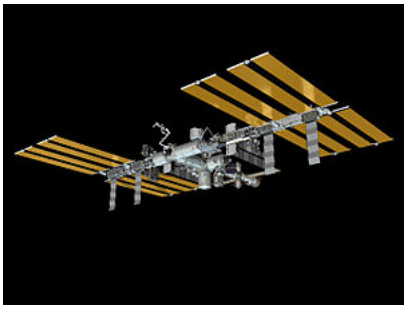
Assembly of the International Space Station

The process of assembling the International Space Station (ISS) has been under way since the 1990s. *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 maximum crew of two astronauts or cosmonauts to be on the ISS permanently.

The ISS has a planned 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 required more than 40 assembly flights. As of March 2011, 26 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 35 Shuttle missions include 9 SpaceHab and 10 MPLM logistics-servicing missions in various combinations. The last two Shuttle flights added one of the two final elements of ISS, followed by one last Proton launch which delivered the ERA. Other assembly flights consisted of modules lifted by the Russian Proton rocket or in the case of Pirs and Poisk by a Soyuz-U rocket.



An artist's impression of theInternational Space Station's configuration as of November 2010.

Some of the larger modules include:

- Zarya (launched 20 November 1998)
- Unity Module (launched 4 December 1998, *also known as Node 1*)
- Zvezda (launched 12 July 2000)
- Destiny Laboratory Module (launched 7 February 2001)
- Columbus orbital facility (launched 7 February 2008)
- Japanese Experiment Module, *also known as Kibo* (launched in multiple flights between 2008-2009)
- The truss and solar panels are also a large part of the station. (launched in multiple flights between 2000-2009)

International Space Station on 16 October 2002

Contents

Rear of the station

Logistics

The space station is located in orbit around the Earth at an altitude of approximately 410 km (250 mi), 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.[1] 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.[2]

International Space Stationmockup at Johnson Space Centerin Houston, Texas.

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 SpaceX Dragon, the Russian Progress, the European ATV and the Japanese HTV, and space station downmass will be carried back to Earth facilities on both the Shuttle and the Dragon.[3]

Columbia disaster and changes in construction plans

Disaster and consequences

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.

Columbia lifting off on its final mission.

Changes in construction plans

ISS construction experienced delays due to the halting of all NASA Shuttle flights following the *Columbia* disaster in early 2003, although there had been prior delays due to Shuttle problems, and 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. 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. However more than 80% of the hardware intended to be part of the ISS in the late 1990s was orbited and is now part of the ISS's configuration.

In March 2006, a meeting of the heads of the five participating space agencies accepted the new ISS construction schedule that planned to complete the ISS by 2010.[4] A crew of six has been established as of May 2009, following 12 Shuttle construction flights after 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.

Later additions included the Bigelow Expandable Activity Module (BEAM) in 2016, and numerous Russian components are planned as part of the in-orbit construction of OPSEK.

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

Construction of the International Space Station over New Zealand.

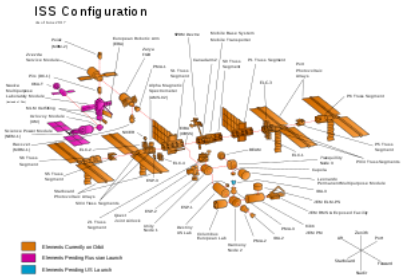
Assembly sequence

The ISS is made up of 16 pressurized modules: five Russian modules (*Zarya*, *Pirs*, *Zvezda*, *Poisk* and *Rassvet*), eight US modules (*BEAM*[5], *Leonardo*, *Harmony*, *Quest*, *Tranquility*, *Unity*, *Cupola*, and *Destiny*), two Japanese modules (the JEM-ELM-PS and JEM-PM) and one European module (*Columbus*). One more Russian pressurized module (*Nauka*) is scheduled to be added to the station.

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

Spacecraft attached 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.



ISS elements

Element	Assembly flight	Launch date	Launch vehicle	Length (m)	Diameter (m)	Mass (kg)	Pressurized Volume (m^3)	Isolated View	Station View	Re
Zarya (FGB)[6]	1A/R	1998-11-20	Proton-K	12.6	4.1	19,323				
Unity (Node 1),[7] PMA-1 & PMA-2	2A	1998-12-04	Space Shuttle *Endeavour* (STS-88)	5.49	4.57	11,612				
Zvezda (Service Module)[8]	1R	2000-07-12	Proton-K	13.1	4.15	19,051	75			
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)[9]	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)							
Canadarm2 (SSRMS)	6A	2001-04-19	Space Shuttle *Endeavour* (STS-100)	17.6	0.35	4,899				
Quest (Joint Airlock)[10]	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	13			
S0 Truss[11]	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[12]	12A	2006-09-09	Space Shuttle *Atlantis* (STS-115)	13.8	4.9	15,900				
P5 Truss[13]	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	13A.1	2007-08-08	Space Shuttle *Endeavour*	13.7	3.9	12,598				

ESP-3			(STS-118)							
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)[14]	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 Arm (JEM-RMS)[15][16]	1J	2008-05-31	Space Shuttle *Discovery* (STS-124)	11.2 (JEM-PM)	4.4 (JEM-PM)	15,900 (JEM-PM)		STS-124 Kibo.jpg	ISS after STS-124 06	
S6 Truss & Solar Arrays	15A	2009-03-15	Space Shuttle *Discovery* (STS-119)	73.2	10.7	15,900		S6 Truss Transfer (STS-	ISS March 2009.jpg	
Japanese Exposed Facility (JEM-EF)	2J/A	2009-07-15	Space Shuttle *Endeavour* (STS-127)			4,100		STS-127 JEM-EF.jpg	ISS & Endeavour Shadow	
Poisk (MRM-2)[17][18]	5R	2009-11-10	Soyuz-U (Progress M-MIM2)			3,670		Poisk.Jpeg	STS-129 Atlantis approaches	
ExPRESS Logistics Carriers 1 & 2	ULF3	2009-11-16	Space Shuttle *Atlantis* (STS-129)					ELC2 STS 129.JPG	ISS ULF3 STS-129.jpg	
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)		Tranquility node3.JPG	ISSpoststs1	
Rassvet (MRM-1)[19]	ULF4	2010-05-14	Space Shuttle *Atlantis* (STS-132)			5,075		MRM-1 at KSC.jpg	Internationa Space Station	
Leonardo (PMM) and EXPRESS Logistics Carrier 4	ULF5	2011-02-24	Space Shuttle *Discovery* (STS-133)			9,896 (Leonardo)		STS-133 ISS-26 Permanent Multipurpo Module.jpg ELC2 STS 129.JPG	STS-133 Internationa Space	
Alpha Magnetic Spectrometer, OBSS and EXPRESS Logistics Carrier 3	ULF6	2011-05-16	Space Shuttle *Endeavour* (STS-134)			6,731 (AMS-02)		Alpha Magnetic Spectromet ELC2 STS 129.JPG	STS-134 Internationa Space	
Bigelow Expandable Activity Module[20]		2016-04-08	Falcon 9 (SpaceX CRS-8)	4	3.2	1,360	16	Beam-instalation-space-	ISS as of Nov 2010.jpg	
Nauka (MLM) European Robotic Arm[21]	3R	mid-2018[22] (scheduled)	Proton-M			20,300 (Nauka)		MLM Nauka module - 3D	ISS post-Nauka installation	
Uzlovoy (UDM)[23]		2018 (scheduled)[24]	Soyuz 2.1b			4,000		Mockup of Uzlovoy Module (Pritchal).jp	ISS post-Nauka installation	
Science-Power Module-1[25]		2019 (scheduled)[26]	Proton-M						ISS post-Nauka installation	
Science-Power Module-2[25]		2019 (scheduled)[26]	Proton-M						ISS post-Nauka installation	

NanoRacks Airlock Module		2019 (scheduled) [27]	Falcon 9 (SpaceX CRS-19)[28]							
Element	**Assembly flight**	**Launch date**	**Launch vehicle**	**Length (m)**	**Diameter (m)**	**Mass (kg)**	**Pressurized Volume (m^3)**	**Isolated View**	**Station View**	**Re**

Cancelled modules

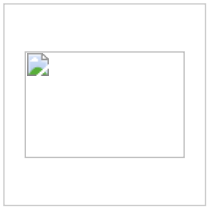
- Interim Control Module - not needed once Zvezda was launched
- ISS Propulsion Module - not needed once Zvezda was launched
- Habitation Module (HAB) - With the cancellation of the Habitation Module, sleeping places are now spread throughout the station. There are two in the Russian segment and four in the US segment. It is not necessary to have a separate 'bunk' in space — many visitors just strap their sleeping bag to the wall of a module, get into it and sleep.
- Crew Return Vehicle (CRV) - replaced by two Soyuz spacecraft
- Centrifuge Accommodations Module (CAM) - would have been attached to Harmony (Node 2)
- 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

Diagram of planned ISS design circa 1999

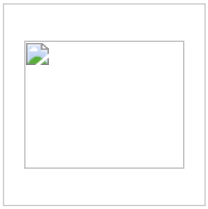
Proposed modules

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

- American Node 4 - Also known as the Docking Hub System (DHS),[29] 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.[30]
- Nautilus-X Centrifuge Demonstration - If produced, this centrifuge will be the first in-space demonstration of sufficient scale centrifuge for artificial partial-g effects. It will be designed to become a sleep module for the ISS crew[31]



Inflatable module attached to Node 4



Nautilus-X ISS demonstrator

See also

- List of unmanned spaceflights to the ISS
- List of human spaceflights to the ISS

References

1. "Consolidated Launch Manifest" (http://www.nasa.gov/mission_pages/station/structure/iss_manifest.html). NASA. Archived (https://web.archive.org/web/20060707132806/http://www.nasa.gov/mission_pages/station/structure/iss_manifest.html) from the original on 7 July 2006. Retrieved 2006-07-15.
2. "What are the ISS attitudes?" (http://spaceflight.nasa.gov/station/flash/iss_attitude.html) (Flash). NASA. Archived (https://web.archive.org/web/20060902031603/http://spaceflight.nasa.gov/station/flash/iss_attitude.html) from the original on 2 September 2006. Retrieved 2006-09-11.
3. Black, Charles (24 December 2012). "When Dragon made commercial spaceflight a reality" (http://www.sen.com/news/when-dragon-made-private-space-real.html). *SEN*. Retrieved 2012-12-26. *"[Dragon's] ability to return goods is currently unique because all the other regular supply ships - Europe's Automated Transfer Vehicle (ATV), Japan's HTV (or "Kounotori") and Russia's Progress - all burn up during controlled re-entry"*
4. Coppinger, Rob (3 March 2006). "NASA commits to Shuttle missions to International Space Station" (http://www.flightglobal.com/articles/2006/03/03/205237/nasa-commits-to-shuttle-missions-to-international-space.html). FlightGlobal. Retrieved 16 September 2006.
5. https://arstechnica.com/science/2017/10/nasa-tries-an-inflatable-room-on-the-space-station-likes-it/. Retrieved 27 November 2017.
6. Wade, Mark (15 July 2008). "ISS Zarya" (http://www.astronautix.com/craft/isszarya.htm). Encyclopaedia Astronautica. Archived (https://web.archive.org/web/20090227060517/http://www.astronautix.com/craft/isszarya.htm) from the original on 27 February 2009. Retrieved 2009-03-11.
7. "Unity Connecting Module: Cornerstone for a Home in Orbit" (http://spaceflight.nasa.gov/spacenews/factsheets/pdfs/unity.pdf) (PDF). NASA. January 1999. Archived (https://web.archive.org/web/20090317204752/http://spaceflight.nasa.gov/spacenews/factsheets/pdfs/unity.pdf) (PDF) from the original on 17 March 2009. Retrieved 2009-03-11.
8. "Zvezda Service Module" (http://www.nasa.gov/mission_pages/station/structure/elements/sm.html). NASA. 11 March 2009. Archived (https://web.archive.org/web/20090323030726/http://www.nasa.gov/mission_pages/station/structure/elements/sm.html) from the original on 23 March 2009. Retrieved 2009-03-11.
9. "US Destiny Laboratory" (http://www.nasa.gov/mission_pages/station/structure/elements/destiny.html). NASA. 26 March 2007. Archived (https://web.archive.org/web/20070709153924/http://www.nasa.gov/mission_pages/station/structure/elements/destiny.html) from the original on 9 July 2007. Retrieved 2007-06-26.
10. "Space Station Extravehicular Activity" (http://spaceflight.nasa.gov/station/eva/outside.html). NASA. 4 April 2004. Archived (https://web.archive.org/web/20090403213449/http://spaceflight.nasa.gov/station/eva/outside.html) from the original on 3 April 2009. Retrieved 2009-03-11.
11. "Space Station Assembly: Integrated Truss Structure" (http://www.nasa.gov/mission_pages/station/structure/elements/its.html). NASA. Archived (https://web.archive.org/web/20071207081810/http://www.nasa.gov/mission_pages/station/structure/elements/its.html) from the original on 7 December 2007. Retrieved 2007-12-02.
12. "P3 and P4 to expand station capabilities, providing a third and fourth solar array" (http://www.boeing.com/defense-space/space/spacestation/components/docs/P3-P4.pdf) (pdf). Boeing. July 2006. Retrieved 2007-12-02.
13. "STS-118 MISSION OVERVIEW: BUILD THE STATION…BUILD THE FUTURE" (http://www.nasa.gov/pdf/182728main_STS-118_Press_Kit.pdf) (PDF). NASA PAO. July 2007. Archived (https://web.archive.org/web/20071201130531/http://www.nasa.gov/pdf/182728main_STS-118_Press_Kit.pdf) (PDF) from the original on 1 December 2007. Retrieved 2007-12-02.
14. "Columbus laboratory" (http://www.esa.int/esaHS/ESAAYI0VMOC_iss_0.html). ESA. 10 January 2009. Archived (https://web.archive.org/web/20090330191925/http://www.esa.int/esaHS/ESAAYI0VMOC_iss_0.html) from the original on 30 March 2009. Retrieved 2009-03-06.
15. "About Kibo" (https://web.archive.org/web/20090310171550/http://kibo.jaxa.jp/en/about/). JAXA. 25 September 2008. Archived from the original (http://kibo.jaxa.jp/en/about/) on 10 March 2009. Retrieved 2009-03-06.

16. "Kibo Japanese Experiment Module" (http://www.nasa.gov/mission_pages/station/structure/elements/jem.html) NASA. 23 November 2007. Archived (https://web.archive.org/web/20081023071601/http://www.nasa.gov/mission_pages/station/structure/elements/jem.html) from the original on 23 October 2008. Retrieved 2008-11-22.
17. Zak, Anatoly. "Docking Compartment-1 and 2" (http://www.russianspaceweb.com/iss_dc.html). RussianSpaceWeb.com. Archived (https://web.archive.org/web/20090210130224/http://www.russianspaceweb.com/iss_dc.html) from the original on 10 February 2009. Retrieved 26 March 2009.
18. Bergin, Chris (9 November 2009). "Russian module launches via Soyuz for Thursday ISS docking" (http://www.nasaspaceflight.com/2009/11/live-russian-module-launch-towards-iss-on-soyuz/). NASASpaceflight.com. Archived (https://web.archive.org/web/20091113190354/http://www.nasaspaceflight.com/2009/11/live-russian-module-launch-towards-iss-on-soyuz/) from the original on 13 November 2009. Retrieved 10 November 2009.
19. "NASA Extends Contract With Russia's Federal Space Agency" (http://www.nasa.gov/home/hqnews/2007/apr/HQ_C07-18_Roscosmos.html) (Press release). NASA. 9 April 2007. Archived (https://web.archive.org/web/20070623120556/http://www.nasa.gov/home/hqnews/2007/apr/HQ_C07-18_Roscosmos.html) from the original on 23 June 2007. Retrieved 2007-06-15.
20. "NASA to Test Bigelow Expandable Module on Space Station" (http://www.nasa.gov/mission_pages/station/news/beam_feature.html) NASA. 16 January 2013. Retrieved 16 January 2013.
21. "FGB-based Multipurpose Lab Module (MLM)" (https://web.archive.org/web/20070927002737/http://www.khrunichev.ru/khrunichev_eng/live/full_mks.asp?id=13190) Khrunichev State Research and Production Space Centre. Archived from the original (http://www.khrunichev.ru/khrunichev_eng/live/full_mks.asp?id=13190) on 27 September 2007. Retrieved 2008-10-31.
22. Karasev, Sergey (7 November 2016). "Запуск лабораторного модуля «Наука» к МКС откладывается" (https://3dnews.ru/942263) [Launch of the Nauka laboratory module to the ISS postponed] (in Russian) Retrieved 13 January 2017.
23. Zak, Anatoly (20 November 2012). "Node Module" (http://www.russianspaceweb.com/iss_node.html). RussianSpaceWeb. Retrieved 7 December 2012.
24. "Node Module" (http://www.russianspaceweb.com/iss_node.html).
25. "NEM-1 module for the ISS RKK "Energy" to be built in cooperation" (http://ria.ru/science/20121204/913358552.html) (in Russian). Korolyov, Moscow Oblast: RIANovosti. 4 December 2012. Retrieved 7 December 2012.
26. "Russia works on a new-generation station module" (http://www.russianspaceweb.com/nem.html).
27. https://www.nasa.gov/feature/progress-underway-for-first-commercial-airlock-on-space-station
28. http://nanoracks.com/nanoracks-adds-thales-alenia-space-to-airlock/
29. ISS Managers review long-term configuration of International Space Station | NASASpaceFlight.com (http://www.nasaspaceflight.com/2010/12/issmanagers-long-term-configuration-international-space-station/)
30. Test article could facilitate space station applications - 31 August 2010 (http://spaceflightnowcom/news/n1008/31node/)
31. Nautilus-X-Holderman_1-26-11 (https://www.scribd.com/doc/51592987/Nautilus-X-Holderman-1-26-11)

External links

- Animated ISS assembly process, mission designations and dates are included.
- Diagram of planned components of the ISS, positions of cancelled modules can be seen.

Media articles

- How It Works magazine - ISS nears completion