilometres (17,227 mi) per hour, and completes 15.7 orbits per day. The normal maximum altitude is 425 km (264 mi) to allow Soyuz rendezvous missions. As the ISS constantly loses altitude because of a slight atmospheric drag, it needs to be boosted to a higher altitude several times each year. This boost can be performed by the station's two main engines on the *Zvezda* service module, a docked space shuttle, a Progress resupply vessel, or by ESA's ATV. It takes approximately two orbits (three hours) for the boost to a higher altitude to be completed.

In December 2008 NASA signed an agreement with the Ad Astra Rocket Company which may result in the testing on the ISS of a VASIMR plasma propulsion engine. This technology could allow station-keeping to be done more economically than at present. The station's navigational position and velocity, or state vector, is independently established using the US Global Positioning System (GPS) and a combination of state vector updates from Russian Ground Sites and the Russian GLONASS system.

The attitude (orientation) of the station is independently determined by a set of sun, star and horizon sensors on *Zvezda* and the US GPS with antennas on the S0 truss and a receiver processor in the US lab. The attitude knowledge is propagated between updates by rate sensors. Attitude control is maintained by either of two mechanisms; normally, a system of four control moment gyroscopes (CMGs) keeps the station oriented, with *Destiny* forward of *Unity*, the P truss on the port side, and *Rassvet* on the Earth-facing (nadir) side. When the CMG system becomes 'saturated'—when the set of CMGs exceed their operational range or cannot track a series of rapid movements—they can lose their ability to control station attitude. In this event, the Russian attitude control system is designed to provide desaturating thruster firings, taking over automatically whilst the CMG system is reset. This automatic attitude control safing has only occurred once, during Expedition 10. When a space shuttle is docked to the station, it can also be used to maintain station attitude. This occurs during portions of every mated shuttle ISS mission. Shuttle control was used exclusively during STS-117 as the S3/S4 truss was installed.

Communications



The communications systems used by the ISS

* Luch satellite not currently in use.

Radio communications provide telemetry and scientific data links between the station and Mission Control Centres. Radio links are also used during rendezvous and docking procedures and for audio and video communication between crewmembers, flight controllers and family members. As a result, the ISS is equipped with internal and external communication systems used for different purposes.

The Russian Orbital Segment communicates directly with the ground via the *Lira* antenna mounted to *Zvezda*. The *Lira* antenna also has the capability to use the *Luch* data relay satellite system. This system, used for communications with *Mir*, fell into disrepair during the 1990s, and as a result is no longer in use, although two new *Luch* satellites—*Luch*-5A and *Luch*-5B—are planned for launch in 2011 to restore the operational capability of the system. Another Russian communications system is the Voskhod-M, which enables internal telephone communications between *Zvezda*, *Zarya*, *Pirs*, *Poisk* and the USOS, and also provides a VHF radio link to ground control centres via antennas on *Zvezda's* exterior.

The US Orbital Segment (USOS) makes use of two separate radio links mounted in the Z1 truss structure: the S band (used for audio) and K_u band (used for audio, video and data) systems. These transmissions are routed via the US Tracking and Data Relay Satellite System (TDRSS) in geostationary orbit, which allows for almost continuous real-time communications with NASA's Mission Control Center (MCC-H) in Houston. Data channels for the Canadarm2, European *Columbus* laboratory and Japanese *Kibō* modules are routed via the S band and K_u band systems, although the European Data Relay Satellite System and a similar Japanese system will eventually complement the TDRSS in this role. Communications between modules are carried on an internal digital wireless network.

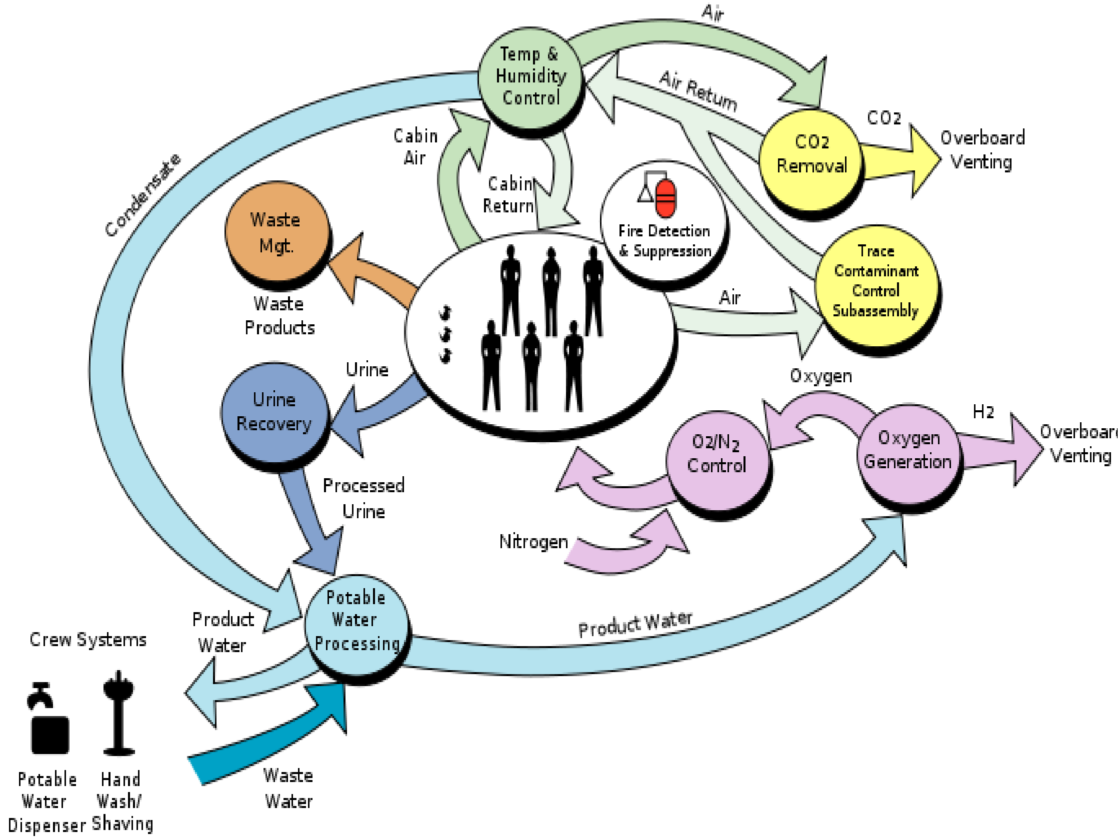
UHF radio is used by astronauts and cosmonauts conducting EVAs. UHF is employed by other spacecraft that dock to or undock from the station, such as Soyuz, Progress, HTV, ATV and the Space Shuttle (except the shuttle also makes use of the S band and K_u band systems via TDRSS), to receive commands from Mission Control and ISS crewmembers. Automated spacecraft are fitted with their own communications equipment; the ATV uses a laser attached to the spacecraft and equipment attached to *Zvezda*, known as the Proximity Communications Equipment, to accurately dock to the station.

Microgravity

At the station's orbital altitude, the gravity from the Earth is 88% of that at sea level. While the constant free fall of the ISS offers a perceived sensation of weightlessness, the environment onboard is not one of weightlessness or zero-gravity, instead often being described as microgravity. This state of perceived weightlessness is not perfect, however, being disturbed by four separate effects:

- The drag resulting from the residual atmosphere.
- Vibratory acceleration caused by mechanical systems and the crew on board the ISS.
- Orbital corrections by the on-board gyroscopes or thrusters.
- The spatial separation from the real centre of mass of the ISS. Any part of the ISS not at the exact centre of mass will tend to follow its own orbit. However, as each point is physically part of the station, this is impossible, and so each component is subject to small accelerations from the forces which keep them attached to the station as it orbits. This is also called the tidal force.
- The differences in orbital plane between different locations aboard the ISS.

Life support



The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS)

The ISS Environmental Control and Life Support System (ECLSS) provides or controls atmospheric pressure, fire detection and suppression, oxygen levels, waste management and water supply. The highest priority for the ECLSS is the ISS atmosphere, but the system also collects, processes, and stores waste and water produced and used by the crew—a process that recycles fluid from the sink, toilet, and condensation from the air. The *Elektron* system aboard *Zvezda* and a similar system in *Destiny* generate oxygen aboard the station. The crew has a backup option in the form of bottled oxygen and Solid Fuel Oxygen Generation (SFOG) canisters. Carbon dioxide is removed from the air by the Vozdukh system in *Zvezda*. Other by-products of human metabolism, such as methane from the intestines and ammonia from sweat, are removed by activated charcoal filters.

The atmosphere on board the ISS is similar to the Earth's. Normal air pressure on the ISS is 101.3 kPa (14.7 psi); the same as at sea level on Earth. An Earth-like atmosphere offers benefits for crew comfort, and is much safer than the alternative, a pure oxygen atmosphere, because of the increased risk of a fire such as that responsible for the deaths of the Apollo 1 crew.

Sightings

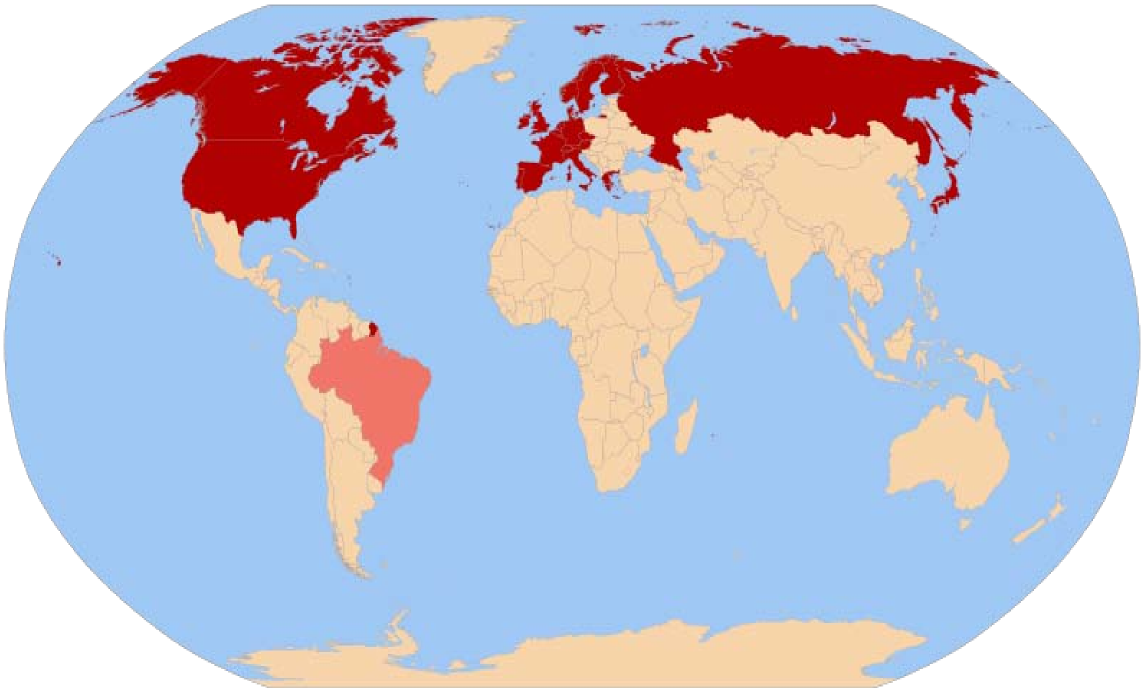
A January 2008 sighting of the International Space Station in a time exposure

Because of the size of the ISS (about that of an American football field) and the large reflective area offered by its solar panels, ground based observation of the station is possible with the naked eye if the observer is in the right location at the right time. In many cases, the station is one of the brightest naked-eye objects in the sky, although it is visible only for periods ranging from two to five minutes.

If the following conditions are fulfilled (assuming the weather is clear), the station will appear as a very bright object in the sky: The station must be above the observer's horizon, and it must pass within about 2,000 kilometres (1,200 mi) of the observation site (the closer the better). It must be dark enough at the observer's location for stars to be visible, and the station must be in sunlight rather than in the Earth's shadow. It is common for the third condition to begin or end during what would otherwise be a good viewing opportunity. In the evening, as the station moves further from the dusk, going from west to east it will appear to suddenly fade and disappear. In the reverse situation, it may suddenly appear in the sky as it approaches the dawn. With the station's maximum theoretical brightness at approximately magnitude −5.9 (with a typical maximum of −3.8), it is bright enough to be spotted during broad daylight conditions without optical aid.

Politics, utilisation and financing

Legal aspects



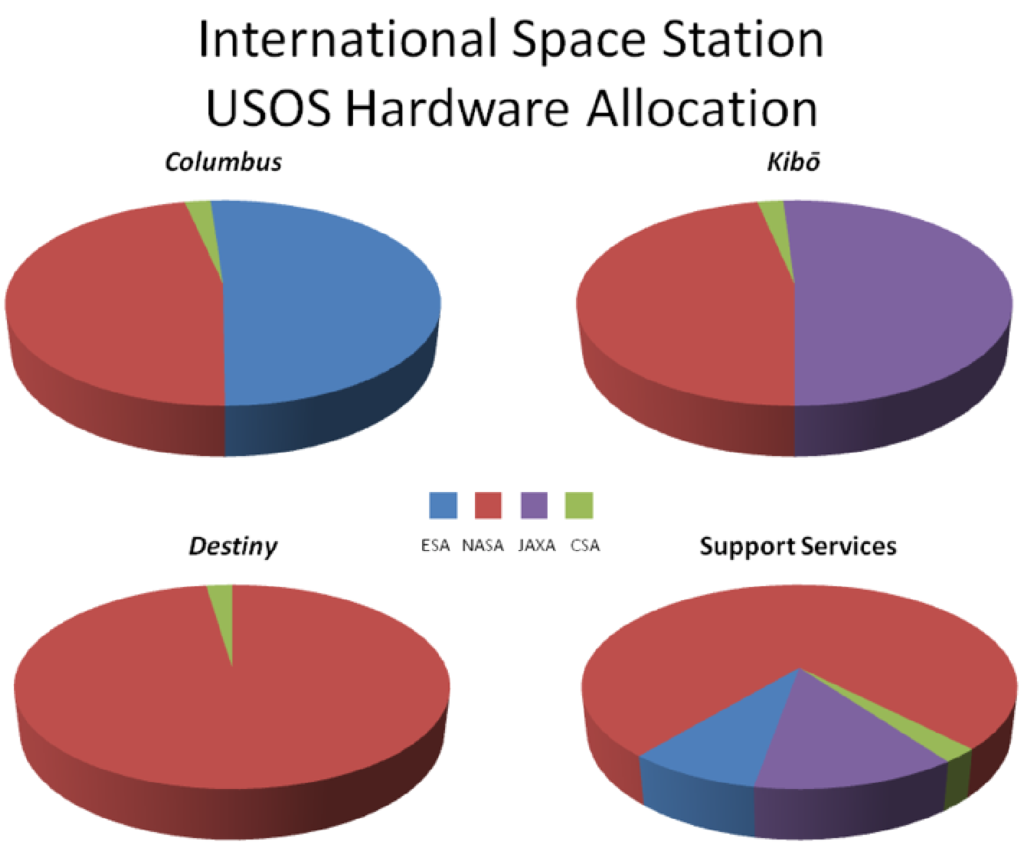
Primary contributing nations
NASA contracted nations

The ISS is a joint project of several space agencies: the US National Aeronautics and Space Administration (NASA), the Russian Federal Space Agency (RKA), the Japan Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA) and the European Space Agency (ESA).

As a multinational project, the legal and financial aspects are complex. Issues of concern include the ownership of modules, station utilisation by participant nations, and responsibilities for station resupply. Obligations and rights are established by the Space Station Intergovernmental Agreement (IGA). This international treaty was signed on 28 January 1998 by the primary nations involved in the Space Station project; the United States of America, Russia, Japan, Canada and eleven member states of the European Space Agency (Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom). A second layer of agreements was then achieved, called Memoranda of Understanding (MOU), between NASA and ESA, CSA, RKA and JAXA. These agreements are then further split, such as for the contractual obligations between nations, and trading of partners' rights and obligations. Use of the Russian Orbital Segment is also negotiated at this level.

In addition to these main intergovernmental agreements, Brazil joins as a bilateral partner of the United States by a contract with NASA to supply hardware. In return, NASA will provide Brazil with access to its ISS facilities on-orbit, as well as a flight opportunity for one Brazilian astronaut during the course of the ISS programme. Italy has a similar contract with NASA to provide comparable services, although Italy also takes part in the programme directly via its membership in ESA. China has reportedly expressed interest in the project, especially if it would be able to work with the RKA. However, as of December 2010 China is not involved because of US objections. The heads of both the South Korean and Indian space agency ISRO announced at the first plenary session of the 2009 International Astronautical Congress that their nations intend to join the ISS programme, with talks due to begin in 2010. The heads of agency also expressed support for extending ISS lifetime. European countries not a part of the International Space Station program will be allowed access to the station in a three-year trial period, ESA officials say.

Utilisation rights



Allocation of American segment hardware utilisation between nations

The Russian part of the station is operated and controlled by the Russian Federation's space agency and provides Russia with the right to nearly one-half of the crew time for the ISS. The allocation of remaining crew time (three to four crew members of the total permanent crew of six) and hardware within the other sections of the station has been assigned as follows:

- *Columbus*: 51% for the ESA, 46.7% for NASA, and 2.3% for CSA.
- *Kibō*: 51% for the JAXA, 46.7% for NASA, and 2.3% for CSA.
- *Destiny*: 97.7% for NASA and 2.3% for CSA.
- Crew time, electrical power and rights to purchase supporting services (such as data upload and download and communications) are divided 76.6% for NASA, 12.8% for JAXA, 8.3% for ESA, and 2.3% for CSA.

Costs

The cost estimates for the ISS range from 35 billion to 160 billion dollars. ESA, the one agency which actually presents potential overall costs, estimates €100 billion for the entire station over 30 years. A precise cost estimate for the ISS is unclear, as it is difficult to determine which costs should be attributed to the ISS programme, or how the Russian contribution should be measured.

Criticism

Critics of the ISS contend that the time and money spent on the ISS could be better spent on other projects—whether they be robotic spacecraft missions, space exploration, investigations of problems on Earth, colonisation of Mars, or just tax savings. Some critics, such as Robert L. Park, argue that little scientific research was convincingly planned for the ISS, and that the primary feature of a space-based laboratory, its microgravity environment, can be studied less expensively with a "vomit comet".

The research capabilities of the ISS have been criticised, particularly following the cancellation of the ambitious Centrifuge Accommodations Module, which, alongside other equipment cancellations, means scientific research performed on the station is generally limited to experiments which do not require any specialised apparatus. For example, in the first half of 2007, ISS research dealt primarily with human biological responses to living and working in space, covering topics like kidney stones, circadian rhythm, and the effects of cosmic rays on the nervous system. Other criticisms hinge on the technical design of the ISS, including the high inclination of the station's orbit, which leads to a higher cost for US-based launches to the station.

End of mission and deorbit plans

NASA had planned to deorbit the ISS in the first quarter of 2016. However, the plan to end the ISS programme in 2015, as determined in 2004 by then-President George W. Bush, has been rejected by the current Obama administration. With the new budget announced on 1 February 2010, the administration aims to extend the lifetime through 2020. The Augustine Commission, which reviewed NASA's human space flight program, recommended in its final report of 23 October 2009 the extension of the ISS programme to at least 2020. In particular, Leroy Chiao, a former space station commander and space shuttle astronaut who sat on the advisory panel, stated in a CNN interview: "You've got all of these different countries working together on this common project in space. And if we go ahead and stop [...] it is going to break up that framework.

The different countries around the world will lose confidence in the US as a leader in space exploration." NASA officials received confirmation from the Obama administration on the future direction of the ISS in particular and the human spaceflight programme in general on 1 February 2010, with a budget proposing an extension to the ISS programme until at least 2020, with talks between ISS partners suggesting that the station could conceivably remain operational until 2025 or 2028.

The Multilateral Coordination Board (MCB) of the ISS international partners, in a videoconference on 21 September 2010, learned that the Japanese and Russian governments have approved operation continuing to 2020. The Canadian Space Agency (CSA) and the European Space Agency (ESA) are working with their governments to confirm consensus on extending operations beyond 2016, while NASA continues working with the US Congress on extension plans.

NASA has the responsibility to deorbit the ISS. Although *Zvezda* has a propulsion system used for station-keeping, it is not powerful enough for a controlled deorbit. Options for controlled deorbit of the ISS include the use of a modified European ATV or a specially constructed deorbit vehicle. According to a 2009 report, RKK Energia is considering methods to remove from the station some modules of the Russian Orbital Segment when the end of mission is reached and use them as a basis for a new station, known as the Orbital Piloted Assembly and Experiment Complex. The modules under consideration for removal from the current ISS include the Multipurpose Laboratory Module (MLM), currently scheduled to be launched at the end of 2011, with other Russian modules which are currently planned to be attached to the MLM until 2015, although still currently unfunded. Neither the MLM nor any additional modules attached to it would have reached the end of their useful lives in 2016 or 2020. The report presents a statement from an unnamed Russian engineer who believes that, based on the experience from *Mir*, a thirty-year life should be possible, except for micrometeorite damage, because the Russian modules have been built with on-orbit refurbishment in mind.

Life on board

Tracy Caldwell-Dyson in the Cupola, observing the Earth below, during Expedition 24.

Crew schedule

The time zone used on board the ISS is Coordinated Universal Time (UTC). The windows are covered at night hours to give the impression of darkness because the station experiences 16 sunrises and sunsets a day. During visiting space shuttle missions, the ISS crew will mostly follow the shuttle's Mission Elapsed Time (MET), which is a flexible time zone based on the launch time of the shuttle mission. Because the sleeping periods between the UTC time zone and the MET usually differ, the ISS crew often has to adjust its sleeping pattern before the space shuttle arrives and after it leaves to shift from one time zone to the other in a practice known as sleep shifting.

A typical day for the crew begins with a wake-up at 06:00, followed by post-sleep activities and a morning inspection of the station. The crew then eats breakfast and takes part in a daily planning conference with Mission Control before starting work at around 08:10. The first scheduled exercise of the day follows, after which the crew continues work until 13:05. Following a one-hour lunch break, the afternoon consists of more exercise and work before the crew carries out its pre-sleep activities beginning at 19:30, including dinner and a crew conference. The scheduled sleep period begins at 21:30. In general, the crew works ten hours per day on a weekday, and five hours on Saturdays, with the rest of the time their own for relaxation or work catch-up.

Sleeping in space

The crews of STS-127 and Expedition 20 enjoy a meal inside *Unity*.

The station provides crew quarters for each member of permanent Expedition crews, with two 'sleep stations' in the Russian Orbital Segment and four more, due to be installed in *Tranquility*, currently spread around the USOS. The American quarters are private, approximately person-sized soundproof booths. A crewmember can sleep in them in a tethered sleeping bag, listen to music, use a laptop, and store personal items in a large drawer or in nets attached to the module's walls. The module also provides a reading lamp, a shelf and a desktop. Visiting crews have no allocated sleep module, and attach a sleeping bag to an available space on a wall—it is possible to sleep floating freely through the station, but this is generally avoided because of the possibility of bumping into sensitive equipment. It is important that crew accommodations be well ventilated; otherwise, astronauts can wake up oxygen-deprived and gasping for air, because a bubble of their own exhaled carbon dioxide has formed around their heads.

Hygiene

The ISS does not feature a shower, although it was planned as part of the now cancelled Habitation Module. Instead, crewmembers wash using a water jet and wet wipes, with soap dispensed from a toothpaste tube-like container. Crews are also provided with rinseless shampoo and edible toothpaste to save water.

There are two space toilets on the ISS, both of Russian design, located in *Zvezda* and *Tranquility*. These Waste and Hygiene Compartments use a fan-driven suction system similar to the Space Shuttle Waste Collection System. Astronauts first fasten themselves to the toilet seat, which is equipped with spring-loaded restraining bars to ensure a good seal. A lever operates a powerful fan and a suction hole slides open: the air stream carries the waste away. Solid waste is collected in individual bags which are stored in an aluminium container. Full containers are transferred to Progress spacecraft for disposal. Liquid waste is evacuated by a hose connected to the front of the toilet, with anatomically correct "urine funnel adapters" attached to the tube so both men and women can use the same toilet. Waste is collected and transferred to the Water Recovery System, where it is recycled back into drinking water.

Food and drink

Most of the food eaten by station crews is frozen, refrigerated or canned. Menus are prepared by the astronauts, with the help of a dietitian, before the astronauts' flight to the station. As the sense of taste is reduced in orbit because of fluid shifting to the head, spicy food is a favourite of many crews. Each crewmember has individual food packages and cooks them using the onboard galley, which features two food warmers, a refrigerator, and a water dispenser that provides both heated and unheated water. Drinks are provided in dehydrated powder form, and are mixed with water before consumption. Drinks and soups are sipped from plastic bags with straws, while solid food is eaten with a knife and fork, which are attached to a tray with magnets to prevent them from floating away. Any food which does float away, including crumbs, must be collected to prevent it from clogging up the station's air filters and other equipment.

Exercise

Astronaut Sunita "Suni" Williams is attached to the TVIS treadmill with bungee cords aboard the International Space Station

The most significant adverse effects of long-term weightlessness are muscle atrophy and deterioration of the skeleton, or spaceflight osteopenia. Other significant effects include fluid redistribution, a slowing of the cardiovascular system, decreased production of red blood cells, balance disorders, and a weakening of the immune system. Lesser symptoms include loss of body mass, nasal congestion, sleep disturbance, excess flatulence, and puffiness of the face. These effects begin to reverse quickly upon return to the Earth.

To prevent some of these adverse physiological effects, the station is equipped with two treadmills (including the COLBERT), the aRED (advanced Resistive Exercise Device) which enables various weightlifting exercises, and a stationary bicycle; each astronaut spends at least two hours per day exercising on the equipment. Astronauts use bungee cords to strap themselves to the treadmill. Researchers believe that exercise is a good countermeasure for the bone and muscle density loss that occurs when humans live for a long time without gravity.

Station operations

Expeditions

Each permanent station crew is given a sequential expedition number. Expeditions have an average duration of half a year, and they commence following the official handover of the station from one Expedition commander to another. Expeditions 1 through 6 consisted of three person crews, but the *Columbia* accident led to a reduction to two crew members for Expeditions 7 to 12. Expedition 13 saw the restoration of the station crew to three, and the station has been permanently staffed as such since. While only three crew members are permanently on the station, several expeditions, such as Expedition 16, have consisted of up to six astronauts or cosmonauts, who are flown to and from the station on separate flights.

On 27 May 2009, Expedition 20 began. Expedition 20 was the first ISS crew of six. Before the expansion of the living volume and capabilities from STS-115 the station could only host a crew of three. Expedition 20's crew was lifted to the station in two separate Soyuz-TMA flights launched at two different times (each Soyuz-TMA can hold only three people): Soyuz TMA-14 on 26 March 2009 and Soyuz TMA-15 on 27 May 2009. However, the station would not be permanently occupied by six crew members all year. For example, when the Expedition 20 crew (Roman Romanenko, Frank De Winne and Bob Thirsk) returned to Earth in November 2009, for a period of about two weeks only two crew members (Jeff Williams and Max Surayev) were aboard. This increased to five in early December, when Oleg Kotov, Timothy Creamer and Soichi Noguchi arrived on Soyuz TMA-17. It decreased to three when Williams and Surayev departed in March 2010, and finally returned to six in April 2010 with the arrival of Soyuz TMA-18, carrying Aleksandr Skvortsov, Mikhail Korniyenko and Tracy Caldwell Dyson.

The International Space Station is the most-visited spacecraft in the history of space flight. As of 15 December 2010, it had received 297 visitors (196 different people). *Mir* had 137 visitors (104 different people).

Visiting spacecraft

The Space Shuttle *Endeavour* approaching the ISS during STS-118

Spacecraft from four different space agencies visit the ISS, serving a variety of purposes. The Automated Transfer Vehicle from the European Space Agency, the Russian Roskosmos Progress spacecraft and the HTV from the Japan Aerospace Exploration Agency have provided resupply services to the station. In addition, Russia supplies a Soyuz spacecraft used for crew rotation and emergency evacuation, which is replaced every six months. Finally, the US services the ISS through its Space Shuttle programme, providing resupply missions, assembly and logistics flights, and crew rotation. As of 15 September 2010, there have been 23 Soyuz, 39 Progress, 1 ATV, 1 HTV and 34 Space Shuttle flights to the station. Expeditions require, on average, 2,722 kg of supplies, and as of 15 September 2010, crews had consumed a total of around 22,000 meals. Soyuz crew rotation flights and Progress resupply flights visit the station on average two and three times respectively each year, with the ATV and HTV planned to visit annually from 2010 onwards.

Following the retirement of the Space Shuttle, a number of other spacecraft are expected to fly to the station. Two, the Orbital Sciences Cygnus and SpaceX Dragon, will fly under NASA's Commercial Orbital Transportation Services and Commercial Resupply Services contracts, delivering cargo to the station until at least 2015. In addition, the Orion spacecraft, developed as a Space Shuttle replacement as part of NASA's Constellation Programme, was retasked by President Barack Obama on 15 April 2010 to provide

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lifeboat services to the station. The spacecraft had until that point been entirely cancelled under the US 2011 fiscal year budget.

Currently Docked

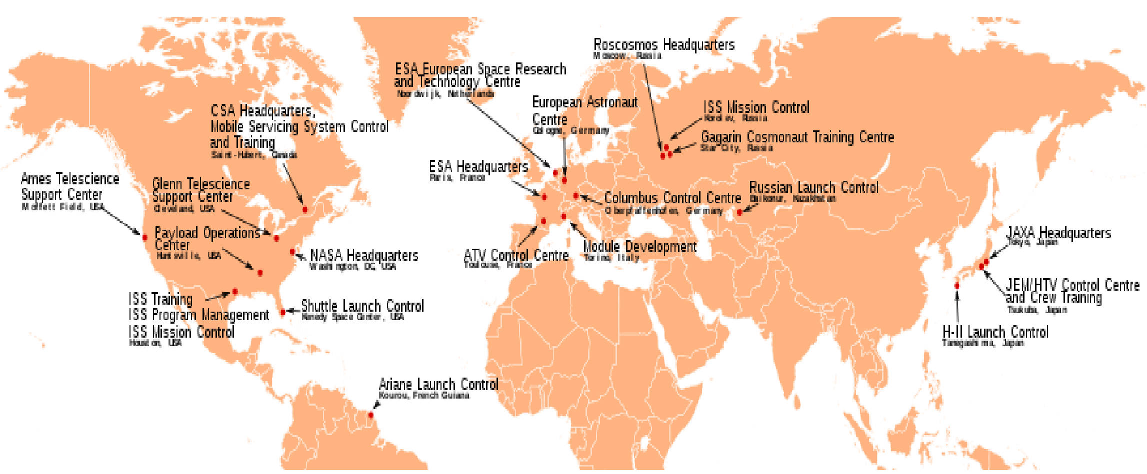
As of 30 January 2011, there are five spacecraft docked with the ISS:

Spacecraft	Mission	Docking port	Date docked (UTC)	Notes
		Zvezda aft		Awaiting Johannes Kepler docking on 24 February 2011
Soyuz TMA-01M	Expedition 25/ Expedition 26	*Poisk*	10 October 2010 00:01	Scheduled to undock on 16 March 2011
Soyuz TMA-20	Expedition 26/ Expedition 27	*Rassvet*	17 December 2010 20:12	
Kounotori 2	HTV-2	*Harmony* zenith	27 January 2011 14:51 (to Harmony nadir)	Scheduled to be moved back to Harmony nadir on 7 March 2011
Progress M-09M	ISS Progress 41	*Pirs*	29 January 2011 02:39	Scheduled to undock on 26 April 2011

Scheduled to be Docked

Spacecraft	Mission	Docking port	Date of scheduled docking (UTC)	Notes
Johannes Kepler	ATV-2	*Zvezda* aft	24 February 2011	
Space Shuttle *Discovery*	STS-133/ULF5	*Harmony* forward (PMA-2)	26 February 2011	

Mission control centres



Space centres involved with the ISS programme

The components of the ISS are operated and monitored by their respective space agencies at control centres across the globe, including:

- NASA's Mission Control Center at Lyndon B. Johnson Space Center in Houston, Texas, serves as the primary control facility for the US segment of the ISS and also controls the Space Shuttle missions that visit the station.
- NASA's Payload Operations and Integration Center at Marshall Space Flight Center in Huntsville, Alabama, serves as the centre that coordinates all payload operations in the US Segment.
- Roskosmos's Mission Control Center at Korolyov, Moscow, controls the Russian Orbital Segment of the ISS, in addition to individual Soyuz and Progress missions.
- ESA's Columbus Control Centre at the German Aerospace Centre (DLR) in Oberpfaffenhofen, Germany, controls the European *Columbus* research laboratory.
- ESA's ATV Control Centre, at the Toulouse Space Centre (CST) in Toulouse, France, controls flights of the unmanned European Automated Transfer Vehicle.
- JAXA's JEM Control Centre and HTV Control Centre at Tsukuba Space Centre (TKSC) in Tsukuba, Japan, are responsible for operating the Japanese Experiment Module complex and all flights of the unmanned Japanese HTV respectively.
- CSA's MSS Control at Saint-Hubert, Quebec, Canada, controls and monitors the Mobile Servicing System, or Canadarm2.

Safety aspects

Anomalies

Since construction started, the ISS programme has had to deal with several major incidents, unexpected problems and failures. These incidents have impacted the station's assembly timeline, led to periods of reduced capabilities and, in some cases, could have forced abandonment of the station for safety reasons, had these problems not been resolved.

The first major impact to station operations came with the Space Shuttle *Columbia* disaster on 1 February 2003 (during STS-107), which resulted in a two-and-a-half-year suspension of the US Space Shuttle programme, followed by another one-year suspension following STS-114 (because of continued foam shedding on the external tank). This halted station assembly plans and reduced the station's operational capabilities, as, due to a lack of logistics, caretaker crews of just two astronauts were launched from Expedition 7 until Expedition 12. The *Columbia* disaster was followed by a number of smaller issues aboard the station, including an air leak from the USOS in 2004, the venting of smoke from an *Elektron* oxygen generator in 2006, and the failure of the computers in the ROS in 2007 during STS-117 which left the station without thruster, *Elektron*, *Vozdukh* and other environmental control system operations, the root cause of which was found to be condensation inside the electrical connectors leading to a short-circuit.

These issues with internal station equipment were then followed by a spate of issues with external components; during STS-120 on 2007, following the relocation of the P6 truss and solar arrays, it was noted during the redeployment of the array that it had become torn and was not deploying properly. An emergency EVA was carried out by Scott Parazynski, assisted by Douglas Wheelock, to repair the array, an activity which was considerably more dangerous than most EVAs due to the short planning time and the risk of electric shock from the arrays themselves. The issues with the array were followed in the same year by problems with the starboard Solar Alpha Rotary Joint (SARJ), which rotates the arrays on the starboard side of the station. Excessive vibration and high-current spikes in the array drive motor were noted, resulting in a decision to substantially curtail motion of the starboard SARJ until the cause was understood. Inspections during EVAs on STS-120 and STS-123 showed extensive contamination from metallic shavings and debris in the large drive gear and confirmed damage to the large metallic race ring at the heart of the joint, and so the joint was locked to prevent further damage. Repairs to the joint were carried out during STS-126 with lubrication of both joints and the replacement 11 of 12 trundle bearings on the joint.

More recently, problems have been noted with the station's engines and cooling. In 2009, the engines on *Zvezda* were issued an incorrect command which caused excessive vibrations to propagate throughout the station structure which persisted for over two minutes. While no damage to the station was immediately reported, some components may have been stressed beyond their design limits. Further analysis confirmed that the station was unlikely to have suffered any structural damage, and it appears that "structures will still meet their normal lifetime capability". Further evaluations are under way. 2009 also saw damage to the S1 radiator, one of the components of the station's cooling system. The problem was first noticed in Soyuz imagery in September 2008, but was not thought to be serious. The imagery showed that the surface of one sub-panel has peeled back from the underlying central structure, possibly due to micro-meteoroid or debris impact. It is also known that a Service Module thruster cover, jettisoned during an EVA in 2008, had struck the S1 radiator, but its effect, if any, has not been determined. On 15 May 2009 the damaged radiator panel's ammonia tubing was mechanically shut off from the rest of the cooling system by the computer-controlled closure of a valve. The same valve was used immediately afterwards to vent the ammonia from the damaged panel, eliminating the possibility of an ammonia leak from the cooling system via the damaged panel.

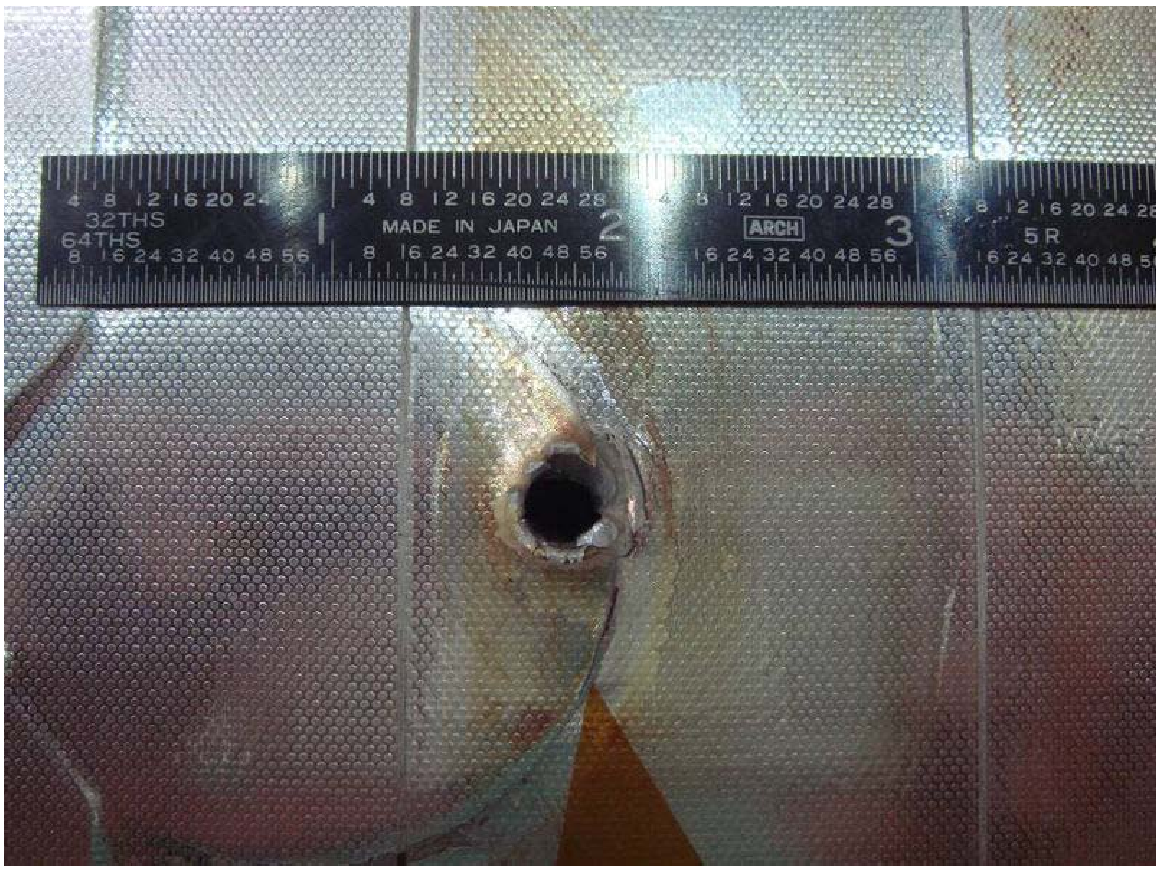
Cooling loop A failure

Early on 1 August 2010, a failure in cooling Loop A (starboard side), one of two external cooling loops, left the station with only half of its normal cooling capacity and zero redundancy in some systems. The problem appeared to be in the ammonia pump module that circulates the ammonia cooling fluid. Several subsystems, including two of the four CMGs, were shut down.

Planned operations on the ISS were interrupted through a series of EVAs to address the cooling system issue. A first EVA on 7 August 2010, to replace the failed pump module, was not fully completed due to an ammonia leak in one of four quick-disconnects. A second EVA on 11 August successfully removed the failed pump module. A third EVA was required to restore Loop A to normal functionality.

The station's cooling system is largely built by the American company Boeing, which is also the manufacturer of the failed pump.

Orbital debris



The entry hole in Space Shuttle *Endeavour*'s radiator panel caused by space debris during STS-118

At the low altitudes at which the ISS orbits there is a variety of space debris, consisting of everything from entire spent rocket stages and defunct satellites, to explosion fragments, paint flakes, slag from solid rocket motors, coolant released by RORSAT nuclear powered satellites, small needles, and many other objects. These objects, in addition to natural micrometeoroids, pose a threat to the station as they have the ability to puncture the pressurised modules and cause damage to other parts of the station. Micrometeoroids also pose a risk to spacewalking astronauts, as such objects could puncture their spacesuits, causing them to depressurise.

Space debris objects are tracked remotely from the ground, and the station crew can be notified of many objects with sufficient size to cause damage on impact. This allows for a Debris Avoidance Manoeuvre (DAM) to be conducted, which uses thrusters on the Russian Orbital Segment to alter the station's orbital altitude, avoiding the debris. DAMs are not uncommon, taking place if computational models show the debris will approach within a certain threat distance. Eight DAMs had been performed prior to March 2009, the first seven between October 1999 and May 2003. Usually the orbit is raised by one or two kilometres by means of an increase in orbital velocity of the order of 1 m/s. Unusually there was a lowering of 1.7 km on 27 August 2008, the first such lowering for 8 years. There were two DAMs in 2009, on 22 March and 17 July. If a threat from orbital debris is identified too late for a DAM to be safely conducted, the station crew close all the hatches aboard the station and retreat into their Soyuz spacecraft, so that they would be able to evacuate in the event it was damaged by the debris. This partial station evacuation has occurred twice, on 6 April 2003 and 13 March 2009.

Radiation

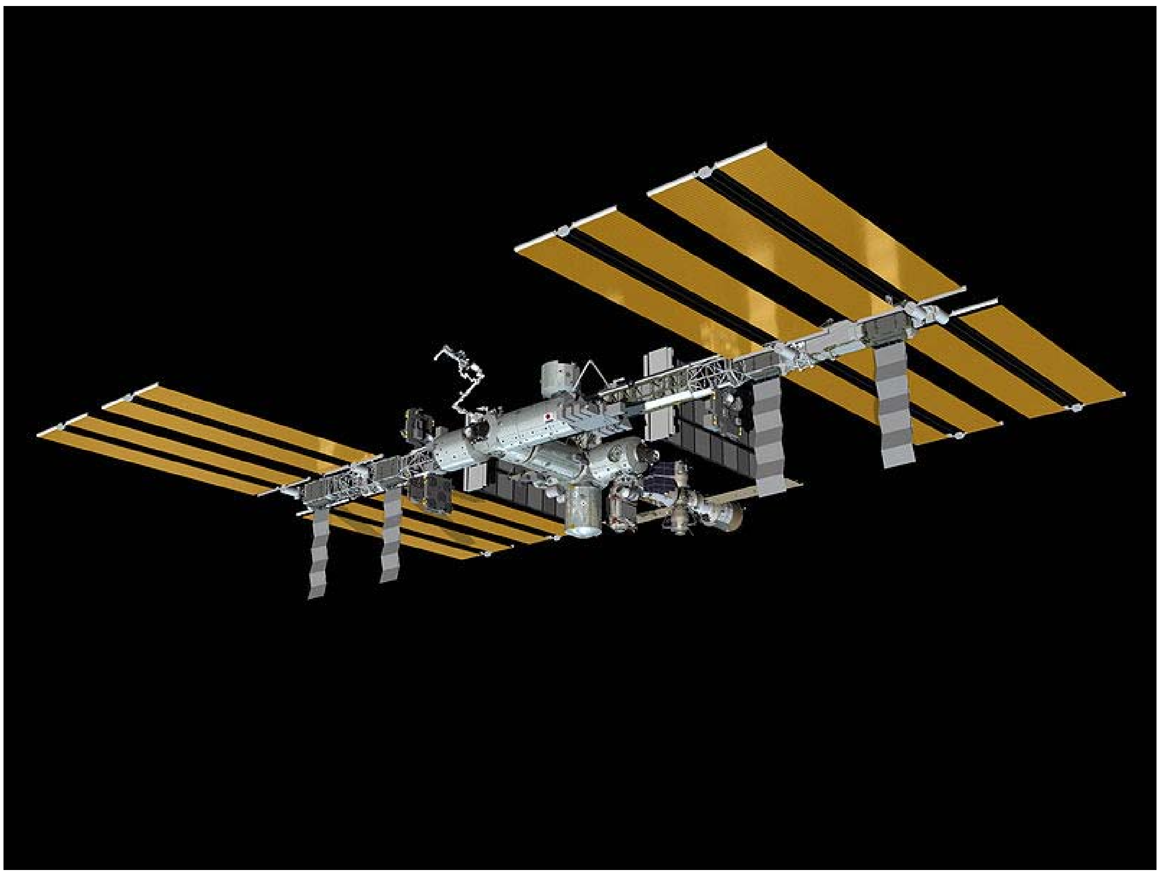
Without the protection of the Earth's atmosphere, astronauts are exposed to higher levels of radiation from a steady flux of cosmic rays. The station's crews are exposed to about 1 millisievert of radiation each day, which is about the same as someone would get in a year on Earth, from natural sources. This results in a higher risk of astronauts' developing cancer. High levels of radiation can cause damage to the chromosomes of lymphocytes. These cells are central to the immune system and so any damage to them could contribute to the lowered immunity experienced by astronauts. Over time lowered immunity results in the spread of infection between crew members, especially in such confined areas. Radiation has also been linked to a higher incidence of cataracts in astronauts. Protective shielding and protective drugs may lower the risks to an acceptable level, but data is scarce and longer-term exposure will result in greater risks.

Despite efforts to improve radiation shielding on the ISS compared to previous stations such as *Mir*, radiation levels within the station have not been vastly reduced, and it is thought that further technological advancement will be required to make long-duration human spaceflight further into the Solar System a possibility.

It should be noted, however, that the radiation levels experienced on ISS are not excessively greater than those experienced by airline passengers. The Earth's electromagnetic field provides almost the same level of protection against solar and other radiation in low Earth orbit as in the stratosphere. Airline passengers, however, experience this level of radiation for no more than 15 hours for the longest transcontinental flights (London-Sydney or Chicago-Delhi). For example, on a 12 hour flight from Boston to Beijing, an airline passenger would experience 0.1 millisievert of radiation, or a rate of 0.2 millisieverts per day, only 1/5th the rate experienced by an astronaut in LEO.

Chapter- 2

Assembly of the International Space Station



An artist's impression of The International Space Station after STS-133


Cosmonaut Sergei Krikalev inside the Zvezda Service Module, November 2000.

The **Assembly of the International Space Station** is a major aerospace engineering endeavour being conducted in Low Earth orbit by a consortium of governmental and inter-governmental space agencies.

Zarya, the first ISS module, was launched by a Proton rocket on 20 November 1998. The STS-88 shuttle mission followed two weeks after *Zarya* was launched, bringing *Unity*, the first of three node modules, and connecting it to *Zarya*. This bare 2-module core of the ISS remained unmanned for the next one and a half years, until in July 2000 the Russian module *Zvezda* was added, allowing a minimum crew of two astronauts or cosmonauts to be on the ISS permanently.

When assembly is complete, the ISS will have a pressurized volume of approximately 1,000 cubic meters, a mass of approximately 400,000 kilograms, approximately 100 kilowatts of power output, a truss 108.4 meters long, modules 74 meters long, and a crew of six. Building the complete station will require more than 40 assembly flights. As of Summer 2010, 25 Space Shuttle flights have docked with ISS to add elements, and 9 other Shuttle flights have flown logistics-servicing missions to ISS without adding major external elements. These 34 Shuttle missions include 9 SpaceHab and 10 MPLM logistics-servicing missions in various combinations. The last two planned Shuttle flights are due to add two of the three final elements of ISS, followed by one last Proton launch with the planned delivery of the ERA. Other assembly flights have consisted of modules lifted by the Russian Proton rocket or in the case of Pirs and Poisk by a Soyuz-U rocket.

Logistics

International Space Station mockup at Johnson Space Center in Houston, Texas.

The space station is located in orbit around the Earth at an altitude of approximately 360 km (220 miles), a type of orbit usually termed low Earth orbit (the actual height varies over time by several kilometers due to atmospheric drag and reboosts). It orbits Earth in a period of about 90 minutes; by August 2007 it had completed more than 50,000 orbits since launch of *Zarya* on 20 November 1998.

A total of 14 main pressurized modules are scheduled to be part of the ISS by its completion date in 2010. A number of smaller pressurized sections will be adjunct to them (Soyuz spacecraft (permanently 2 as lifeboats - 6 months rotations), Progress transporters (2 or more), the Quest and Pirs airlocks, as well as periodically the Multi-Purpose Logistics Module, the Automated Transfer Vehicle and the H-II Transfer Vehicle).

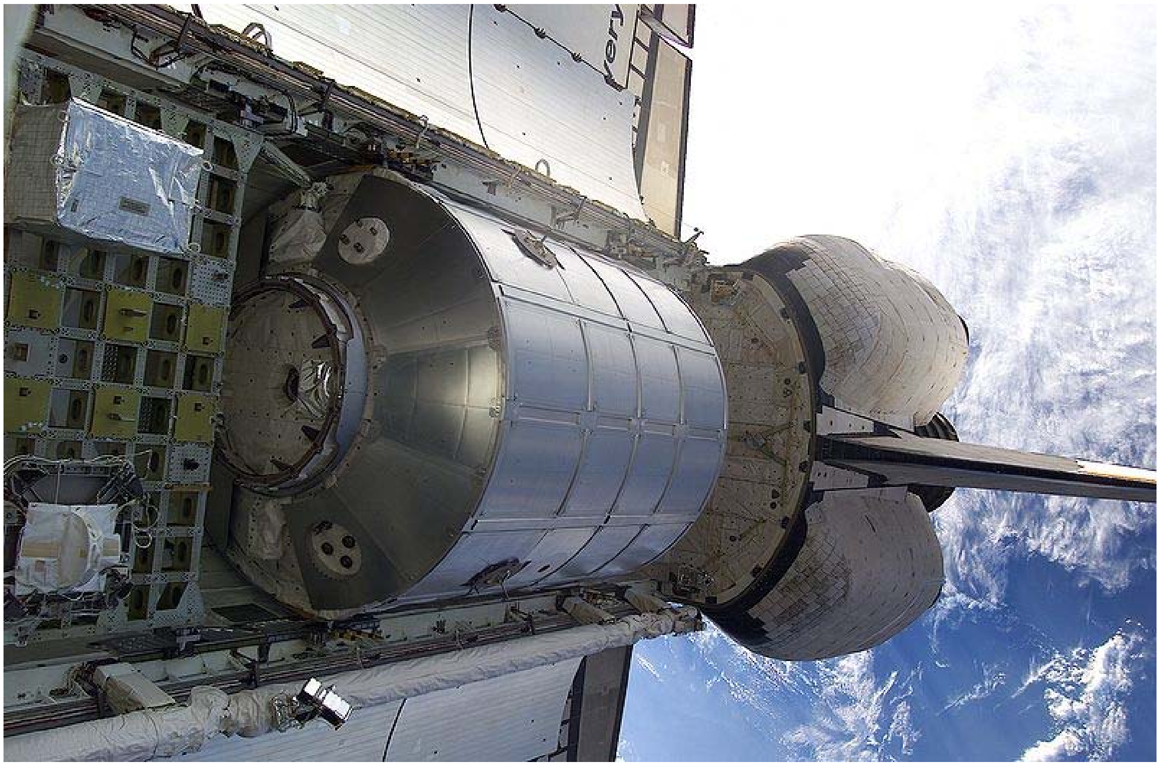
The ISS, when completed, will consist of a set of communicating pressurized modules connected to a truss, on which four large pairs of photovoltaic modules (solar panels) are attached. The pressurized modules and the truss will be perpendicular: the truss spanning from starboard to port and the habitable zone extending on the aft-forward axis. Although during the construction the station attitude may vary, when all four photovoltaic modules are in their definitive position the aft-forward axis will be parallel to the velocity vector.

In addition to the assembly and utilization flights, approximately 30 Progress spacecraft flights are required to provide logistics until 2010. Experimental equipment, fuel and consumables are and will be delivered by all vehicles visiting the ISS: the Shuttle, the Russian Progress, the European ATV and the Japanese HTV.

Columbia disaster and changes in construction plans

Columbia lifting off on its final mission.

Disaster and consequences



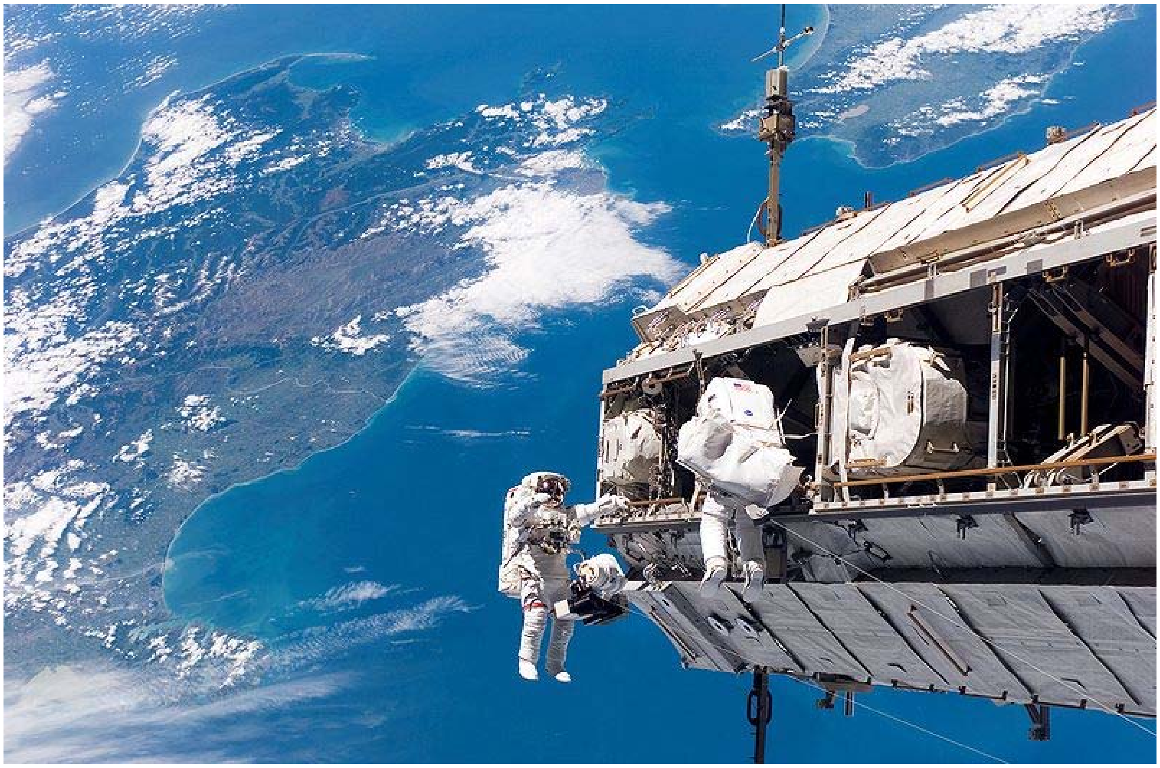
10 March 2001 - The *Leonardo* Multi-Purpose Logistics Module rests in *Discovery*'s payload bay during STS-102.

At one point, there was some uncertainty over the future of the ISS. The Space Shuttle *Columbia* disaster on 1 February 2003, the subsequent two and a half year suspension of the U.S. Space Shuttle program, followed by problems with resuming flight operations in 2005, were major obstacles.

The Space Shuttle program resumed flight on 26 July 2005, with the STS-114 mission of *Discovery*. This mission to the ISS was intended both to test new safety measures implemented since the *Columbia* disaster, and to deliver supplies to the station. Although the mission succeeded safely, it was not without risk; foam was shed by the external tank, leading NASA to announce future missions would be grounded until this issue was resolved.

Between the *Columbia* disaster and the resumption of Shuttle launches, crew exchanges were carried out solely using the Russian Soyuz spacecraft. Starting with Expedition 7, two-astronaut caretaker crews were launched in contrast to the previously launched crews of three. Because the ISS had not been visited by a shuttle for an extended period, a larger than planned amount of waste accumulated, temporarily hindering station operations in 2004. However Progress transports and the STS-114 shuttle flight took care of this problem.

Changes in construction plans



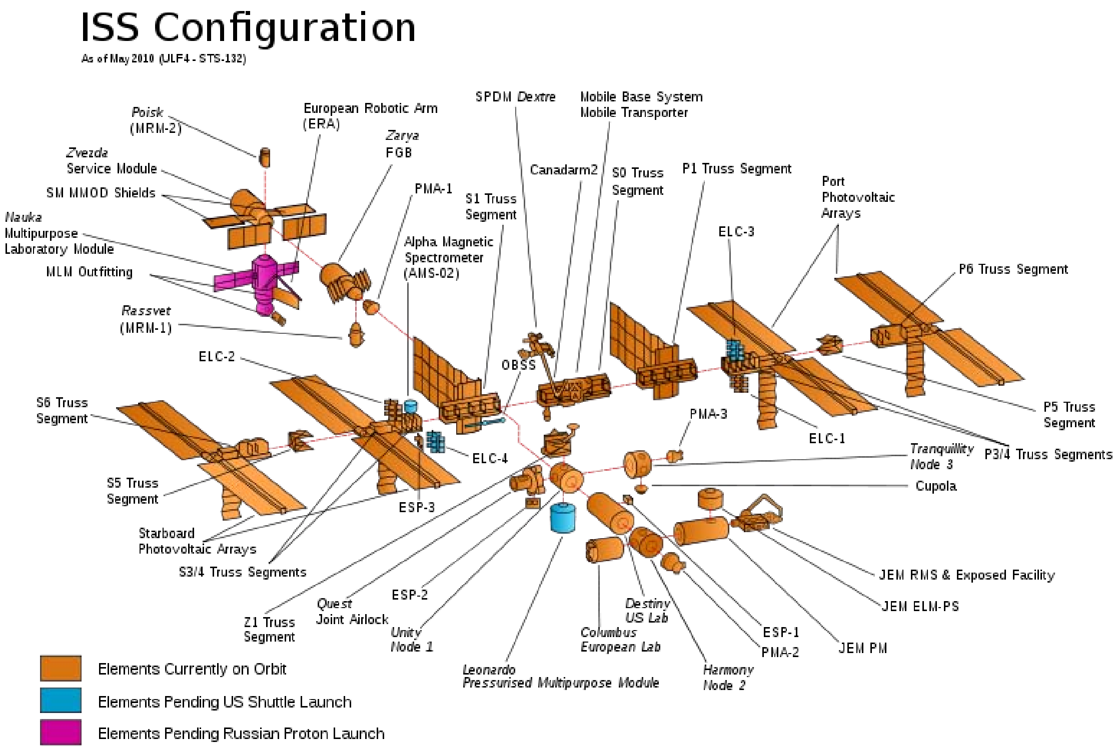
Upgrading the International Space Station over New Zealand.

ISS construction is now far behind the original planned schedule for completion in 2004 or 2005. This is mainly due to the halting of all NASA Shuttle flights following the *Columbia* disaster in early 2003 (although there had been prior delays due partly to Shuttle problems, and partly to delays stemming from the Russian space agency's budget constraints). During the shuttle stand-down, construction of the ISS was halted and the science conducted aboard was limited due to the crew size of two.

As of the beginning of 2006, many changes were made to the originally planned ISS, even before the *Columbia* disaster. Modules and other structures were cancelled or replaced and the number of Shuttle flights to the ISS was reduced from previously planned numbers. Still, the newest ISS Shuttle launch manifest and the ISS design scheme reveal that more than 80% of the hardware intended to be part of the ISS in the late 90s is still planned to be orbited to the ISS by its scheduled completion date in 2010.

In March 2006, a meeting of the heads of the five participating space agencies accepted the new ISS construction schedule that plans to complete the ISS by 2010. A crew of six has been established as of May 2009, after the Shuttle's next 12 construction flights following the second "Return to Flight" mission STS-121. Requirements for stepping up the crew size included enhanced environmental support on the ISS, a second Soyuz permanently docked on the station to function as a second 'lifeboat', more frequent Progress flights to provide double the amount of consumables, more fuel for orbit raising maneuvers, and a sufficient supply line of experimental equipment.

Assembly sequence



ISS elements as of May 2010

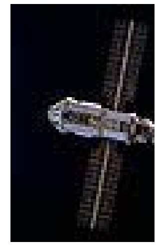
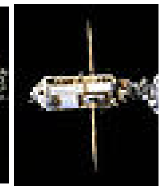
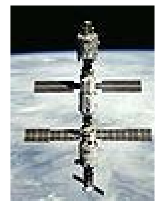
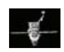
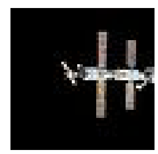
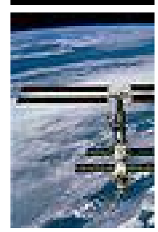
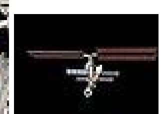
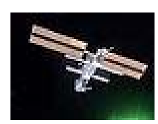
The ISS consists of 13 main pressurized modules: five US modules (*Destiny*, *Unity*, *Quest*, *Tranquility* and *Harmony*), five Russian modules (*Zarya*, *Zvezda*, *Pirs*, *Poisk* and *Rassvet*), two Japanese modules (the JEM-ELM-PS and JEM-PM) and one European module (*Columbus*). One more US module (*Leonardo PMM*) and one more Russian module (*Nauka*) are scheduled to be added to the station.

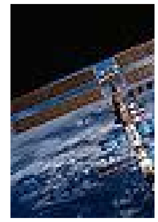
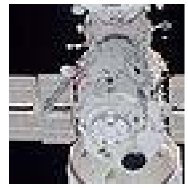
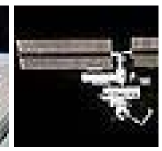
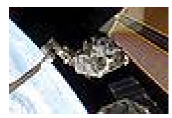
Although not permanently docked with the ISS, Multi-Purpose Logistics Modules (MPLMs) form part of the ISS during some Shuttle missions. An MPLM is attached to *Harmony* (initially to *Unity*) and is used for resupply and logistics flights.

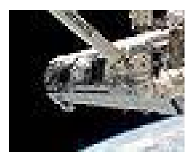
Spacecraft docked to the ISS also extend the pressurized volume. At least one Soyuz spacecraft is always docked as a 'lifeboat' and is replaced every six months by a new Soyuz as part of crew rotation.

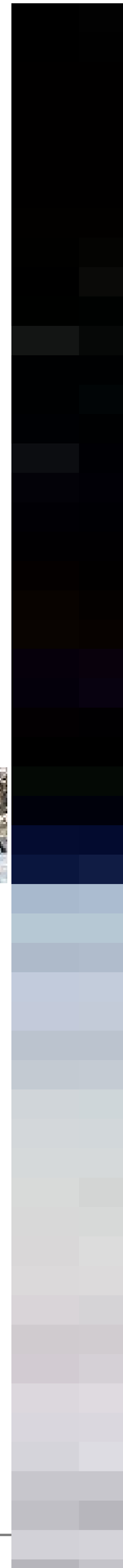
The table below shows the sequence in which these components were or will be added to the ISS. The numbers provided are indications and represent launch weight and dimensions.

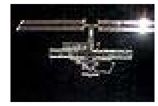
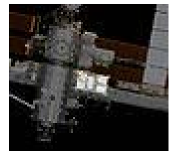
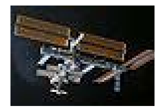
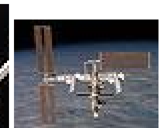
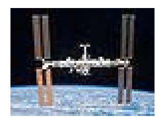
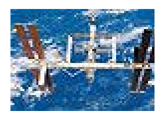
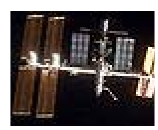
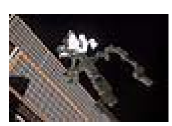
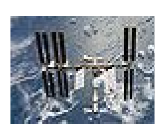
Element	Assembly flight	Launch date	Launch vehicle	Length (m)	Diameter (m)	Mass (kg)	Isolated View	Station View

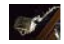
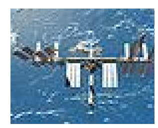
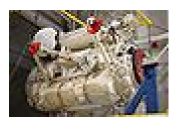
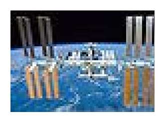
Zarya (FGB)	1A/R	1998-11-20	Proton-K	12.6	4.1	19,323		
Unity (Node 1), PMA-1 & PMA-2	2A	1998-12-04	Space Shuttle *Endeavour* (STS-88)	5.49	4.57	11,612		
Zvezda (Service Module)	1R	2000-07-12	Proton-K	13.1	4.15	19,051		
Z1 Truss & PMA-3	3A	2000-10-11	Space Shuttle *Discovery* (STS-92)	4.9 (Z1)	4.2 (Z1)	8,755 (Z1)		
P6 Truss & Solar Arrays	4A	2000-11-30	Space Shuttle *Endeavour* (STS-97)	73.2	4,9	15,824		
Destiny (US Laboratory)	5A	2001-02-07	Space Shuttle *Atlantis* (STS-98)	8.53	4.27	14,515		
External Stowage Platform-1	5A.1	2001-03-08	Space Shuttle *Discovery* (STS-102)					
Canadarm 2 (SSRMS)	6A	2001-04-19	Space Shuttle *Endeavour* (STS-100)	17.6	0.35	4,899		

Quest (Joint Airlock)	7A	2001-07-12	Space Shuttle *Atlantis* (STS-104)	5.5	4	6,064		
Pirs (Docking Compartment & Airlock)	4R	2001-09-14	Soyuz-U (Progress M-SO1)	4.91	2.55	3,580		
S0 Truss	8A	2002-04-08	Space Shuttle *Atlantis* (STS-110)	13.4	4.6	13,970		
Mobile Base System	UF2	2002-06-05	Space Shuttle *Endeavour* (STS-111)	5.7	2.9	1,450		

S1 Truss	9A	2002-10-07	Space Shuttle *Atlantis* (STS-112)	13.7	4.6	14,120	



P1 Truss	11A	2002-11-23	Space Shuttle *Endeavour* (STS-113)	13.7	4.6	14,000		
ESP-2	LF1	2005-07-26	Space Shuttle *Discovery* (STS-114)	3.65	4.9	2,676		
P3/P4 Truss & Solar Arrays	12A	2006-09-09	Space Shuttle *Atlantis* (STS-115)	13.8	4.9	15,900		
P5 Truss	12A.1	2006-12-09	Space Shuttle *Discovery* (STS-116)	3.4	4.6	1,818		
S3/S4 Truss & Solar Arrays	13A	2007-06-08	Space Shuttle *Atlantis* (STS-117)	13.8	4.9	15,900		
S5 Truss and ESP-3	13A.1	2007-08-08	Space Shuttle *Endeavour* (STS-118)	13.7	3.9	12,598		
Harmony (Node 2) Relocation of P6 Truss	10A	2007-10-23	Space Shuttle *Discovery* (STS-120)	7.2	4.48	14,288		
Columbus (European Laboratory)	1E	2008-02-07	Space Shuttle *Atlantis* (STS-122)	7	4.5	12,800		
Dextre (SPDM) Japanese Logistics Module (ELM-PS)	1J/A	2008-03-11	Space Shuttle *Endeavour* (STS-123)	3.9 (ELM-PS)	4.4 (ELM-PS)	4,200 (ELM-PS)		
Japanese Pressurized Module (JEM-PM) JEM Robotic	1J	2008-05-31	Space Shuttle *Discovery* (STS-124)	11.2 (JEM-PM)	4.4 (JEM-PM)	15,900 (JEM-PM)		

Arm (JEM-RMS)								
S6 Truss & Solar Arrays	15A	2009-03-15	Space Shuttle *Discovery* (STS-119)	73.2	10.7	15,900		
Japanese Exposed Facility (JEM-EF)	2J/A	2009-07-15	Space Shuttle *Endeavour* (STS-127)			4,100		
Poisk (MRM-2)	5R	2009-11-10	Soyuz-U (Progress M-MIM2)			3670		
ExPRESS Logistics Carriers 1 & 2	ULF3	2009-11-16	Space Shuttle *Atlantis* (STS-129)					
Cupola & *Tranquility* (Node 3)	20A	2010-02-08	Space Shuttle *Endeavour* (STS-130)	6.5 (Node 3) 1.5 (Cupola)	4.25 (Node 3) 2.95 (Cupola)	12,247 (Node 3) 1,800 (Cupola)		
Rassvet (MRM-1)	ULF4	2010-05-14	Space Shuttle *Atlantis* (STS-132)			5075		
Leonardo (PMM) and EXPRESS Logistics Carrier 4	ULF5	2011-02-24 (scheduled)	Space Shuttle *Discovery* (STS-133)					
Alpha Magnetic Spectrometer, OBSS and EXPRESS Logistics Carrier 3	ULF6	2011-04-19 (scheduled)	Space Shuttle *Endeavour* (STS-134)			6,731 (AMS-02)		
Nauka (MLM) European Robotic Arm	3R	2011-12-?? (scheduled)	Proton-M					

Cancelled modules

- Interim Control Module - no need to replace Zvezda (in storage ready to launch at short notice if required)
- ISS Propulsion Module - no need to replace Zvezda
- Habitation Module (HAB) - With the cancellation of the Habitations Module, sleeping places are now spread throughout the station. There will be three in the Russian segment once the ISS is completed and three in the US segment. It is not necessary to have a separate 'bunk' in space at all—many visitors just strap their sleeping bag to the wall of a module, get into it and sleep.
- Crew Return Vehicle (CRV) - utilizing two Soyuz crafts instead
- Centrifuge Accommodations Module (CAM) - would have been attached to Node 2, now named Harmony
- Science Power Platform (SPP) - power will be provided to the Russian segments partly by the US solar cell platforms
- Russian Research Modules (RM1 and RM2) - to be replaced by single Multipurpose Laboratory Module (Nauka)
- Universal Docking Module (UDM) - canceled along with the Research modules which were to connect to it

Proposed modules

The following modules are proposed, but not yet confirmed in the ISS launch manifests.

- Russian Nodal Module - UDM with proposed launch in 2013
- Russian Science-Power Module-1 - combination of RM1 and parts of SPP with proposed launch in 2014
- Russian Science-Power Module-2 - combination of RM2 and parts of SPP with proposed launch in 2015
- American Node 4 - Also known as the Docking Hub System (DHS) , would allow the station to have more docking ports for visiting vehicles and would allow inflatable habitats and technology demonstrations to be tested as part of the station.
- Bigelow Aerospace inflatable module - proposed for post-2013 launched atop an Expendable Launch Vehicle. The Bigelow inflatable module would be berthed to the currently unfunded Node 4.

Formerly proposed and later abandoned modules:

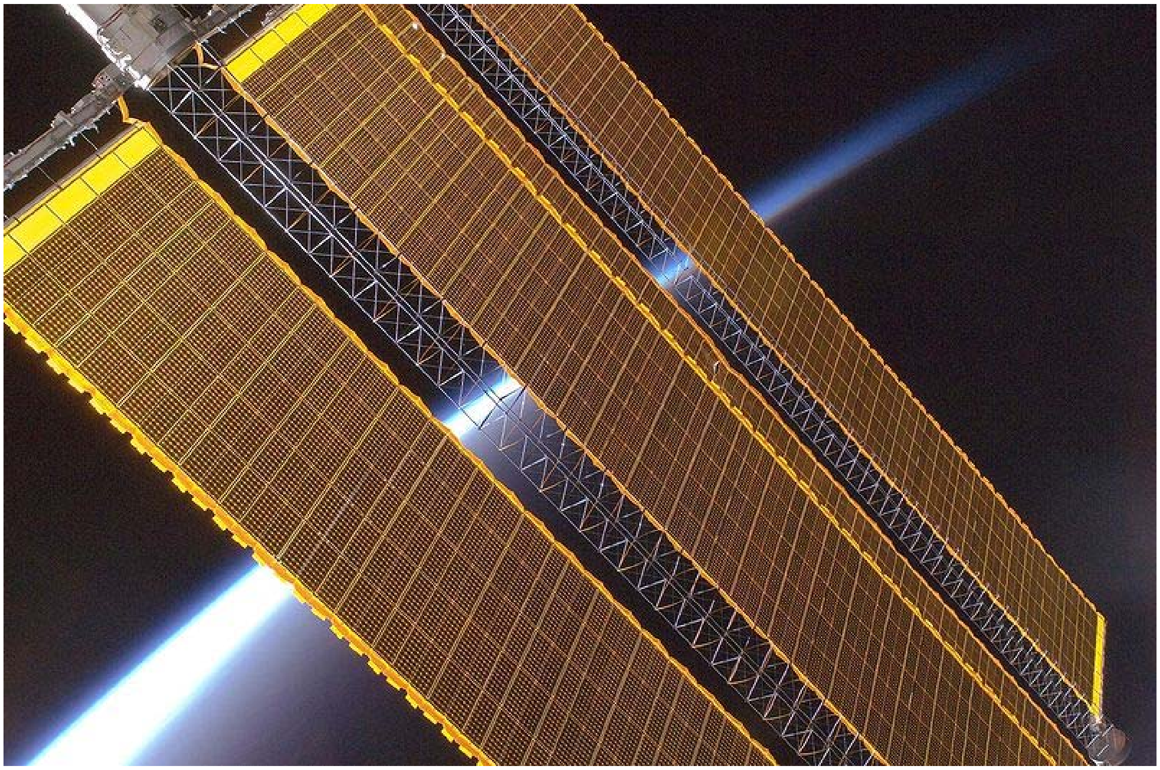
- Russian Commercial Enterprise Module entertainment and studio module.

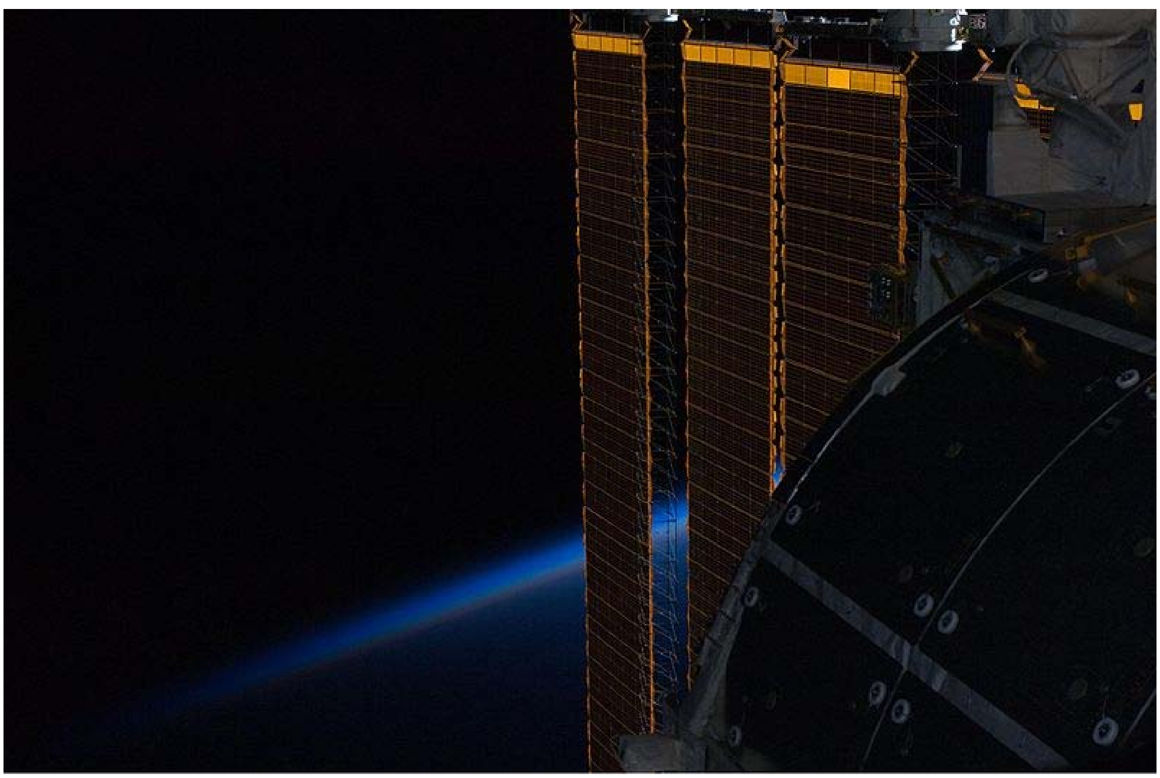
Chapter- 3

Electrical System of the International Space Station

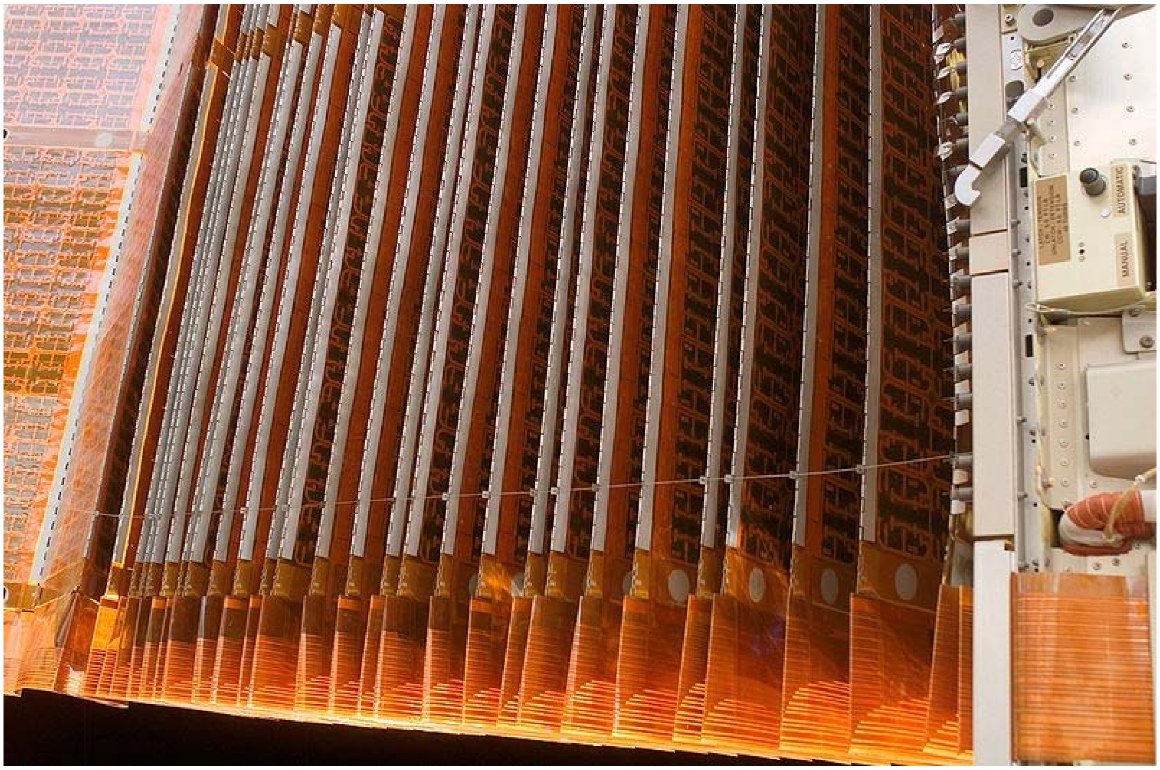
The **electrical system of the International Space Station** is a critical resource for the International Space Station (ISS) because it allows the crew to live comfortably, to safely operate the station, and to perform scientific experiments. The ISS electrical system uses solar cells to directly convert sunlight to electricity. Large numbers of cells are assembled in arrays to produce high power levels. This method of harnessing solar power is called photovoltaics.

The process of collecting sunlight, converting it to electricity, and managing and distributing this electricity builds up excess heat that can damage spacecraft equipment. This heat must be eliminated for reliable operation of the space station in orbit. The ISS power system uses radiators to dissipate the heat away from the spacecraft. The radiators are shaded from sunlight and aligned toward the cold void of deep space.


International Space Station solar array wing (Expedition 17 crew, August 2008).


An ISS solar panel intersecting Earth's horizon.

Solar array wing



Close-up view of folded solar array.

Each ISS solar array wing (often abbreviated "SAW") consists of two retractable "blankets" of solar cells with a mast between them. Each wing uses nearly 33,000 solar cells and when fully extended is 35 m (115 ft) long and 12 m (38 ft) wide. When retracted, each wing folds into a solar array blanket box just 51 cm (20 inches) high and 4.57 m (15 ft) long. The ISS now has the full complement of eight solar array wings.

The solar arrays normally track the Sun, with the **alpha gimbal** used as the primary rotation to follow the Sun as the space station moves around the Earth, and the **beta gimbal** used to adjust for the angle of the space station's orbit to the ecliptic. Several different tracking modes are used in operations, ranging from full Sun-tracking, to the drag-reduction mode ("Night glider" and "Sun slicer" modes), to a drag-maximization mode used to lower the altitude.

Batteries

Since the station is often not in direct sunlight, it relies on rechargeable nickel-hydrogen batteries to provide continuous power during the "eclipse" part of the orbit (35 minutes of every 90 minute orbit). The batteries ensure that the station is never without power to sustain life-support systems and experiments. During the sunlit part of the orbit, the batteries are recharged. The batteries have a working life of 6.5 years which means that they must be replaced multiple times during the expected 20-year life of the station. The batteries, and the battery charge/discharge units (BCDUs), are manufactured by Space Systems/Loral (SS/L), under contract to Boeing.

Power management and distribution

The power management and distribution subsystem operates at a primary bus voltage set to V_{mp}, the peak power point of the solar arrays. As of December 30, 2005, V_{mp} was 160 volts DC (direct current). It can change over time as the arrays degrade from ionizing radiation. Microprocessor-controlled switches control the distribution of primary power throughout the station.

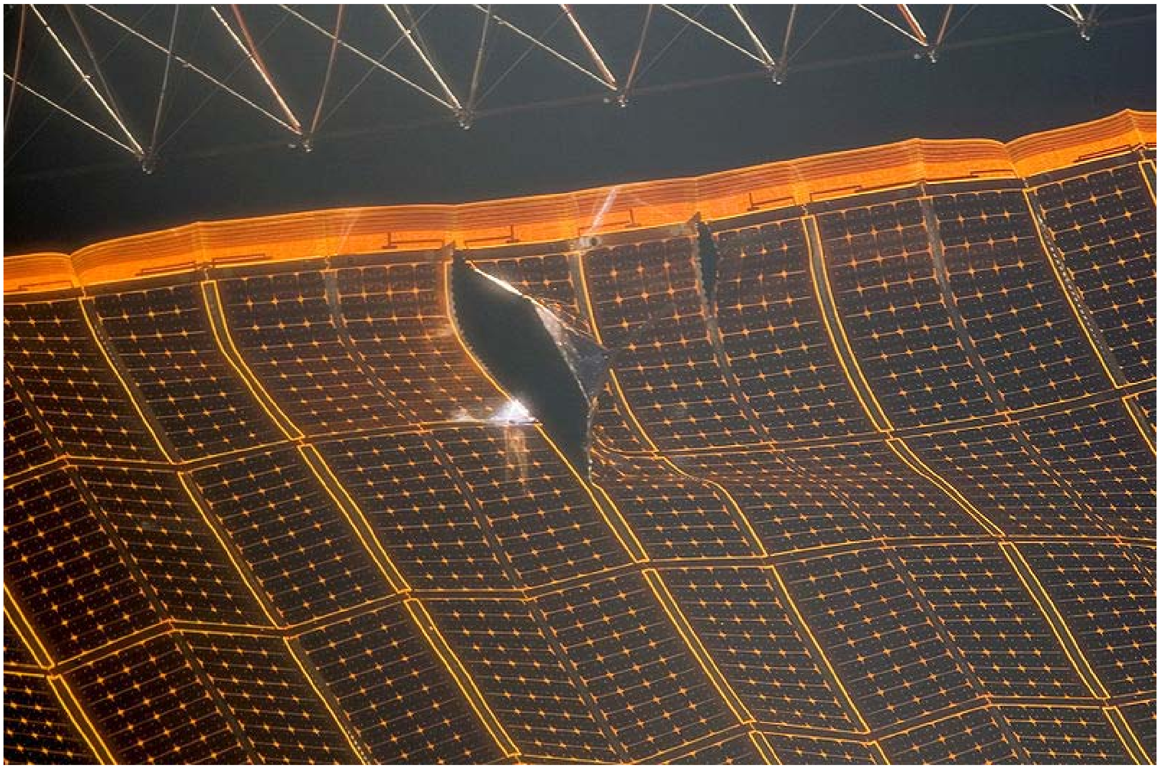
SSU

Eighty-two separate solar array strings feed a sequential shunt unit (SSU) that provides coarse voltage regulation at the desired V_{mp}. The SSU applies a "dummy" (resistive) load that increases as the station's load decreases (and vice versa) so the array operates at a constant voltage and load. The SSUs are provided by SS/L.

DC-to-DC conversion

DC-to-DC converter units supply the secondary power system at a constant 124.5 volts DC, allowing the primary bus voltage to track the peak power point of the solar arrays.

Station to shuttle power transfer system



Damage to the 4B wing of the P6 solar array wing found when it was redeployed after being moved to its final position on the STS-120 mission.

The Station-to-Shuttle Power Transfer System (SSPTS; pronounced *spits*) allows a docked Space Shuttle to make use of power provided by the International Space Station's solar arrays. Using this system reduces usage of a shuttle's on-board power-generating fuel cells, allowing it to stay docked to the space station for an additional four days.

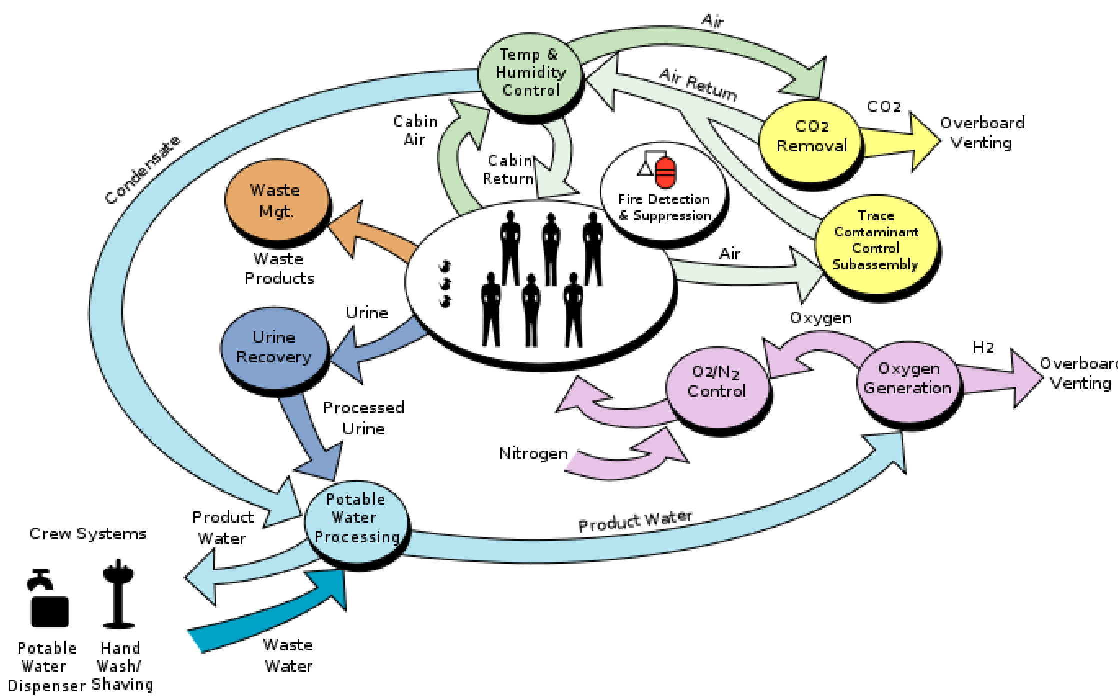
SSPTS is a shuttle upgrade that replaces the Assembly Power Converter Unit (APCU) with a new device called the Power Transfer Unit (PTU). The APCU had the capacity to convert shuttle 28 VDC main bus power to 124 VDC compatible with ISS's 120 VDC power system. This was used in the initial construction of the space station to augment the power available from the Russian *Zvezda* service module. The PTU adds to this the capability to convert the 120 VDC supplied by the ISS to the orbiter's 28 VDC main bus power. It is capable of transferring up to eight kilowatts of power from the space station to the orbiter. With this upgrade both the shuttle and the ISS are now able to use each other's power systems when needed, although it is not expected that the ISS will ever again require the use of an orbiter's power systems.

During mission STS-116, PMA-2 (at the forward end of the *Harmony* module) was rewired to allow for the use of the SSPTS. The first mission to make actual use of the system was STS-118 with Space Shuttle *Endeavour*.

Currently only *Discovery* and *Endeavour* are equipped with the SSPTS. As of May 2010, *Atlantis* is not equipped with the SSPTS.

Chapter- 4

ISS ECLSS



The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS)

The International Space Station **Environmental Control and Life Support System** (**ECLSS**) is a life support system that provides or controls atmospheric pressure, fire detection and suppression, oxygen levels, waste management and water supply. The highest priority for the ECLSS is the ISS atmosphere, but the system also collects, processes, and stores waste and water produced and used by the crew—a process that recycles fluid from the sink, shower, toilet, and condensation from the air. The Elektron system aboard *Zvezda* and a similar system in *Destiny* generate oxygen aboard the station. The crew has a backup option in the form of bottled oxygen and Solid Fuel Oxygen Generation (SFOG) canisters. Carbon dioxide is removed from the air by the *Vozdukh* system in *Zvezda*. Other by-products of human metabolism, such as methane from the intestines and ammonia from sweat, are removed by activated charcoal filters.

Water recovery systems

The ISS has two water recovery systems. *Zvezda* contains a water recovery system that processes waste water from showers, sinks, and other crew systems and water vapor from the atmosphere that could be used for drinking in an emergency but is normally fed to the Elektron system to produce oxygen. The American segment has a Water Recovery System installed during STS-126 in *Destiny* that can process water vapour collected from the atmosphere, waste water from showers, sinks, and other crew systems, and also urine into water that is intended for drinking.

The Water Recovery System consists of a Urine Processor Assembly and a Water Processor Assembly.

The Urine Processor Assembly uses a low pressure vacuum distillation process that uses a centrifuge to compensate for the lack of gravity and thus aid in separating liquids and gasses.

Water from the Urine Processor Assembly and from waste water sources are combined to feed the Water Processor Assembly that filters out gasses and solid materials before passing through filter beds and then a high-temperature catalytic reactor assembly. The water is then tested by onboard sensors and unacceptable water is cycled back through the water processor assembly.

The Volatile Removal Assembly flew on STS-89 in January 1998 to demonstrate the Water Processor Assembly's catalytic reactor in microgravity. A Vapour Compression Distillation Flight Experiment flew, but was destroyed, in STS-107.

The Water Recovery System failed during the first tests and required astronauts to remove several rubber vibration isolators as the way the system was configured when it was first installed caused balance issues with the centrifuge in the vacuum distillation assembly that resulted in it failing with an error code after two hours of use. Six litres of water will be returned with STS-126 to calibrate the on-board analysis and after running successfully for 90 days, the station will be able to support an additional three astronauts.

Atmosphere

Several systems are currently used on board the ISS to maintain the spacecraft's atmosphere, which is similar to the Earth's. Normal air pressure on the ISS is 101.3 kPa (14.7 psi); the same as at sea level on Earth. An Earth-like atmosphere offers benefits for crew comfort, and is much safer than the alternative, a pure oxygen atmosphere, because of the increased risk of a fire such as that responsible for the deaths of the Apollo 1 crew.

Air revitalisation system

Carbon dioxide and trace contaminants are removed by the Air Revitalisation System. This is a NASA rack, to be placed in *Tranquillity*, designed to provide a Carbon Dioxide Removal Assembly (CDRA), a Trace Contaminant Control Subassembly (TCCS) to remove hazardous trace contamination from the atmosphere and a Major Constituent Analyser (MCA) to monitor Nitrogen, Oxygen, Carbon dioxide, Methane, hydrogen, and water vapour. The Air Revitalization System was flown to the station aboard STS-128 and was temporarily installed in the Japanese Experiment Module Pressurised Module. The system is scheduled to be transferred to *Tranquillity* now that the module has arrived and was installed during Space Shuttle *Endeavour* mission STS-130.

Oxygen generating system

The Oxygen Generating System (OGS) is a NASA rack designed to electrolyse water from the Water Recovery System to produce oxygen and hydrogen. The oxygen is delivered to the cabin atmosphere and the hydrogen is vented overboard . The unit is installed in the *Destiny* module. During one of the spacewalks conducted by STS-117 astronauts, a hydrogen vent valve required to begin using the system was installed. The system became operational on 12 July 2007.

Elektron

Elektron is a Russian oxygen generator, which uses electrolysis to produce oxygen. This process splits water molecules reclaimed from other uses on board the station into oxygen and hydrogen via electrolysis. The oxygen is vented into the cabin and the hydrogen is vented into space. The three Elektron oxygen generators on board the International Space Station have been plagued with problems, sometimes forcing the crew to use backup sources of bottled oxygen and Solid Fuel Oxygen Generation (SFOG) canisters. Each canister can supply the oxygen needs of one crewmember for one day. NASA delivered a similar American-built system with Discovery flight STS-121, to supplement the Russian Elektron oxygen system and eventually support a crew of six. It became operational in 2007.

Elektron failures

- 8 September 2004: The Elektron unit shut down mysteriously. Two weeks of troubleshooting resulted in the unit starting up again, then immediately shutting down. The cause was eventually traced to gas bubbles in the unit, which remained non-functional until a Progress resupply mission in October 2004.

- 1 January 2005: ISS personnel tapped into the oxygen supply of the recently-arrived Progress resupply ship, when the Elektron unit failed.

- 18 September 2006: Fumes from a malfunctioning Elektron unit prompted NASA flight engineers to declare a "spacecraft emergency". A burning smell led the ISS crew to suspect another Elektron fire, but the unit was only "very hot". A leak of corrosive, odorless potassium hydroxide forced the ISS crew to don gloves and face masks. It has been conjectured that the smell came from overheated rubber seals. The incident occurred shortly after STS-115 left and just before arrival of a resupply mission (including space tourist Anousheh Ansari) . The Elektron did not come back online until November 2006, after new valves and cables arrived on the October 2006 Progress resupply vessel.

Elektron Fixes

The ERPTC (Electrical Recovery Processing Terminal Current) was inserted into the ISS to prevent harm to the systems.

Vika

A backup to the temperamental Elektron system used on both the ISS and *Mir* is the *Vika* solid-fuel oxygen generator (SFOG), which contains a replaceable cartridge, a thin walled steel tube with a three-part block of oxygen-releasing mixture based on lithium perchlorate. Two parts are tablets of the chemical mixture and the third one is the igniter tablet with a flash igniter. The igniter is struck by a firing pin when the device is activated. One cartridge releases 600 litres (160 US gal) of oxygen and burns for 5–20 minutes at 450–500 °C (842–932 °F) The oxygen is cooled and filtered from dust and odours, and released into the space station atmosphere.

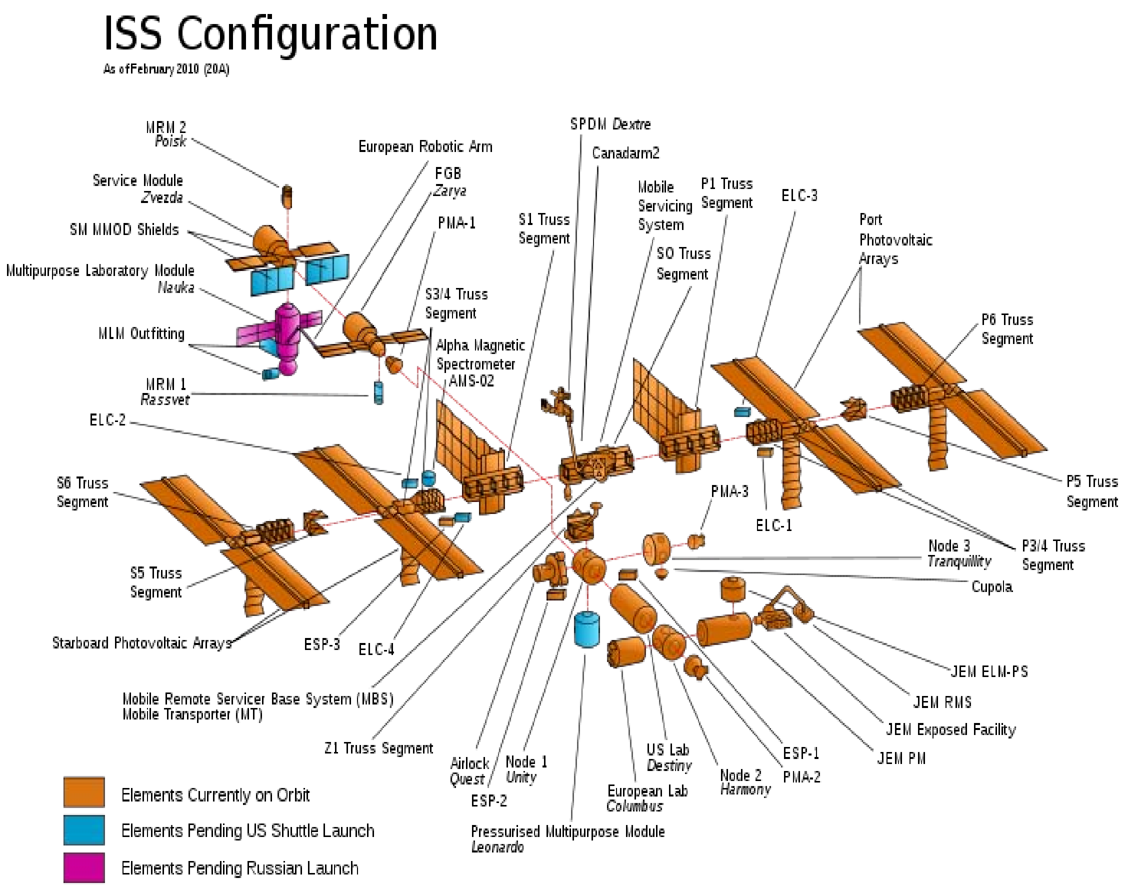
On 23 February 1997, during the exchange of an air filter, a failed chemical oxygen generator spewed a torch-like jet of a molten metal and sparks across one of the Mir space station modules, burning for 14 minutes and blocking the escape route to one of the Soyuz spacecraft. The accident was caused by a leak of the lithium perchlorate from one of the canisters.

Vozdukh

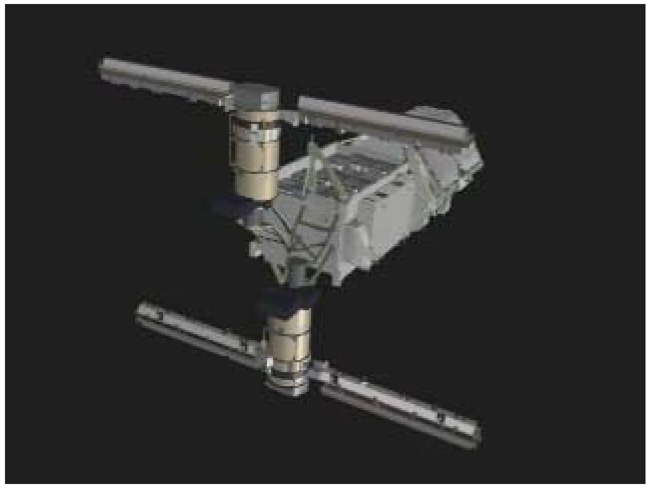
Another Russian system, Vozdukh (Russian *Воздух*, meaning "air"), removes carbon dioxide from the air based on the use of regenerable absorbers of carbon dioxide gas.

Chapter- 5

Integrated Truss Structure



ISS elements as of February 2010

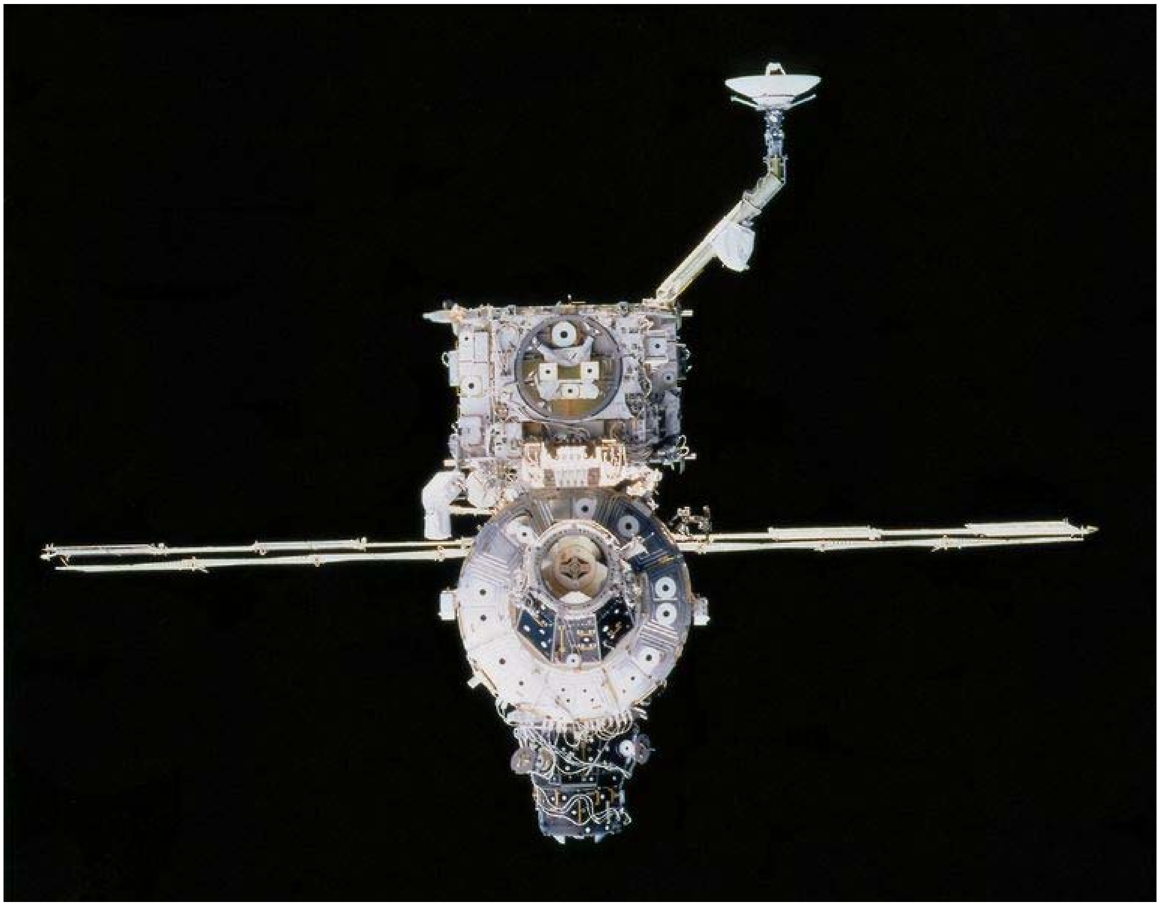

The components and the unfolding of the P3/P4 Truss in Detail (Animation)

The **Integrated Truss Structure** forms the backbone of the International Space Station, with mountings for unpressurized logistics carriers, radiators, solar arrays, and other equipment.

In the initial Space Station Freedom plans, a variety of designs for the truss were used, all of them intended to be shipped up as girders where they would be assembled and their equipment installed by astronauts on spacewalks once it had been launched. After the 1991 redesign, NASA switched to shorter, prefabricated pieces that were easier to install.

Truss components

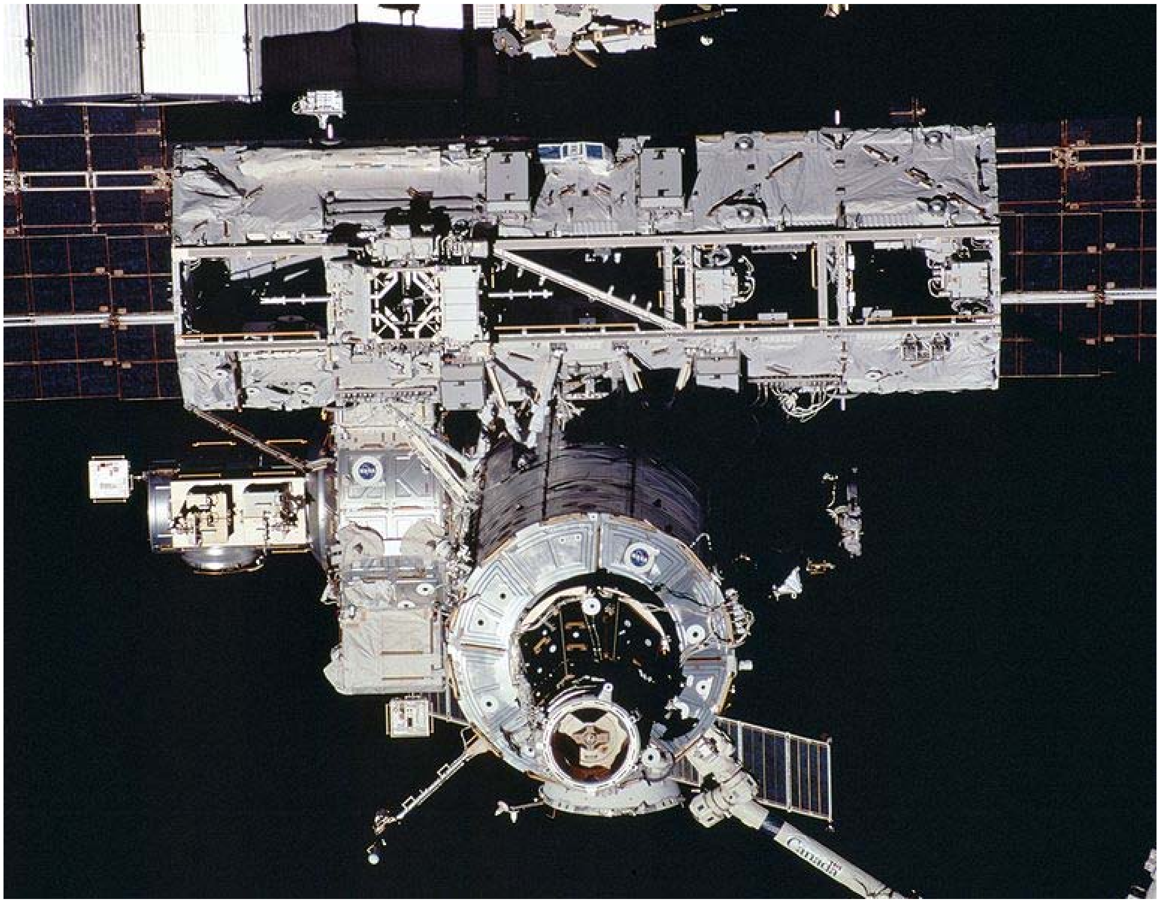
Z1 truss



Z1 truss (above) and Unity Module (below) from STS-92 in October 2000

The first truss piece, the Z1 truss, launched aboard STS-92 in October 2000 was used as a temporary mounting position for the P6 truss and solar array until its relocation to the end of the P5 truss during STS-120. Though not a part of the main truss, the Z1 truss was the first permanent lattice-work structure for the ISS, very much like a girder, setting the stage for the future addition of the station's major trusses or backbones. It contains the control moment gyroscope (CMG) assemblies, electrical wiring, communications equipment, and two plasma contactors designed to neutralize the static electrical charge of the space station. It is unpressurized (with the exception of a small vestibule), but features two Common Berthing Mechanism docking ports for easy connecting and data communications. One port (nadir) is used to connect the Z1 truss to the zenith port of *Unity*. The other port (forward) was used to temporarily berth PMA-2 during the placing of the *Destiny* lab onto the *Unity* node during STS-98. In October 2007, the P6 was moved to its permanent position next to P5, and the Z1 truss is now not used for connecting other elements, but solely to house the CMGs, communications equipment and the plasma contactors.

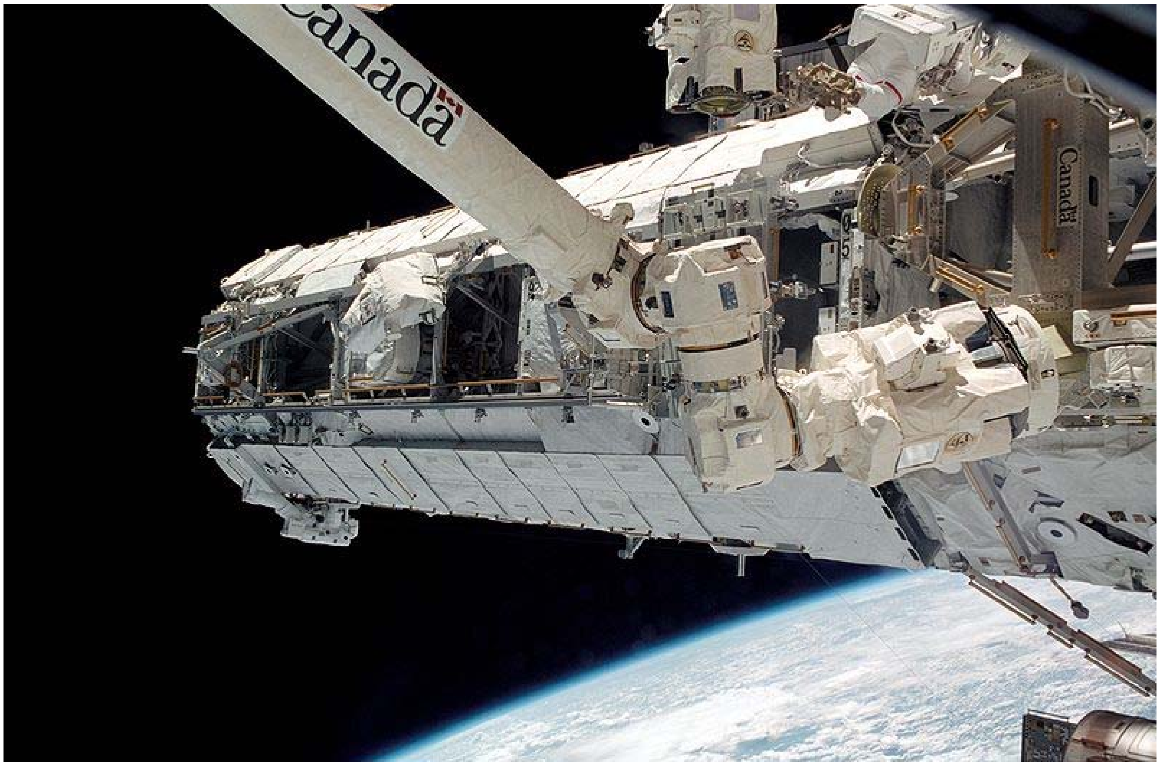
S0 truss



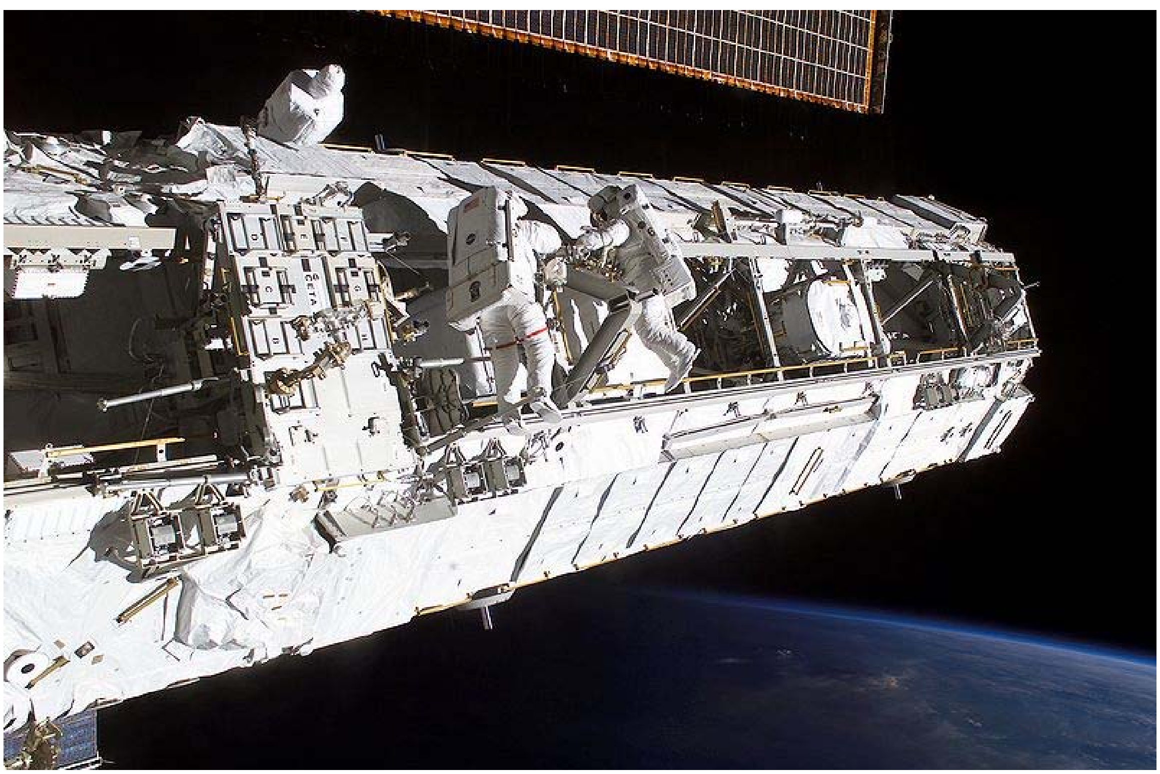
The **S0 truss** (above) from STS-110 April 17, 2002

The S0 truss, (also called the *Center Integrated Truss Assembly Starboard 0 Truss*) forms the center backbone of the Space Station. It was attached on the top of the Destiny Laboratory Module during STS-110 in April 2002. S0 is used to route power to the pressurized station modules and conduct heat away from the modules to the S1 and P1 Trusses. The S0 truss is not docked to the ISS, but is connected with four Module to Truss Structure (MTS) struts.

P1, S1 trusses



ISS **S1 truss** element being installed on STS-112 October 10, 2002

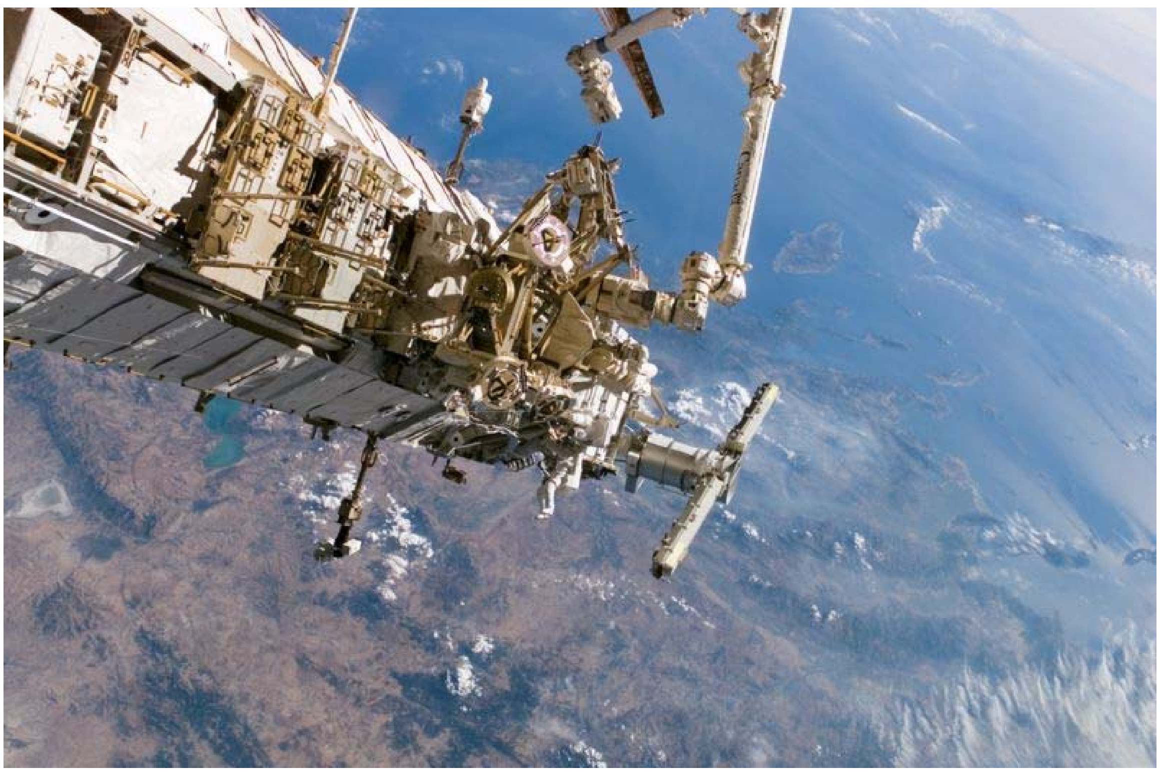

ISS **P1 truss** element being installed on STS-113 November 28, 2002

The P1 and S1 trusses (also called the *Port and Starboard Side Thermal Radiator Trusses*) are attached to the S0 truss, and contain carts to transport the Canadarm2 and astronauts to worksites along the space station. They each flow 290 kg (637 lb) of anhydrous ammonia through three heat rejection radiators. The S1 truss was launched on STS-112 in October 2002 and the P1 truss was launched on STS-113 in November 2002. Detailed design, test and construction of the S1 and P1 structures was conducted by McDonnell Douglas (now Boeing) in Huntington Beach, CA. First parts were cut for the structure in 1996, and delivery of the first truss occurred in 1999.

P2, S2 trusses

The P2 and S2 trusses were planned as locations for rocket thrusters in the original design for Space Station Freedom. Since the Russian parts of the ISS also provided that capability, the reboost capability of the Space Station Freedom design was no longer needed at that location. So P2 and S2 were canceled.

P3/P4, S3/S4 truss assemblies



The **P3/P4 truss assembly** being installed during STS-115 September 13, 2006. Astronauts give scale to the image.

The newly installed **S3/S4 truss assembly** during the first EVA of mission STS-117 on June 11, 2007.

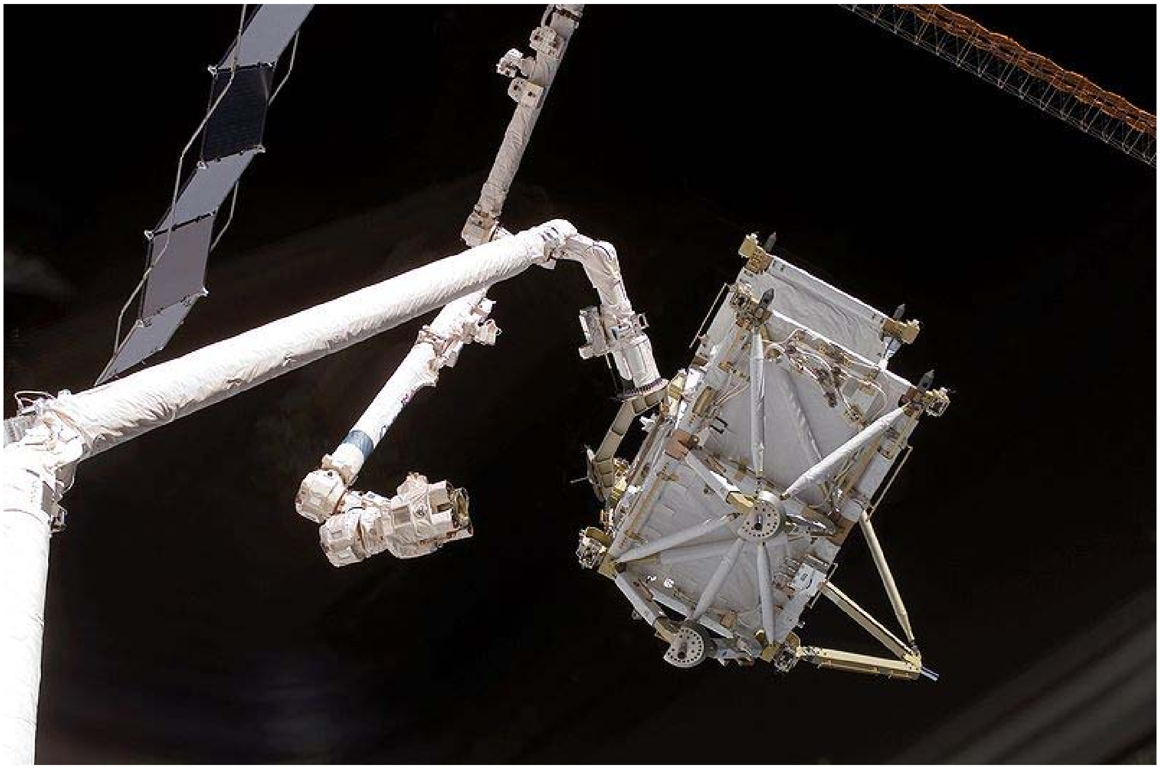
The P3/P4 truss assembly was installed by the Space Shuttle *Atlantis* STS-115 mission, launched September 9, 2006, and attached to the P1 segment. The P3 and P4 segments together contain a pair of solar arrays, a radiator and a rotary joint that will aim the solar arrays, and connects P3 to P4. Upon its installation, no power was flowing across the rotary joint, so the electricity generated by the P4 solar array wings was only being used on the P4 segment, and not the rest of the station. Then in December 2006 a major electrical rewiring of the station by STS-116 routed this power to the entire grid. The S3/S4 truss assembly—a mirror-image of P3/P4—was installed on June 11, 2007 also by Space Shuttle *Atlantis* during flight STS-117, mission 13A and mounted to the S1 truss segment.

Major P3 and S3 subsystems include the Segment-to-Segment Attach System (SSAS), Solar Alpha Rotary Joint (SARJ), and Unpressurized Cargo Carrier Attach System (UCCAS). The primary functions of the P3 truss segment are to provide mechanical, power and data interfaces to payloads attached to the two UCCAS platforms; axial indexing for solar tracking, or rotating of the arrays to follow the sun, via the SARJ; movement and work site accommodations for the Mobile Transporter. The P3/S3 primary structure is made of a hexagonal shaped aluminum structure and includes four bulkheads and six longerons. The S3 truss also supports EXPRESS Logistics Carrier locations, first to be launched and installed in the 2009 time frame.

Major subsystems of the P4 and S4 Photovoltaic Modules (PVM) include the two Solar Array Wings (SAW), the Photovoltaic Radiator (PVR), the Alpha Joint Interface

Structure (AJIS), and Modified Rocketdyne Truss Attachment System (MRTAS), and Beta Gimbal Assembly (BGA).

P5, S5 trusses



Space Shuttle *Discovery*'s Canadarm-1 robotic arm hands off the P5 truss section to the International Space Station's Canadarm-2 during shuttle mission STS-116 in December, 2006.

Space Shuttle *Endeavour* approaches the International Space Station during mission STS-118 with the S5 truss section ready to be installed.

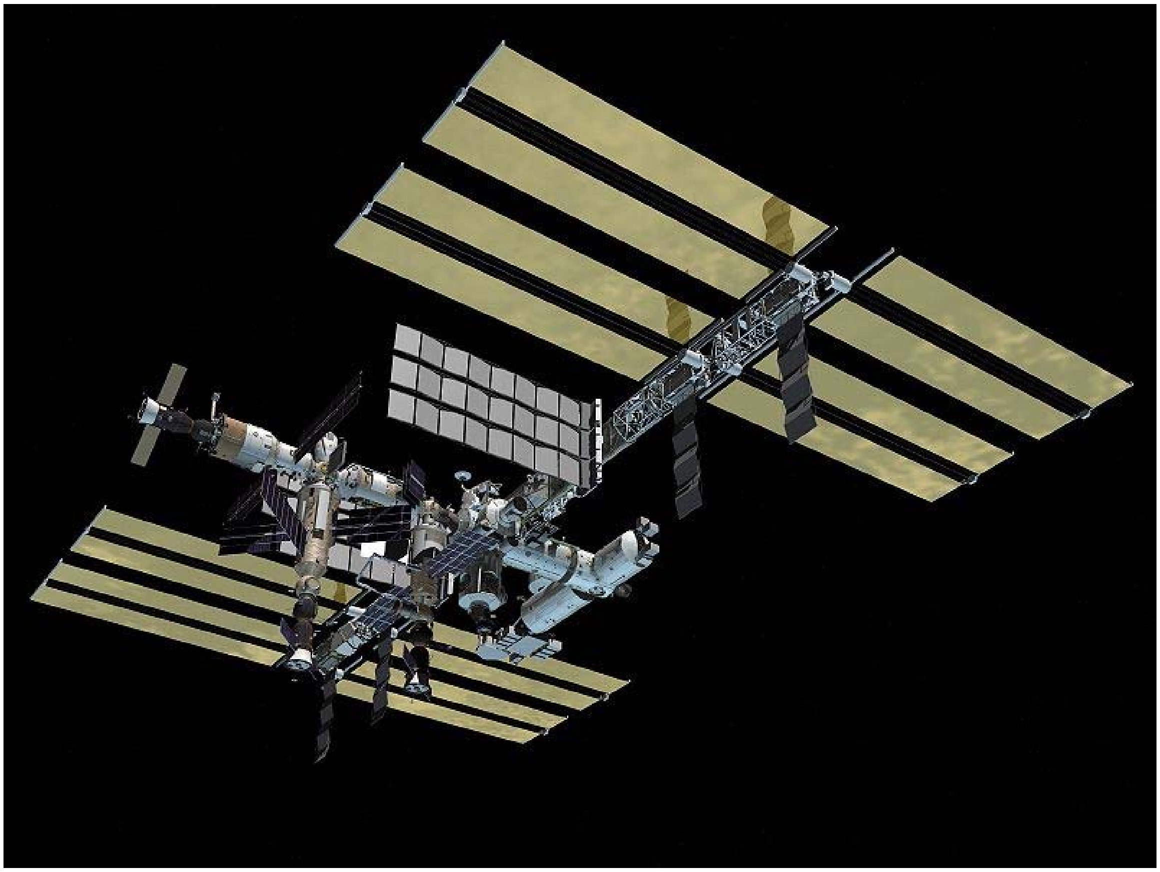
The P5 and S5 trusses are connectors which support the P6 and S6 trusses, respectively. The P3/P4 and S3/S4 truss assemblies' length was limited by the cargo bay capacity of the Space Shuttle, so these small connectors are needed to extend the truss. The P5 truss was installed on December 12, 2006 during the first EVA of mission STS-116. The S5 truss was brought into orbit by mission STS-118 and installed on August 11, 2007.

P6, S6 trusses

The P6 truss was the second truss segment to be added, because it contains a large Solar Array Wing (SAW) that generated essential electricity for the station, prior to activation of the SAW on the P4 truss. It was originally mounted to the Z1 truss and had its SAW extended during STS-97, but SAW was folded, one half at a time, to make room for the SAWs on the P4 and S4 trusses, during STS-116 and STS-117 respectively. Shuttle mission STS-120 (assembly mission 10A) detached the P6 truss from Z1, remounted it on the P5 truss, redeployed its radiator panels and attempted to redeploy its SAWs. One SAW (2B) was deployed successfully but the second SAW (4B) developed a significant tear that temporarily stopped deployment at around 80%. This was subsequently fixed and the array is now fully deployed. A later assembly mission (the out of sequence STS-119) mounted the S6 truss on the S5 truss, which provided a fourth and final set of solar arrays and radiators.

Truss subsystems

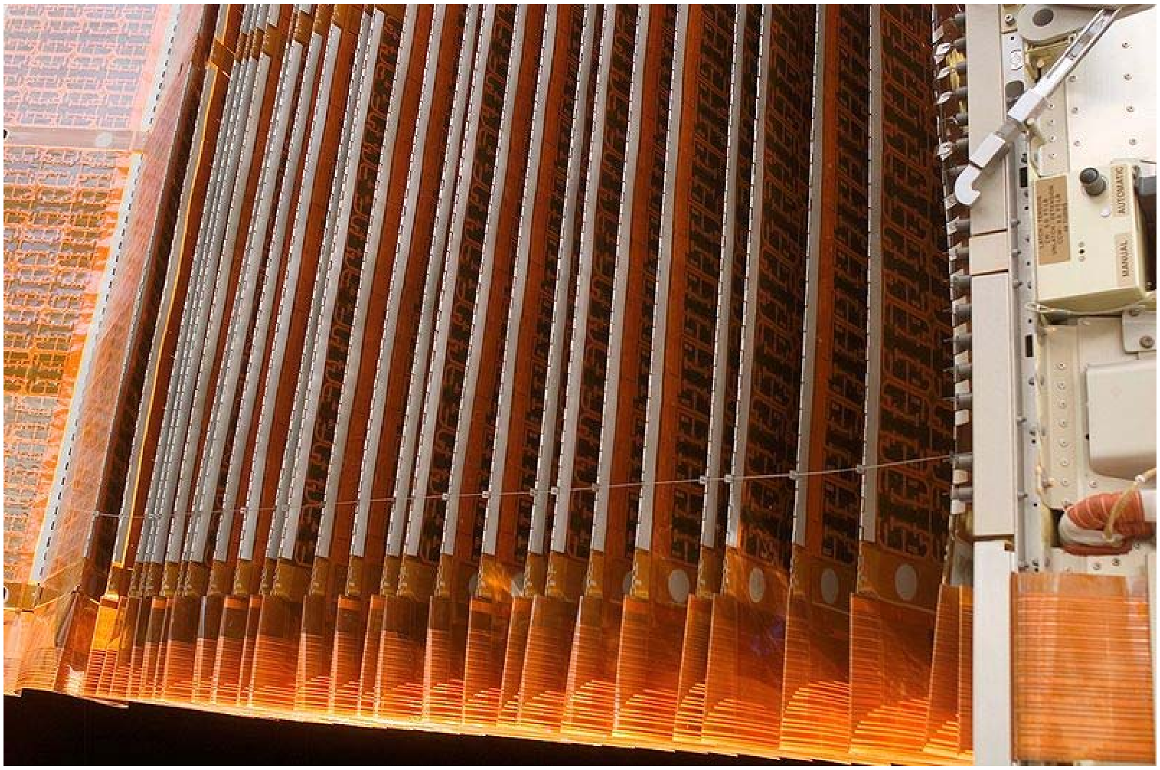
International Space Station on November 5, 2007 after relocation of the P6 truss assembly (far right) by STS-120


Computer model of the planned completed station (as of June 2006)

Solar arrays

The International Space Station's main source of energy is from three of the four large U.S.-made photovoltaic arrays currently on the station, sometimes referred to as the *Solar Array Wings* (SAW). The first pair of arrays are attached to the P6 truss segment, which was launched and installed on top of Z1 in late 2000 during STS-97. The P6 segment was relocated to its final position, bolted to the P5 truss segment, in November 2007 during STS-120. The second pair of arrays was launched and installed in September 2006 during STS-115, but they didn't provide electricity until STS-116 in December 2006 when the station got an electrical rewiring. A third pair of arrays was installed during STS-117 in June 2007. A final pair arrived mid March 2009 on STS-119. More solar power was to have been available via the Russian-built Science Power Platform, but it was cancelled.

Each of the Solar Array Wings are 34 m (112 ft) long by 12 m (39 ft) wide, and are capable of generating nearly 32.8 kW of DC power. They are split into two photovoltaic blankets, with the deployment mast in between. Each blanket has 16,400 silicon photovoltaic cells, each cell 8 cm by 8 cm, grouped into 82 active panels, each consisting of 200 cells, with 4,100 diodes.



close-up view of solar array folded like an accordion.

Each pair of blankets is folded like an accordion for compact delivery to space. Once in orbit, the deployment mast between each pair of blankets unfolds the array to its full length. Gimbals, known as the *Beta Gimbal Assembly* (BGA) are used to rotate the arrays so that they face the Sun to provide maximum power to the International Space Station.

Solar Alpha Rotary Joint

The **Alpha** joint is the main rotary joint allowing the solar arrays to track the sun; in nominal operation the alpha joint rotates by 360° each orbit. One Solar Alpha Rotary Joint (SARJ) is located between the P3 and P4 truss segments and the other is located between the S3 and S4 truss segments. When in operation, these joints continuously rotate to keep the solar array wings on the outboard truss segments oriented towards the Sun. Each SARJ is 10 feet in diameter, weighs approximately 2,500 pounds and can be rotated continuously using bearing assemblies and a servo control system. On both the port and starboard sides, all of the power flows through the Utility Transfer Assembly (UTA) in the SARJ. Roll ring assemblies allow transmission of data and power across the rotating interface so it never has to unwind. The SARJ was designed, built and tested by Lockheed Martin and its subcontractors.

In 2007, a problem was detected in the starboard SARJ. Damage had occurred due to excessive and premature wear of a track in the joint mechanism. The SARJ was frozen during problem diagnosis, and in 2008 lubrication was applied to the track to address the issue.

Power Conditioning and Storage

The Sequential Shunt Unit (SSU) is designed to coarsely regulate the solar power collected during periods of insolation – when the arrays collect power during sun-pointing periods. A sequence of 82 separate strings, or power lines, leads from the solar array to the SSU. Shunting, or controlling, the output of each string regulates the amount of power transferred. The regulated voltage setpoint is controlled by a computer located on the IEA and is normally set to around 140 volts. The SSU has an overvoltage protection feature to maintain the output voltage below 200 V DC maximum for all operating conditions. This power is then passed through the BMRRM to the DCSU located in the IEA. The SSU measures 32” by 20” by 12” and weighs 185 pounds.

The power storage system consists of a Battery Charge/Discharge Unit (BCDU) and two nickel hydrogen battery assemblies.

The BCDU serves a dual function of charging the batteries during solar collection periods, and providing conditioned battery power to the primary power busses (via the DCSU) during eclipse periods. The BCDU has a battery charging capability of 8.4 kW and a discharge capability of 6.6 kW. The BCDU also includes provisions for battery status monitoring and protection from power circuit faults. Commanding of the BCDU is from the IEA computer.

Each battery assembly consist of 38 lightweight Nickel Hydrogen cells and associated electrical and mechanical equipment. Each battery assembly has a nameplate capacity of 81 A·hr and 4 kW·hr. This power is fed to the ISS via the BCDU and DCSU respectively. The batteries have a design life of 6.5 years and can exceed 38,000 charge/discharge cycles at 35% depth of discharge. Each battery measures 40” by 36” by 18” and weighs 375 pounds.

Truss and solar array assembly sequence

- All truss segments are in orbit (S2 and P2 were cancelled).

Element	Flight	Launch date	Length (m)	Diameter (m)	Mass (kg)
Z1 truss	3A – STS-92	October 11, 2000	4.9	4.2	8,755
P6 truss – solar array	4A – STS-97	November 30, 2000	73.2	10.7	15,824
S0 truss	8A – STS-110	April 8, 2002	13.4	4.6	13,971
S1 truss	9A – STS-112	October 7, 2002	13.7	4.6	14,124
P1 truss	11A – STS-113	November 23, 2002	13.7	4.6	14,003
P3/P4 truss – solar array	12A – STS-115	September 9, 2006	13.8	4.8	15,824

P5 truss - spacer	12A.1 – STS-116	December 9, 2006	3.37	4.55	1,864
S3/S4 truss – solar array	13A – STS-117	June 8, 2007	73.2	10.7	15,824
S5 truss - spacer	13A.1 – STS-118	August 8, 2007	3.37	4.55	1,818
P6 truss – solar array (relocation)	10A – STS-120	October 23, 2007	73.2	10.7	15,824
S6 truss – solar array	15A – STS-119	March 15, 2009	73.2	10.7	15,824

Chapter- 6

International Space Station Program

The **International Space Station program** is tied together by a complex set of legal, political and financial agreements between the fifteen nations involved in the project, governing ownership of the various components, rights to crewing and utilisation, and responsibilities for crew rotation and station resupply. These agreements tie together the five space agencies and their respective International Space Station Programs and govern how they interact with each other on a daily basis to maintain station operations, from traffic control of spacecraft to and from the station, to utilization of space and crew time. In spring 2010, the International Space Station Program Managers from each of the five partner agencies were presented with Aviation Week's Laureate Award in the Space category, and NASA's International Space Station Program was awarded the 2009 Collier Trophy.

International Space Station Program

A Commemorative Plaque honoring Space Station Intergovernmental Agreement signed on January 28, 1998.

International Space Station Program Managers	
Canadian Space Agency	Pierre Jean

European Space Agency	Bernardo Patti
Japan Aerospace Exploration Agency	Yoshiyuki Hasegawa
Roscosmos	Alexey Krasnov
NASA	Michael Suffredini

Legal aspects

Agreement

The legal structure that regulates the space station is multi-layered. The primary layer establishing obligations and rights between the ISS partners is the Space Station Intergovernmental Agreement (IGA), an international treaty signed on January 28, 1998 by fifteen governments involved in the Space Station project. The ISS consists of Canada, Japan, the Russian Federation, the United States, and eleven Member States of the European Space Agency (Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom). Article 1 outlines its purpose:

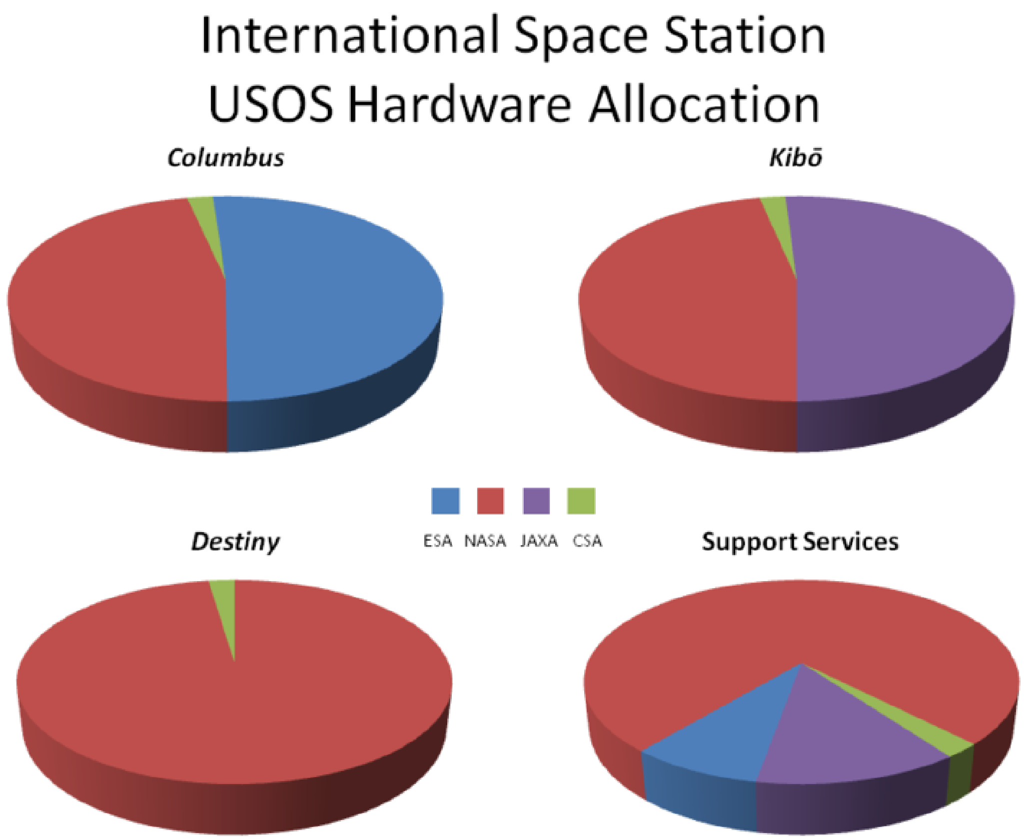
This Agreement is a long term international co-operative framework on the basis of genuine partnership, for the detailed design, development, operation, and utilisation of a permanently inhabited civil Space Station for peaceful purposes, in accordance with international law.

The IGA sets the stage for a second layer of agreements between the partners referred to as 'Memoranda of Understanding' (MOUs), of which four exist between NASA and each of the four other partners. There are no MOUs between ESA, Roskosmos, CSA and JAXA because NASA is the designated *manager* of the ISS. The MOUs are used to describe the roles and responsibilities of the partners in more detail.

A third layer consists of bartered contractual agreements or the trading of the partners' rights and duties, including the 2005 commercial framework agreement between NASA and Roskosmos that sets forth the terms and conditions under which NASA purchases seats on Soyuz crew transporters and cargo capacity on unmanned Progress transporters.

A fourth legal layer of agreements implements and supplements the four MOUs further. Notably among them is the ISS code of conduct, setting out criminal jurisdiction, anti-harassment and certain other behavior rules for ISS crewmembers.

Utilization



Allocation of ISS hardware between nations.

There is no fixed percentage of ownership for the whole space station. Rather, Article 5 of the IGA sets forth that *each partner shall retain jurisdiction and control over the elements it registers and over personnel in or on the Space Station who are its nationals*. Therefore, for each ISS module only one partner retains sole ownership. Still, the agreements to use the space station facilities are more complex.

The three planned Russian segments Zvezda, the Multipurpose Laboratory Module and the Docking Cargo Modules are made and owned by Russia, which, as of today, also retains its current and prospective usage (Zarya, although constructed and launched by Russia, has been paid for and is officially owned by NASA). In order to use the Russian parts of the station, the partners use bilateral agreements (third and fourth layer of the above outlined legal structure). The rest of the station, (the U.S., the European and Japanese pressurized modules as well as the truss and solar panel structure and the two robotic arms) has been agreed to be utilized as follows (% refers to time that each structure may be used by each partner):

- *Columbus*: 51% for ESA, 46.7% for NASA and 2.3% for CSA.
- *Kibō*: 51% for JAXA, 46.7% for NASA and 2.3% for CSA.
- *Destiny*: 97.7% for NASA and 2.3% for CSA.

- Crew time, electrical power and rights to purchase supporting services (such as data upload & download and communications) are divided 76.6% for NASA, 12.8% for JAXA, 8.3% for ESA, and 2.3% for CSA.

Program operations

Expeditions

Long duration flights to the International Space Station are broken into expeditions. Expeditions have an average duration of half a year, and they commence following the official handover of the station from one Expedition commander to another. Expeditions 1 through 6 consisted of three person crews, but the Space Shuttle Columbia disaster led to a reduction to two crew members for Expeditions 7 to 12. Expedition 13 saw the restoration of the station crew to three. While only three crew members are permanently on the station, several expeditions, such as Expedition 16, have consisted of up to six astronauts or cosmonauts. Only 3 members were active at any given time, one of the 'seats' was rotated out during separate flights.

STS-115 expanded of the living volume and capabilities of the station so that it could host a crew of six. Expedition 20 was the first ISS crew of this size. Expedition 20's crew was lifted to the station in two separate Soyuz-TMA flights launched at two different times (each Soyuz-TMA can hold only three people): Soyuz TMA-14 on 26 March 2009 and Soyuz TMA-15 on 27 May 2009. However, the station would not be permanently occupied by six crew members all year. For example, when the Expedition 20 crew (Roman Romanenko, Frank De Winne and Bob Thirsk) returned to Earth in November 2009, for a period of about two weeks only two crew members (Jeff Williams and Max Surayev) were aboard. This increased to five in early December, when Oleg Kotov, Timothy Creamer and Soichi Noguchi arrived on Soyuz TMA-17. It decreased to three when Williams and Surayev departed in March 2010, and finally returned to six in April 2010 with the arrival of Soyuz TMA-18, carrying Aleksandr Skvortsov, Mikhail Korniyenko and Tracy Caldwell Dyson.

The International Space Station is the most-visited spacecraft in the history of space flight. As of 24 November 2009, it had had 266 visitors (185 different people). *Mir* had 137 visitors (104 different people).

Visiting spacecraft

The Space Shuttle *Endeavour* approaching the ISS during STS-118

Spacecraft from four different space agencies visit the ISS, serving a variety of purposes. The Automated Transfer Vehicle from the European Space Agency, the Russian Roskosmos Progress spacecraft and the H-II Transfer Vehicle from the Japan Aerospace Exploration Agency have provided resupply services to the station. In addition, Russia supplies a Soyuz spacecraft used for crew rotation and emergency evacuation, which is replaced every six months. Finally, the US services the ISS through its Space Shuttle program, providing resupply missions, assembly and logistics flights, and crew rotation.

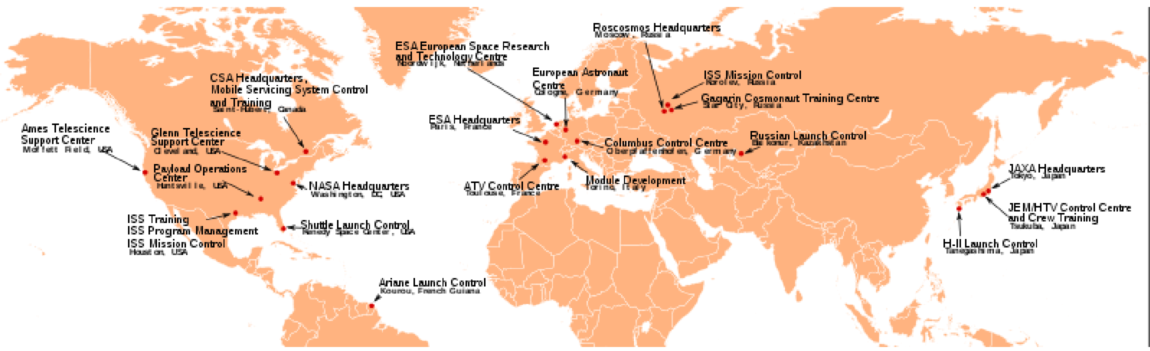
The availability of docking ports on the station, and traffic from four different agencies and launch sites must be coordinated. Spacecraft launches can see delays while waiting for traffic to clear   A particular tight traffic jam occurred during the latch of ESA's Jules Verne Automated Transfer Vehicle in spring 2008. The cargo ship launched 2 day prior to STS-123, and had to wait in a holding orbit performing system tests while waiting for the shuttle to clear the station.

As of 27 November 2009, there have been 20 Soyuz, 35 Progress, 1 ATV, 1 HTV and 31 Space Shuttle flights to the station. Expeditions require, on average, 2,722 kg of supplies, and as of 27 November 2009, crews had consumed a total of around 19,000 meals. Soyuz crew rotation flights and Progress resupply flights visit the station on average two and three times respectively each year, with the ATV and HTV planned to visit annually from 2010 onwards.

As of 29 May 2010, there were three spacecraft docked with the ISS:

Spacecraft	Mission	Docking port	Date docked	Notes
Soyuz TMA-17	Expedition 22/Expedition 23	*Zvezda* aft	22 December 2009 16:48 UTC	
Soyuz TMA-18	Expedition 23/Expedition 24	*Poisk*	5 April 2010 05:24 UTC	
Progress M-05M	ISS Progress 37	*Pirs*	1 May 2010 18:30 UTC	

Mission control centers



Space centers involved with the ISS programme

The components of the ISS are operated and monitored by their respective space agencies at control centers across the globe, including:

- NASA's Mission Control Center at Lyndon B. Johnson Space Center in Houston, Texas, serves as the primary control facility for the US segment of the ISS and also controls the Space Shuttle missions that visit the station.
- NASA's Payload Operations and Integration Center at Marshall Space Flight Center in Huntsville, Alabama, serves as the center that coordinates all payload operations in the US Segment. This center links Earth-bound researchers around the world with their experiments and astronauts aboard the International Space Station.
- Roskosmos's Mission Control Center at Korolyov, Moscow, controls the Russian Orbital Segment of the ISS, in addition to individual Soyuz and Progress missions.
- ESA's Columbus Control Center at the German Aerospace Center (DLR) in Oberpfaffenhofen, Germany, controls the European *Columbus* research laboratory.
- ESA's ATV Control Center, at the Toulouse Space Centre (CST) in Toulouse, France, controls flights of the unmanned European Automated Transfer Vehicle.
- JAXA's JEM Control Centre and HTV Control Centre at Tsukuba Space Center (TKSC) in Tsukuba, Japan, are responsible for operating the Japanese Experiment

Module complex and all flights of the unmanned Japanese H-II Transfer Vehicle respectively.

- CSA's MSS Control at Saint-Hubert, Quebec, Canada, controls and monitors the Mobile Servicing System, or Canadarm2.

Commercial Orbital Transportation Services

On January 18, 2006 NASA announced *Commercial Orbital Transportation Services* programme. NASA has suggested that "Commercial services to ISS will be necessary through at least 2015." Instead of flying payloads to ISS on government-operated vehicles, NASA would spend $500 million (less than the cost of a single Space Shuttle flight) through 2010 to finance the demonstration of orbital transportation services from commercial providers.

COTS must be distinguished from the related Commercial Resupply Services (CRS) program. COTS relates to the development of the vehicles, CRS to the actual deliveries. COTS involves a number of Space Act Agreements, with NASA providing milestone-based payments.

On December 23, 2008, NASA entered into CRS contracts with Orbital Sciences and SpaceX to utilize their COTS cargo vehicles—Cygnus and Dragon, respectively—for cargo delivery to the International Space Station.

Constellation Program

Constellation Program, a human spaceflight program, was developed by NASA. On February 1, 2010, President Barack Obama announced a proposal to cancel the program effective with the U.S. 2011 fiscal year budget, but later announced changes to the proposal in a major space policy speech at Kennedy Space Center on April 15, 2010, which including reviving the Orion capsule for use as a rescue spacecraft for ISS.

Future of the ISS

The heads of the ISS agencies from Canada, Europe, Japan, Russia and the United States meet in Tokyo to review ISS cooperation.

Former NASA Administrator Michael D. Griffin says the International Space Station has a role to play as NASA moves forward with a new focus for the manned space programme, which is to go out beyond Earth orbit for purposes of human exploration and scientific discovery. "The International Space Station is now a stepping stone on the way, rather than being the end of the line," Griffin said. Griffin has said that station crews will not only continue to learn how to live and work in space, but also will learn how to build hardware that can survive and function for the years required to make the round-trip voyage from Earth to Mars.

Despite this view, however, in an internal e-mail leaked to the press on 18 August 2008 from Griffin to NASA managers, Griffin apparently communicated his belief that the current US administration had made no viable plan for US crews to participate in the ISS beyond 2011, and that the Office of Management and Budget (OMB) and Office of Science and Technology Policy (OSTP) were actually seeking its demise. The e-mail appeared to suggest that Griffin believed the only reasonable solution was to extend the operation of the space shuttle beyond 2010, but noted that Executive Policy (i.e. the White House) was firm that there will be no extension of the space shuttle retirement date, and thus no US capability to launch crews into orbit until the Ares I/Orion system becomes operational in 2014, at the earliest. He did not see purchase of Russian launches for NASA crews as politically viable following the 2008 South Ossetia war, and hoped the incoming Barack Obama administration would resolve the issue in 2009 by extending space shuttle operations beyond 2010.

A solicitation issued by NASA JSC indicates NASA's intent to purchase from Roscosmos "a minimum of 3 Soyuz seats up to a maximum of 24 seats beginning in the Spring of 2012" to provide ISS crew transportation.

On 7 September 2008, NASA released a statement regarding the leaked email, in which Griffin said:

"The leaked internal email fails to provide the contextual framework for my remarks, and my support for the administration's policies. Administration policy is to retire the shuttle in 2010 and purchase crew transport from Russia until Ares and Orion are available. The administration continues to support our request for an INKSNA exemption. Administration policy continues to be that we will take no action to preclude continued operation of the International Space Station past 2016. I strongly support these administration policies, as do OSTP and OMB."
—Michael D. Griffin

On 15 October 2008, President Bush signed the NASA Authorization Act of 2008, giving NASA funding for one additional mission to "deliver science experiments to the station". The Act allows for an additional space shuttle flight, STS-134, to the ISS to install the Alpha Magnetic Spectrometer, which was previously cancelled.

President Barack Obama has supported the continued operation of the station, and supported the NASA Authorization Act of 2008. Obama's plan for space exploration includes finishing the station and completion of the *Orion* spacecraft programme.

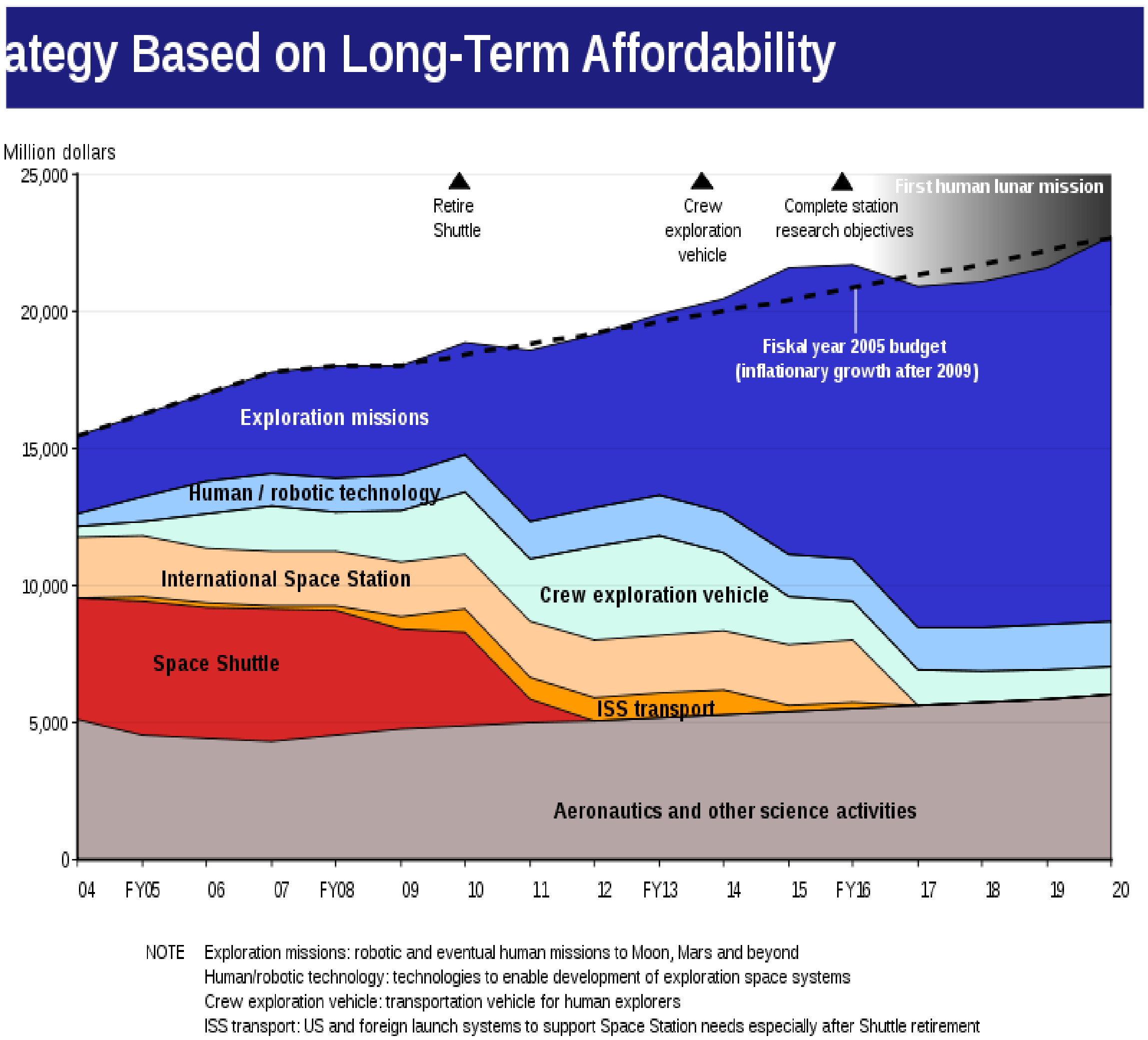
New partners

China has reportedly expressed interest in the project, especially if it would be able to work with the RKA. However, as of 2009 China is not involved because of US objections. The heads of both the South Korean and Indian space agencies announced at the first plenary session of the 2009 International Astronautical Congress on 12 October that their nations intend to join the ISS program. The talks are due to begin in 2010. The heads of agency also expressed support for extending ISS lifetime. European countries not a part of the International Space Station program will be allowed access to the station in a three-year trial period, ESA officials say.

Costs

The most cited figure of an estimate of overall costs of the ISS ranges from 35 billion to 100 billion USD. ESA, the only agency actually stating potential overall costs on its website, estimates €100 billion. Giving a precise cost estimate for the ISS is not straightforward, as it is difficult to determine which costs should actually be contributed to the ISS program, or how the Russian contribution should be measured.

NASA



NASA's current budget projections see an end to ISS funding in 2017, in order to free funds for the Vision for Space Exploration.

The overall majority of costs for NASA are incurred by flight operations and expenses for the overall management of the ISS. Costs for initially building the U.S. portion of the ISS modules and external structure on the ground and construction in space as well as crew and supply flights to the ISS do account for far less than the general operating costs.

NASA does not include the basic Space Shuttle program costs in the expenses incurred for the ISS program, despite the fact that the Space Shuttle has been nearly exclusively used for ISS construction and supply flights since December 1998.

NASA's 2007 budget request lists costs for the ISS (without Shuttle costs) as $25.6 billion for the years 1994 to 2005. For each of 2005 and 2006 about $1.7 to 1.8 billion are allocated to the ISS program. The annual expenses will increase until 2010 when they will reach $2.3 billion and should then stay at the same level, however inflation-adjusted, until 2016, the defined end of the program. NASA has allocated between $300 and 500 million for program shutdown costs in 2017.

2005 ISS budget allocation

NASA allocates about 125 million US dollars (USD) annually to EVAs.

The $1.8 billion expensed in 2005 consisted of:

- **Development of new hardware**: $70 million were allocated to core development, for instance development of systems like navigation, data support or environmental.
- **Spacecraft Operations**: $800 million consisting of $125 million for each of software, extravehicular activity systems, and logistics and maintenance. An additional $150 million is spent on flight, avionics and crew systems. The rest of $250 million goes to overall ISS management.
- **Launch and Mission operations**: Although the Shuttle launch costs are not considered part of the ISS budget, mission and mission integration ($300 million), medical support ($25 million) and Shuttle launch site processing ($125 million) is within the ISS budget.

- **Operations Program Integration**: $350 million was spent on maintaining and sustaining U.S. flight and ground hardware and software to ensure integrity of the ISS design and the continuous, safe operability.
- **ISS cargo/crew**: $140 million was spent for purchase of supplies, cargo and crew capability for Progress and Soyuz flights.

Shuttle costs as part of ISS costs

The only non-ISS-related Shuttle flight between 2005 and 2010 was a Hubble Space Telescope servicing mission on STS-125.

Only costs for mission and mission integration and launch site processing for the 33 ISS-related Shuttle flights are included in NASA's ISS program costs. Basic costs of the Shuttle program are, as mentioned above, not considered part of the overall ISS costs by NASA, because the Shuttle program is considered an independent program aside from the ISS. Since December 1998 the Shuttle has, however, been used nearly exclusively for ISS flights (since the first ISS flight in December 1998, until October 2007 only 5 flights out of 28 flights have not been to the ISS, and only the planned Hubble Space Telescope servicing mission in 2009 will not be ISS-related out of 13 planned missions until the end of the Space Shuttle program in 2010).

ESA

ESA calculates that its contribution over the 15 year lifetime of the project will be €9 billion. Just the costs for the Columbus Laboratory tops more than €1.4 billion (about

$2.1 billion), including the money spent on the ground control infrastructure known as Columbus Control Center to operate it. The total development costs for ATV amount to approximately €1.35 billion and considering that each Ariane 5 launch costs around €150 million, each ATV launch will incur considerable costs as well.

The ISS has been far more expensive than originally anticipated. The ESA estimates the overall cost from the start of the project in the early 1990s to the prospective end in 2017 to be in the region of €100 billion ($157 billion or £65.3 billion).

JAXA

The development of the Japanese Experiment Module, JAXA's main contribution to the ISS, has cost about 325 billion yen (about $2.8 billion). In the year 2005, JAXA allocated about 40 billion yen (about 350 million USD) to the ISS program. The annual running costs for Japanese Experiment Module will total around $350 to 400 million. In addition JAXA has committed itself to develop and launch the H-II Transfer Vehicle, for which development costs total nearly $1 billion. In total, over the 24 year lifespan of the ISS program, JAXA will contribute well over $10 billion to the ISS program.

Roskosmos

A considerable part of the Russian Space Agency's budget is used for the ISS. Since 1998 there have been over two dozen Soyuz and Progress flights, the primary crew and cargo transporters since 2003. The question of how much Russia spends on the station (measured in USD), is, however, not easy to answer. The two modules currently in orbit are derivatives of the Mir program and therefore development costs are much lower than for other modules. In addition, the exchange rate between ruble and USD is not adequately giving a real comparison to what the costs for Russia really are.

CSA

Canada, whose three main contributions to the ISS are the Canadarm2, the mobile base system, and Dextre (the Special Purpose Dexterous Manipulator, also known as the Canada Hand), estimates that through the last 20 years it has contributed about C$1.4 billion to the ISS. Canada has continued to be a vital member of ISS through the past ten years and continues to play a major role in the ISS.

Criticism

The International Space Station has been the target of varied criticism over the years. Critics contend that the time and money spent on the ISS could be better spent on other projects—whether they be robotic spacecraft missions, space exploration, investigations of problems here on Earth, or just tax savings. Some critics, like Robert L. Park, argue that very little scientific research was convincingly planned for the ISS in the first place.

They also argue that the primary feature of a space-based laboratory is its microgravity environment, which can usually be studied more cheaply with a "vomit comet".

One of the most ambitious ISS projects to date, the Centrifuge Accommodations Module, has been cancelled due to the prohibitive costs NASA faces in simply completing the ISS. As a result, the research done on the ISS is generally limited to experiments which do not require any specialized apparatus. For example, in the first half of 2007, ISS research dealt primarily with human biological responses to being in space, covering topics like kidney stones, circadian rhythm, and the effects of cosmic rays on the nervous system.

Other critics have attacked the ISS on some technical design grounds:

1. Jeff Foust argued that the ISS requires too much maintenance, especially by risky, expensive EVAs. The magazine *The American Enterprise* reports, for instance, that ISS astronauts "now spend 85 percent of their time on construction and maintenance" alone.
2. The Astronomical Society of the Pacific has mentioned that its orbit is rather highly inclined, which makes Russian launches cheaper, but US launches more expensive. This was intended as a design point, to encourage Russian involvement with the ISS—and Russian involvement saved the project from abandonment in the wake of the Space Shuttle Columbia disaster—but the choice may have increased the costs of completing the ISS substantially.

In response to some of these criticisms, advocates of manned space exploration say that criticism of the ISS project is short-sighted, and that manned space research and exploration have produced billions of dollars' worth of tangible benefits to people on Earth. Jerome Schnee estimated that the indirect economic return from spin-offs of human space exploration has been many times the initial public investment. A review of the claims by the Federation of American Scientists argued that NASA's rate of return from spin-offs is actually "astoundingly bad", except for aeronautics work that has led to aircraft sales.

Critics also say that NASA is often casually credited with "spin-offs" (such as Velcro and portable computers) that were developed independently for other reasons. NASA maintains a list of spin-offs from the construction of the ISS, as well as from work performed on the ISS. However, NASA's official list is much narrower and more arcane than dramatic narratives of billions of dollars of spin-offs.

It is therefore debatable whether the ISS, as distinct from the wider space program, will be a major contributor to society. Some advocates argue that apart from its scientific value, it is an important example of international cooperation. Others claim that the ISS is an asset that, if properly leveraged, could allow more economical manned Lunar and Mars missions. Either way, advocates argue that it misses the point to expect a hard financial return from the ISS; rather, it is intended as part of a general expansion of spaceflight capabilities.

Chapter- 7

Major Incidents Involving the International Space Station

Since construction started, the International Space Station programme has had to deal with several **Major incidents**, unexpected problems and failures. These incidents have affected the assembly timeline, led to periods of reduced capabilities of the station and in some cases could have forced the crew to abandon the space station for safety reasons, had these problems not been resolved.

2003 – *Columbia* disaster

Columbia breaks up over Texas at the end of STS-107.

The Space Shuttle *Columbia* disaster on 1 February 2003 (during STS-107) resulted in a two-and-a-half-year suspension of the US Space Shuttle program. Another one-year suspension following STS-114 (because of continued foam shedding on the external tank) led to some uncertainty about the future of the International Space Station. All crew exchanges between February 2003 and July 2006 were carried out using the Russian Soyuz spacecraft; a STS-114 visit in July 2005 was purely logistical. Starting with Expedition 7, caretaker crews of just two astronauts were launched, in contrast to the previously launched crews of three. Because the ISS had not been visited by a space shuttle for over three years, more waste had accumulated than anticipated, which temporarily hindered station operations in 2004. Automated Progress transports and the STS-114 mission were able to eliminate this waste build-up.

2004 – Air leak

On 2 January 2004, an air leak was detected on board the ISS, which had been slowly building up from ten days earlier. At one point, five pounds of air per day were leaking into space and the internal pressure of the ISS dropped from nominal 14.7 psi down to 14.0 psi, although this did not pose an immediate threat to Michael Foale and Aleksandr Kaleri, the two astronauts on board.

Using an ultrasonic probe, Foale traced the leak on Sunday 10 January to a vacuum jumper hose connected to a multipaned window in the US segment of the station. The search for the leak had been hampered by noise emitted from scientific equipment on board. Successful identification and repair of the leak narrowly averted a planned lock down of the station in an attempt to isolate the leak, which would have affected station operations.

2006 – Smoke problem

On 18 September 2006, the Expedition 13 crew activated a smoke alarm in the Russian segment of the International Space Station when fumes from one of the three Elektron oxygen generators triggered momentary fear about a possible fire. The crew initially reported smoke in the cabin, as well as a smell. The alarm was later found to be caused by a leak of potassium hydroxide from an oxygen vent. The associated equipment was turned off, and officials said there was no fire and the crew was not in any danger.

The station's ventilation system was shut down to prevent the spread of smoke or contaminants through the rest of the complex. A charcoal air filter was put in place to scrub the atmosphere of any lingering potassium hydroxide fumes. The space station's programme manager said the crew never donned gas masks, but as a precaution put on surgical gloves and masks to prevent contact with any contaminants.

On 2 November 2006, the payload brought by the Russian Progress M-58 allowed the crew to repair the Elektron using spare parts.

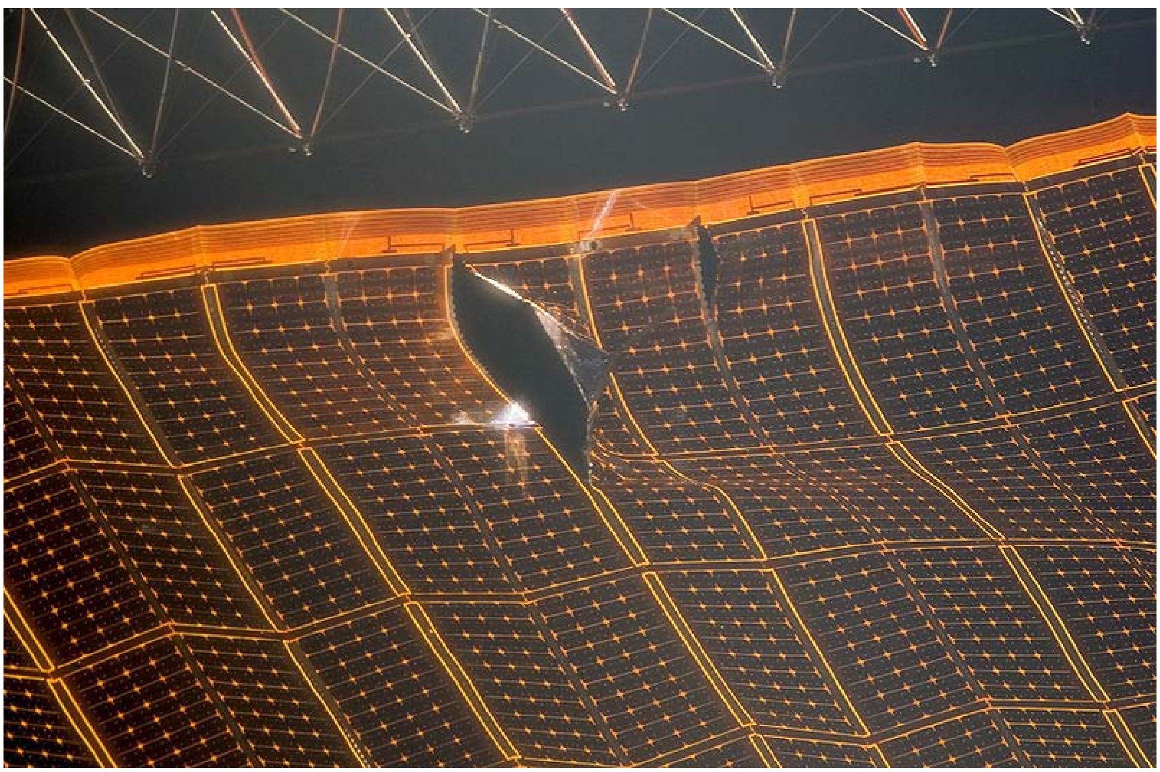
2007 – Computer failure

On 14 June 2007, during Expedition 15 and flight day 7 of STS-117's visit to ISS, a computer malfunction on the Russian segments at 06:30 UTC left the station without thrusters, oxygen generation, carbon dioxide scrubber, and other environmental control systems, causing the temperature on the station to rise. A successful restart of the computers resulted in a false fire alarm that woke the crew at 11:43 UTC.

By June 15, the primary Russian computers were back online, and communicating with the US side of the station by bypassing a circuit, but secondary systems remained offline. NASA reported that without the computer that controls the oxygen levels, the station had 56 days of oxygen available.

By the afternoon of June 16, ISS Program Manager Michael Suffredini confirmed that all six computers governing command and navigation systems for Russian segments of the station, including two thought to have failed, were back online and would be tested over several days. The cooling system was the first system brought back online. Troubleshooting of the failure by the ISS crew found that the root cause was condensation inside the electrical connectors, which led to a short-circuit that triggered the power off command to all three of the redundant processing units. This was initially a concern because the European Space Agency uses the same computer systems, supplied by EADS Astrium Space Transportation, for the *Columbus* laboratory module and the Automated Transfer Vehicle. Once the cause of the malfunction was understood, plans were implemented to avoid the problem in the future.

2007 – Torn solar panel



Damage to the 4B wing of the P6 solar array found when it was redeployed after being moved to its final position on STS-120.

On 30 October 2007, during Expedition 16 and flight day 7 of STS-120's visit to ISS, following the repositioning of the P6 truss segment, ISS and Space Shuttle *Discovery* crew members began the deployment of the two solar arrays on the truss. The first array deployed without incident, and the second array deployed about 80% before astronauts noticed a 76-centimetre (2.5 ft) tear. The arrays had been deployed in earlier phases of the space station's construction, and the retraction necessary to move the truss to its final position had gone less smoothly than planned.

A second, smaller tear was noticed upon further inspection, and the mission's spacewalks were replanned in order to devise a repair. Normally, such spacewalks take several months to plan and are settled upon well in advance. On November 3, spacewalker Scott Parazynski, assisted by Douglas Wheelock, fixed the torn panels using makeshift cufflinks and riding on the end of the Space Shuttle's OBSS inspection arm. Parazynski was the first ever spacewalker to use the robotic arm in this way. The spacewalk was regarded as significantly more dangerous than most because of the possibility of shock from the electricity generating solar arrays, the unprecedented usage of the OBSS, and the lack of spacewalk planning and training for the impromptu procedure. Parazynski was, however, able to repair the damage as planned, and the repaired array was fully deployed. Also, the OBSS will be left on the International Space Station because of its demonstrated versatility and ability to be left on the station for longer periods of time.

2007 – Damaged starboard Solar Alpha Rotary Joint

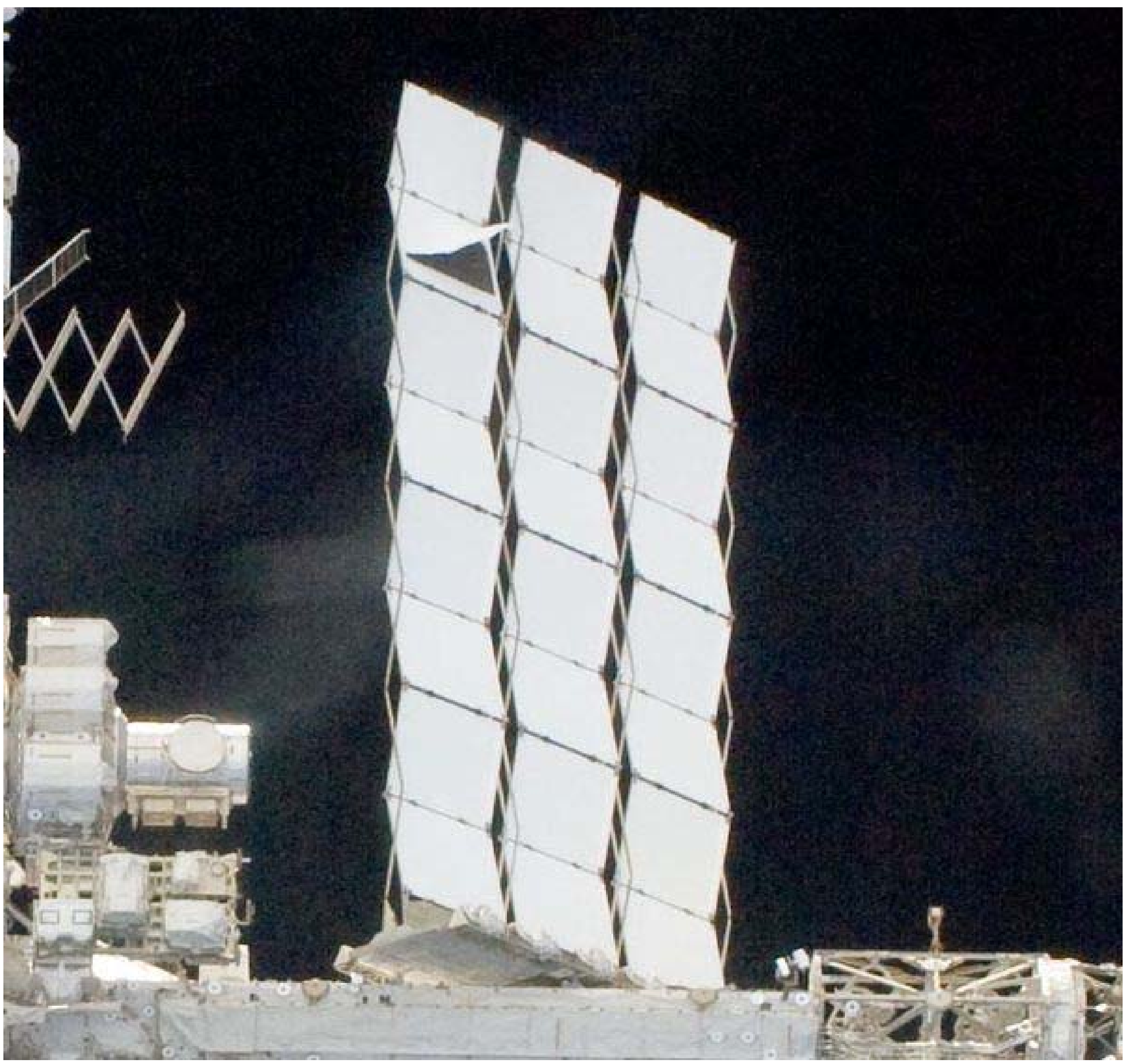
During STS-120, a problem was detected in the starboard Solar Alpha Rotary Joint (SARJ). This joint, together with a similar device on the port side of the station's truss structure, rotates the large solar arrays to keep them facing the Sun. Excessive vibration and high-current spikes in the array drive motor were noted, resulting in a decision to substantially curtail motion of the starboard SARJ until the cause was understood. Inspections during EVAs on STS-120 and STS-123 showed extensive contamination from metallic shavings and debris in the large drive gear and confirmed damage to the large metallic race ring at the heart of the joint. The station had sufficient operating power to carry out its near-term programme with only modest impacts on operations, so to prevent further damage, the joint was locked in place.

On 25 September 2008, NASA announced significant progress in diagnosing the source of the starboard SARJ problem and a programme to repair it on orbit. The repair programme began with the flight of the Space Shuttle *Endeavour* on STS-126. The crew carried out servicing of both the starboard and port SARJs, lubricating both joints and replacing 11 of 12 trundle bearings on the starboard SARJ. It was hoped that this servicing would provide a temporary solution to the problem. A long-term solution is a 10-EVA plan called 'SARJ-XL', which calls for the installation of structural supports between the two segments of the SARJ and a new race ring to be inserted between them to completely replace the failed joint. However, following the cleaning and lubrication of the joint, the results that have been noted so far have been extremely encouraging, to the point that it is now believed that the joint could be maintained by occasional servicing EVAs by resident station crews. Nevertheless, the data from the SARJ will require some time to fully analyse before a decision as to the future of the joint is made.

2009 – Excessive vibration during reboost

On 14 January 2009, an incorrect command sequence caused the *Zvezda* service module orbital altitude maintenance rocket propulsion control system to misfire during an altitude re-boost manoeuvre. This resulted in resonant vibrations into the station structure which persisted for over two minutes. While no damage to the station was immediately reported, some components may have been stressed beyond their design limits. Further analysis confirmed that the station was unlikely to have suffered any structural damage, and it appears that "structures will still meet their normal lifetime capability". Further evaluations are under way.

2009 – Potential ammonia leak from S1 radiator due to damaged panel



The damaged S1 radiator on the ISS starboard truss.

The S1 radiator has a damaged cooling panel that may require on-orbit repair or replacement, as the damage may have the potential to create a leak in the External Thermal Control System (ETCS) of the station, possibly leading to unacceptable loss of the ammonia coolant.

There are two such radiators, one on the starboard truss, and one on the port truss, each consisting of 3 panels. They appear as the large white pleated objects extending in the aft direction from the trusses, between the central habitable modules and the large solar panel arrays at the ends of the truss structure, and control the temperature of the ISS by dumping excess heat to space. The panels are double-sided, and radiate from both sides, with ammonia circulating between the top and bottom surfaces.

The problem was first noticed in Soyuz imagery in September 2008, but was not thought to be serious. The imagery showed that the surface of one sub-panel has peeled back from the underlying central structure, possibly due to micro-meteoroid or debris impact. It is also known that a Service Module thruster cover, jettisoned during a spacewalk in 2008, had struck the S1 radiator, but its effect, if any, has not been determined. Further imagery during the fly-around from STS-119 raised concerns that structural fatigue, due to thermal cycling stress, could cause a serious leak to develop in the ammonia cooling loop, although there is as yet no evidence of a leak or of degradation in the thermal performance of the panel. Various options for repair are under consideration, including replacement of the entire S1 radiator in a future flight, possibly with return of the damaged unit to ground for detailed study.

On May 15, 2009, the damaged radiator panel's ammonia tubing was mechanically shut off from the ETCS, by the computer-controlled closure of a valve. The same valve was used immediately afterwards to vent the ammonia from the damaged panel. This eliminates the possibility of an ammonia leak from the cooling system via the damaged panel.

2010 – Failure in cooling loop A

Early on August 1, 2010, a failure in cooling Loop A (starboard side), one of two external cooling loops, left the station with only half of its normal cooling capacity and zero redundancy in some systems. The problem appeared to be in the ammonia pump module that circulates the ammonia cooling fluid. Several subsystems, including two of the four CMGs, were shut down.

Planned operations on the ISS were interrupted through a series of EVAs to address the cooling system issue. A first EVA on Saturday, August 7, 2010, to replace the failed pump module, was not fully completed due to an ammonia leak in one of four quick-disconnects. A second EVA on Wednesday, August 11, successfully removed the failed pump module. A third EVA was required to restore Loop A to normal functionality.