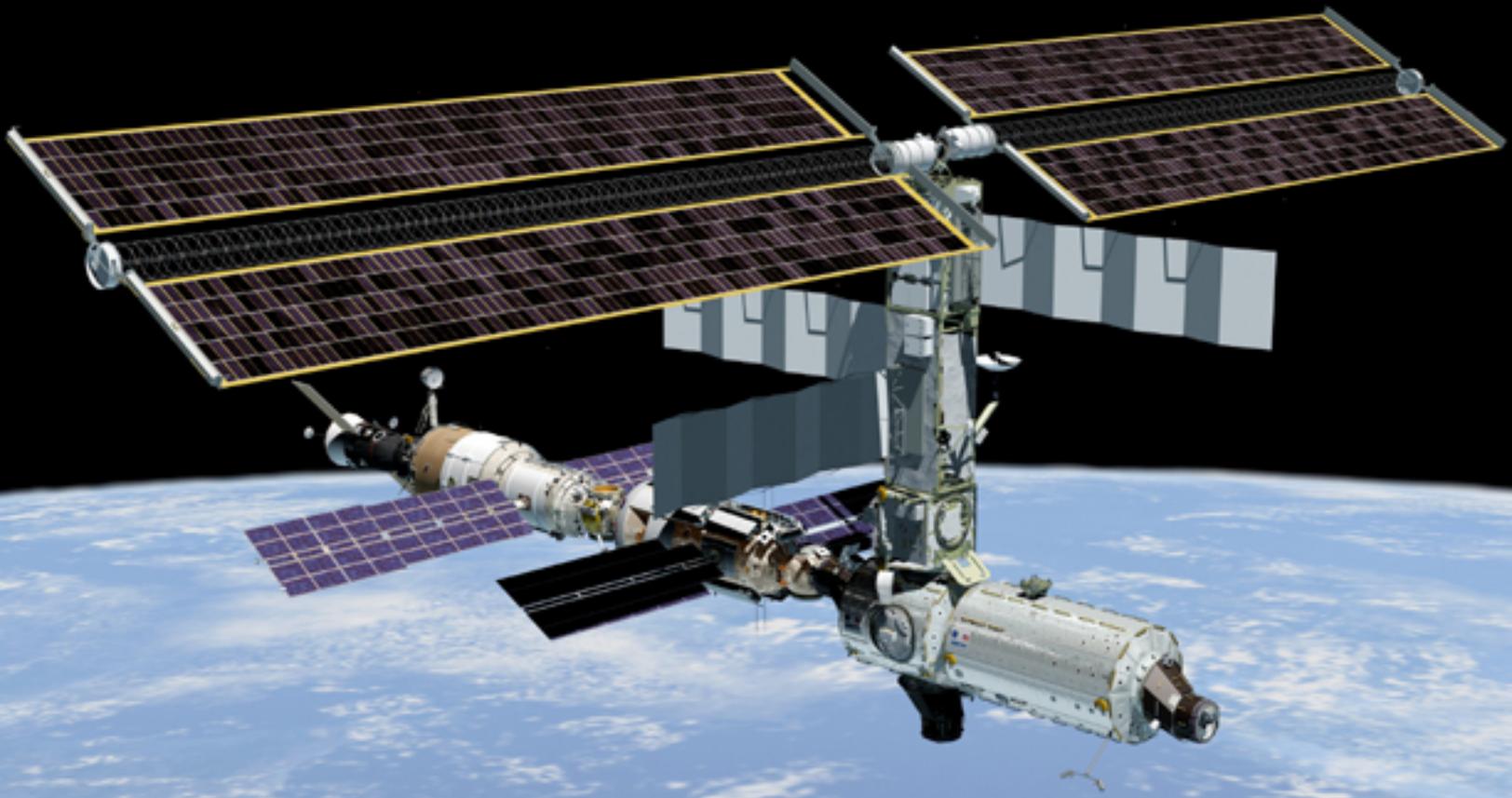


Support Vehicles, Components and Modules of the International Space Station



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Colt Rico

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Chapter 1

Soyuz

Soyuz



Soyuz spacecraft (TMA version)

Deliver personnel to Low Earth Orbit.

Mission type Intended originally for Soviet Manned Lunar program missions.

Mission duration Up to six months docked at a space station.

Height

24.54 ft (7.48 m)

Diameter

Dimensions 8.92 ft (2.72 m)

Volume

254.27 cu ft (7.200 m³)

Soyuz is a series of spacecraft designed for the Soviet space program by the Korolyov Design Bureau in the 1960s, and still in service today. The Soyuz succeeded the Voskhod spacecraft and was originally built as part of the Soviet Manned Lunar program.

The Soyuz spacecraft is launched by the Soyuz rocket, the most frequently used and most reliable launch vehicle to date. The Soyuz rocket design is based on the Vostok launcher, which in turn was based on the 8K74 or R-7a intercontinental ballistic missile.

The first unmanned Soyuz mission was launched November 28, 1966; the first Soyuz mission with a crew (Soyuz 1) was launched April 23, 1967, but the cosmonaut on board, Vladimir Komarov, died during the flight's crash-landing. Soyuz 2 was an unmanned mission, and Soyuz 3, launched on October 26, 1968, was the first successful Soyuz manned mission. The only other fatal mission, Soyuz 11, killed the crew of three also during re-entry due to premature cabin depressurization. Despite these early fatalities, Soyuz is presently widely considered the world's safest, most cost-effective human spaceflight system due to unparalleled length of operational history.

The Soyuz spacecraft family is still in service. Soyuz spacecraft were used to carry personnel to and from Salyut and later Mir Soviet space stations, and are now used for transport to and from the International Space Station. The International Space Station maintains docked Soyuz spacecraft at all times to be used as escape craft in the event of an emergency.

Design

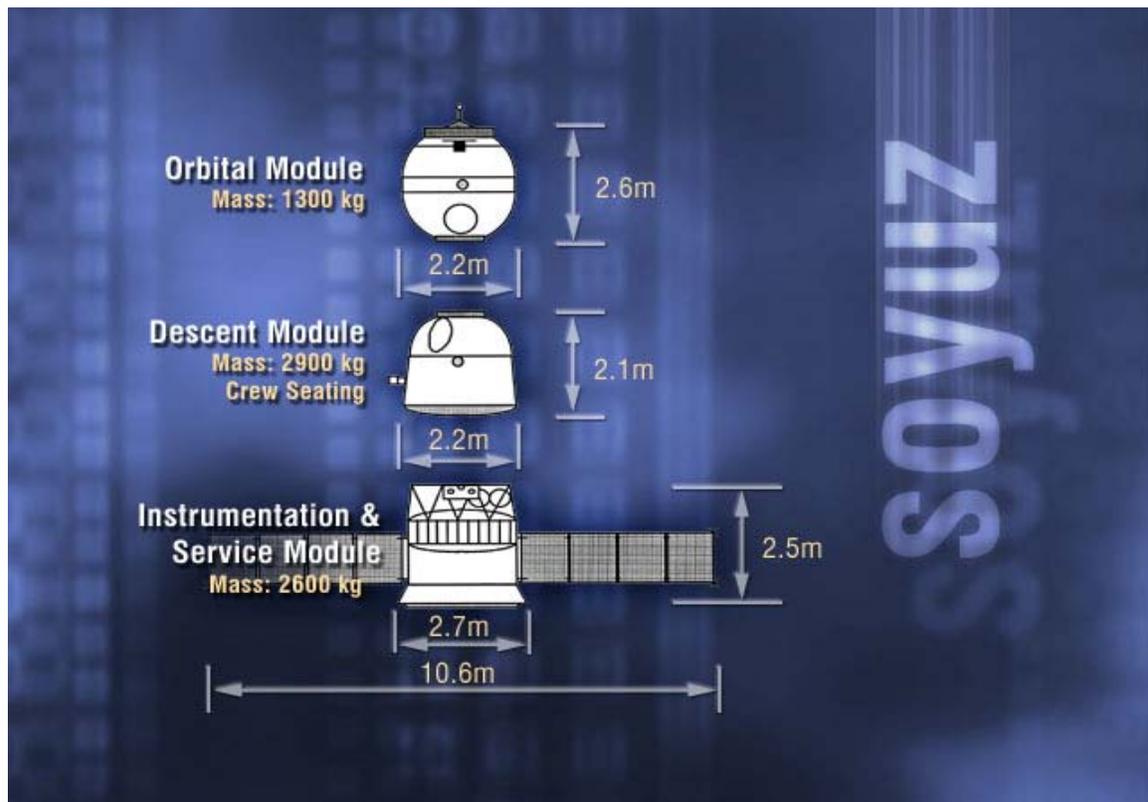


Diagram showing the three elements of the Soyuz-TMA spacecraft

A Soyuz spacecraft consists of three parts (from front to back):

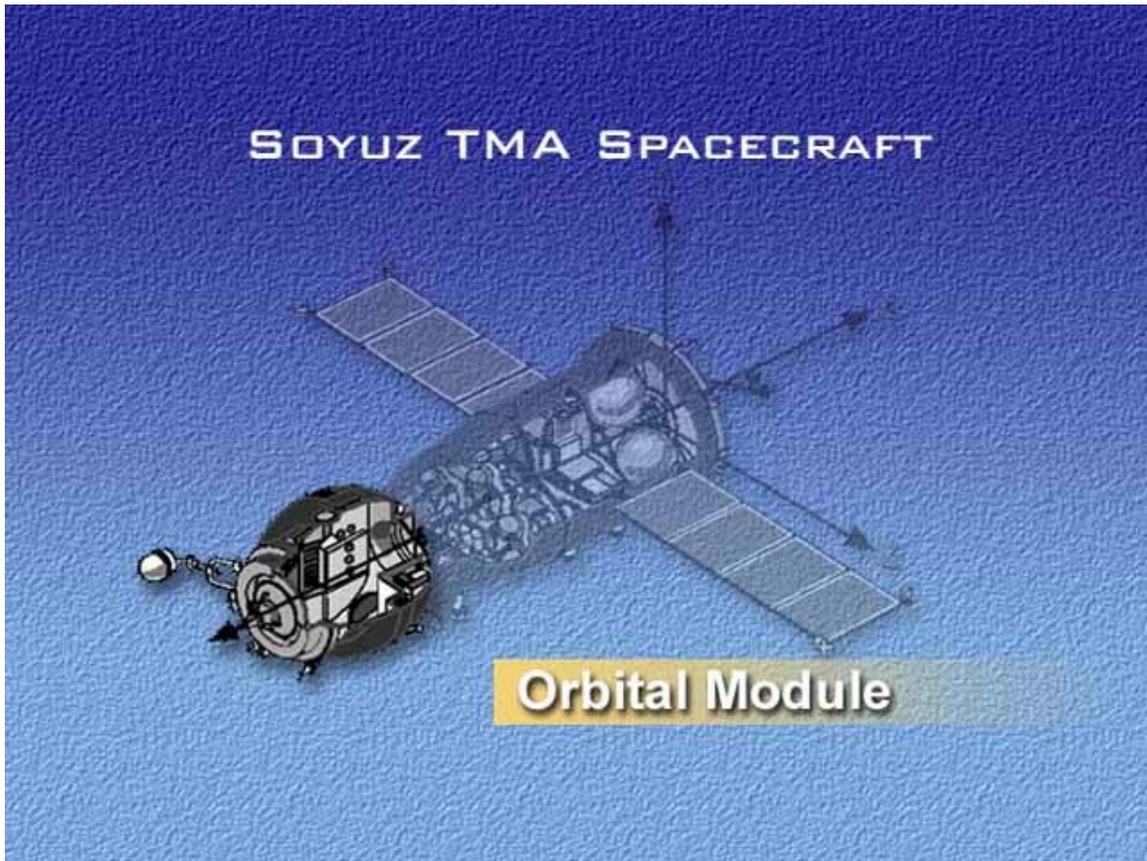
- A spheroid orbital module, which provides accommodation for the crew during their mission;
- A small aerodynamic reentry module, which returns the crew to Earth;
- A cylindrical service module with solar panels attached, which contains the instruments and engines.

The orbital and service modules are single-use and are destroyed upon re-entry in the atmosphere. The orbital and reentry portions are habitable living space. By moving as much equipment as possible into the orbital module, which does not have to be shielded or decelerated during atmospheric re-entry, the Soyuz is both larger and lighter than the contemporary Apollo spacecraft's command module. The Apollo command module had six cubic meters of living space and a mass of 5000 kg; the three-part Soyuz provides the same crew with nine cubic meters of living space, an airlock, and a service module for the mass of the Apollo capsule alone.

Soyuz can carry up to three crew members and provide life support for them for about 30 person days. The life support system provides a nitrogen/oxygen atmosphere at sea level partial pressures. The atmosphere is regenerated through KO_2 cylinders, which absorb most of the CO_2 and water produced by the crew and regenerates the oxygen, and LiOH cylinders which absorb leftover CO_2 .

The vehicle is protected during launch by a nose fairing, which is jettisoned after passing through the atmosphere. It has an automatic docking system. The ship can be operated automatically, or by a pilot independently of ground control.

Orbital Module



Soyuz spacecraft's Orbital Module

The forepart of the spacecraft is the orbital module (Russian: *бытовой отсек (БО)*; Bytvoi otsek (BO)) also known as Habitation section. It houses all the equipment that will not be needed for reentry, such as experiments, cameras or cargo. The module also contains a toilet, docking avionics and communications gear. On the latest Soyuz versions, a small window was introduced, providing the crew with a forward view.

A hatch between it and the descent module can be closed so as to isolate it to act as an airlock if needed, crew members exiting through its side port (near the descent module). On the launch pad, the crew enter the spacecraft through this port.

This separation also lets the orbital module be customized to the mission with less risk to the life-critical descent module. The convention of orientation in zero gravity differs from that of the descent module, as crew members stand or sit with their heads to the docking port.

Reentry Module



Soyuz spacecraft's Descent Module

The reentry module (Russian: *спускаемый аппарат (СА)*; Spuskaemyi apparat (SA)) is used for launch and the journey back to Earth. Half of the reentry module is covered by a heat-resistant covering to protect it during re-entry; this half faces the Earth during re-entry. It is slowed initially by the atmosphere, then by a braking parachute, followed by the main parachute which slows the craft for landing. At one meter above the ground, solid-fuel braking engines mounted behind the heat shield are fired to give a soft landing. One of the design requirements for the reentry module was for it to have the highest possible volumetric efficiency (internal volume divided by hull area). The best shape for this is a sphere, but such a shape can provide no lift, which results in a purely ballistic reentry. Ballistic reentries are hard on the occupants due to high deceleration and cannot be steered beyond their initial deorbit burn. That is why it was decided to go with the "headlight" shape that the Soyuz uses—a hemispherical forward area joined by a barely angled conical section (seven degrees) to a classic spherical section heat shield. This shape allows a small amount of lift to be generated due to the unequal weight distribution. The nickname was thought up at a time when nearly every headlight was circular.

Service Module



Soyuz spacecraft's Instrumentation/Propulsion Module

At the back of the vehicle is the service module (Russian: *приборно-агрегатный отсек (ПАО)*; *Priborno-Agregatnyi Otsek (PAO)*). It has a pressurized container shaped like a bulging can (*Instrumentation compartment, PO (Priborniy Otsek)*) that contains systems for temperature control, electric power supply, long-range radio communications, radio telemetry, and instruments for orientation and control. A non-pressurized part of the service module (*Propulsion compartment, AO (Agregatniy Otsek)*) contains the main engine and a liquid-fuelled propulsion system for maneuvering in orbit and initiating the descent back to Earth. The ship also has a system of low-thrust engines for orientation, attached to the Intermediate compartment (*PkhO or Perekhodnoi Otsek*). Outside the service module are the sensors for the orientation system and the solar array, which is oriented towards the sun by rotating the ship.

Re-entry procedure

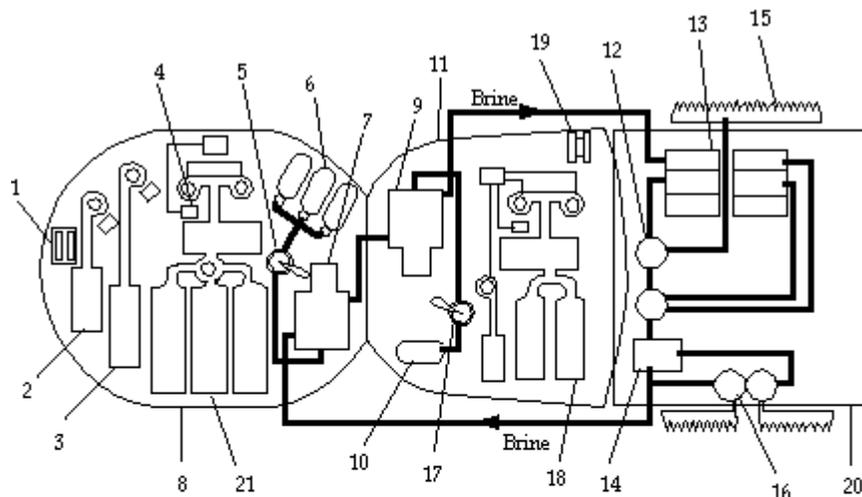
Because its modular construction differs from that of previous designs, the Soyuz has an unusual sequence of events prior to re-entry. The spacecraft is turned engine-forward and the main engine is fired for de-orbiting fully 180° ahead of its planned landing site. This

requires the least propellant for re-entry, the spacecraft traveling on an elliptical Hohmann orbit to a point where it will be low enough in the atmosphere to re-enter.

Early Soyuz spacecraft would then have the service and orbital modules detach simultaneously. As they are connected by tubing and electrical cables to the descent module, this would aid in their separation and avoid having the descent module alter its orientation. Later Soyuz spacecraft detach the orbital module before firing the main engine, which saves even more propellant, enabling the descent module to return more payload. The orbital module cannot remain in orbit as an addition to a space station, because the airlock hatch is part of the descent module.

Re-entry firing is done on the "dawn" side of the earth, so that the spacecraft can be seen by recovery helicopters as it descends in the evening twilight, illuminated by the sun when it is above the shadow of the Earth. The Soyuz craft is designed to come down on land, usually somewhere in the deserts of Kazakhstan in central Asia. This is in contrast to early US manned missions which "splashed down" in the ocean.

Spacecraft systems



- | | |
|--|---|
| (1) Compressed Air for Leakage Makeup | (11) Landing Module |
| (2) LiOH for Topping CO ₂ Removal | (12) Temperature Control Valves |
| (3) KO ₂ Oxygen Supply and Primary CO ₂ Removal Beds | (13) Equipment Cooler (Primary and Topping) |
| (4) Flowmeter and Fans | (14) Primary Heat Exchanger |
| (5) Manual Pump | (15) Primary Space Radiator |
| (6) H ₂ O Storage Tanks | (16) Sequencing Space Radiators |
| (7) Condensing Heat Exchanger with wick-type H ₂ O separator | (17) Manual Pump |
| (8) Flight Module | (18) Trace Contaminant Control Bed |
| (9) Condensing Heat Exchanger with wick-type H ₂ O separator | (19) Pressure Relief Valve |
| (10) H ₂ O Storage Tank | (20) Equipment Module |
| | (21) KO ₂ Beds for Oxygen Supply and Trace Contaminant Removal with Activated Charcoal and Bacteria Filter |

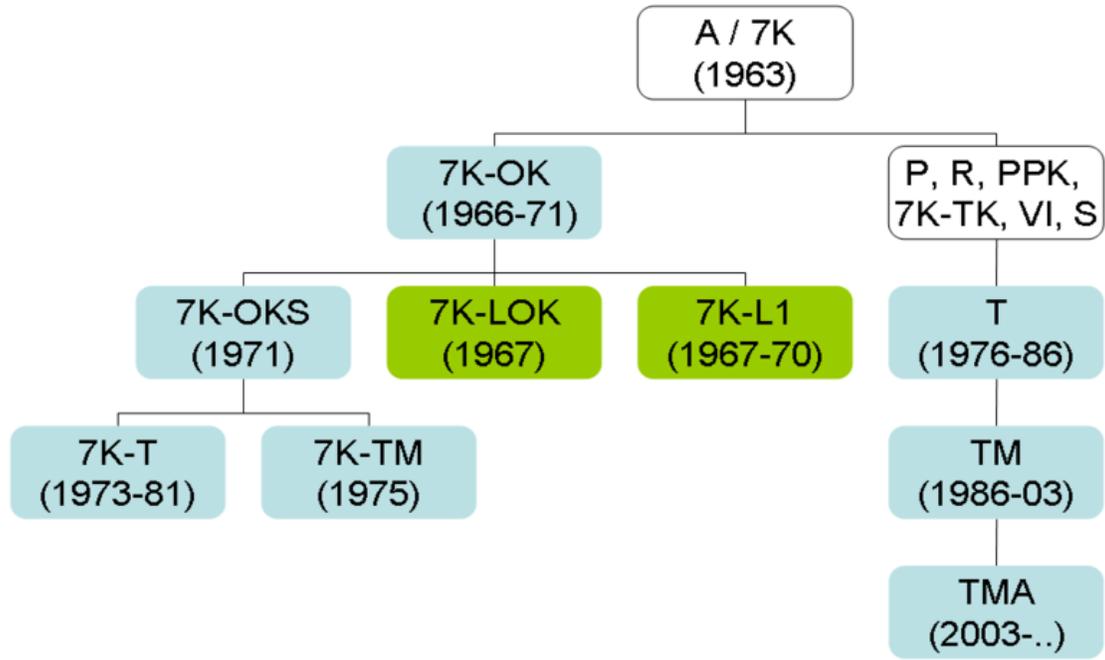
Soyuz diagram

- **Thermal Control System**—*Sistema Obespecheniya Teplovogo Rezhima, SOTR*

- **Life Support System**—*Kompleks Sredstv Obespecheniya Zhiznideyatelnosti, KSOZh*
- **Power Supply System**—*Sistema Elektropitaniya, SEP*
- **Communication and Tracking Systems**—Rassvet (Dawn) radio communications system, Onboard Measurement System (SBI), Kvant-V spacecraft control, Klyost-M television system, Orbit Radio Tracking (RKO)
- **Onboard Complex Control System**—*Sistema Upravleniya Bortovym Kompleksom, SUBK*
- **Combined Propulsion System**—*Kompleksnaya Dvigatel'naya Ustanovka, KDU*
- **Chaika-3 Motion Control System (SUD)**
- *'Optical/Visual Devices (OVP)*—VSK-4 (Vizir Spetsialniy Kosmicheskiy-4), Night Vision Device (VNUK-K, Visir Nochnogo Upravleniya po Kursu), Docking light, Pilot's Sight (VP-1, Vizir Pilota-1), Laser Range Finder (LPR-1, Lazerniy Dalnomer-1)
- **Kurs rendezvous system**
- **Docking System**—*Sistema Stykovki i Vnutrennego Perekhoda, SSVP*
- **Teleoperator Control Mode**—*Teleoperatorniy Rezhim Upravleniya, TORU*
- **Entry Actuators System**—*Sistema Iсполnitel'nikov Organov Spuska, SIO-S*
- **Landing Aids Kit**—*Kompleks Sredstv Prizemleniya, KSP*
- **Portable Survival Kit**—*Nosimiy Avariyniy Zapas, NAZ*, containing a TP-82 or other pistol
- **Soyuz Launch Escape System**—*Sistema Avariynogo Spaseniya, SAS*

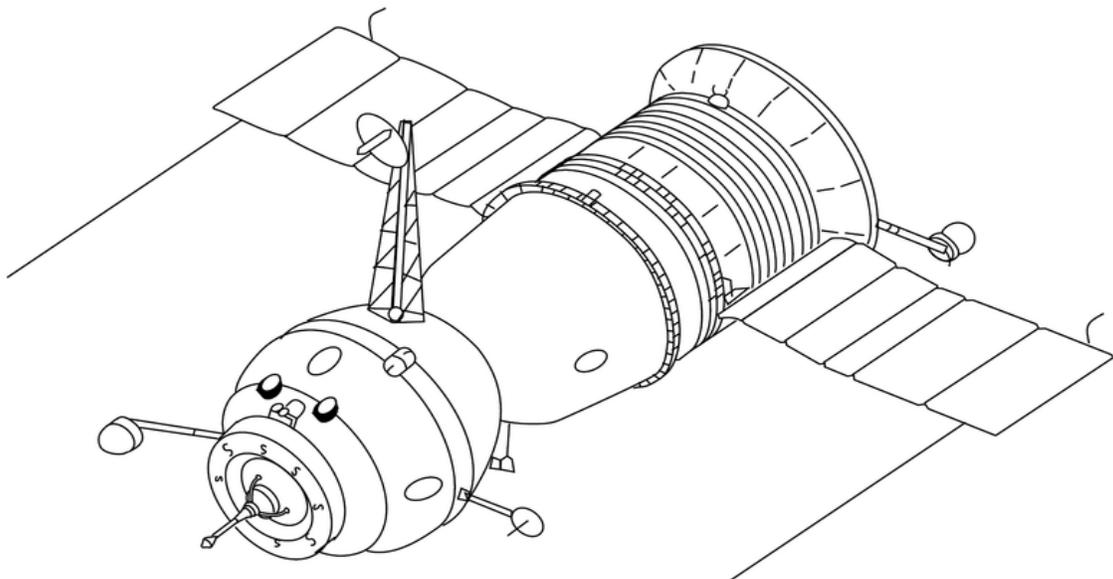
Variants

Soyuz spacecraft models

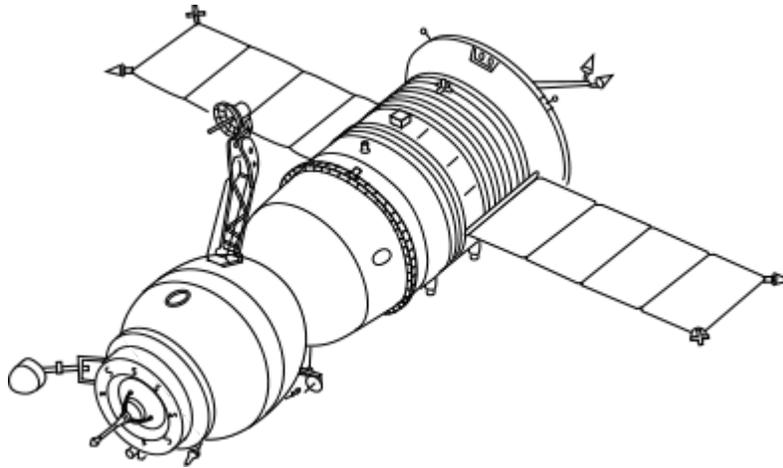


White: proposed, green: lunar, blue: flown

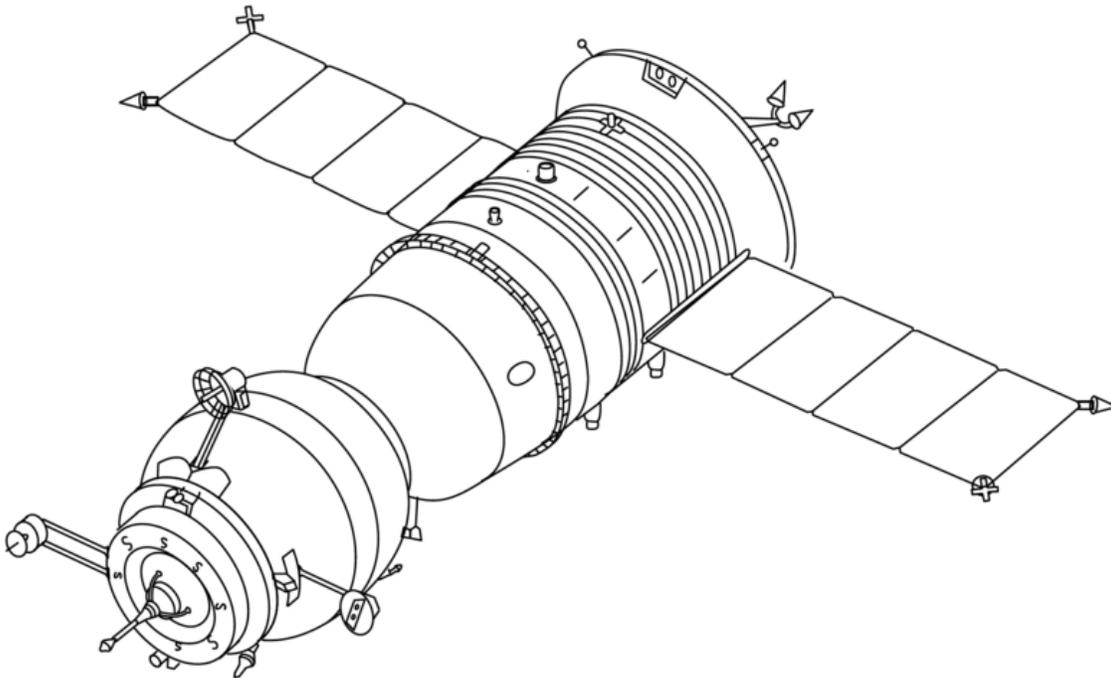
Soyuz family tree



Salyut 1-type Soyuz 7K-T/A9 for three cosmonauts without space suits



Soyuz-T spacecraft



Soyuz-TM spacecraft. Compare the antennae on the orbital module to those on Soyuz-T. Differences reflect the change from the Igla rendezvous system used on Soyuz-T to the Kurs rendezvous system used on Soyuz-TM.



The Soyuz TMA-6

The Soyuz spacecraft has been the subject of continuous evolution since the early 1960s. Thus several different actual versions, proposals and projects exist.

Technical data

Version:	Soyuz A (1963)	Soyuz 7K-OK (1967–1971)	Soyuz 7K-L3 (LOK)	Soyuz 7K-T (1973–1981)	Soyuz 7K-TM (1975)	Soyuz-T (1976–1986)	Soyuz-TM (1986–2002)	Soyuz-TMA (2003–....)	Soyuz TMA-M (2010–....)
Total									
Mass (kg)	5 880	6 560	9 850	6 800	6 680	6 850	7 250	7 220	7 150
Length (m)	7.40	7.95	10.06	7.48	7.48	7.48	7.48	7.48	7.48
Max Diameter (m)	2.50	2.72	2.930	2.72	2.72	2.72	2.72	2.72	2.72
Span (m)	?	9.80	?	9.80/–	8.37	10.6	10.6	10.7	10.7
Orbital Module (BO)									

Mass (kg)	1 000	1 100	-	1 350	1 224	1 100	1 450	1 370
Length (m)	3 .00	3 .45	2 .26	2 .98	3 .10	2 .98	2 .98	2 .98
Diameter (m)	2 .20	2 .25	2 .3	2 .26	2 .26	2 .26	2 .26	2 .26
Volume (m ³)	2 .20	5 .00	-	5 .00	5 .00	5 .00	5 .00	5 .00

Reentry module (SA)

Mass (kg)	2 480	2 810	2 804	2 850	2 802	3 000	2 850	2 950
Length (m)	2 .30	2 .24	2 .19	2 .24	2 .24	2 .24	2 .24	2 .24
Diameter (m)	2 .17	2 .17	2 .2	2 .17	2 .17	2 .17	2 .17	2 .17
Volume (m ³)	4 .00	4 .00	-	3 .50	4 .00	4 .00	3 .50	3 .50

Service module (PAO)

Mass (kg)	2 400	2 650	-	2 700	2 654	2 750	2 950	2 900
Usable mass (kg)	830	500	3152	500	500	700	880	880
Length (m)	2 .10	2 .26	2 .82	2 .26	2 .26	2 .26	2 .26	2 .26
Diameter (m)	2 .50	2 .72	2 .2	2 .72	2 .72	2 .72	2 .72	2 .72

Soyuz A (part of the circumlunar complex) (1963)

Korolyov initially promoted the Soyuz A-B-C circumlunar complex (*7K-9K-11K*) concept (also known as L1) in which a two-man craft Soyuz-A 7K would rendezvous with other components (9K and 11K) in Earth orbit to assemble a lunar excursion vehicle, the components being delivered by the proven R-7 rocket.

First generation

The manned Soyuz spacecraft can be classified into design generations. Soyuz 1 through Soyuz 11 (1967–1971) were first-generation vehicles, carrying a crew of up to three without spacesuits and distinguished from those following by their bent solar panels and their use of the Igla automatic docking navigation system, which required special radar antennas. This first generation was called Soyuz 7K-OK and encompassed the original Soyuz and Salyut 1 Soyuz.

The Soyuz 7K-L1 was designed to launch a crew from the Earth to circle the moon, and was the primary hope for a Soviet circumlunar flight. It had several test flights in the Zond program from 1967–1970 (Zond 4 to Zond 8), which produced multiple failures in the 7K-L1's re-entry systems. The remaining 7K-L1s were scrapped. The Soyuz 7K-L3 was designed and developed in parallel to the Soyuz 7K-L1, but was also scrapped.

The next manned version of the Soyuz was the Soyuz 7K-OKS. It was designed for space station flights and had a docking port that allowed internal transfer between spacecraft. The Soyuz 7K-OKS had two manned flights, both in 1971. Soyuz 11, the second flight, depressurized upon re-entry, killing its three-man crew.

Second generation

The second generation, called *Soyuz Ferry* or Soyuz 7K-T, comprised Soyuz 12 through Soyuz 40 (1973–1981). It was developed out of the military Soyuz concepts studied in previous years. The Soyuz 7K-T/A9 version was used for the flights to the military Almaz space station.

Soyuz 7K-TM was the spacecraft used in the Apollo-Soyuz Test Project in 1975, which saw the first and only docking of a Soyuz spacecraft with an Apollo spacecraft. It was also flown in 1976 for the earth-science mission, Soyuz 22. Soyuz 7K-TM served as a technological bridge to the third generation, the Soyuz-T spacecraft.

Several military Soyuz models were planned, but none actually flew in space. These versions were named *Soyuz 7K-P*, *Soyuz 7K-PPK*, *Soyuz R*, *Soyuz 7K-VI*, and *Soyuz OIS* (*Orbital Research Station*).

Third generation

The third generation Soyuz-T (Т: транспортный, *Transportnyi* meaning transport) spacecraft (1976–1986) featured solar panels allowing longer missions, a revised Igla rendezvous system and new translation/attitude thruster system on the Service module. It could carry a crew of three, now wearing spacesuits.

Fourth generation

The Soyuz-TM crew transports (М: модифицированный, *Modifitsirovannyi* meaning modified) were fourth generation Soyuz spacecraft, and were used from 1986 to 2003 for ferry flights to Mir and the International Space Station.

Soyuz-TMA (2003–....)

Soyuz TMA (А: антропометрический, *Antropometricheskii* meaning anthropometric) features several changes to accommodate requirements requested by NASA in order to service the International Space Station, including more latitude in the height and weight of the crew and improved parachute systems. It is also the first expendable vehicle to

feature "glass cockpit" technology. Soyuz-TMA looks identical to a Soyuz-TM spacecraft on the outside, but interior differences allow it to accommodate taller occupants with new adjustable crew couches.

Soyuz TMA-M (2010/....)

In 2004, Russian space officials announced that they intended to replace Soyuz with the new Kliper and Parom spacecrafts by early 2011. Since then, Kliper appears to have been indefinitely postponed due to lack of government funding. It has since been announced that the Soyuz will receive an upgrade to make it suitable for up to one year in space, as well as new digital interior displays and updated docking equipment. This new version, known as Soyuz TMA-M, debuted on 7 October 2010 with the launch of TMA-01M, carrying the ISS Expedition 25 crew.

Soyuz ACTS (2012/....)

Soyuz ACTS (Advanced Crew Transportation System), also known as Soyuz-K, is a proposed version of the Soyuz design capable of achieving lunar orbit. The upgrades could include a new habitation module developed by the European Space Agency. A novel, rocket-based precision landing system may also be implemented. Missions could be launched from Baikonur or Guiana Space Centre.

Related craft

The unmanned Progress spacecraft were derived from Soyuz and are used for servicing space stations.

While not being direct derivatives of Soyuz, the Chinese Shenzhou spacecraft and the Indian Orbital Vehicle follow the same general layout as that pioneered by Soyuz.

Operators

- Russian Federation: 1992 to present
- Union of Soviet Socialist Republics: 1966 through 1991

Chapter 2

Progress

Progress spacecraft	
	
Progress cargo spacecraft	
Description	
Role:	Used to supply the International Space Station, originally used to supply Soviet and Russian space stations
Crew:	0
Dimensions	
Height:	7.23 m (23.72 ft)
Diameter:	2.72 m (8.92 ft)
Volume:	7.6 m ³ (268 ft ³)
Payload:	2,350 kg (5,200 lb)
Performance	

Endurance:	6 months docked to station
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The **Progress** (Russian: **Прогресс**) is a Russian expendable freighter spacecraft. The spacecraft is an unmanned resupply spacecraft during its flight but upon docking with a space station it allows astronauts inside, hence it is classified *manned* by the manufacturer. It was derived from the Soyuz spacecraft, and is launched with the Soyuz rocket. It is currently used to supply the International Space Station, but was originally used to supply Soviet space stations for many years. There are three to four flights of the Progress spacecraft to the ISS per year. Each spacecraft remains docked until shortly before the new one, or a Soyuz (which uses the same docking ports) arrives. Then it is filled with waste, disconnected, deorbited, and destroyed in the atmosphere. Because of the different Progress variants used for ISS, NASA uses its own nomenclature where "**ISS 1P**" means the first Progress spacecraft to ISS.

It has carried fuel and other supplies to all the space stations since Salyut 6. The idea for the Progress came from the realisation that in order for long duration space missions to be possible, there would have to be a constant source of supplies. It had been determined that a cosmonaut needed consumables (water, air, food, etc.) plus there was a need for maintenance items and payloads for experiments. It was impractical to launch this along with passengers in the small space available in the Soyuz.

Design

Progress is of much the same size and shape as Soyuz. It consists of three modules:

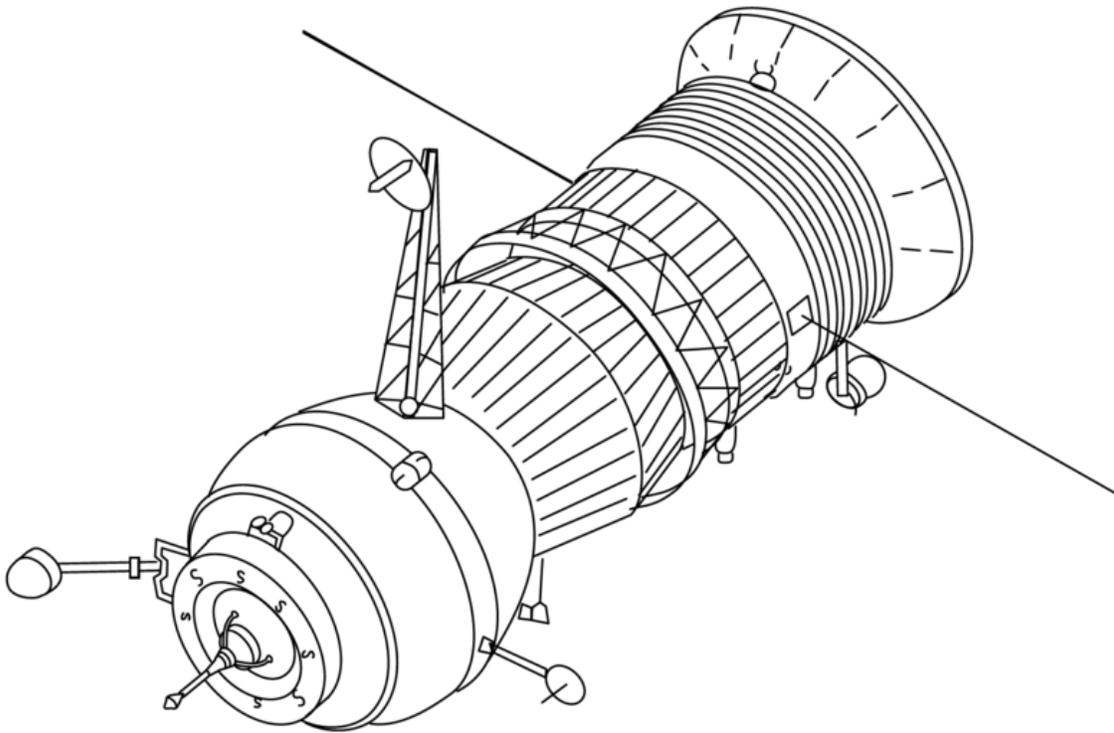
- A pressurized forward module. This carries the supplies for the crew such as scientific equipment, clothes, prepackaged and fresh food, and letters from home. The docking drogue is similar to that of the Soyuz but features ducting for the UDMH fuel and N₂O₄ oxidiser.
- A fuel compartment. The reentry module of the Soyuz was replaced with an unpressurized propellant and refueling compartment with ducting along the outside of the spacecraft. This meant that if a leak occurred, the poisonous gas would not enter the station's atmosphere. The fuel is carried in two tanks.
- A propulsion module. The propulsion module, at the rear of the spacecraft, remained unchanged and contains the orientation engines used for the automatic docking. It may be used to boost the orbit of the station once docked.

Reduction in mass was possible because the Progress was designed to be unmanned and disposable. This means that there is no need for bulky life support systems and heat shields. The spacecraft also has no ability to split into separate modules. After undocking, the spacecraft performs a retrofiring and burns up in the atmosphere.

Versions

There were many small variations between the different flights, but the major upgrades are reflected in the change of name.

Progress (1978-1990)



Progress logistics resupply spacecraft. It consists of the dry cargo module (left); the tanker compartment (center); and a stretched service module (right).

There were 42 spacecraft built using the initial **Progress** design, the last one being launched in May 1990.

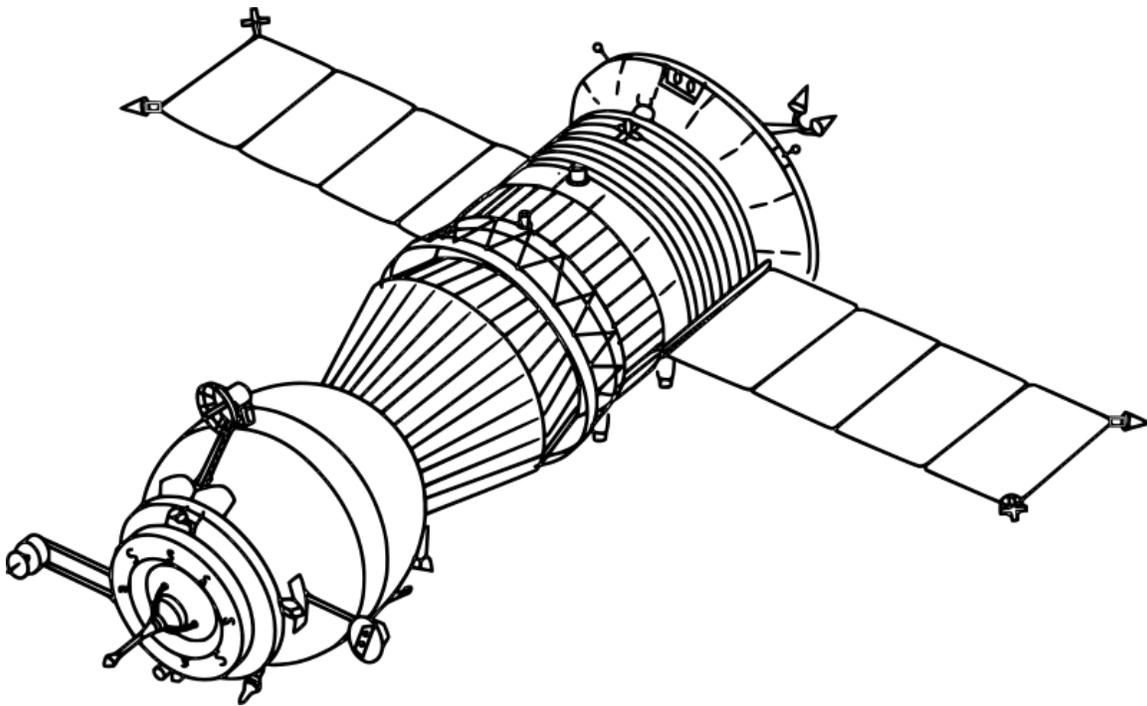
The bureau in charge of designing the freighter was TsKBEM (now RKK Energia). They began work on the design in mid-1973, assigning Progress the GRAU index 11F615A15. The design was complete by February 1974, and the first production model was ready for launch in November 1977. Progress 1 launched on January 20, 1978 aboard the same rocket used to launch the Soyuz. It still featured the same launch shroud as the Soyuz, though this was purely for aerodynamic purposes as the launch escape system had been deactivated.

This first version of Progress had a mass of 7,020 kg and carried 2,300 kg of cargo, or 30% of its launch weight. It had the same diameter as the Soyuz at 2.2 metres, but was 8 metres in length—slightly longer. The autonomous flight time was 3 days, the same time

as that of the Soyuz ferry. It could spend one month docked. Progress always docked to the aft port of the station it was resupplying.

- Launch weight 7,020-7,249 kg
- Weight of cargo (Progress 1-24) ~2,300 kg
- Weight of cargo (Progress 24-42) ~2,500 kg
- Length 7.94 m
- Diameter of cargo modules 2.2 m
- Maximum diameter 2.72 m
- Volume of cargo compartment 6.6 m³

Progress-M 11F615A55 (1989-2009)



Progress-M logistics resupply spacecraft

The upgraded **Progress M** (GRAU: 11F615A55, manufacturer's designation: 7K-TGM) was first launched in August 1989. The first 43 flights all went to Mir; following Mir's re-entry, Progress was used as the resupply vehicle for the International Space Station. As of June 2009, there have been 33 Progress flights to the ISS and more are scheduled.

The Progress M is essentially the same spacecraft as the Progress, but it features improvements based on the Soyuz T and TM designs. It can spend up to 30 days in autonomous flight and is able to carry 100 kg more. Also, unlike the old Progress crafts, it can return items to Earth. This is accomplished by using the Raduga capsule, which can carry up to 150 kg of cargo. It is 1.5 m long and 60 cm in diameter and has a "dry weight" of 350 kg. Progress M can also dock to the forward port of the station and still

transfer fuel. It uses the same rendezvous system as the Soyuz, and it features solar panels for the first time.

- Launch weight 7,130 kg
- Cargo weight 2,600 kg
- Dry cargo weight 1,500 kg
- Liquid cargo weight 1,540 kg
- Length 7.23 m
- Diameter of cargo modules 2.2 m
- Maximum diameter 2.72 m
- Dry cargo compartment volume 7.6 m³
- Solar array span 10.6 m

Progress-M 11F615A60 (2008-present)

A new modification of the Progress spacecraft, with new TsVM-101 digital flight computer and MBITS digital telemetry system, was first launched on November 26, 2008, at 12:38 UTC from the Kazakhstan's Baikonur Cosmodrome spaceport aboard a Russian Soyuz rocket. The first spacecraft of this series was Progress M-01M

The spacecraft belongs to the so-called 400 series (GRAU: 11F615A60), and all modifications applied to it will be subsequently used in the production of new Soyuz-TMA-M manned spacecraft.

Progress M1 (2000-2004)

Progress M1 is another variant, capable of carrying more propellant (but less total cargo) to the space stations. There have been 11 of these flights.

- Mass: 7,150 kg
- Capacity cargo: 2,230 kg
- Capacity dry cargo: 1,800 kg
- Capacity propellant: 1,950 kg

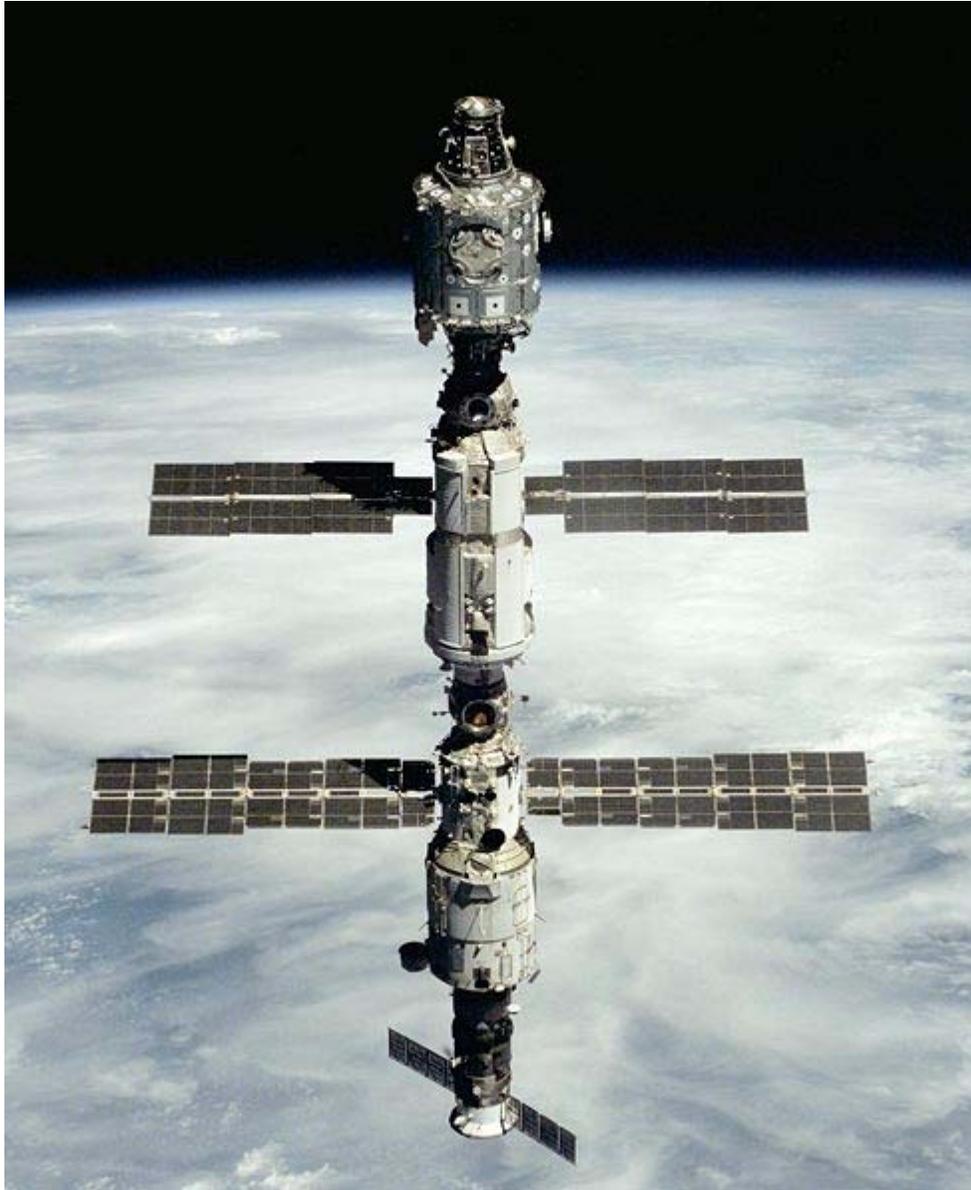
Progress M2

Progress M2 was a planned variant, which was a proposed design for the proposed Mir-2 space station, but was dropped due to financial issues. The M2 variant would have a larger service module for larger cargo or space station modules and would have been launched on a Zenit launch vehicle.

Current status



The 24P vehicle on January 16, 2007, preparing for launch from the Baikonur Cosmodrome



Progress M1-3 seen docked at the bottom of the *Zvezda* module of the ISS during STS-106.

Progress spacecraft are currently used to resupply the International Space Station (ISS). Between February 1, 2003 and July 26, 2005, they were the only spacecraft available to transport large quantities of supplies to the station, as the Space Shuttle fleet was grounded after the breakup of *Columbia* at the end of STS-107. For ISS missions, the Progress M1 variant is used, which moves the water tanks from the propellant and refueling module to the pressurized section, and as a result is able to carry more propellant. Progress M-67, the final flight of a Progress-M spacecraft, was launched July 24, 2009 on a Soyuz-U. The Progress M-08M is currently docked to the International Space Station.

The European Space Agency (ESA) operates its own type of supply freighter, the Automated Transfer Vehicle (ATV). The first of these, named *Jules Verne*, was launched at 04:03 GMT on March 9, 2008. ATVs can carry up to 9 tonnes of cargo into space, roughly three times as much as the Progress, and will be launched every 12–18 months by Ariane 5 rockets.

The new American Orion spacecraft, which was to replace the Space Shuttle after 2015, was initially designed to have an unmanned variant like Progress, however this capability has since been deleted. It is expected that commercial resupply by Space-X and Orbital Sciences will handle most of the American logistics after the end of the Space Shuttle program.

RKK Energia has proposed the Parom (*ferry*) spacecraft as a replacement for Progress. This new spacecraft would retrieve either the proposed Kliper spacecraft or any cargo container with a Russian airlock and weighing up to 15 short tons (14 t) back to the ISS.

Chapter 3

Automated Transfer Vehicle

Automated Transfer Vehicle	
	
Description	
Role:	Supply the International Space Station with propellant, water, air, payload and experiments.
Crew:	Unmanned, but human-rated.
Dimensions	
Height:	10.3 m (34 ft)
Diameter:	4.5 m (15 ft)
Launch Payload:	7,667 kg (16,900 lb)
Return Payload:	None
Mass at launch:	20,750 kg
Pressurized Volume:	48 m ³
Electrical Energy	
Source:	4 solar panel wings of 4 panels each and 40Ah rechargeable batteries

Size:	total span 22,3 m
Generated Power:	3,800 W
On-board engines	
Main engine:	4 x 490N, Aerojet (GenCorp) Model R-4D-11
Thrusters :	28 x 220N for Altitude control & braking, Astrium Lampoldshausen
Performance	
Endurance:	Docked with the ISS for six months
Apogee:	400 km
Perigee:	300 km
Inclination:	51.6 degrees
Launch	
Location:	ESA's Guiana Space Centre, Kourou in French Guiana
Site:	ELA-3
Booster:	Ariane 5

The **Automated Transfer Vehicle** or **ATV** is an expendable, unmanned resupply spacecraft developed by the European Space Agency (ESA). ATVs are designed to supply the International Space Station (ISS) with propellant, water, air, payload and experiments. In addition, ATVs can reboost the station into a higher orbit.

The first ATV, *Jules Verne*, was successfully launched in March 2008. ESA has already contracted suppliers to produce at least four more ATV's to be flown until 2015. A total of seven ATVs could eventually be launched to the International Space Station, mission managers said. Further development of the ATV towards a cargo return version and a human launch version are now being studied.

Design

The ATV is designed to complement the Progress spacecraft, having three times its capacity. Like the Progress, it carries both bulk liquids and relatively fragile freight which is stored in a cargo hold kept in a pressurized shirt-sleeve environment so that astronauts can have access to it without putting on a spacesuit. The ATV pressurized

cargo section is based on the Italian-built Multi-Purpose Logistics Module (MPLM), which is already in service as a Shuttle-carried 'space barge' transporting equipment to and from the Station.

The ATV docking system consists of two videometers and two telegoniometers built by Sodern, a subsidiary of EADS. Data processing system for the abortion of the rendezvous and docking maneuvers have been designed and manufactured by CRISA. Additional monitoring data is supplied by a redundant Russian-made antenna built for the Ukrainian-built Kurs, an automatic docking system similar to those used on Soyuz manned ferries and on the Progress re-supply ship. Visual imagery is provided by a camera on the Zvezda module.

Also like the Progress, the ATV will additionally serve as a container for the station's waste.

Each ATV weighs 20.7 tonnes at launch and has a cargo capacity of 8 tonnes:

- 1,500 kilograms (3,300 lb) to 5,500 kilograms (12,000 lb) of dry cargo (re-supply goods, scientific payload, etc.),
- Up to 840 kilograms (1,900 lb) of water,
- Up to 100 kilograms (220 lb) of gas (nitrogen, oxygen, air), with up to two gases per flight,
- Up to 4,700 kilograms (10,000 lb) of propellant for the *re-boost* maneuver and refueling the station. The ATV propellant used for *re-boost* (monomethylhydrazine fuel and N₂O₄ oxidizer) is of a different type from the *payload* Russian refueling propellant (UDMH fuel and N₂O₄ oxidizer).

Development

The prime contractor for the ATV is EADS Astrium Space Transportation, leading a consortium of many sub-contractors. Development was started in Les Mureaux, France and moved to Bremen, Germany, as the project moved from its development to production stage of the four initial units starts. In order to facilitate the relationship between the contractor and ESA, an integrated ESA team at the Les Mureaux site has been established for the duration of the development.

The first ATV arrived at the ESA spaceport in Kourou, French Guiana on 31 July 2007 after a nearly two week journey from Rotterdam harbour and was launched on 9 March 2008. The *Jules Verne* was the first ATV to be launched. EADS Astrium Space Transportation builds the ATVs in its facility in Bremen. Contracts and accords were signed in 2004 for four more ATVs, which should be launched about once every two years, bringing the total order, including Jules-Verne, to five.

To this end, RSC Energia has signed a 40 million euro contract with one of the main subcontractors of EADS Astrium Space Transportation, the Italian company Alenia Spazio (now Thales Alenia Space), to supply the Russian Docking System, refuelling

system, and Russian Equipment Control System. Within the EADS Astrium Space Transportation led project, Thales Alenia Space is in charge of the pressurized cargo carrier of the ATV. These pressurized cargo carriers are produced in Turin, Italy.

In addition to its use by ESA and Russia, the ATV was in the running to service NASA under the Commercial Orbital Transportation Services program. Under the proposal, a joint venture between EADS and Boeing, an ATV would be launched from Cape Canaveral, Florida, using a Delta IV rocket. Ultimately, it was not awarded a contract.

Use



Jules Verne seen at the bottom of the ISS making the relative size clearly visible



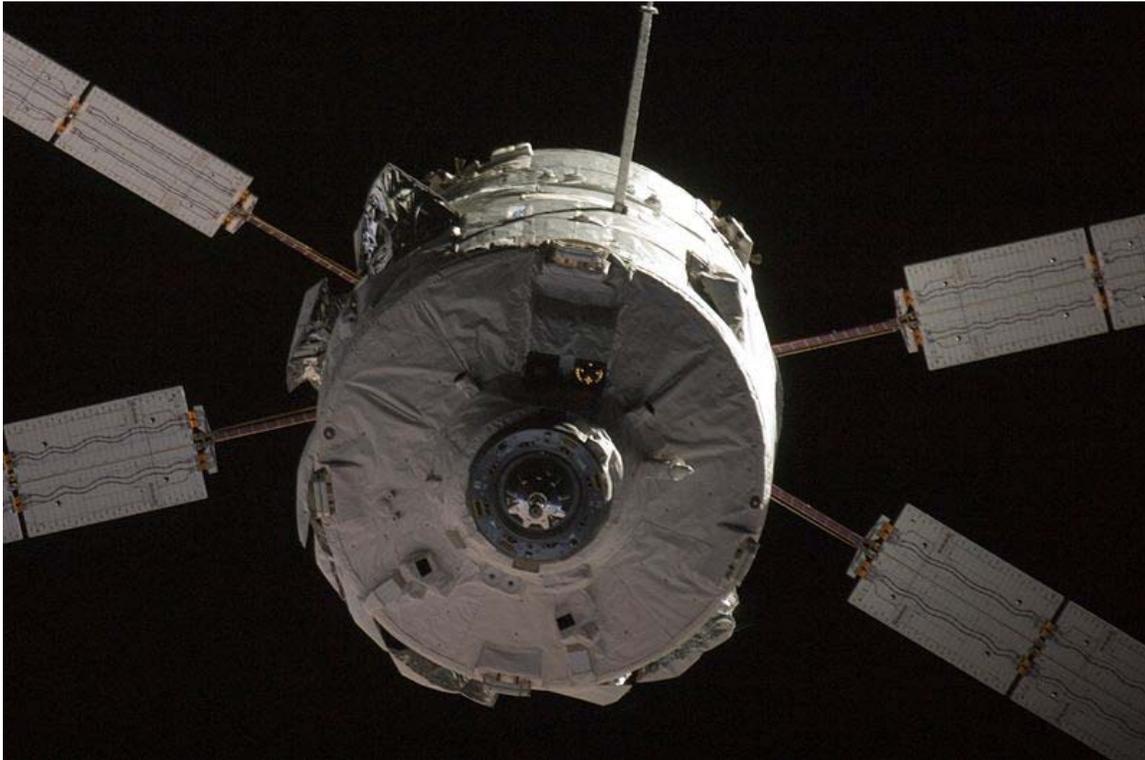
ATV *Jules Verne* as it re-enters Earth's atmosphere in a controlled burn-up after undocking from ISS.

ATVs are intended to be launched every 17 months in order to resupply the International Space Station. They use GPS and a star tracker to automatically rendezvous with the Space Station. At a distance of 249 m, the ATV computers use videometer and telegoniometer data for final approach and docking manoeuvres. The actual docking to *Zvezda* is fully automatic. If there are any last-minute problems, a pre-programmed sequence of anti-collision manoeuvres, fully independent of the main navigation system, can be activated by the flight engineers aboard the station.

With the ATV docked, the station crew enters the cargo section and removes the payload. The ATV's liquid tanks are connected to the station's plumbing and discharge their contents. The station crew manually releases air components directly into the ISS's atmosphere. For up to six months, the ATV, mostly in dormant mode, remains attached to the ISS with the hatch remaining open. The crew then steadily fills the cargo section with the station's waste. At intervals of 10 to 45 days, the ATV's thrusters are used to boost the station's altitude.

Once its mission is accomplished, the ATV, filled with up to 6.5 tonnes of waste, separates. Its thrusters move the spacecraft out of orbit (de-orbit) and place it on a steep flight path to perform a controlled destructive re-entry high above the Pacific Ocean.

Scheduled missions



Jules Verne Automated Transfer Vehicle approaches the International Space Station on Monday, 31 March 2008

Designation	Name	Launch date	Result	Re-entry
ATV-001	Jules Verne	9 March 2008	<i>Docked</i> 3 April 2008	29 September 2008
ATV-002	Johannes Kepler	16 February 2011	<i>launched - mission in progress</i>	<i>Planned</i>
ATV-003	Edoardo Amaldi	29 February 2012	<i>Planned</i>	<i>Planned</i>
ATV-004	unnamed	February 2013	<i>Planned</i>	<i>Planned</i>
ATV-005	unnamed	February 2014	<i>Planned</i>	<i>Planned</i>

Jules Verne

The first flight of the ATV was delayed many times before its launch on 9 March 2008. It was named *Jules Verne*, in memory of the first science fiction writer of modern times. The *Jules Verne* carried two of the author's original handwritten manuscripts, to be received by the ISS crew as symbolic tokens of the success of the first flight.

The craft was launched into a 300-kilometre (190 mi) orbit atop an Ariane 5 from the equatorial ELA-3 launch site at the Guiana Space Centre. The ATV separated from the Ariane rocket and after weeks of tests and orbit adjustments successfully docked in the International Space Station at 14:45 UTC on 3 April 2008.

In the early morning hours of 29 September 2008, the Jules Verne burnt up on entering the atmosphere above an uninhabited section of the Pacific Ocean, southwest of Tahiti.

ATV Control Centre

ATV missions are monitored and controlled from the ATV Control Centre (ATV-CC) located at the Toulouse Space Centre (CST) in Toulouse, France. The centre is responsible for all planning and executing of every orbital maneuver and mission task of the ATV, from the moment of separation from its launch vehicle, until it burns up in the Earth's atmosphere. The centre has a direct communication line with the Columbus Control Center (Col-CC) in Oberpfaffenhofen, Germany. Col-CC provides ATV-CC with access to both the American TDRSS and the European Artemis communication networks in order to communicate with ATV and the space station. ATV-CC will coordinate its actions with NASA's Mission Control Center (MCC-H) in Houston and the Russian FKA Mission Control Center (TsUP or MCC-M) in Moscow, Russia as well as the ATV launch site at the Guiana Space Centre in Kourou, French Guiana.

ATV Evolution proposals



An **MSS** could be used as a small orbital lab

Following the decision by NASA to retire the Space Shuttle in 2011, the European Space Agency launched a series of studies to determine the potential for evolutions and

adaptations of the ATV. Following these studies the cargo return version (CARV) became a candidate for further development. The goal of this variant is to provide ESA with the capability to transport scientific data and cargo from the ISS to Earth. Beyond this, CARV could be enhanced to become a man-carrying spacecraft which would be launched by an adapted Ariane 5.

Mini Space Station

The MSS concept is an ATV evolution proposal for the construction of multiple ATVs with two docking ports, one at each end. The current version of the ATV is already prepared for a docking port at the back, with the main propulsion system arranged in a cylindrical fashion leaving room for a tunnel through the middle. This concept would allow Soyuz, Progress and other ATVs to dock to the back of the ATV, allowing a steady flow of Russian vehicles using the available docking ports whilst an ATV is docked for an average of around 6 months at a time.



PARES capsules would be able to hold a few kg of cargo

Payload Retrieval System

The PARES would have included a small ballistic capsule similar to VBK-Raduga embedded into the ATV docking interface, which would have brought back a few tens of kilograms of payload. PARES could have featured a deployable heat shield system. The European Space Agency was also proposing the system for use with the Progress spacecraft and the H-II Transfer Vehicle (HTV).



CARV would be used to transport a large amount of cargo to Earth

Cargo Ascent and Return Vehicle

The CARV would deliver a redesigned capsule, capable of bringing back payload from orbit. It could be installed in place of the ATV pressurized cargo hold. In addition, it could be adapted to dock at the US side of the station. Given the larger docking ports there, it would be possible to transfer complete International Standard Payload Racks (ISPRs) from the ATV to the station, which is not currently possible.

Crew Transport Vehicle

This is another option under consideration. Similar to the CARV variant, this would replace the current Integrated Cargo Carrier with a pressurized re-entry capsule. A significant difference with the cargo-only variant would be the presence of a Crew Escape System, consisting of a number of booster rockets able to pull the crew capsule away from the launcher (Ariane 5) and/or Service Module in the event of an emergency. The CTV variant of the ATV could be able to seat 4 or 5 crew members.

Possibilities for launching of the ATV on other launchers than the Ariane 5 have also been investigated, in particular in the frame of Commercial Orbital Transportation Services. ESA and its member states will consider approval for further ATV development in the coming years.

Proposed crewed version



A 3D rendering of the proposed ATV derived manned transportation system

The aerospace company EADS Astrium and the German Space Agency (the DLR), announced on 14 May 2008 that they would pursue a project to adapt the ATV into a crew transportation system. The craft would be able to launch a 3 man crew beyond LEO via use of a modified version of the Ariane 5 rocket and would be more spacious than the Russian Soyuz. A mock-up of the proposed craft was shown at the 2008 International Aerospace Exhibition in Berlin. If the project is given ESA approval development will proceed in two stages:

- The first stage would see the development of an Advanced Reentry Vehicle (ARV) capable of transporting up to 1,500 kg of cargo from space to earth safely by 2015. This capability would be available to ESA even if further development were to be halted. It would prove useful in the ISS program as well as the proposed Mars Sample Return Mission with NASA. ARV development would make use of work done on the Atmospheric Reentry Demonstrator, Crew Return Vehicle and related projects. The budget for this stage of the ATV overhaul would reportedly be €300 million.
- The second stage would adapt the then existing capsule to be able to transport people safely as well as upgrade the propulsion and other systems in the service module and would last 4 to 5 years at a cost of "a couple of billion (€)" according to a senior Astrium representative.

Subsequent activity

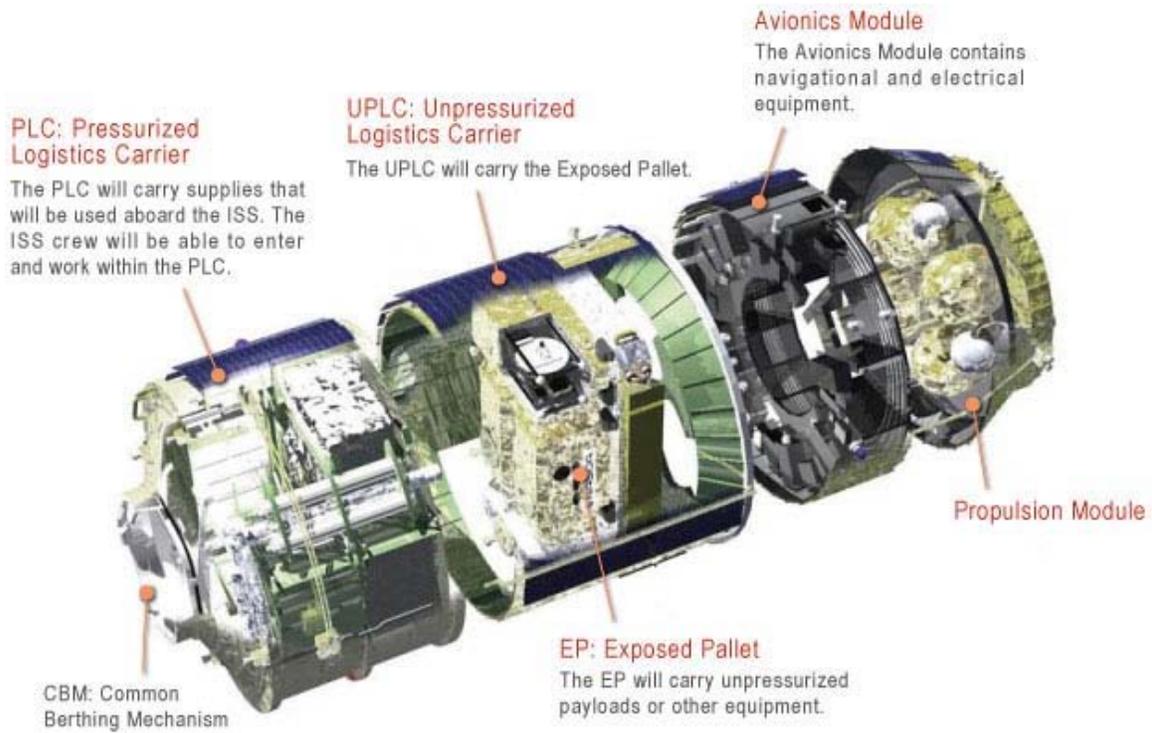
In November 2008, ESA ministers budgeted for a feasibility study into developing a re-entry capsule for the ATV, a requirement for developing either a cargo return capacity or a manned version of the ATV. ESA signed a €21 million study contract with EADS Astrium on 7 July 2009.

Chapter 4

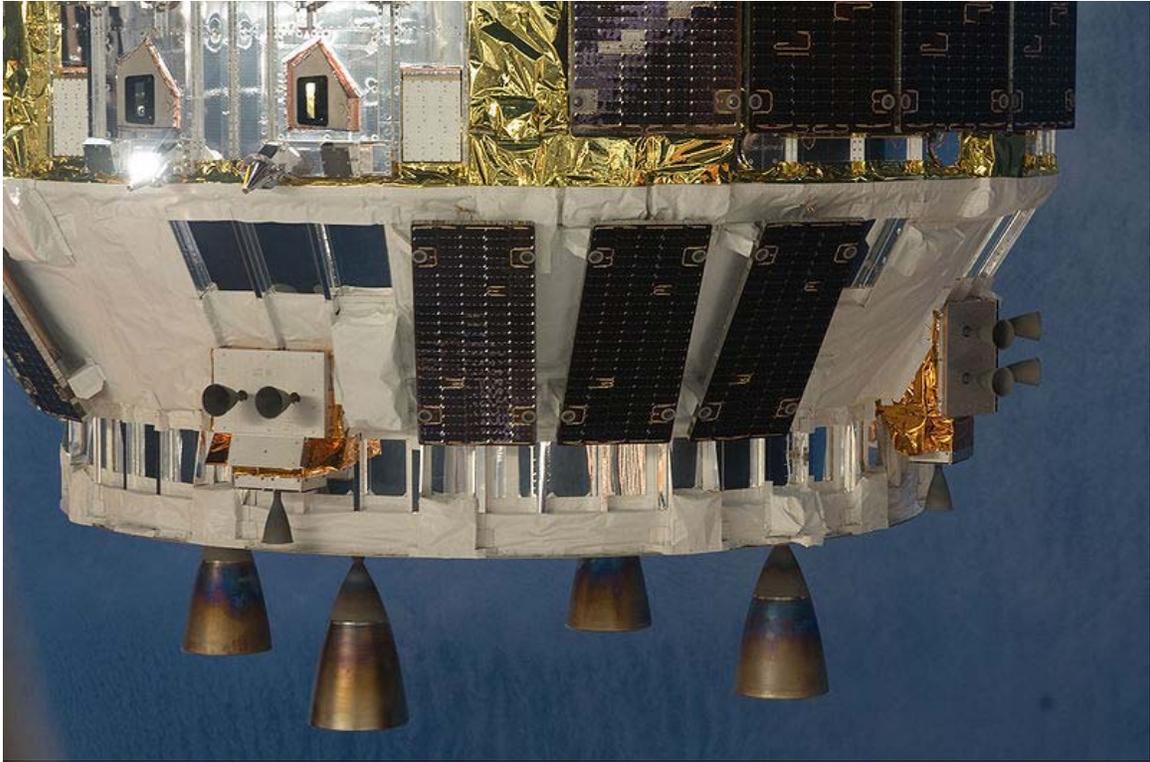
H-II Transfer Vehicle

H-II Transfer Vehicle	
	
H-II Transfer Vehicle (HTV-1) approaching the ISS	
Description	
Role:	Unmanned spacecraft intended to resupply the <i>Kibō</i> Japanese Experiment Module on the International Space Station, and the rest of the station, if necessary.
Crew:	Unmanned
Dimensions	
Height:	10 m (including thrusters)
Diameter:	4.4 m
Spacecraft weight:	10,500 kg
Total Launch Payload:	6,000 kg
Pressurized Payload:	5,200 kg
Unpressurized	1,500 kg

Payload:	
Return Payload:	None
Mass at launch:	16.5 ton
Performance	
Endurance:	Solo flight about 100 hours, stand-by more than a week, docked with the ISS about 30 days
Apogee:	460 km
Perigee:	350 km
Inclination:	51.6 degrees



Structure

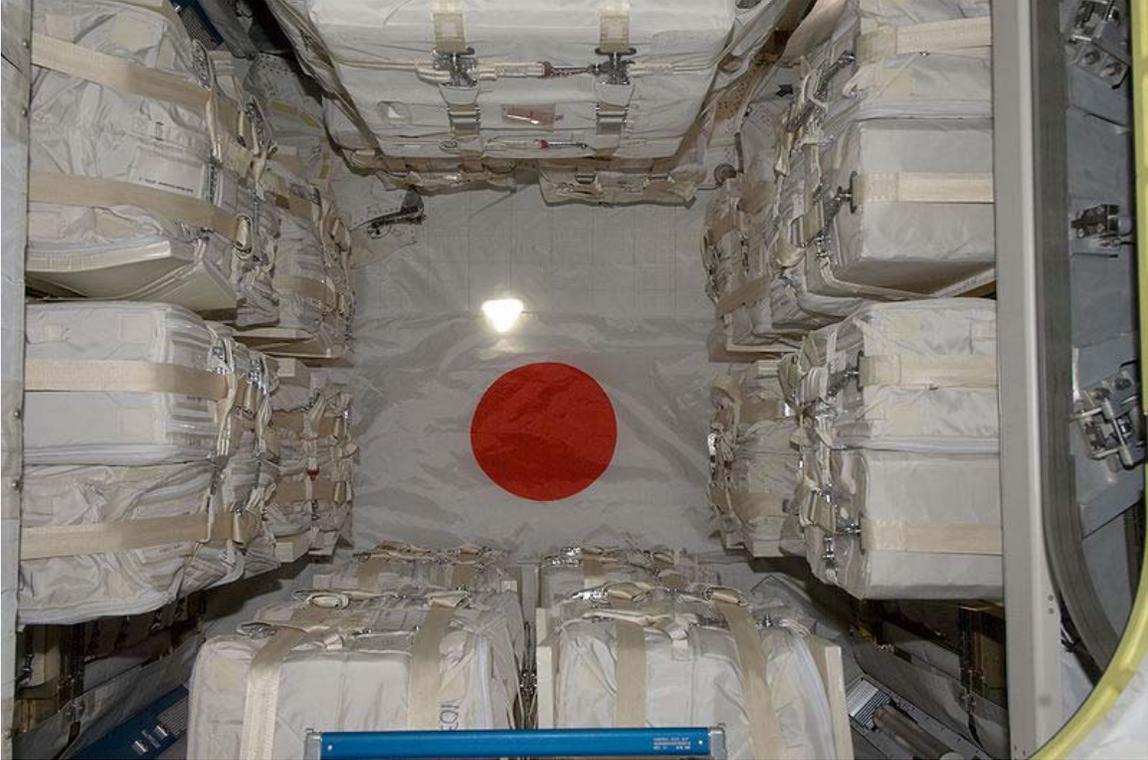


At the bottom the four main thrusters. Smaller attitude control thrusters can be seen at the right side of this view of HTV-1.

The **H-II Transfer Vehicle (HTV)**, nicknamed *Kounotori* (こうのとり?, Oriental Stork or White Stork), is an unmanned resupply spacecraft used to resupply the *Kibō* Japanese Experiment Module (JEM) and the rest of the International Space Station (ISS). The Japan Aerospace Exploration Agency (JAXA) has been working on the design since the early 1990s. The first mission, HTV-1, was originally intended to be launched in 2001. It lifted-off at 17:01 UTC on September 10, 2009 on an H-IIB launch vehicle.

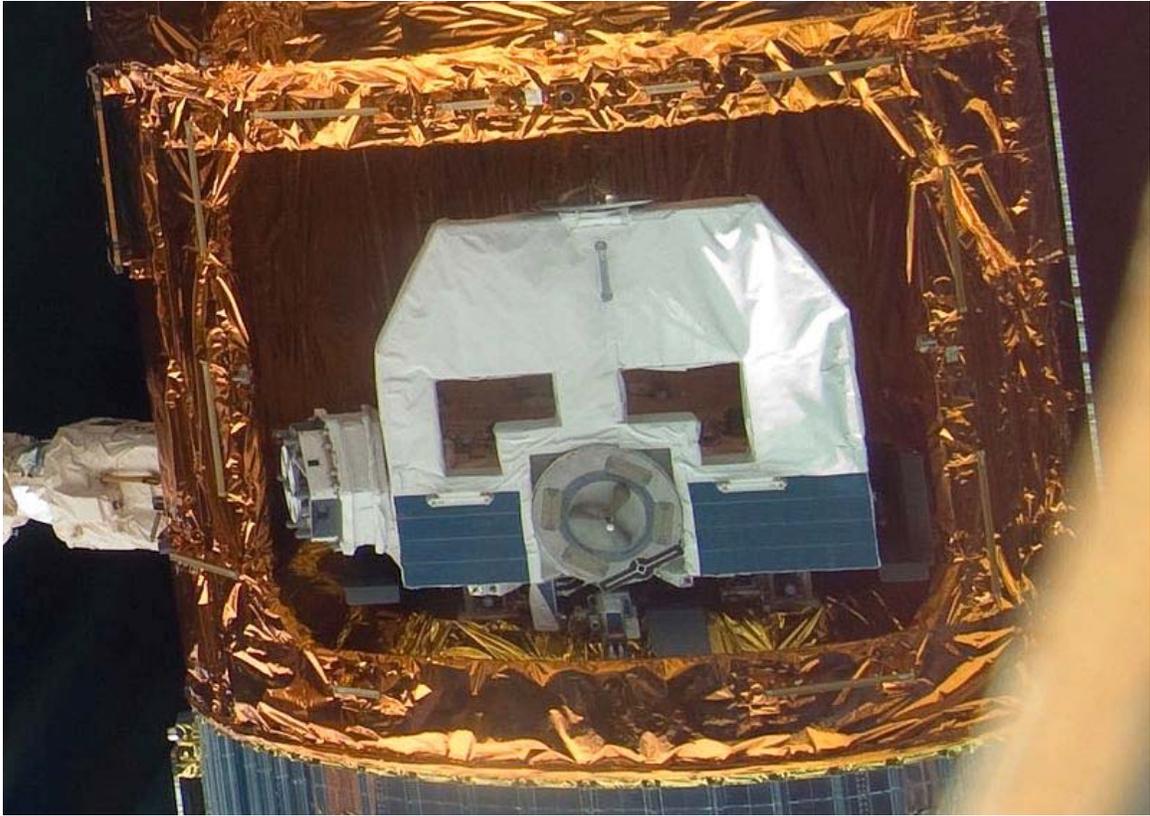
Design

HTV is about 10 m long (including maneuvering thrusters at one end) and 4.4 m in diameter. Total mass is 10.5 tonnes, with a 6,000 kilograms (13,000 lb) payload. HTV is a larger and simpler vehicle than the Progress spacecraft currently used by Russia to bring supplies to the station, since it does not have a complex docking and approach system. Instead, it will be flown just close enough to the station to allow capture by Canadarm2, which will pull it to a berthing port on the ISS *Harmony* module.



Inside view of the Pressurised Logistics Carrier section of HTV-1

HTV can carry supplies in a combination of two different "segments" that can be attached together. One is a pressurized hold with a capacity of 6,000 kg, which includes an optional docking adapter at one end to allow it to be unloaded in a shirt-sleeves environment. It is designed specifically to carry eight International Standard Payload Racks (ISPRs) in total. After the planned retirement of NASA's Space Shuttle in 2010, HTV will be the only vehicle which can carry ISPRs to the ISS. It will also have a tank to deliver up to 300 kg of water to the station. The other is a lighter and slightly longer unpressurized segment, which includes a hatch on the side to allow it to be unloaded remotely.



The Unpressurised Logistics Carrier section of HTV-1

The baseline configuration, known as the "Mixed Logistics Carrier", uses one pressurized and one unpressurized segment and can carry 7,600 kg of cargo in total and is 9.2 m long. When two pressurized units are used together the cargo decreases slightly to about 7,000 kg, and the overall length is reduced to 7.4 m. These numbers are somewhat vague in the various sources, some suggesting that the pressurized/unpressurized combination carries only 6,000 kg in total, less than the pressurized/pressurized combination, which should be heavier. No sources suggest an unpressurized/unpressurized combination is planned, perhaps due to the overall length.

HTV propulsion is used to generate the torque to control the HTV attitude and the thrust to perform the orbital maneuvers such as rendezvous and re-entry. The HTV has four 500 N class main thrusters and twenty-eight 110 N class attitude control thrusters. Both are using bipropellant, namely monomethylhydrazine (MMH) as fuel and the mixed oxides of nitrogen (MON3) as oxidizer.

Both types of thrusters are manufactured by Aerojet, the 500 N is of the R-4D type of Apollo heritage and the 110 N is of the R-1E type (Shuttle vernier engine). The HTV carries about 2400 kg of propellant in four tanks.

After the on-orbit unloading process is completed, the HTV will be loaded with waste and undocked. The vehicle will then be de-orbited and destroyed during re-entry, the debris falling into the Pacific Ocean.

Possible usage by NASA

In July 2008, it was reported that the United States space agency NASA had begun unofficial negotiations with JAXA on the purchase of HTV spacecraft as the successor to the space shuttle fleet due to NASA's concerns about refueling and servicing the ISS after it retires the shuttle fleet in 2010. A day later, NASA released a press statement declaring that "NASA has not officially or unofficially been discussing the purchase of H-II Transfer Vehicles." The space agency remains committed to "domestic commercial cargo resupply to the space station." NASA has been working with private launch firms such as SpaceX and Orbital Sciences Corporation.

Flights

The first vehicle was launched on an H-IIB rocket, a more powerful version of the earlier H-IIA, at 17:01 GMT on September 10, 2009, from Launch Pad 2 of the Yoshinobu Launch Complex at the Tanegashima Space Center. Six subsequent missions are planned.

HTV	Launch date/time	Carrier rocket	Re-entry date/time
HTV-1	September 10, 2009, 17:01 (UTC)	H-IIB F1	November 1, 2009, 21:26 (UTC)
HTV-2	January 22, 2011, 05:37:57 (UTC)	H-IIB F2	
HTV-3	January 12, 2012 planned	H-IIB	
HTV-4		H-IIB	
HTV-5		H-IIB	
HTV-6		H-IIB	
HTV-7		H-IIB	

Chapter 5

Space Shuttle

Space Transportation System



Space Shuttle *Discovery* launches at the start of STS-120.

Function	Manned orbital launch and reentry
Manufacturer	United Space Alliance: Thiokol/Alliant Techsystems (SRBs) Lockheed Martin (Martin Marietta) – (ET) Rockwell/Boeing (orbiter)
Country of origin	United States
	Size
Height	184.2 ft (56.1 m)
Diameter	28.5 ft (8.7 m)

Mass	4,470,000 lbm (2,030 t)
Capacity	
Payload to LEO	24,400 kg (53,600 lb)
Payload to GTO	3,810 kg (8,390 lbm)
Payload to Polar orbit	12,700 kg (28,000 lb)
Launch history	
Status	Active
Launch sites	LC-39, Kennedy Space Center SLC-6, Vandenberg AFB (unused)
Total launches	132
Successes	130
Failures	2 (launch failure, <i>Challenger</i>), (re-entry failure, <i>Columbia</i>)
Maiden flight	April 12, 1981
	Tracking and Data Relay Satellites Spacelab
Notable payloads	Great Observatories (including Hubble) Galileo, Magellan, Ulysses Mir Docking Module ISS components
Boosters (Stage 0) - Solid Rocket Boosters	
№ boosters	2
Engines	1 solid
Thrust	2,800,000 lbf each, sea level liftoff (12.5 MN)
Specific impulse	269 s
Burn time	124 s
Fuel	solid
First stage - External Tank	
Engines	3 SSMEs located on Orbiter
Thrust	1,225,704 lbf total, sea level liftoff (5.45220 MN)
Specific impulse	455 s
Burn time	480 s
Fuel	LOX/LH2
Second stage - Orbiter	
Engines	2 OME
Thrust	53.4 kN combined total vacuum thrust (12,000 lbf)
Specific impulse	316 s
Burn time	1250 s
Fuel	MMH/N ₂ O ₄

The **Space Shuttle**, or Space Transportation System (STS), is a reusable launch system and orbital spacecraft operated by the U.S. National Aeronautics and Space Administration (NASA) for human spaceflight missions. The system combines rocket launch, orbital spacecraft, and re-entry spaceplane with modular add-ons. The first of four orbital test flights occurred in 1981 leading to operational flights beginning in 1982, all launched from the Kennedy Space Center, Florida. The system is scheduled to be retired from service in 2011 after 135 launches. Major missions have included launching numerous satellites and interplanetary probes, conducting space science experiments, and servicing and construction of space stations.

It has been used for orbital space missions by NASA, the U.S. Department of Defense, the European Space Agency, Japan, and Germany. The United States funded STS development and shuttle operations except for Spacelab D1 and D2 — sponsored by West Germany and reunified Germany respectively. In addition, SL-J was partially funded by Japan.

At launch, the Space Shuttle consists of the shuttle stack, which includes a dark orange-colored external tank (ET); two white, slender Solid Rocket Boosters (SRBs); and the Orbiter Vehicle (OV), which contains the crew and payload. Payloads can be launched into higher orbits with either of two different booster stages developed for the STS (single-stage Payload Assist Module or two-stage Inertial Upper Stage). The Space Shuttle is "stacked" in the Vehicle Assembly Building and the stack mounted on a mobile launch platform held down by four explosive bolts on each SRB which are detonated at launch.

The shuttle stack launches vertically, like a conventional rocket, from a mobile launch platform. It lifts off under the power of its two SRBs and the three main engines, which are fueled by liquid hydrogen and liquid oxygen from the external tank. The Space Shuttle has a two-stage ascent. The SRBs provide additional thrust during liftoff and first-stage flight. About two minutes after liftoff, explosive bolts are fired, releasing the SRBs, which then parachute into the ocean, to be retrieved by ships for refurbishment and reuse. The shuttle orbiter and external tank continue to ascend on an increasingly horizontal flight path under power from the three main engines. Upon reaching 17,500 mph (7.8 km/s), necessary for low Earth orbit, the main engines are shut down. The external tank is then jettisoned downward to burn up in the atmosphere. It is, however, possible for the external tank to be re-used in orbit. After jettisoning the external tank, the orbital maneuvering system (OMS) engines may be used to adjust the orbit.

The orbiter carries astronauts and payload such as satellites or space station parts into low earth orbit, into the Earth's upper atmosphere or thermosphere. Usually, five to seven crew members ride in the orbiter. Two crew members, the Commander and Pilot, are sufficient for a minimal flight, as in the first four "test" flights, STS-1 through STS-4. A typical payload capacity is about 22,700 kilograms (50,000 lb), but can be raised depending on the choice of launch configuration. The orbiter carries the payload in a large cargo bay with doors that open along the length of its top, a feature which makes the Space Shuttle unique among present spacecraft. This feature made possible the

deployment of large satellites such as the Hubble Space Telescope, and also to capture and return large payloads back to Earth.

When the orbiter's space mission is complete, it fires its OMS thrusters to drop out of orbit and re-enter the lower atmosphere. During the descent, the shuttle orbiter passes through different layers of the atmosphere and decelerates from hypersonic speed primarily by aerobraking. In the lower atmosphere and landing phase, it is more like a glider but with reaction control system (RCS) thrusters and fly-by wire controlled hydraulically actuated flight surfaces controlling its descent. It then makes a landing on a long runway as a spaceplane. The aerodynamic shape is a compromise between the demands of radically different speeds and air pressures during re-entry, hypersonic flight, and subsonic atmospheric flight. As a result, the orbiter has a relatively high sink rate at low altitudes, and transitions during re-entry from using RCS thrusters at very high altitudes to flight surfaces in the lower atmosphere.

Early history

Though design and construction of the Space Shuttle began in the early 1970s, conceptualization actually began two decades earlier, even before the Apollo program of the 1960s. The concept of a spacecraft returning from space to a horizontal landing began within NACA, in 1954, in the form of an aeronautics research experiment later named the X-15. The NACA proposal was submitted by Walter Dornberger.

In 1958, the X-15 concept further developed into another X-series spaceplane proposal, called the X-20, which was never constructed. Neil Armstrong was selected to pilot both the X-15 and the X-20. Though the X-20 was never built, another spaceplane similar to the X-20 was built several years later and delivered to NASA in January 1966. It was called the HL-10. "HL" indicated "horizontal landing".

In the mid-1960s, the US Air Force conducted a series of classified studies on next-generation space transportation systems and concluded that semi-reusable designs were the cheapest choice. They proposed a development program with an immediate start on a "Class I" vehicle with expendable boosters, followed by slower development of a "Class II" semi-reusable design and perhaps a "Class III" fully reusable design later. In 1967 George Mueller held a one-day symposium at NASA headquarters to study the options. Eighty people attended and presented a wide variety of designs, including earlier Air Force designs as the Dyna-Soar (X-20).

In 1968, NASA officially began work on what was then known as the "Integrated Launch and Re-entry Vehicle" (ILRV). At the same time, NASA held a separate Space Shuttle Main Engine (SSME) competition. NASA offices in Houston and Huntsville jointly issued a Request for Proposal (RFP) for ILRV studies to design a spacecraft that could deliver a payload to orbit but also re-enter the atmosphere and fly back to Earth. One of the responses was for a two-stage design, featuring a large booster and a small orbiter, called the DC-3.

In 1969, President Richard Nixon decided to proceed with Space Shuttle development. In August 1973, the X-24B proved that an unpowered spaceplane could re-enter Earth's atmosphere for a horizontal landing.

Across the Atlantic, European ministers met in Belgium in 1973 to authorize Western Europe's manned orbital project and its main contribution to Space Shuttle — the *Spacelab* program. Spacelab would provide a multi-disciplinary orbital space laboratory and additional space equipment for the Shuttle.

Description



STS-1 on the launch pad (1981)

The Space Shuttle is the first orbital spacecraft designed for reuse. It carries different payloads to low Earth orbit, provides crew rotation for the International Space Station (ISS), and performs servicing missions. The orbiter can also recover satellites and other payloads from orbit and return them to Earth. Each Shuttle was designed for a projected lifespan of 100 launches or ten years of operational life, although this was later extended. The person in charge of designing the STS was Maxime Faget, who had also overseen the Mercury, Gemini, and Apollo spacecraft designs. The crucial factor in the size and shape

of the Shuttle Orbiter was the requirement that it be able to accommodate the largest planned commercial and classified satellites, and have the cross-range recovery range to meet the requirement for classified USAF missions for a once-around abort from a launch to a polar orbit. Factors involved in opting for solid rockets and an expendable fuel tank included the desire of the Pentagon to obtain a high-capacity payload vehicle for satellite deployment, and the desire of the Nixon administration to reduce the costs of space exploration by developing a spacecraft with reusable components.



STS-127, Space Shuttle *Endeavour* landing

Each Space Shuttle is a reusable launch system that is composed of three main assemblies: the reusable Orbiter Vehicle (OV), the expendable external tank (ET), and the two reusable solid rocket boosters (SRBs). Only the orbiter enters orbit shortly after the tank and boosters are jettisoned. The vehicle is launched vertically like a conventional rocket, and the orbiter glides to a horizontal landing like an airplane, after which it is refurbished for reuse. The SRBs parachute to splashdown in the ocean where they are towed back to shore and refurbished for later shuttle missions.

Six airworthy orbiters have been built; the first, *Enterprise* (OV-101), was not built for orbital space flight, and was used only for testing glide and landing. Five space-worthy orbiters were built: *Columbia* (OV-102), *Challenger* (OV-099), *Discovery* (OV-103), *Atlantis* (OV-104), and *Endeavour* (OV-105). *Enterprise* was originally intended to be made fully space-worthy after use for the approach and landing test (ALT) program, but it was found more economical to upgrade the structural test article STA-099 into orbiter

Challenger (OV-099). *Challenger* disintegrated 73 seconds after launch in 1986, and *Endeavour* was built as a replacement for *Challenger* from structural spare components. *Columbia* broke apart during re-entry in 2003. Building Space Shuttle *Endeavour* cost about US\$1.7 billion. One Space Shuttle launch costs around \$450 million.

Roger A. Pielke, Jr. has estimated that the Space Shuttle program has cost about US\$170 billion (2008 dollars) through early 2008. This works out to an average cost per flight of about US\$1.5 billion. However, two missions were paid for by Germany, Spacelab D1 and D2 (D for *Deutschland*) with a payload control center in Oberpfaffenhofen, Germany. D1 was the first time that control of a manned STS mission payload was not in U.S. hands.

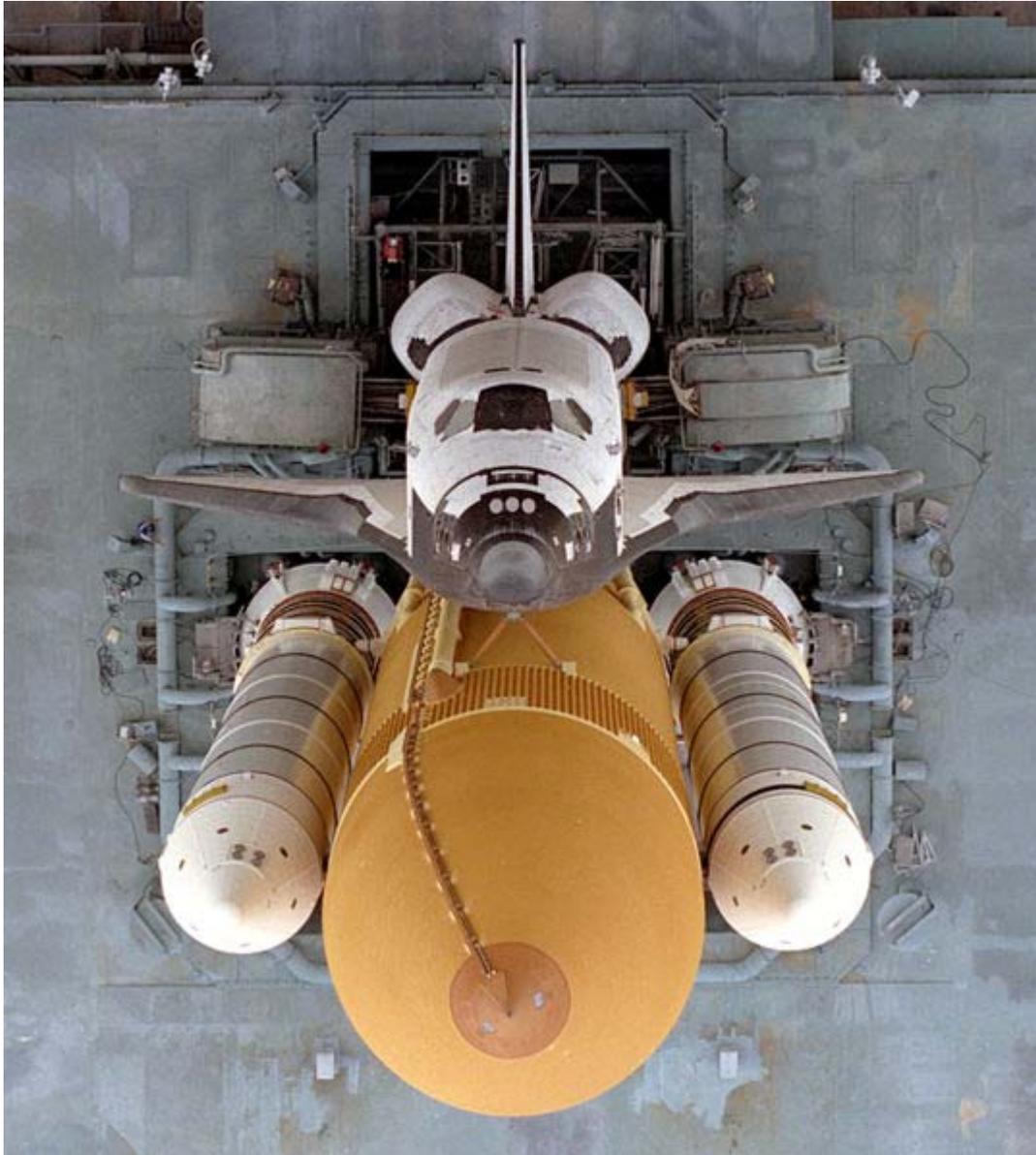
At times, the orbiter itself is referred to as the Space Shuttle. Technically, this is a slight misnomer, as the actual "Space Transportation System" (Space Shuttle) is the combination of the orbiter, the external tank, and the two solid rocket boosters. Combined, these are referred to as the "Stack"; the components are assembled in the Vehicle Assembly Building, which was originally built to assemble the Apollo Saturn V rocket stacks.



Space Shuttle *Atlantis* transported by a Boeing 747 Shuttle Carrier Aircraft (SCA), 1998 (NASA).



Space Shuttle *Endeavour* being transported by a Boeing 747



An overhead view of *Atlantis* as it sits atop the Mobile Launcher Platform (MLP) before STS-79. Two Tail Service Masts (TSMs) to either side of the orbiter's tail provide umbilical connections for propellant loading and electrical power.



Water is released onto the mobile launcher platform on Launch Pad 39A at the start of a sound suppression system test in 2004. During launch, 300,000 US gallons (1,100 m³) are poured onto the pad in only 41 seconds.

Orbiter vehicle

The orbiter resembles a conventional aircraft, with double-delta wings swept 81° at the inner leading edge and 45° at the outer leading edge. Its vertical stabilizer's leading edge is swept back at a 50° angle. The four elevons, mounted at the trailing edge of the wings, and the rudder/speed brake, attached at the trailing edge of the stabilizer, with the body flap, control the orbiter during descent and landing.

The orbiter has a large payload bay measuring 15 by 60 feet (4.6 by 18 m) comprising most of the fuselage. Two mostly symmetrical lengthwise payload bay doors hinged on either side of the bay comprise its entire top. Payloads are generally loaded horizontally into the bay while the orbiter is oriented vertically on the launch pad and unloaded vertically in the near-weightless orbital environment by the orbiter's robotic remote manipulator arm (under astronaut control), EVA astronauts, or under the payloads' own power (as for satellites attached to a rocket "upper stage" for deployment.)

Three Space Shuttle main engines (SSMEs) are mounted on the orbiter's aft fuselage in a triangular pattern. The three engine nozzles can swivel 10.5 degrees up and down, and 8.5 degrees from side to side during ascent to change the direction of their thrust to steer

the shuttle. The orbiter structure is made primarily from aluminum alloy, although the engine structure is made primarily from titanium alloy.

The space-capable orbiters built are OV-102 *Columbia*, OV-099 *Challenger*, OV-103 *Discovery*, OV-104 *Atlantis*, and OV-105 *Endeavour*.

External tank

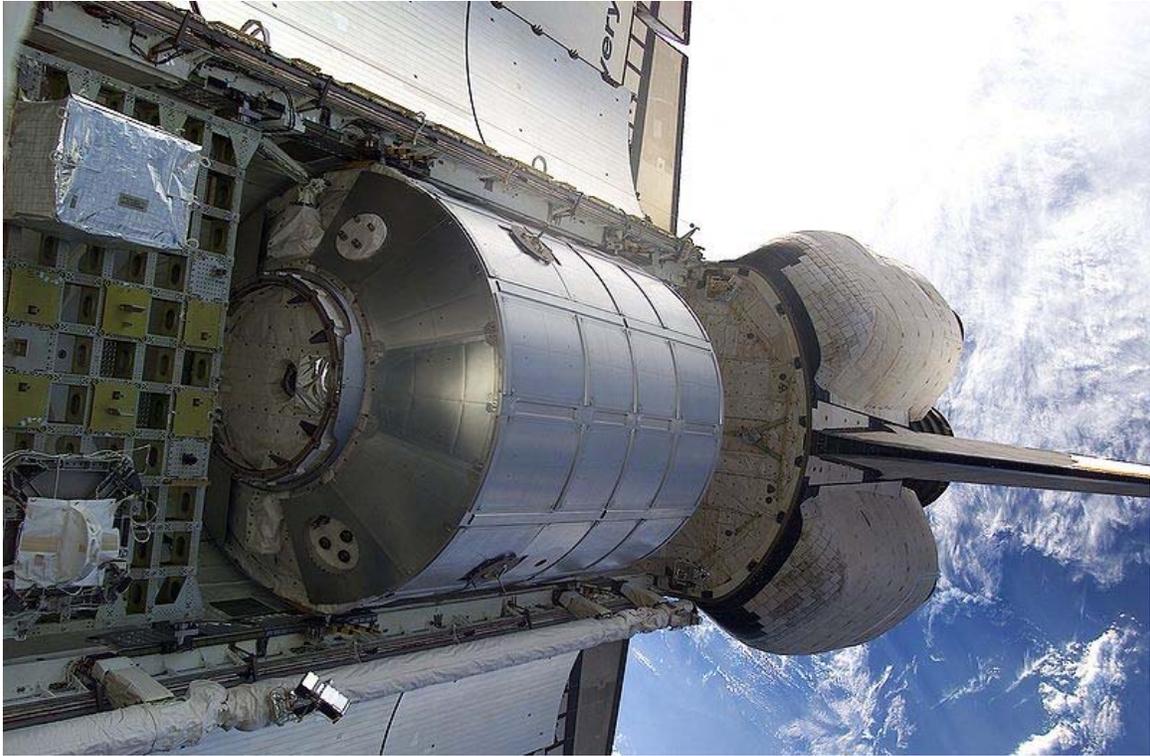
The main function of the Space Shuttle external tank is to supply the liquid oxygen and hydrogen fuel to the Space Shuttle main engines. It is also the backbone of the launch vehicle providing attachment points for the two Solid Rocket Boosters and the Orbiter. The external tank is the only part of the shuttle system that is not reused. Although the external tanks have always been discarded, it is possible to take them into orbit and re-use them (such as for incorporation into a space station).

Solid Rocket Boosters

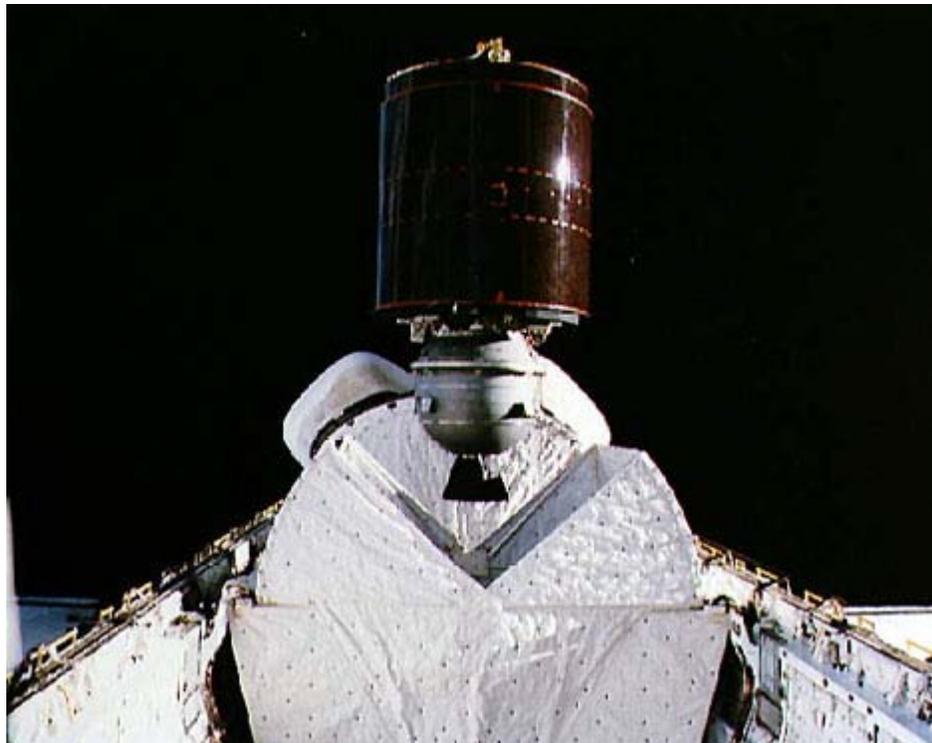
Two solid rocket boosters (SRBs) each provide 12.5 million newtons (2.8 million lbf) of thrust at liftoff, which is 83% of the total thrust needed for liftoff. The SRBs are jettisoned two minutes after launch at a height of about 150,000 feet (46 km), and then deploy parachutes and land in the ocean to be recovered. The SRB cases are made of steel about ½ inch (13 mm) thick. The Solid Rocket Boosters are re-used many times; the casing used in Ares I engine testing in 2009 consisted of motor cases that have been flown, collectively, on 48 shuttle missions, including STS-1.

Orbiter add-ons

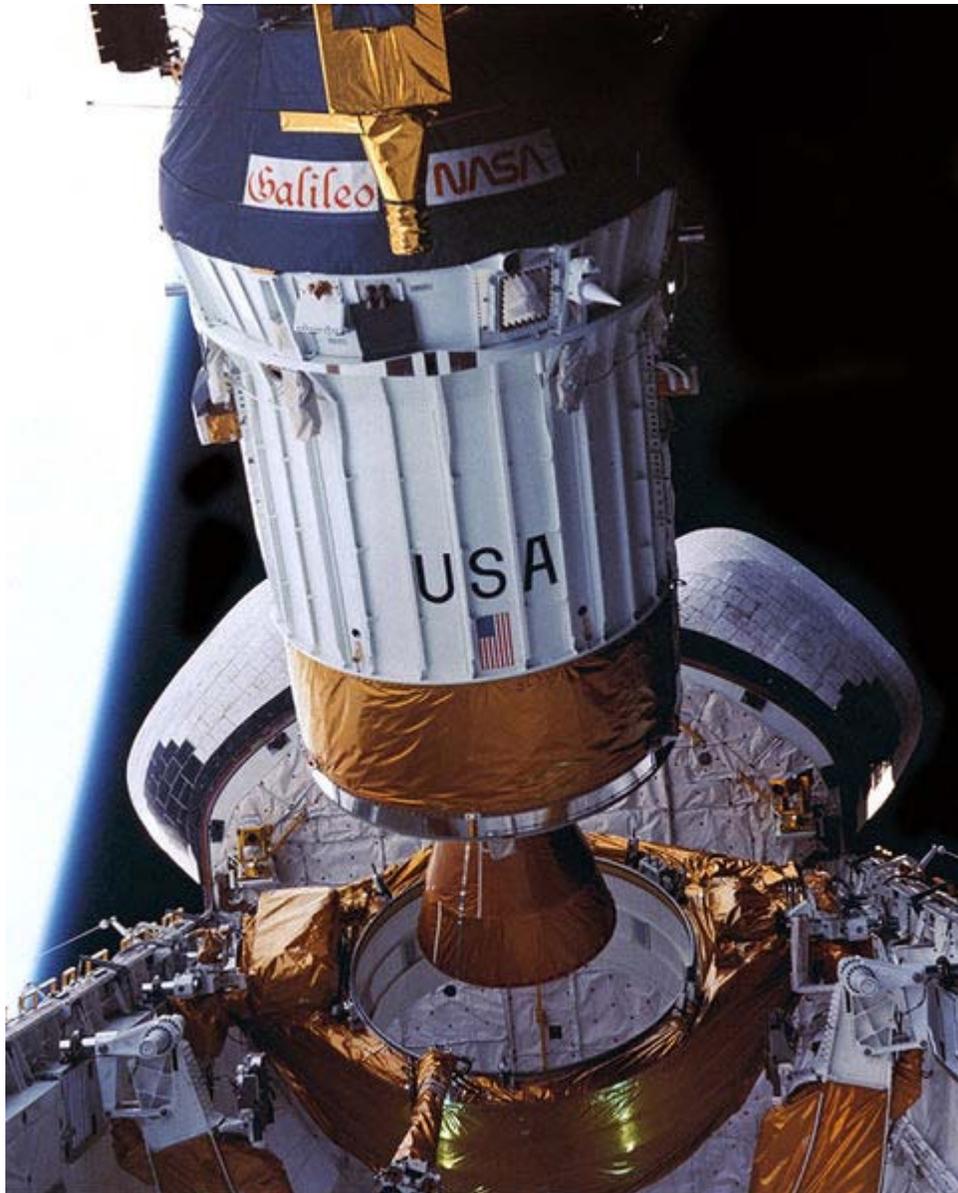
The orbiter can be used in conjunction with a variety of add-ons depending on the mission. This has included orbital laboratories (Spacelab, Spacehab), boosters for launching payloads farther into space (Inertial Upper Stage, Payload Assist Module), and other functions, such as provided by Extended Duration Orbiter, Multi-Purpose Logistics Modules, or Canadarm (RMS). An upper-stage kick motor called TOS-21 (from Orbital Science Corp.) was also used once. Other types of systems and racks were part of the modular Spacelab system — pallets, igloo, IPS, etc., which also supported special missions such as SRTM.



MPLM *Leonardo*



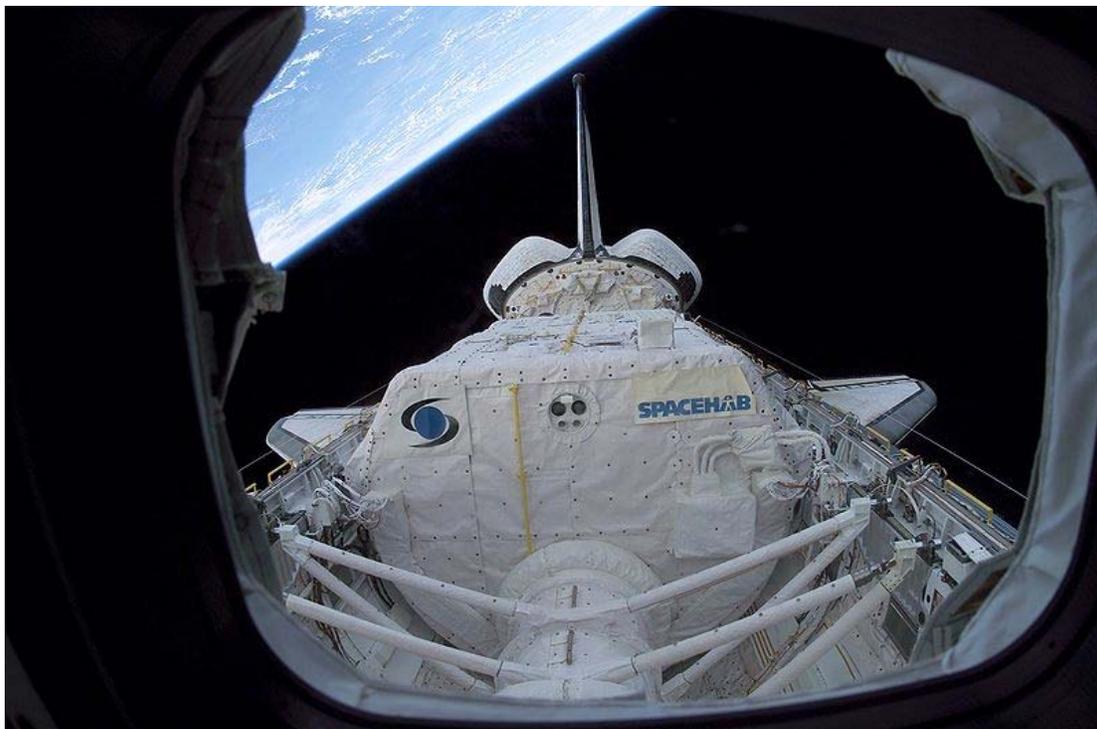
PAM-D with satellite



IUS deploying with Galileo

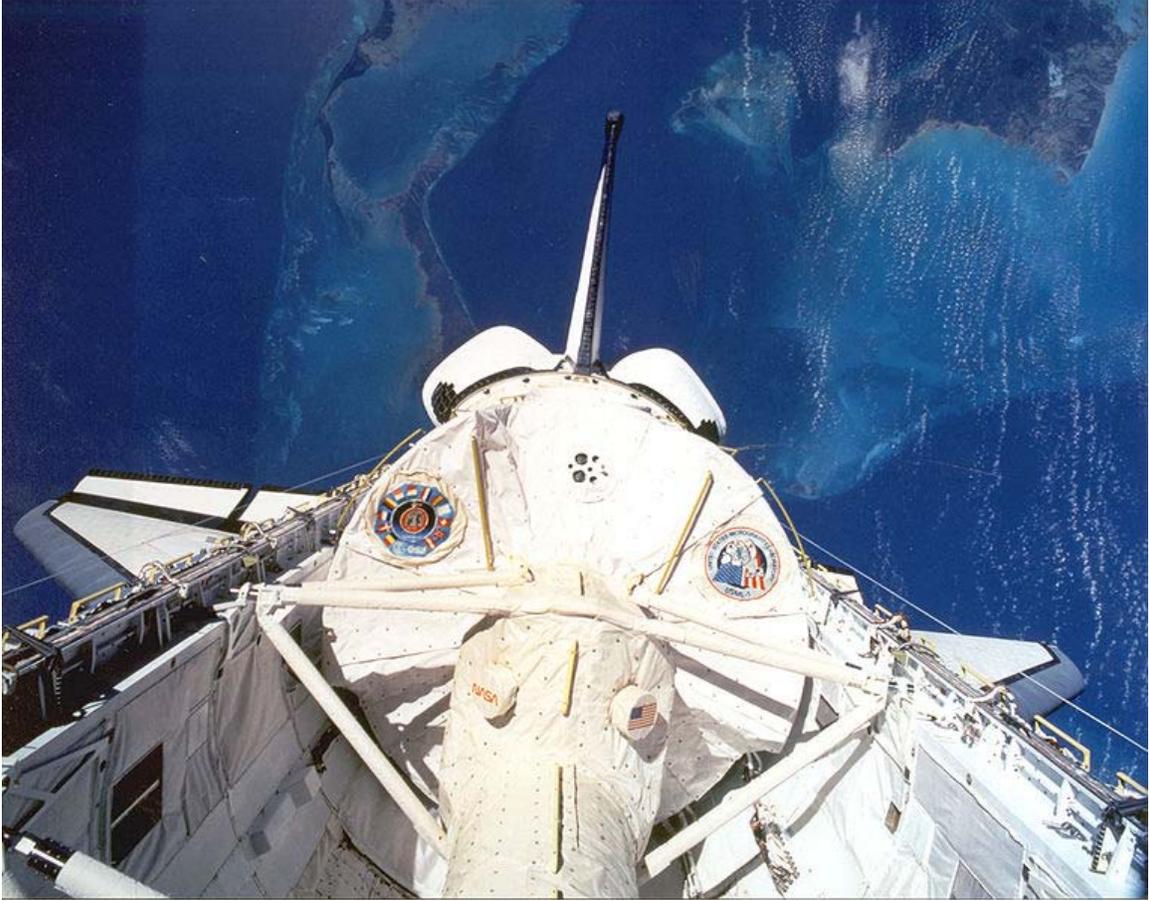


EDO being installed



S107E05359

Spacehab



Spacelab in orbit



RMS (Canadarm)

Spacelab

A major component of the Space Shuttle Program was Spacelab, primarily contributed by a consortium of European countries, and operated in conjunction with the United States and international partners. Supported by a modular system of pressurized modules, pallets, and systems, Spacelab missions executed on multidisciplinary science, orbital logistics, international cooperation. Over 29 missions flew on subjects ranging from astronomy, microgravity, radar, and life sciences, to name a few. Spacelab hardware also supported missions such as Hubble (HST) servicing and space station resupply. STS-2 and STS-3 provided testing, and the first full mission was Spacelab-1 (STS-9, STS-41A) launched on November 28, 1983.

Spacelab formally began in 1973, after a meeting in Brussels, Belgium, by European heads of state. Within the decade, Spacelab would go into orbit and provide not only Europe, but also the United States, with an orbital workshop and hardware system. The international cooperation, science, and exploration realized by Spacelab is both the fulfillment of a vision, and a foundation, for what space can do for mankind.

Flight systems



Atlantis deploys the landing gear before landing on a selected runway just like a common aircraft.

The shuttle was one of the earliest craft to use a computerized fly-by-wire digital flight control system. This means no mechanical or hydraulic linkages connect the pilot's control stick to the control surfaces or reaction control system thrusters.

A primary concern with digital fly-by-wire systems is reliability. Much research went into the shuttle computer system. The shuttle uses five identical redundant IBM 32-bit general purpose computers (GPCs), model AP-101, constituting a type of embedded system. Four computers run specialized software called the Primary Avionics Software System (PASS). A fifth backup computer runs separate software called the Backup Flight System (BFS). Collectively they are called the Data Processing System (DPS).

The design goal of the shuttle's DPS is fail-operational/fail-safe reliability. After a single failure, the shuttle can still continue the mission. After two failures, it can still land safely.

The four general-purpose computers operate essentially in lockstep, checking each other. If one computer fails, the three functioning computers "vote" it out of the system. This isolates it from vehicle control. If a second computer of the three remaining fails, the two functioning computers vote it out. In the rare case of two out of four computers simultaneously failing (a two-two split), one group is picked at random.

The Backup Flight System (BFS) is separately developed software running on the fifth computer, used only if the entire four-computer primary system fails. The BFS was created because although the four primary computers are hardware redundant, they all run the same software, so a generic software problem could crash all of them. Embedded system avionic software is developed under totally different conditions from public commercial software: the number of code lines is tiny compared to a public commercial software, changes are only made infrequently and with extensive testing, and many programming and test personnel work on the small amount of computer code. However, in theory it can still fail, and the BFS exists for that contingency. While BFS will run in parallel with PASS, to date, BFS has never been engaged to take over control from PASS during any shuttle mission.

The software for the shuttle computers is written in a high-level language called HAL/S, somewhat similar to PL/I. It is specifically designed for a real time embedded system environment.

The IBM AP-101 computers originally had about 424 kilobytes of magnetic core memory each. The CPU could process about 400,000 instructions per second. They have no hard disk drive, and load software from magnetic tape cartridges.

In 1990, the original computers were replaced with an upgraded model AP-101S, which has about 2.5 times the memory capacity (about 1 megabyte) and three times the processor speed (about 1.2 million instructions per second). The memory was changed from magnetic core to semiconductor with battery backup.

Early shuttle missions, starting in November 1983, took along the GRiD Compass, arguably one of the first laptop computers. The GRiD was given the name SPOC, for Shuttle Portable Onboard Computer. Use on the Shuttle required both hardware and software modifications which were incorporated into later versions of the commercial product. It was used to monitor and display the Shuttle's ground position, path of the next two orbits, show where the shuttle had line of sight communications with ground stations, and determine points for location-specific observations of the Earth. The Compass sold poorly, as it cost at least US\$8000, but it offered unmatched performance for its weight and size. NASA was one of its main customers.



Space Shuttle program insignia

Markings and insignia

The typeface used on the Space Shuttle Orbiter is Helvetica. On the side of the shuttle between the cockpit windows and the cargo bay doors is the name of the orbiter. Underneath the rear of the cargo bay doors is the NASA insignia, the text 'United States' and a flag of the United States. Another United States flag appears on the right wing.

Upgrades



During STS-101, *Atlantis* was the first shuttle to fly with a glass cockpit

The Space Shuttle was initially developed in the 1970s-era but has received many upgrades and modifications since then for improvements ranging from performance and reliability to safety. Internally, the shuttle remains largely similar to the original design, with the exception of the improved avionics computers. In addition to the computer upgrades, the original analog primary flight instruments were replaced with modern full-color, flat-panel display screens, similar to those of contemporary airliners like the Airbus A380 and Boeing 777. This is called a glass cockpit. With the coming of the ISS, the orbiter's internal airlocks have been replaced with external docking systems to allow for a greater amount of cargo to be stored on the shuttle's mid-deck during station resupply missions.

The Space Shuttle Main Engines (SSMEs) have had several improvements to enhance reliability and power. This explains phrases such as "Main engines throttling up to 104%." This does not mean the engines are being run over a safe limit. The 100% figure is the original specified power level. During the lengthy development program, Rocketdyne determined the engine was capable of safe reliable operation at 104% of the originally specified thrust. They could have rescaled the output number, saying in essence 104% is now 100%. To clarify this would have required revising much previous documentation and software, so the 104% number was retained. SSME upgrades are denoted as "block numbers", such as block I, block II, and block IIA. The upgrades have improved engine reliability, maintainability and performance. The 109% thrust level was finally reached in flight hardware with the Block II engines in 2001. The normal maximum throttle is 104%, with 106% or 109% used for mission aborts.

For the first two missions, STS-1 and STS-2, the external tank was painted white to protect the insulation that covers much of the tank, but improvements and testing showed that it was not required. The weight saved by not painting the tank results in an increase in payload capability to orbit. Additional weight was saved by removing some of the internal "stringers" in the hydrogen tank that proved unnecessary. The resulting "light-weight external tank" has been used on the vast majority of shuttle missions. STS-91 saw the first flight of the "super light-weight external tank". This version of the tank is made of the 2195 aluminum-lithium alloy. It weighs 3.4 metric tons (7,500 lb) less than the last run of lightweight tanks. As the shuttle cannot fly unmanned, each of these improvements has been "tested" on operational flights.

The SRBs (Solid Rocket Boosters) have undergone improvements as well. Design engineers added a third O-ring seal to the joints between the segments after the Space Shuttle *Challenger* disaster.



The three nozzles of the Main Engine cluster with the two Orbital Maneuvering System (OMS) pods, and the vertical stabilizer above.

Several other SRB improvements were planned in order to improve performance and safety, but never came to be. These culminated in the considerably simpler, lower cost, probably safer and better performing Advanced Solid Rocket Booster. These rockets entered production in the early to mid-1990s to support the Space Station, but were later canceled to save money after the expenditure of \$2.2 billion. The loss of the ASRB program resulted in the development of the Super LightWeight external Tank (SLWT), which provides some of the increased payload capability, while not providing any of the safety improvements. In addition, the Air Force developed their own much lighter single-piece SRB design using a filament-wound system, but this too was canceled.

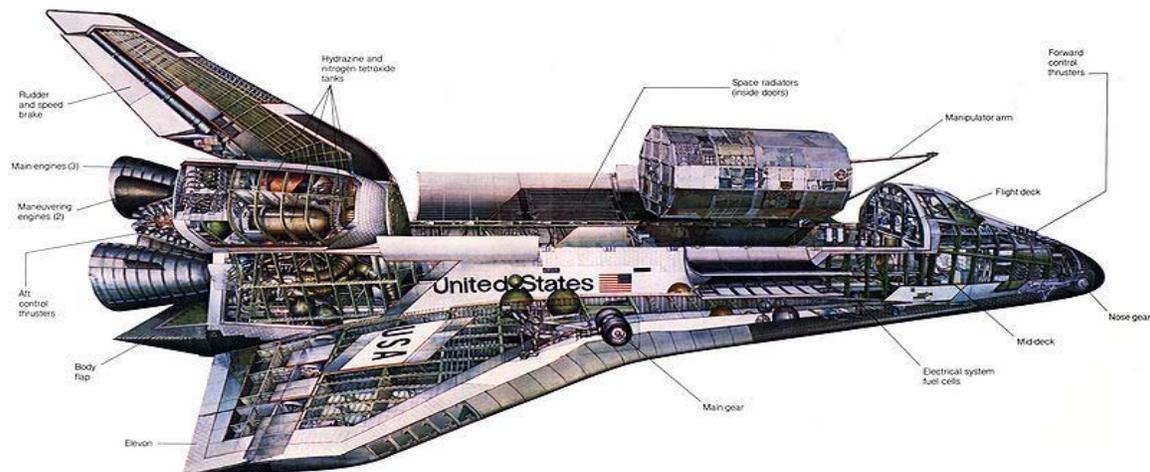
STS-70 was delayed in 1995, when woodpeckers bored holes in the foam insulation of *Discovery's* external tank. Since then, NASA has installed commercial plastic owl decoys and inflatable owl balloons which must be removed prior to launch. The delicate nature of the foam insulation has been the cause of damage to the Thermal Protection System, the tile heat shield and heat wrap of the orbiter, during recent launches. NASA remains confident that this damage, while it was the primary cause of the Space Shuttle *Columbia* disaster on February 1, 2003, will not jeopardize the objective of NASA to complete the International Space Station (ISS) in the projected time allotted.

A cargo-only, unmanned variant of the shuttle has been variously proposed, and rejected since the 1980s. It was called the Shuttle-C, and would have traded re-usability for cargo capability, with large potential savings from reusing technology developed for the Space Shuttle. Another proposals was to convert the payload bay into a passenger area, with proposals ranging from 30 to 74 seats, three days in orbit, and 1.5 million USD a seat.

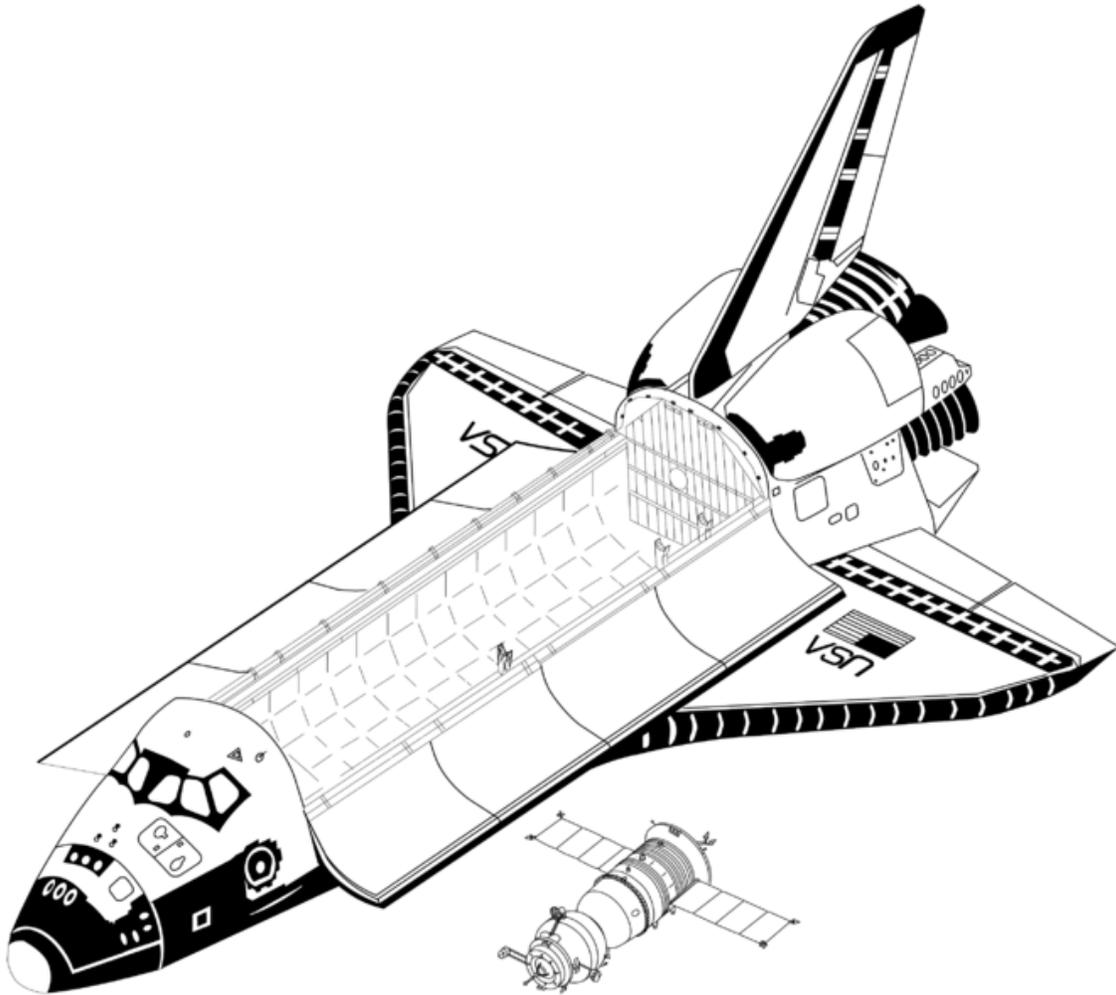
On the first four shuttle missions, astronauts wore modified U.S. Air Force high-altitude full-pressure suits, which included a full-pressure helmet during ascent and descent. From the fifth flight, STS-5, until the loss of *Challenger*, one-piece light blue nomex flight suits and partial-pressure helmets were worn. A less-bulky, partial-pressure version of the high-altitude pressure suits with a helmet was reinstated when shuttle flights resumed in 1988. The Launch-Entry Suit ended its service life in late 1995, and was replaced by the full-pressure Advanced Crew Escape Suit (ACES), which resembles the Gemini space suit in design, but retains the orange color connected to the Launch-Entry Suit.

To extend the duration that orbiters can stay docked at the ISS, the Station-to-Shuttle Power Transfer System (SSPTS) was installed. The SSPTS allows these orbiters to use power provided by the ISS to preserve their consumables. The SSPTS was first used successfully on STS-118.

Technical data



Space Shuttle orbiter illustration



Space Shuttle Orbiter and Soyuz-TM (drawn to scale)

Orbiter specifications (for *Endeavour*, OV-105)

- Length: 122.17 ft (37.237 m)
- Wingspan: 78.06 ft (23.79 m)
- Height: 58.58 ft (17.86 m)
- Empty weight: 172,000 lb (78,000 kg)
- Gross liftoff weight: 240,000 lb (110,000 kg)
- Maximum landing weight: 230,000 lb (100,000 kg)
- Maximum payload: 55,250 lb (25,060 kg)
- Payload to LEO: 53,600 lb (24,310 kg)
- Payload to LEO (ISS):
- Payload to GTO: 8,390 lb (3,806 kg)
- Payload to Polar Orbit: 28,000 lb (12,700 kg)
- Payload bay dimensions: 15 by 59 ft (4.6 by 18 m)
- Operational altitude: 100 to 520 nmi (190 to 960 km; 120 to 600 mi)
- Speed: 7,743 m/s (27,870 km/h; 17,320 mph)

- Crossrange: 1,085 nmi (2,009 km; 1,249 mi)
- First Stage (SSME with external tank)
 - Main engines: Three Rocketdyne Block II SSMEs, each with a sea level thrust of 393,800 lbf (1.752 MN) at 104% power
 - Thrust (at liftoff, sea level, 104% power, all 3 engines): 1,181,400 lbf (5.255 MN)
 - Specific impulse: 455 s
 - Burn time: 480 s
 - Fuel: Liquid Oxygen/Liquid Hydrogen
- Second Stage
 - Engines: 2 Orbital Maneuvering Engines
 - Thrust: 53.4 kN (12,000 lbf) combined total vacuum thrust
 - Specific impulse: 316 s
 - Burn time: 1250 s
 - Fuel: MMH/N₂O₄
- Crew: Varies.

The earliest shuttle flights had the minimum crew of two; many later missions a crew of five. Today, typically seven people fly (commander, pilot, several mission specialists, and rarely a flight engineer). On two occasions, eight astronauts have flown (STS-61-A, STS-71). Eleven people could be accommodated in an emergency mission.

External tank specifications (for SLWT)

- Length: 46.9 m (154 ft)
- Diameter: 8.4 m (28 ft)
- Propellant volume: 2,025 m³ (534,900 US gal)
- Empty weight: 26,535 kg (58,500 lb)
- Gross liftoff weight: 756,000 kg (1,670,000 lb)

Solid Rocket Booster specifications

- Length: 45.46 m (149 ft)
- Diameter: 3.71 m (12.2 ft)
- Empty weight (per booster): 68,000 kg (150,000 lb)
- Gross liftoff weight (per booster): 571,000 kg (1,260,000 lb)
- Thrust (at liftoff, sea level, per booster): 12.5 MN (2,800,000 lbf)
- Specific impulse: 269 s
- Burn time: 124 s

System Stack specifications

- Height: 56 m (180 ft)
- Gross liftoff weight: 2,000,000 kg (4,400,000 lb)
- Total liftoff thrust: 30.16 MN (6,780,000 lbf)

Mission profile



STS mission profile



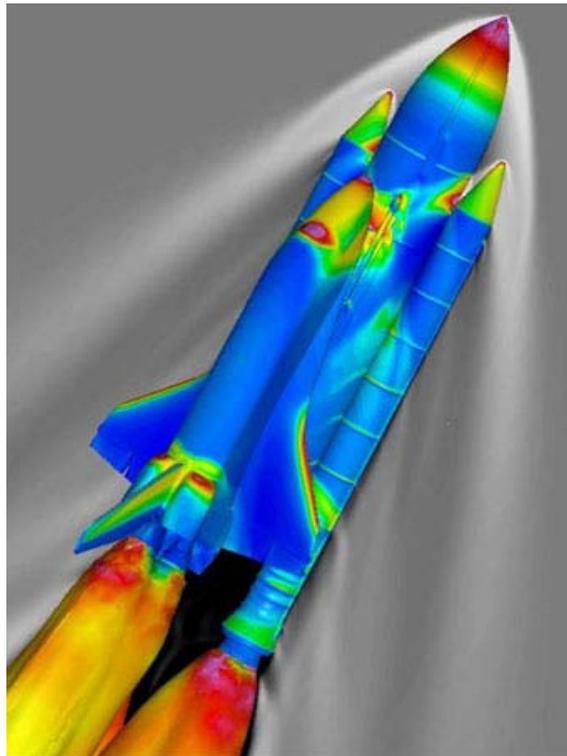
Two Space Shuttles sit at launch pads. This particular occasion is due to the final Hubble servicing mission, where the International Space Station is unreachable, which necessitates having a Shuttle on standby for a possible rescue mission.



Shuttle launch of *Atlantis* at sunset in 2001. The sun is behind the camera, and the plume's shadow intersects the moon across the sky.



Multicolored afterglow of the STS-131 launch



SSLV at Mach 2.46 and 66,000 ft (20,000 m). The surface of the vehicle is colored by the pressure coefficient, and the gray contours represent the density of the surrounding air, as calculated using the overflow codes.

Launch

All Space Shuttle missions are launched from Kennedy Space Center (KSC). The weather criteria used for launch include, but are not limited to: precipitation, temperatures, cloud cover, lightning forecast, wind, and humidity. The shuttle will not be launched under conditions where it could be struck by lightning. Aircraft are often struck by lightning with no adverse effects because the electricity of the strike is dissipated through its conductive structure and the aircraft is not electrically grounded. Like most jet airliners, the shuttle is mainly constructed of conductive aluminum, which would normally shield and protect the internal systems. However, upon liftoff the shuttle sends out a long exhaust plume as it ascends, and this plume can trigger lightning by providing a current path to ground. The NASA Anvil Rule for a shuttle launch states that an anvil cloud cannot appear within a distance of 10 nautical miles. The Shuttle Launch Weather Officer will monitor conditions until the final decision to scrub a launch is announced. In addition, the weather conditions must be acceptable at one of the Transatlantic Abort Landing sites (one of several Space Shuttle abort modes) to launch as well as the solid rocket booster recovery area. While the shuttle might safely endure a lightning strike, a similar strike caused problems on Apollo 12, so for safety NASA chooses not to launch the shuttle if lightning is possible (NPR8715.5).

Historically, the Shuttle was not launched if its flight would run from December to January (a year-end rollover or YERO). Its flight software, designed in the 1970s, was not designed for this, and would require the orbiter's computers be reset through a change of year, which could cause a glitch while in orbit. In 2007, NASA engineers devised a solution so Shuttle flights could cross the year-end boundary.

On the day of a launch, after the final hold in the countdown at T minus 9 minutes, the Shuttle goes through its final preparations for launch, and the countdown is automatically controlled by the Ground Launch Sequencer (GLS), software at the Launch Control Center, which stops the count if it senses a critical problem with any of the Shuttle's on-board systems. The GLS hands off the count to the Shuttle's on-board computers at T minus 31 seconds, in a process called auto sequence start.

At T minus 16 seconds, the massive sound suppression system (SPS) begins to drench the Mobile Launcher Platform (MLP) and SRB trenches with 300,000 US gallons (1,100 m³) of water to protect the Orbiter from damage by acoustical energy and rocket exhaust reflected from the flame trench and MLP during liftoff.

At T-minus 10 seconds, hydrogen igniters are activated under each engine bell to quell the stagnant gas inside the cones before ignition. Failure to burn these gases can trip the onboard sensors and create the possibility of an overpressure and explosion of the vehicle during the firing phase. The main engine turbopumps also begin charging the combustion chambers with liquid hydrogen and liquid oxygen at this time. The computers reciprocate this action by allowing the redundant computer systems to begin the firing phase.

The three Space Shuttle Main Engines (SSMEs) start at T minus 6.6 seconds. The main engines ignite sequentially via the shuttle's general purpose computers (GPCs) at 120 millisecond intervals. The GPCs require that the engines reach 90% of their rated performance to complete the final gimbal of the main engine nozzles to liftoff configuration. When the SSMEs start, the water from the sound suppression system flashes into a large volume of steam that shoots southward. All three SSMEs must reach the required 100% thrust within three seconds, otherwise the onboard computers will initiate an RLS abort. If the onboard computers verify normal thrust buildup, at T minus 0 seconds, the 8 pyrotechnic nuts holding the vehicle to the pad are detonated and the SRBs are ignited. At this point the vehicle is committed to liftoff, as the SRBs cannot be turned off once ignited. The plume from the solid rockets exits the flame trench in a northward direction at near the speed of sound, often causing a rippling of shockwaves along the actual flame and smoke contrails. At ignition, the GPCs mandate the firing sequences via the Master Events Controller, a computer program integrated with the shuttle's four redundant computer systems. There are extensive emergency procedures (abort modes) to handle various failure scenarios during ascent. Many of these concern SSME failures, since that is the most complex and highly stressed component. After the Challenger disaster, there were extensive upgrades to the abort modes.

After the main engines start, but while the solid rocket boosters are still clamped to the pad, the offset thrust from the Shuttle's three main engines causes the entire launch stack (boosters, tank and shuttle) to pitch down about 2 m at cockpit level. This motion is called the "nod", or "twang" in NASA jargon. As the boosters flex back into their original shape, the launch stack pitches slowly back upright. This takes approximately six seconds. At the point when it is perfectly vertical, the boosters ignite and the launch commences. The Johnson Space Center's Mission Control Center assumes control of the flight once the SRBs have cleared the launch tower.

Shortly after clearing the tower the Shuttle begins a combined roll, pitch and yaw maneuver that positions the orbiter head down, with wings level and aligned with the launch pad. The Shuttle flies upside down during the ascent phase. This orientation allows a trim angle of attack that is favorable for aerodynamic loads during the region of high dynamic pressure, resulting in a net positive load factor, as well as providing the flight crew with use of the ground as a visual reference. The vehicle climbs in a progressively flattening arc, accelerating as the weight of the SRBs and main tank decrease. To achieve low orbit requires much more horizontal than vertical acceleration. This is not visually obvious, since the vehicle rises vertically and is out of sight for most of the horizontal acceleration. The near circular orbital velocity at the 380 kilometers (236 mi) altitude of the International Space Station is 7.68 kilometers per second (27,650 km/h (17,180 mph), roughly equivalent to Mach 23 at sea level. As the International Space Station orbits at an inclination of 51.6 degrees, the Shuttle has to set its inclination to the same value to rendezvous with the station.

Around a point called Max Q, where the aerodynamic forces are at their maximum, the main engines are temporarily throttled back to 72% to avoid overspeeding and hence overstressing the Shuttle, particularly in vulnerable areas such as the wings. At this point,

a phenomenon known as the Prandtl-Glauert singularity occurs, where condensation clouds form during the vehicle's transition to supersonic speed. At $T+70$ seconds, the main engines throttle up to their maximum cruise thrust of 104% rated thrust.

At $T+126$ seconds after launch, explosive bolts release the SRBs and small separation rockets push them laterally away from the vehicle. The SRBs parachute back to the ocean to be reused. The Shuttle then begins accelerating to orbit on the Space Shuttle main engines. The vehicle at that point in the flight has a thrust-to-weight ratio of less than one – the main engines actually have insufficient thrust to exceed the force of gravity, and the vertical speed given to it by the SRBs temporarily decreases. However, as the burn continues, the weight of the propellant decreases and the thrust-to-weight ratio exceeds 1 again and the ever-lighter vehicle then continues to accelerate towards orbit.

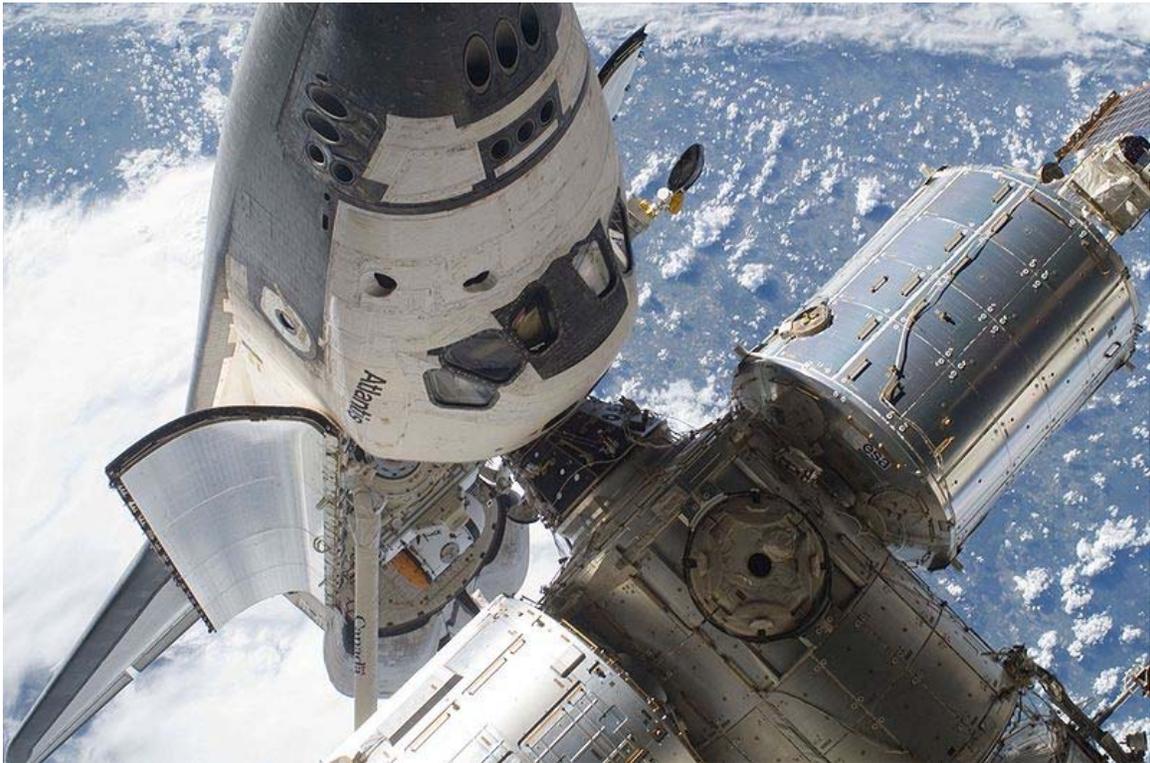
The vehicle continues to climb and takes on a somewhat nose-up angle to the horizon – it uses the main engines to gain and then maintain altitude while it accelerates horizontally towards orbit. At about five and three-quarter minutes into ascent, the orbiter's direct communication links with the ground begin to fade, at which point it rolls heads up to reroute its communication links to the Tracking and Data Relay Satellite system.

Finally, in the last tens of seconds of the main engine burn, the mass of the vehicle is low enough that the engines must be throttled back to limit vehicle acceleration to 3 g (29.34 m/s^2), largely for astronaut comfort.

The main engines are shut down before complete depletion of propellant, as running dry would destroy the engines. The oxygen supply is terminated before the hydrogen supply, as the SSMEs react unfavorably to other shutdown modes. (Liquid oxygen has a tendency to react violently, and supports combustion when it encounters hot engine metal.) The external tank is released by firing explosive bolts and falls, largely burning up in the atmosphere, though some fragments fall into the ocean, in either the Indian Ocean or the Pacific Ocean depending on launch profile. The sealing action of the tank plumbing and lack of pressure relief systems on the external tank helps it break up in the lower atmosphere. After the foam burns away during reentry, the heat causes a pressure buildup in the remaining liquid oxygen and hydrogen until the tank explodes. This ensures that any pieces that fall back to Earth are small.

To prevent the shuttle from following the external tank back into the lower atmosphere, the Orbital maneuvering system (OMS) engines are fired to raise the perigee higher into the upper atmosphere. On some missions (e.g., missions to the ISS), the OMS engines are also used while the main engines are still firing. The reason for putting the orbiter on a path that brings it back to Earth is not just for external tank disposal but also one of safety: if the OMS malfunctions, or the cargo bay doors cannot open for some reason, the shuttle is already on a path to return to earth for an emergency abort landing.

In orbit



Atlantis and Harmony — spring 2010

Once in orbit, the shuttle does any number of tasks, and usually some combination. In the 1980s and 1990s, many flights involved space science missions on the NASA/ESA Spacelab, or launching various types of satellites and science probes. By the 1990s and 2000s the focus shifted more to servicing space stations, with fewer satellite launches. Most missions involve staying in orbit several days to two weeks, although longer missions are possible with the Extended Duration Orbiter add-on or when attached to a space station.

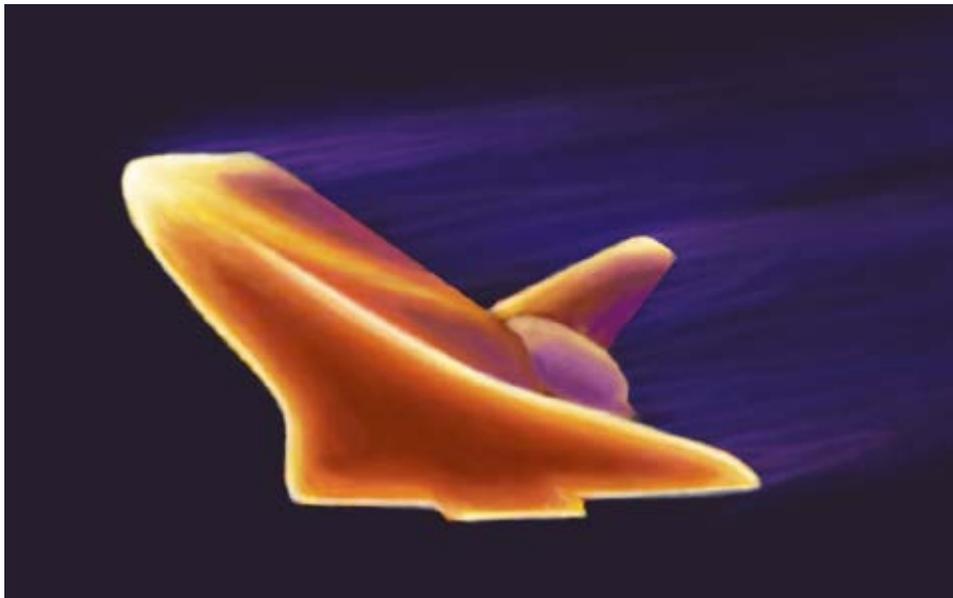
Re-entry and landing

Almost the entire Space Shuttle re-entry procedure, except for lowering the landing gear and deploying the air data probes, is normally performed under computer control. However, the re-entry can be flown entirely manually if an emergency arises. The approach and landing phase can be controlled by the autopilot, but is usually hand flown.

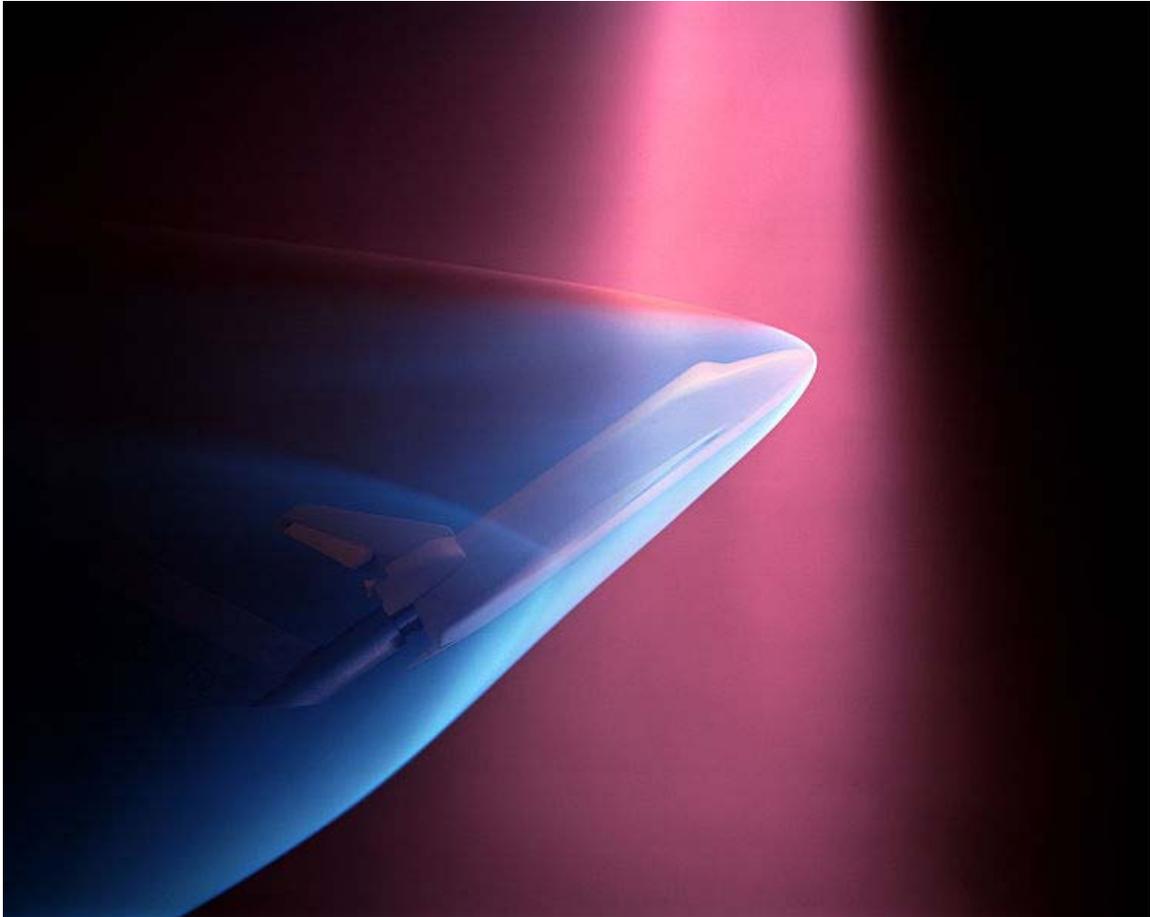
The vehicle begins re-entry by firing the Orbital maneuvering system engines, while flying upside down, backside first, in the opposite direction to orbital motion for approximately three minutes, which reduces the shuttle's velocity by about 200 mph (322 km/h). The resultant slowing of the Shuttle lowers its orbital perigee down into the upper atmosphere. The shuttle then flips over, by pushing its nose down (which is actually "up"

relative to the Earth, because it is flying upside down). This OMS firing is done roughly halfway around the globe from the landing site.

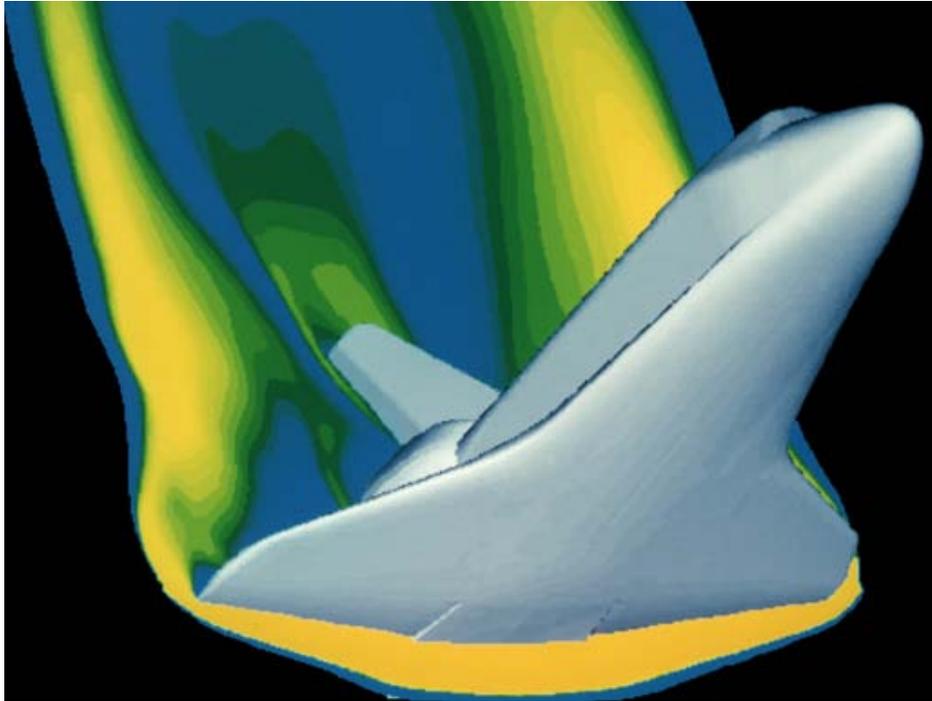
The vehicle starts encountering more significant air density in the lower thermosphere at about 400,000 ft (120 km), at around Mach 25, 8,200 m/s (30,000 km/h; 18,000 mph). The vehicle is controlled by a combination of RCS thrusters and control surfaces, to fly at a 40 degree nose-up attitude, producing high drag, not only to slow it down to landing speed, but also to reduce reentry heating. As the vehicle encounters progressively denser air, it begins a gradual transition from spacecraft to aircraft. In a straight line, its 40 degree nose-up attitude would cause the descent angle to flatten-out, or even rise. The vehicle therefore performs a series of four steep S-shaped banking turns, each lasting several minutes, at up to 70 degrees of bank, while still maintaining the 40 degree angle of attack. In this way it dissipates speed sideways rather than upwards. This occurs during the 'hottest' phase of re-entry, when the heat-shield glows red and the G-forces are at their highest. By the end of the last turn, the transition to aircraft is almost complete. The vehicle levels its wings, lowers its nose into a shallow dive and begins its approach to the landing site.



Simulation of the outside of the Shuttle as it heats up to over 1,500 °C during re-entry



A Space Shuttle model undergoes a wind tunnel test in 1975. This test is simulating the ionized gasses that surround a shuttle as it reenters the atmosphere.



A computer simulation of high velocity air flow around the Space Shuttle during re-entry

The orbiter's maximum glide ratio/lift-to-drag ratio varies considerably with speed, ranging from 1:1 at hypersonic speeds, 2:1 at supersonic speeds and reaching 4.5:1 at subsonic speeds during approach and landing.

In the lower atmosphere, the orbiter flies much like a conventional glider, except for a much higher descent rate, over 50 m/s (180 km/h; 110 mph). At approximately Mach 3, two air data probes, located on the left and right sides of the orbiter's forward lower fuselage, are deployed to sense air pressure related to the vehicle's movement in the atmosphere.

When the approach and landing phase begins, the orbiter is at a 3,000 m (9,800 ft) altitude, 12 km (7.5 mi) from the runway. The pilots apply aerodynamic braking to help slow down the vehicle. The orbiter's speed is reduced from 682 to 346 km/h (424 to 215 mph), approximately, at touch-down (compared to 260 km/h (160 mph) for a jet airliner). The landing gear is deployed while the Orbiter is flying at 430 km/h (270 mph). To assist the speed brakes, a 12 m (39 ft) drag chute is deployed either after main gear or nose gear touchdown (depending on selected chute deploy mode) at about 343 km/h (213 mph). The chute is jettisoned once the orbiter slows to 110 km/h (68.4 mph).

After landing, the vehicle stands on the runway for several minutes to permit the fumes from poisonous hydrazine (which is used as a fuel for attitude control, and the orbiter's three APUs) to dissipate, and for the shuttle fuselage to cool before the astronauts disembark.



Discovery touches down at the end of STS-95



Columbia lands at Kennedy Space Center at the end of STS-73



Endeavour brake chute deploys after touching down



Discovery after landing on Earth for crew disembarkment

Landing sites

NASA prefers Space Shuttle landings to be at Kennedy Space Center. If weather conditions make landing there unfavorable, the shuttle can delay its landing until conditions are favorable, touch down at Edwards Air Force Base, California, or use one of the multiple alternate landing sites around the world. A landing at any site other than Kennedy Space Center means that after touchdown the shuttle must be mated to the Shuttle Carrier Aircraft and returned to Cape Canaveral. Space Shuttle *Columbia* (STS-3) landed at the White Sands Space Harbor, New Mexico; this is viewed as a last resort as NASA scientists believe that the sand could potentially damage the shuttle's exterior.

There are many alternative landing sites that have never been used.

Risk contributors

An example of technical risk analysis for a STS mission is SPRA iteration 3.1 top risk contributors for STS-133:

- (1) Micro-Meteoroid Orbital Debris (MMOD) strikes
- (2) Space Shuttle Main Engine (SSME)-induced or SSME catastrophic failure
- (3) ascent debris strikes to TPS leading to LOCV on orbit or entry
- (4) crew error during entry
- (5) RSRM-induced RSRM catastrophic failure (RSRM are the Solid Rocket Boosters)
- (6) COPV failure (COPV are tanks inside the orbiter that hold gas at high pressure)

An internal NASA risk assessment study (conducted by the Shuttle Program Safety and Mission Assurance Office at Johnson Space Center) released in late 2010 or early 2011 concluded that the agency had seriously underestimated the level of risk involved in operating the shuttle. The report assessed that there was a 1 in 9 chance of a catastrophic disaster during the first nine flights of the shuttle but that safety improvements had later improved the risk ratio to 1 in 100.

Fleet history



OV-101 *Enterprise* takes flight for the first time over Dryden Flight Research Facility, Edwards, California in 1977 as part of the Shuttle program's Approach and Landing Tests (ALT).

Below is a list of major events in the Space Shuttle orbiter fleet.

Space Shuttle major events

Date	Orbiter	Major event / remarks
February 18, 1977	<i>Enterprise</i>	First flight; Attached to Shuttle Carrier Aircraft throughout flight.
August 12, 1977	<i>Enterprise</i>	First free flight; Tailcone on; lakebed landing.
October 26, 1977	<i>Enterprise</i>	Final <i>Enterprise</i> free flight; First landing on Edwards AFB concrete runway.
April 12, 1981	<i>Columbia</i>	First <i>Columbia</i> flight, first orbital test flight; STS-1
November 11, 1982	<i>Columbia</i>	First operational flight of the Space Shuttle, first mission to carry four astronauts; STS-5
April 4, 1983	<i>Challenger</i>	First <i>Challenger</i> flight; STS-6
August 30, 1984	<i>Discovery</i>	First <i>Discovery</i> flight; STS-41-D
October 3, 1985	<i>Atlantis</i>	First <i>Atlantis</i> flight; STS-51-J
January 28,	<i>Challenger</i>	Disaster starting 73 seconds after launch; STS-51-L; all seven

1986		crew members died.
September 29, 1988	<i>Discovery</i>	First post- <i>Challenger</i> mission; STS-26
May 4, 1989	<i>Atlantis</i>	The first Space Shuttle mission to launch a space probe, Magellan; STS-30
April 24, 1990	<i>Discovery</i>	Launch of the Hubble Space Telescope; STS-31
May 7, 1992	<i>Endeavour</i>	First <i>Endeavour</i> flight; STS-49
November 19, 1996	<i>Columbia</i>	Longest Shuttle mission to date at 17 days, 15 hours; STS-80
February 1, 2003	<i>Columbia</i>	Disintegrated during re-entry; STS-107; all seven crew members died.
July 25, 2005	<i>Discovery</i>	First post- <i>Columbia</i> mission; STS-114
May 14, 2010	<i>Atlantis</i>	Last planned <i>Atlantis</i> flight; STS-132

Planned fleet events

February 24, 2011	<i>Discovery</i>	Last planned <i>Discovery</i> flight; STS-133; anticipated launch date
April 19, 2011	<i>Endeavour</i>	Last planned <i>Endeavour</i> flight; last planned flight of the <i>Space Shuttle program</i> ; STS-134 To use the last built external tank ET-138.
June 28, 2011	<i>Atlantis</i>	Last anticipated <i>Atlantis</i> flight; STS-135; Was approved as of October 2010. But not funded or scheduled yet. To use External tank ET-122.

Shuttle disasters

On January 28, 1986, Space Shuttle *Challenger* disintegrated 73 seconds after launch due to the failure of the right SRB, killing all seven astronauts on board. The disaster was caused by low-temperature impairment of an SRB O-ring, a mission critical component. Repeated warnings from design engineers voicing concerns about the lack of evidence of the O-rings' safety when the temperature was below 53 °F (12 °C) were ignored by NASA managers.

On February 1, 2003, Space Shuttle *Columbia* disintegrated during re-entry, killing its crew of seven, because of damage to the carbon-carbon leading edge of the wing caused during launch. Ground control engineers had made three separate requests for high-resolution images taken by the Department of Defense that would have provided an understanding of the extent of the damage, while NASA's chief thermal protection system (TPS) engineer requested that astronauts on board the *Columbia* be allowed to leave the vehicle to inspect the damage. NASA managers intervened to stop the Department of Defense's assistance and refused the request for the spacewalk, and thus the feasibility of scenarios for astronaut repair or rescue by the Space Shuttle *Atlantis* were not considered by NASA management at the time.

Planned retirement



Space Shuttle Atlantis lifts off from Launch Pad 39A at NASA's Kennedy Space Center in Florida on the STS-132 mission to the International Space Station at 2:20 p.m. EDT on May 14, 2010. This was one of the last scheduled flights for Atlantis before it is retired.

NASA's current plans call for the Space Shuttle to be retired from service in 2011, after nearly 30 years of service. Under the current plans, *Discovery* will be the first of NASA's three remaining operational Space Shuttles to be retired as the program winds down.

Michael Suffredini of the ISS program has said that one additional trip will be needed in 2011 to deliver parts to the International Space Station. The Space Shuttle was originally to be retired in late 2010, but has been extended until June 2011 according to the NASA launch and mission schedule.

Final locations of retired orbiters



Space Shuttle Program commemorative patch

Discovery has already been promised to the Smithsonian Institution's National Air and Space Museum in the Udvar Hazy Center, and *Atlantis*, *Endeavour*, and *Enterprise* are planned to be transferred to other education institutions or museums with the museum covering the \$28.8 million cost of preparing and transporting each vehicle for display. *Enterprise* is currently located at the Smithsonian Institution's National Air and Space Museum in the Udvar Hazy Center. Twenty museums have submitted proposals for displaying one of the retired orbiters including NASA visitors centers as well as aviation and science museums around the country.

Flight and mid-deck training hardware from the Johnson Spaceflight Center will go to the National Air and Space Museum and the National Museum of the U.S. Air Force. The full fuselage mockup, which includes the payload bay and aft section but no wings, is to go to the Museum of Flight in Seattle. Mission Simulation and Training Facility's fixed simulator will go to the Adler Planetarium in Chicago, and the motion simulator will go to Texas A&M's Aerospace Engineering Department in College Station, Texas. Other simulators used in shuttle astronaut training will go to the Wings of Dreams Aviation Museum in Starke, Florida and the Virginia Air and Space Center in Hampton, Virginia.

NASA is also donating Space Shuttle thermal protection system tiles to schools and universities for \$23.40 each. About 7,000 tiles are available on a first-come, first-served basis, but limited to one each per institution.

Space Shuttle successors and legacy

Until another launch vehicle is ready, crews would travel to and from the International Space Station aboard Russian Soyuz spacecraft or possibly a future American commercial spacecraft. In the 1980s and 1990s a planned successor to STS was "Shuttle II" and before 2010, Project Constellation.

Successor cancelled

A proposed cancellation of Project Constellation was signed into law on October 11, 2010. To fill the void left by the Shuttle's retirement, a new spacecraft was being developed to ferry not only passengers and cargo to the ISS but also to travel beyond Earth orbit to the Moon and Mars. Originally called the Crew Exploration Vehicle, the concept has evolved into the Orion spacecraft and the project named Project Constellation. President Obama's administration in February 2010 proposed eliminating public funds for the Constellation program and shifting the burden for developing a replacement low-orbit service to private corporations.

Commercial replacement vehicles and services

NASA announced the awarding of contracts for the cargo resupply of the International Space Station (ISS) to SpaceX and Orbital Sciences Corporation on December 23, 2008. SpaceX will use its Falcon 9 launch vehicle and Dragon spacecraft. Orbital Sciences will use its Taurus II launch vehicle and Cygnus spacecraft.

Another proposal is Commercial Space Transportation Service (CSTS), which is commercial operation of the Space Shuttle. Two orbiters would continue to be flown until 2017, or when a replacement is available, for about 1.5 Billion USD per year. The plan would mean restarting production of external tanks, but would save having to develop a new spacecraft and launch system.

Technology transfer

Even though the Space Shuttle program is retiring, NASA and the USAF have been transferring Space Shuttle technology to other programs:

Launch vehicles

Shuttle-Derived Launch Vehicles, including Heavy Lift Launch Vehicles, have been proposed. For example, designs for the Ares I and Ares V have been integrated into meeting those challenges set forth within the Vision for Space Exploration; though the Constellation program was discontinued in October 2010.

Next-generation orbiters

The USAF's Boeing X-37 program represents a next-generation of unmanned reusable spaceplanes. The X-37 reuses the basic aerodynamic lifting body shape of the Space Shuttle Orbiter. According to Deputy Under Secretary of the Air Force (International Affairs) Gary Payton, the X-37 is a "test" for the next-generation beyond the Space Shuttle, designed to remain in orbit for up to 9 months at a time.

Chapter 6

Dragon (Spacecraft)

SpaceX Dragon spacecraft



Description

Role:	<i>Commercial:</i> various roles that put humans and cargo into LEO <i>Government:</i> supply the International Space Station after retirement of the Shuttle
Crew:	<i>Dragon Cargo:</i> 0 <i>Dragon Crew:</i> 7
Carrier Rocket:	Falcon 9

Dimensions

Height:	2.9 m	9.51 ft
Diameter:	3.6 m	11.8 ft
Pressurized Volume:	10 m ³	353 cu ft
Unpressurized Volume:	14 m ³	494 cu ft

**Unpressurized
Volume
(with additional
trunk extended):** 34 m³ 1,200 cu ft

Mass: 4,200 kg 9,260 lb

Launch Payload: 6,000 kg 13,228 lb

Return Payload: 3,000 kg 6,614 lb

Performance

Endurance: 1 week to 2 years

The **SpaceX Dragon** is a spacecraft developed by SpaceX, a space transportation company in Hawthorne, California. In December 2010, it became the first spacecraft ever placed in orbit and recovered by a private company. The first operational Dragon missions will be flown for NASA to deliver cargo to the International Space Station. Dragon is designed to carry up to seven people, or a mixture of personnel and cargo, to and from low Earth orbit. These flights will be contracted under the Commercial Resupply Services program.

Dragon's heat shield is designed to withstand re-entry velocities from potential lunar and Martian space flights. Development was partially funded through a Space Act Agreement under NASA's Commercial Orbital Transportation Services program.

Design

Dragon is a conventional blunt-cone ballistic capsule with a hinged nose-cone cap which opens to reveal a standard International Space Station (ISS) Common Berthing Mechanism. It allows the Dragon to be captured by the Space Station Remote Manipulator System and berthed to the non-Russian segments of the ISS. This approach avoids the weight, cost and complexity of an on-board docking system such as the Androgynous Peripheral Attach System (APAS-89) or the Low Impact Docking System (LIDS).

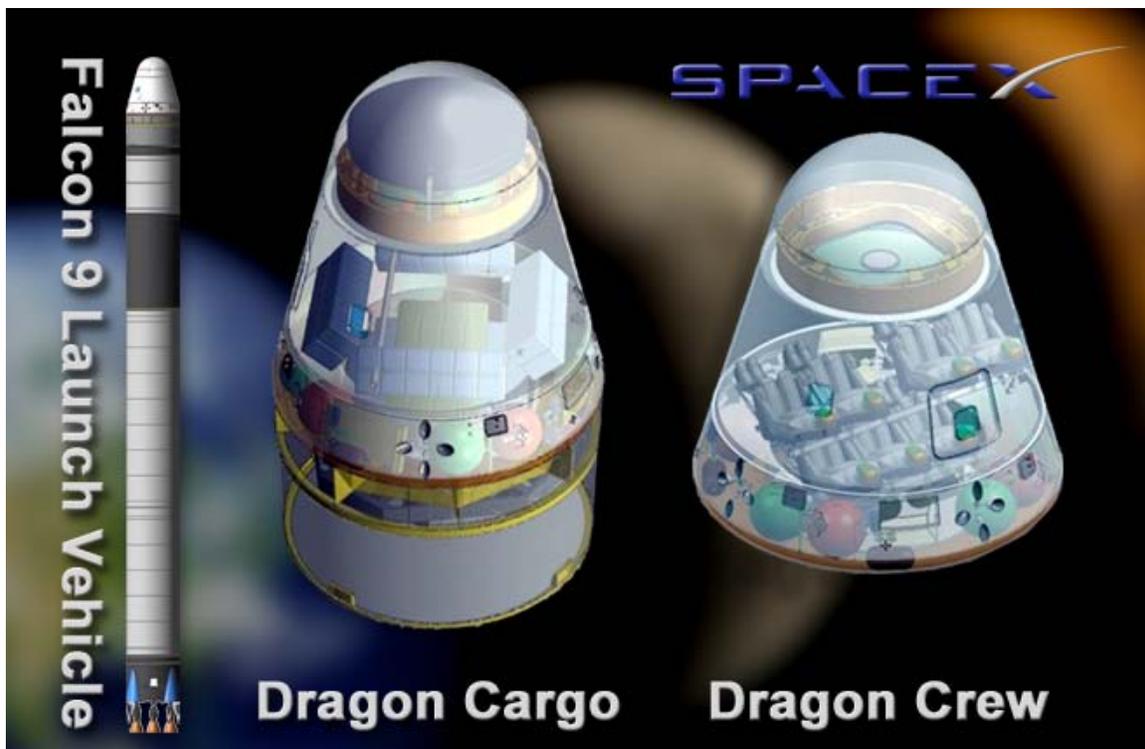
The Dragon capsule is launched atop a Falcon 9 rocket. SpaceX has built a full-sized prototype of the capsule and "thoroughly tested" its life support system.

Development

In June 2009, SpaceX CEO Elon Musk stated that the company planned to conduct the maiden flight of the Dragon spacecraft in 2009, and have the capsule enter service in 2010, before the scheduled final flight of the Space Shuttle.

On February 23, 2009, SpaceX announced that its chosen heat shield material, PICA-X, a proprietary variant of NASA's phenolic impregnated carbon ablator material, had passed heat stress tests in preparation for the first Dragon launch. In 2010 SpaceX's Elon Musk stated that the "Dragon is capable of re-entering from a Lunar velocity, or even a Mars velocity with the heat shield that it has."

The first flight of a stripped down version of the Dragon capsule occurred in June 2010 on the Falcon 9's maiden flight. This Dragon Spacecraft Qualification Unit was originally used as a non-flying test bed to validate several of the capsule's systems. At first flight, its primary mission was to relay aerodynamic data captured during the ascent. The Dragon spacecraft itself first flew on December 8, 2010, during the second flight of the Falcon 9.



Profiles of Dragon Cargo (with trunk) and Dragon Crew spacecraft

The docking target system for the Dragon module, the DragonEye, was tested during STS-127 by mounting it near the docking port on Space Shuttle *Endeavour* and using it while approaching the International Space Station. The DragonEye's LIDAR and thermal imaging capabilities were both checked out. The DragonEye is slated to fly again on STS-133, currently scheduled for February 2011, for further testing.

On November 22, 2010, NASA announced that the FAA had issued a reentry license for Dragon, the first such license ever awarded to a commercial vehicle.

In preparation for crewed use of the Dragon, in summer 2009 SpaceX hired former NASA astronaut Ken Bowersox as vice president of their new Astronaut Safety and Mission Assurance Department.

In 2009 and 2010, Elon Musk has suggested on several occasions that plans for a manned variant of Dragon were proceeding and had a 2–3 year timeline to completion.

For its initial cargo and crew flights, the Dragon will land in the sea and be air-lifted to the shore by helicopter. SpaceX plans to eventually install deployable landing gear and use the vehicle's thrusters to perform a land-based landing.

NASA partnership



Artist rendering of SpaceX Dragon spacecraft delivering cargo to the International Space Station.

Cargo launch contracts

In 2005, NASA solicited commercial rocket companies to submit proposals for resupply of the International Space Station after the retirement of the Space Shuttle. Dragon is part of a proposal submitted by SpaceX in March 2006 for NASA's Commercial Orbital Transportation Services (COTS) program for commercial delivery of cargo to the ISS. SpaceX's team for the COTS proposal consisted of a number of companies including MD Robotics, and the Canadian company that built the ISS's Mobile Servicing System.

On August 18, 2006, NASA announced that SpaceX had been chosen, along with Kistler Aerospace, to develop cargo launch services for the International Space Station. The plan called for three demonstration flights of SpaceX's Dragon capsule between 2008 and 2010. SpaceX may receive up to \$278 million if they meet all NASA milestones. Kistler failed to meet its obligations with NASA, and its contract was terminated in 2007. NASA decided to re-award Kistler's portion of the contract after a competition. On February 19, 2008 NASA announced that it had chosen Orbital Sciences as the new winner.

NASA awarded a cargo delivery contract to SpaceX on December 23, 2008. The contract calls for a minimum of 20,000 kg (44,000 lb) of cargo over up to 12 flights to the ISS at a cost of \$1.6 billion USD, with options that increase the maximum contract value to \$3.1 billion.

The first of the three contracted demonstration flights was successfully flown on December 8, 2010.

Launch escape system design and testing

In December 2010, SpaceX submitted a proposal under a different NASA solicitation to help NASA get crew to the International Space Station after Space Shuttle retirement. Under phase 2 of the NASA Commercial Crew Development program, SpaceX proposes to develop an "integrated launch abort system design" for the Dragon spacecraft, with several reputed advantages over the more traditional tractor tower approaches used on all prior manned space capsules. These advantages include:

- the provision of escape capability later into the launch profile, "all the way to orbit"
- reusability since the integrated escape system returns to earth with the spacecraft, and reduces mission cost
- improves crew safety by the elimination of one "separation event" from the launch profile
- the escape engines may be usable during the landing phase "for a precise land landing of Dragon under rocket power." The emergency parachute will be retained in this design as a redundant backup landing system.

A video simulation of the escape system operation has been released.

Maiden flight



The maiden launch of the SpaceX Dragon on the Falcon 9

On December 8, 2010, a Falcon 9 rocket carrying an unmanned SpaceX Dragon lifted off from Cape Canaveral in Florida on COTS Demo Flight 1. The launch was a success, and the Dragon cleanly separated from the Falcon approximately 10 minutes after launch. Three hours of orbital maneuvering testing were conducted at an altitude of 300 kilometres (190 mi; 160 nmi) before a deorbit burn was conducted, putting the Dragon on a re-entry course that ended in a successful splashdown in the Pacific Ocean, approximately 800 kilometres (500 mi; 430 nmi) west of Mexico's Pacific coast. SpaceX president Gwynne Shotwell stated that this was the first of three primary flight tests. NASA maintains that the Dragon will not be permitted near the International Space Station until its safety has been proven.

Though the Dragon capsule transported neither passengers nor practical cargo, the SpaceX team launched the spacecraft with a small piece of secret payload. It was revealed more than a day after the successful flight that the secret cargo was a wheel of Le Brouère cheese. The stunt was said to be an homage to the well-known Cheese Shop sketch from Monty Python's Flying Circus. SpaceX's CEO would not reveal identity of the cargo during the post-splashdown news conference for fear of the joke overshadowing the company's accomplishments in the next day's headlines.

Specifications (both crewed and uncrewed versions)

- Can carry up to seven passengers in crew configuration
- Can carry 6,000 kg (13,000 lb) and 14 m³ (490 cu ft) of payload to LEO in cargo configuration
- 18 Draco thrusters, dual-redundant in all axes: any two can fail and still have complete vehicle control in pitch, yaw, roll and translation.
- PICA-X heat shield designed to withstand reentry of return velocities from Lunar and Martian destinations.



SpaceX Dragon

Uncrewed capsule

The uncrewed capsule version of the Dragon spacecraft, when it is used for commercial (non-NASA, non-ISS) flights, is named **DragonLab**. It is capable of carrying pressurized and unpressurized payloads, is free-flying, and is reusable. "Subsystems

include propulsion, power, thermal control, environmental control, avionics, communications, thermal protection, flight software, guidance, navigation & control, entry, descent & landing, and recovery."

- 6,000 kilograms (13,000 lb) total combined up-mass; 3,000 kilograms (6,600 lb) maximum down-mass returned to Earth.

Pressure vessel

- 10 m³ (350 cu ft) interior pressurized, environmentally-controlled, payload volume
- Environmental: 10–46 degrees Celsius (50–115 °F); relative humidity 25~75%; 13.9~14.9 psia air pressure (958.4~1027 hPa).

Unpressurized Sensor bay (recoverable payload)

- 0.1 m³ (4 cu ft) unpressurized payload volume
- Sensor bay hatch opens after orbital insertion to allow full sensor access to the space environment, and closes prior to reentry to Earth's atmosphere.

Unpressurized trunk (non-recoverable)

- 14 m³ (490 cu ft) payload volume in the 2.3 m (7 ft 7 in) trunk, aft of the pressure vessel heat shield. With optional trunk extension to 4.3 m (14 ft 1 in) total length, payload volume increases to 34 cubic metres (1,200 cu ft)
- Will support sensors and space apertures up to 3.5 m (11 ft 6 in) in diameter.

Power, telemetry and command

- Power: 1,500 W average, 4000 W peak, at 28 and 120 V_{DC} via twin solar panels.
- Spacecraft communications: commercial standard RS-422 and military standard 1553 serial I/O plus Ethernet communications for IP-addressable standard payload service
- Command uplink: 300 kbps
- Telemetry/data downlink: 300 Mbps standard, fault-tolerant S-band telemetry and video transmitters

Production

As of December 2010, the SpaceX production line is manufacturing one new Dragon spacecraft every three months.

Chapter 7

Zvezda

ISS Zvezda



The *Zvezda* service module of the ISS with *Zarya* to the left and a docked Progress spacecraft to the right.

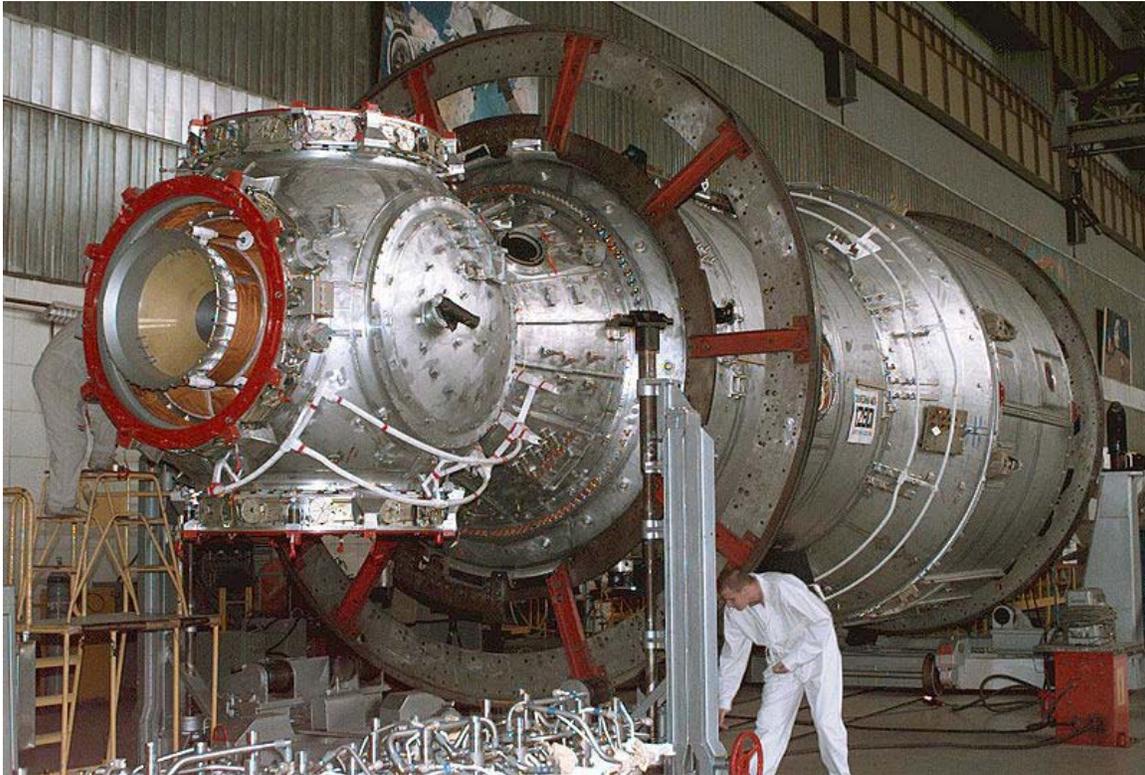


Station statistics

Call sign	International Space Station
Launch	July 12, 2000 Docked with ISS on July 26.
Launch pad	LC-81/23, Baikonur Cosmodrome, Kazakhstan
Mass	19,051 kilograms (42,000 lb)
Length	13.1 metres (43 ft)
Width	29.7 metres (97 ft)
Diameter	4.15 m
Atmospheric pressure	101.3 kPa (29.91 inHg)
Perigee	319.6 kilometres (172.6 nmi)
Apogee	346.9 kilometres (187.3 nmi)
Orbital inclination	51.63 degrees
Typical orbit altitude	333.3 kilometres (180.0 nmi)
Average speed	27,743.8 kilometres per hour

Design

Zvezda consists of a cylindrical "Work Compartment" where the crews work and live, a cylindrical "Transfer Chamber" which has one docking port, an unpressurized "Assembly Compartment" surrounding the Transfer Chamber, and a spherical "Transfer Compartment" with three docking ports. The component weights 18,051 kg (39,800 lb)) and had a length of 13.1 metres (43 ft). The solar panels extend 29.7 metres (97 ft).



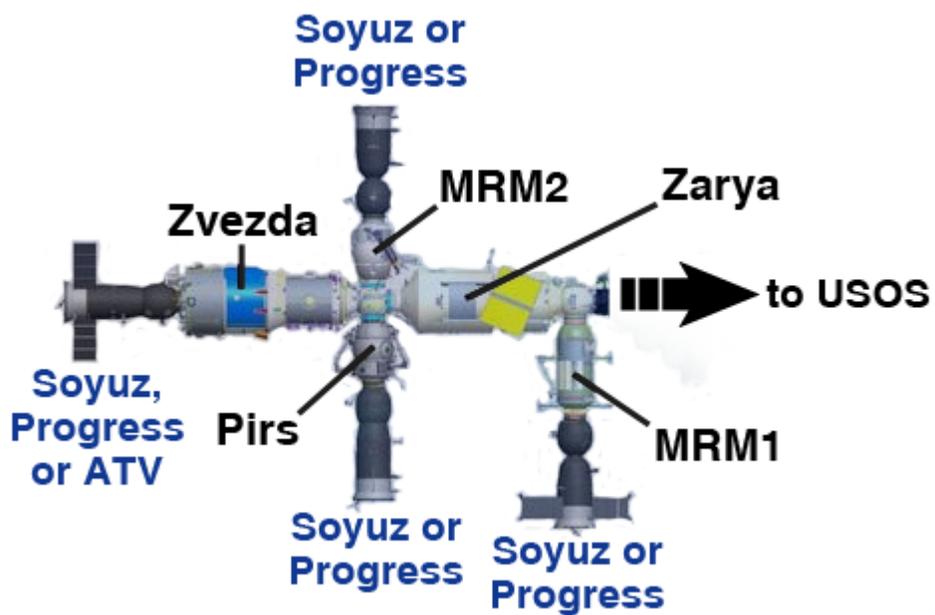
Zvezda service module under construction



The International Space Station as seen during STS-106, following the arrival of *Zvezda*



Zvezda's toilet



The location of *Zvezda* on the Russian Orbital Segment

The "Transfer Compartment" attaches to the *Zarya* module, and has docking ports intended for the Science Power Platform and the Universal Docking Module. Currently the lower port contains the Pirs Docking Compartment and the other contains Mini-Research Module 2. In December 2011, Pirs will be deorbited and replaced by the Multipurpose Laboratory Module.

The "Assembly Compartment" holds external equipment such as thrusters, thermometers, antennas, and propellant tanks.

The "Transfer Chamber" is equipped with automatic docking equipment and is used to service Soyuz and Progress spacecraft.

Zvezda contains sleeping quarters for two cosmonauts, a NASA-provided Treadmill with Vibration Isolation System and a bicycle for exercise, toilet and other hygiene facilities and a galley with a refrigerator and freezer. It contains the primary Russian computers for guidance and navigation. It has a total of 14 windows—three 9-inch-diameter (230 mm) windows in the forward Transfer Compartment, a 16-inch window in the Working Compartment, one in each crew compartment, and several more. It also contains the Elektron system that electrolyzes condensed humidity and waste water to provide hydrogen and oxygen. The hydrogen is expelled into space and the oxygen is used for breathing air. The condensed water and the waste water can be used for drinking in an emergency, but ordinarily fresh water from Earth is used. There are 16 small thrusters and two large thrusters for propulsion, and eight batteries for storing power.

The Elektron system has required significant maintenance work, having failed several times and requiring the crew to use Solid Fuel Oxygen Generator canisters (commonly called "Oxygen Candles", which were the cause of a fire on *Mir*) when it has been broken for extended amounts of time. It also contains the Vozdukh, a system which removes carbon dioxide from the air based on the use of regenerable absorbers of carbon dioxide gas. *Zvezda* has been criticized for being excessively noisy and the crew has been observed wearing earplugs inside it.

Connection to the ISS

On July 26, 2000, *Zvezda* became the third component of the ISS when it docked at the aft port of *Zarya*. (*Zarya* had already been attached to the U.S. *Unity* module.) Later in July, the computers aboard *Zarya* handed over ISS commanding functions to computers on *Zvezda*.

On September 11, 2000, two members of the STS-106 Space Shuttle crew completed final connections between *Zvezda* and *Zarya*; during a 6 hour, 14 minute EVA, astronaut Ed Lu and cosmonaut Yuri Malenchenko connected nine cables between *Zvezda* and *Zarya*, including four power cables, four video and data cables and a fiber-optic telemetry cable. The next day, STS-106 crew members floated into *Zvezda* for the first time, at 05:20 UTC on September 12, 2000.

Zvezda provided early living quarters, a life support system, a communication system (*Zvezda* introduced a 10Mbit/s Ethernet network to the ISS), electrical power distribution, a data processing system, a flight control system, and a propulsion system. These quarters and systems have since been supplemented by additional ISS components.

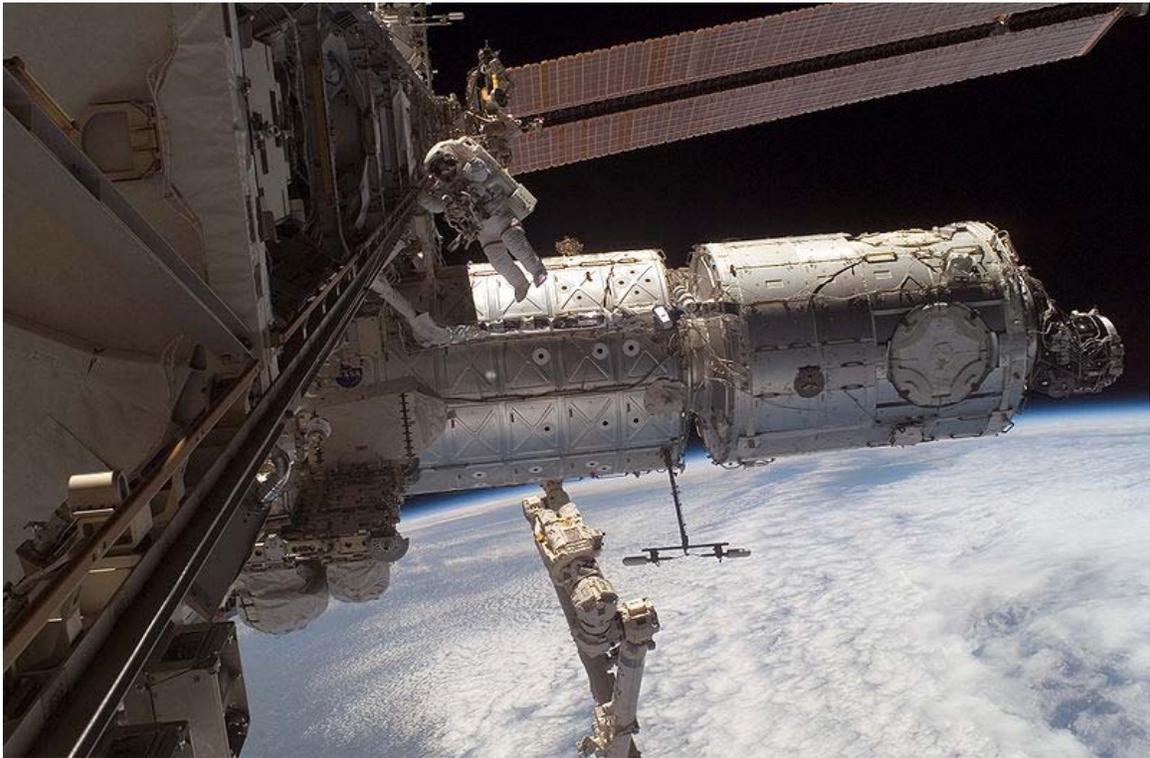
The two main engines on *Zvezda* can be used to raise the station's altitude. This was done on April 25, 2007. This was the first time the engines had been fired since *Zvezda* arrived in 2000.

Launch risks

Due to Russian financial problems, *Zvezda* was launched with no backup and no insurance. Due to this risk, NASA had constructed an Interim Control Module in case it was delayed significantly or destroyed on launch.

Chapter 8

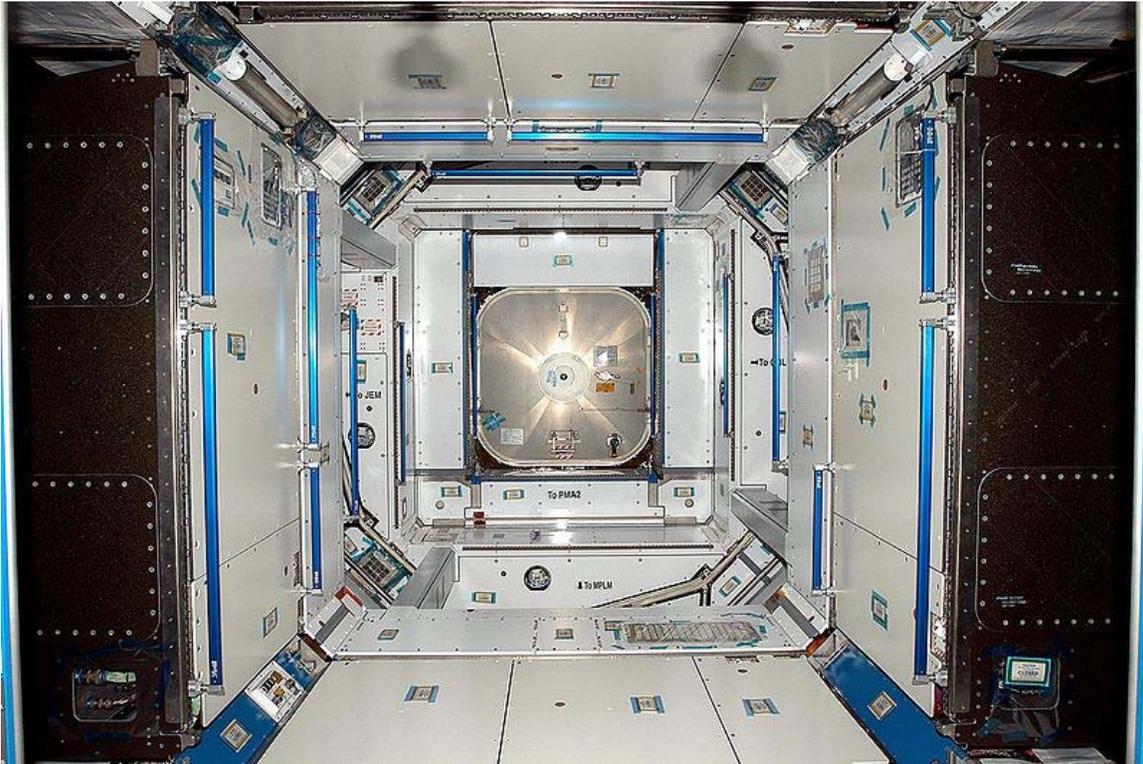
Harmony



Harmony on the Destiny Laboratory Module (NASA)

Harmony, also known as *Node 2*, is the "utility hub" of the International Space Station. The hub contains four racks that provide electrical power, plus electronic data, and act as a central connecting point for several other components via its six Common Berthing Mechanisms (CBMs). *Harmony* added 2,666 cubic feet (75 cubic meters) to the station's living volume, an increase of almost 20 percent, from 15,000 cubic feet (425 m³) to 17,666 cubic feet (500 m³). The successful installation of *Harmony* meant that from NASA's perspective, the station was "U.S. Core Complete". *Harmony* was successfully launched into space aboard Space Shuttle flight STS-120 on October 23, 2007. After temporarily being attached to the port side of the Unity node, it was moved to its permanent location on the forward end of the *Destiny* laboratory on November 14, 2007.

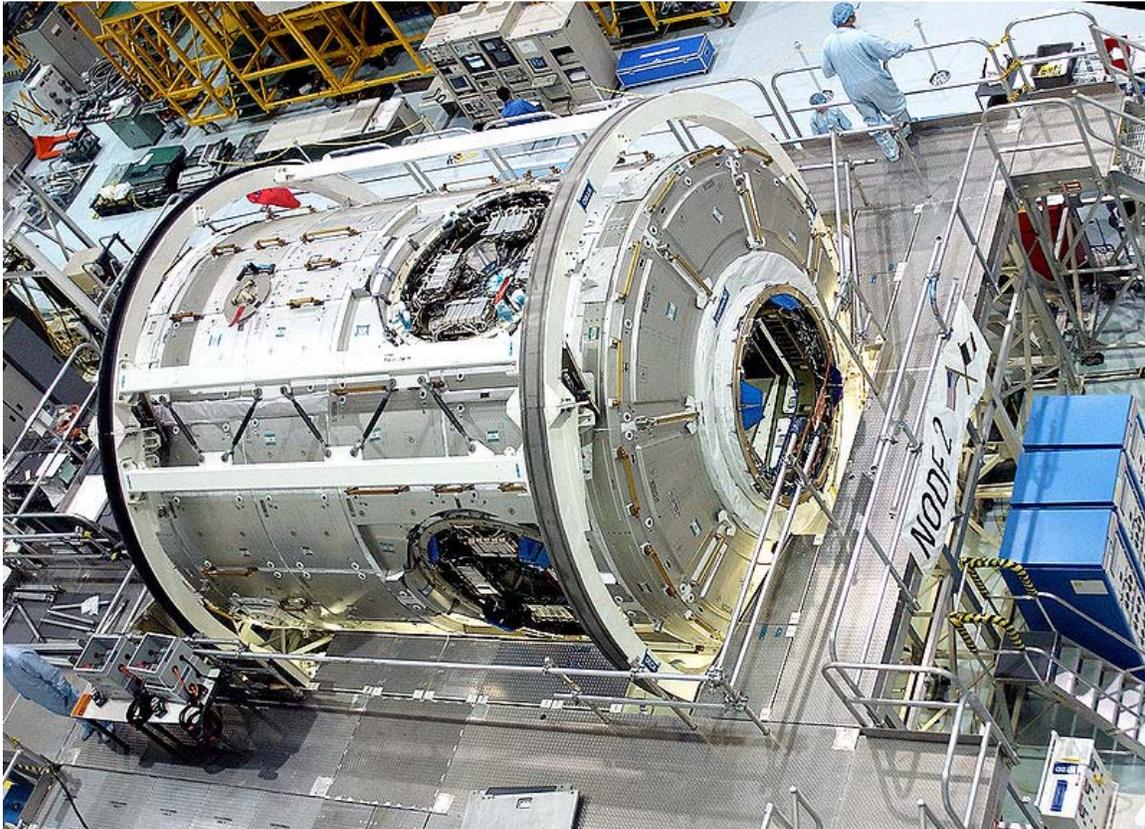
Origin of name



Interior of Harmony

The unit formerly known as *Node 2* was renamed *Harmony* in March 2007. The name was chosen from a competition involving more than 2,200 kindergarten through high school students from 32 states. The *Node 2 Challenge* required students to learn about the space station, build a scale model, and write an essay explaining their proposed name for the module, which will serve as a central hub for science labs.

Specifications



Harmony under assembly (NASA)

Weighing approximately 14,288 kilograms (31,500 lb), *Harmony* is the second of three connectors between the major ISS modules. The design is based on the existing Multi-Purpose Logistics Module, as well as the European Space Agency's Columbus Module. *Harmony* is managed by NASA's Marshall Space Flight Center in Huntsville, Alabama. Its deployment expanded the Space Station, allowing it to grow from the size of a three-bedroom house, to the space equivalent of a typical five-bedroom house, once the Japanese *Kibō* and European *Columbus* laboratories are attached. The Space Station robotic arm, Canadarm2, is able to operate from a powered grapple fixture on the exterior of *Harmony*. The node measures 7.2 meters (24 ft) in length, and it has a diameter of 4.4 meters (14 ft).

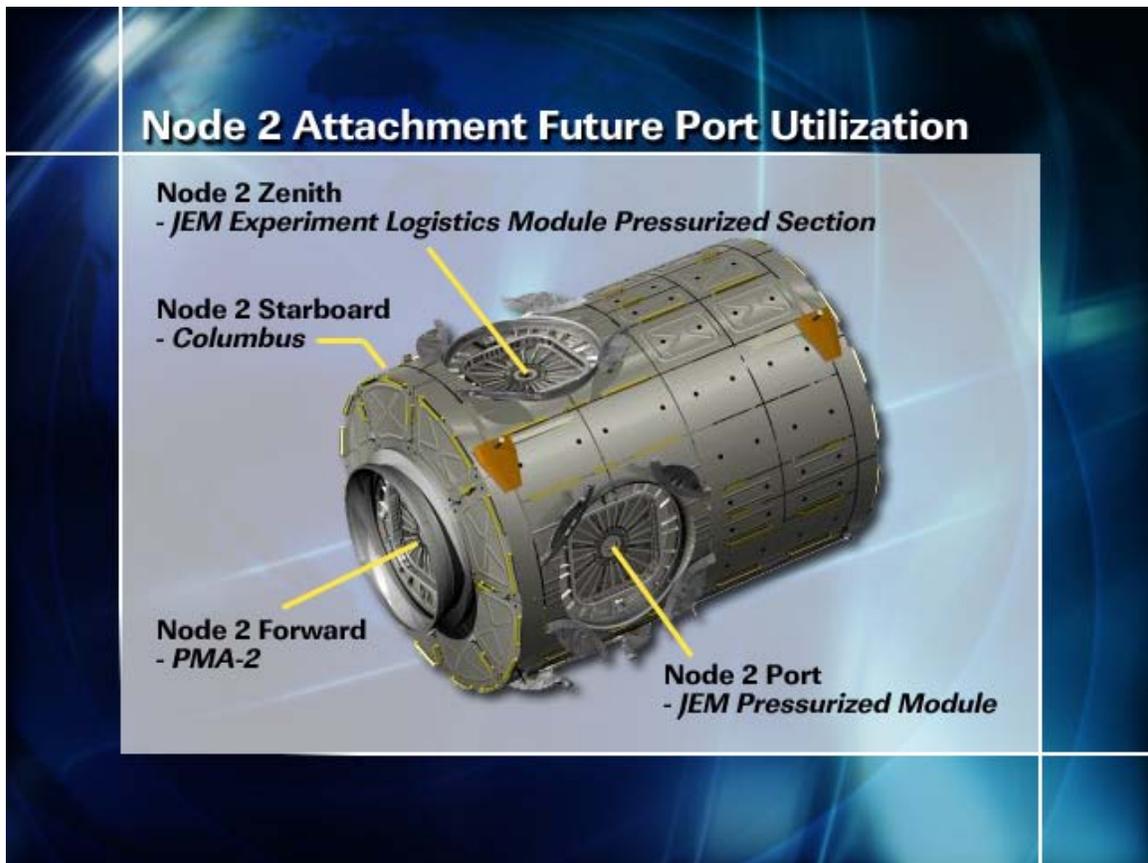
Construction agreement

In an agreement between NASA and the European Space Agency the Rome-based company Thales Alenia Space built *Harmony* at its facility in Turin, Italy. *Harmony* arrived on June 1, 2003 at the Kennedy Space Center in Florida after its flight in an Airbus Beluga oversized cargo vehicle. Following post transportation inspection, the Italian Space Agency formally handed over *Harmony* to the European Space Agency

(ESA). From there, ESA formally transferred ownership of *Harmony* to NASA on June 18, 2003, taking place in the Space Station Processing Facility of the Kennedy Space Center. The handover of *Harmony* completed a major element of the barter agreement, between ESA and NASA, that was signed in Turin on October 8, 1997.

Paolo A. Nespoli, an ESA astronaut born in Milan, Italy, accompanied the *Harmony* module aboard STS-120 as a mission specialist.

Launch



Graphic showing the connecting ports of *Harmony*



Harmony being prepared to be taken out of Space Shuttle Discovery's payload bay

Harmony was launched October 23, 2007 aboard STS-120, as the primary component of assembly mission ISS-10A.

On October 26, the station's Space Station Remote Manipulator System (SSRMS) removed *Harmony* from the shuttle cargo bay and temporarily mated it to the port side of Unity and, on October 27, the crew entered *Harmony*. After the Space Shuttle departed *Harmony* was relocated to the forward dock of the *Destiny* laboratory. It required three EVAs by the station crew to complete the installation.

The Expedition 16 crew moved the Pressurized Mating Adapter (PMA-2) on November 12, 2007 from the *Destiny* Laboratory to the forward berth of *Harmony*. The combined PMA-2/*Harmony* unit was subsequently berthed to its final destination at the forward end of the *Destiny* Laboratory on November 14, 2007.

Connecting modules

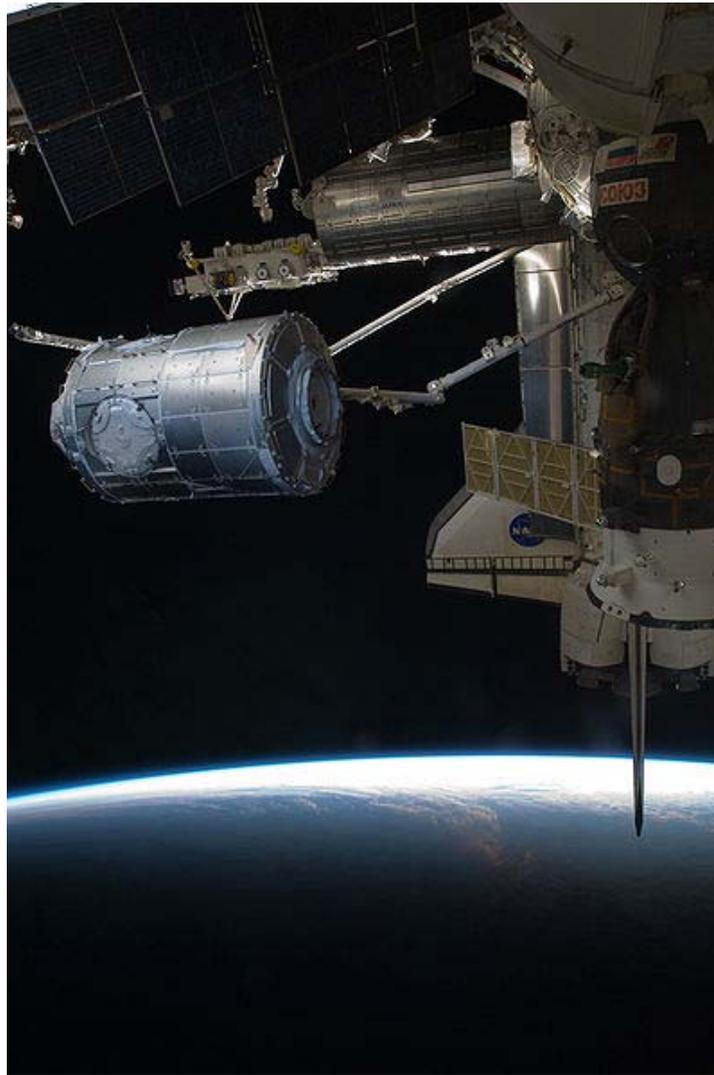
Harmony was the first permanent living space enlargement to the ISS after the Pirs docking compartment was added in 2001. On February 11, 2008, ESA's Columbus laboratory was attached to the starboard hatch of the *Harmony* module during space shuttle mission STS-122. On March 14, 2008 the *Experiment Logistics Module Pressurized Section* (ELM-PS) of Kibō was attached to its interim location: the zenith hatch of *Harmony*. During STS-124 a Space Shuttle mission flown by Space Shuttle

Discovery, the *Pressurized Module* of Kibō was added to the port side of *Harmony* and the ELM-PS was moved, leaving the zenith hatch empty. The zenith hatch was originally intended to be the permanent docking connector for the now canceled Centrifuge Accommodations Module (CAM).

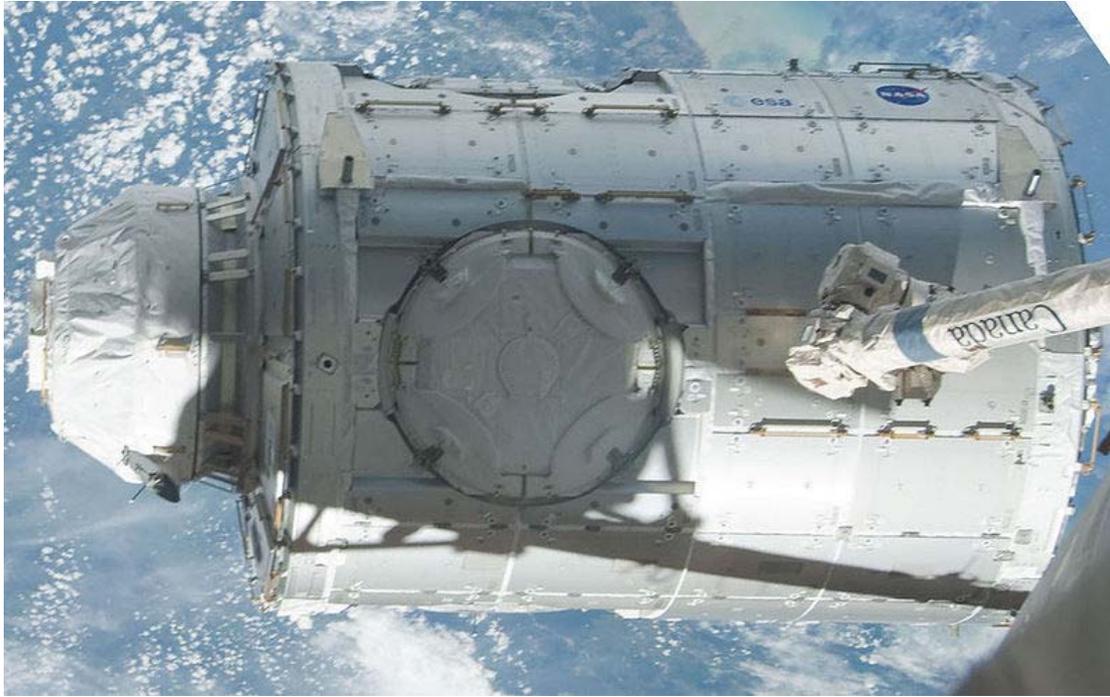
If the shuttle flies the Multipurpose Logistics Modules to the station, then such a module will be temporarily berthed to the nadir hatch of *Harmony*.

Chapter 9

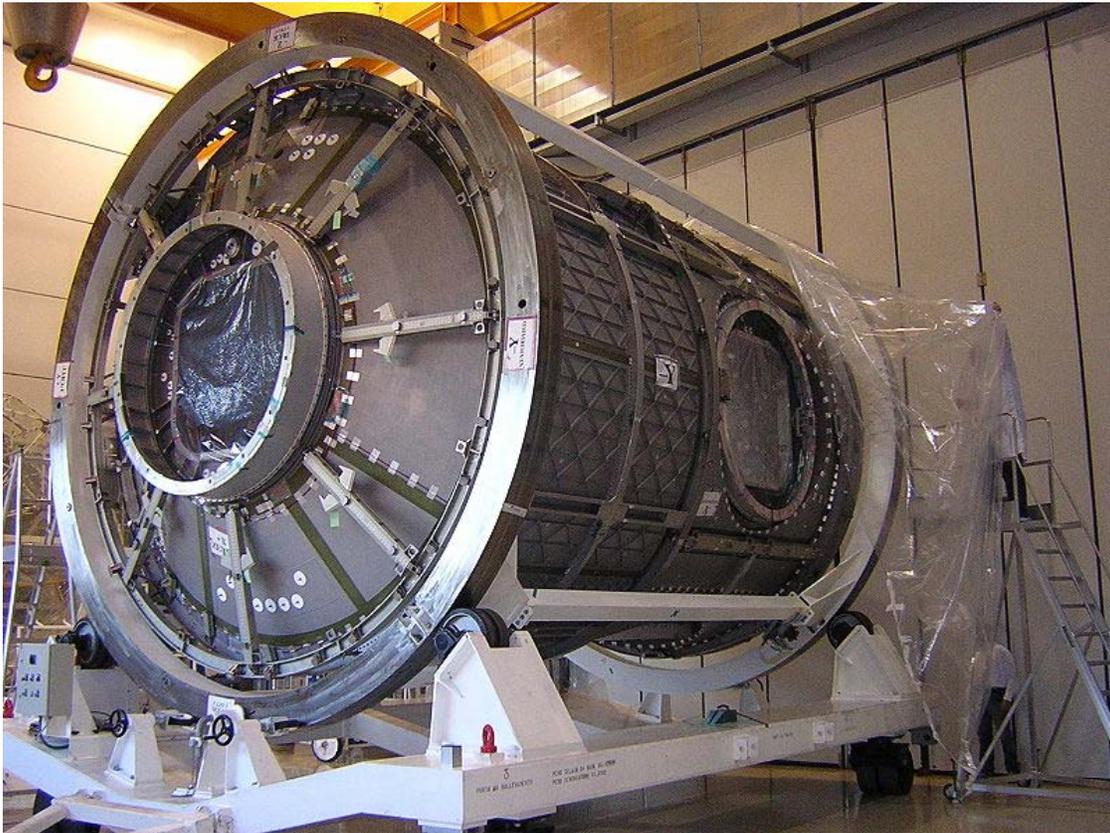
Tranquility



Tranquility photographed just before being installed to Unity node



Tranquility with Cupola

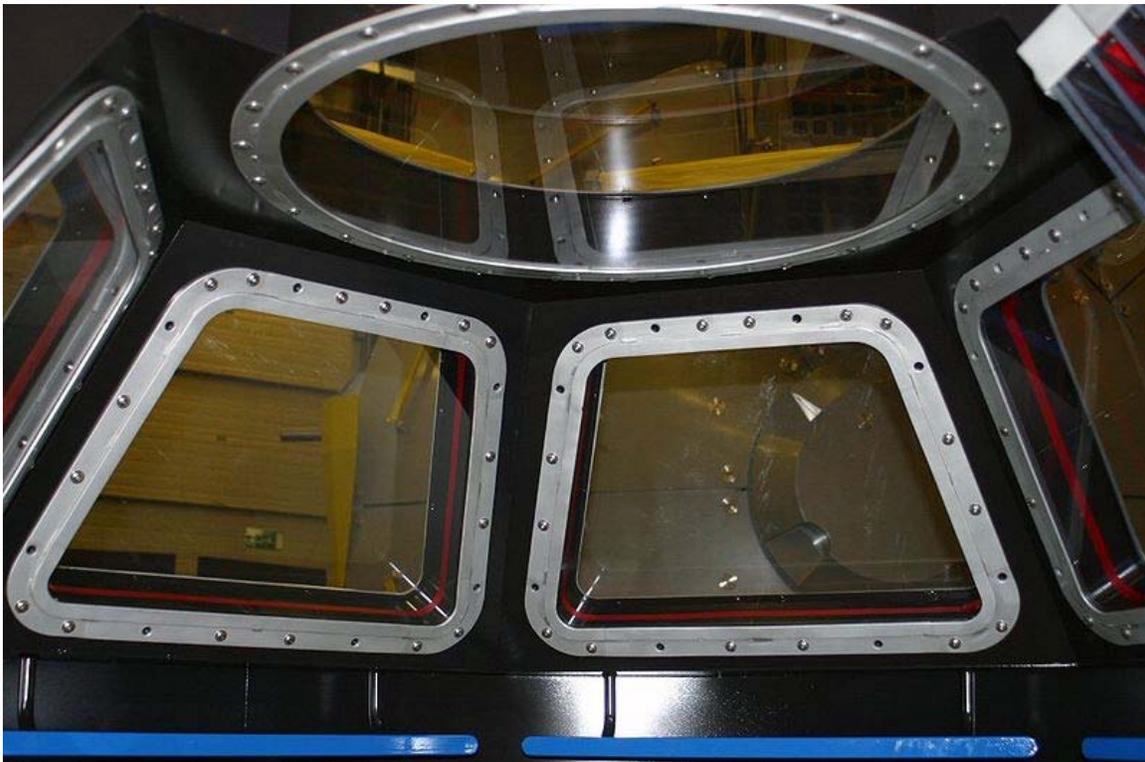


Tranquility

Tranquility, also known as **Node 3**, is a module of the International Space Station (ISS). ESA and the Italian Space Agency had *Tranquility* built by Thales Alenia Space. A ceremony on November 20, 2009 transferred ownership of the module to NASA. On February 8, 2010, NASA launched the module on the Space Shuttle's STS-130 mission.

The module provides six berthing locations, however three of those locations are disabled as modules originally planned to be attached to *Tranquility* were canceled. STS-130 also brought the Cupola, a large window module and robotics work station to the ISS which will be attached to the nadir-side of *Tranquility*. The module also includes various ISS systems, including additional life support systems.

Design

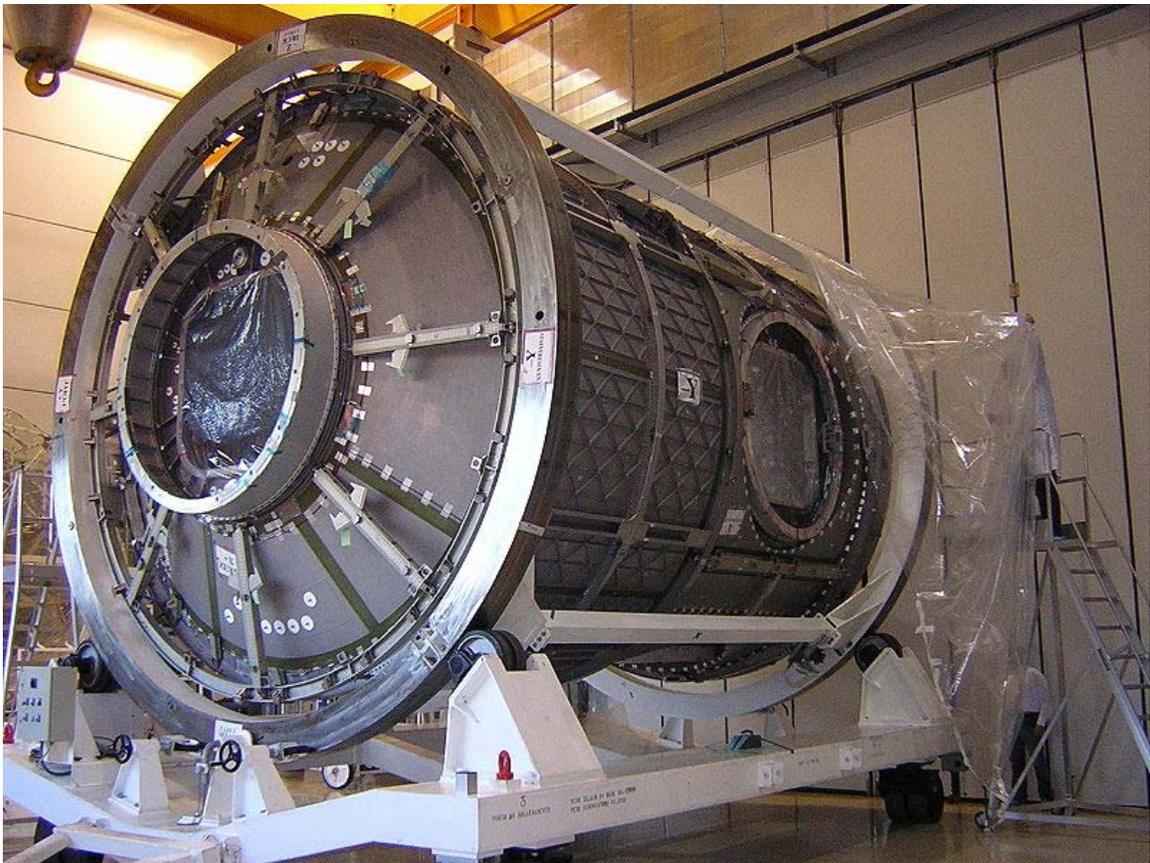


View from inside the Cupola

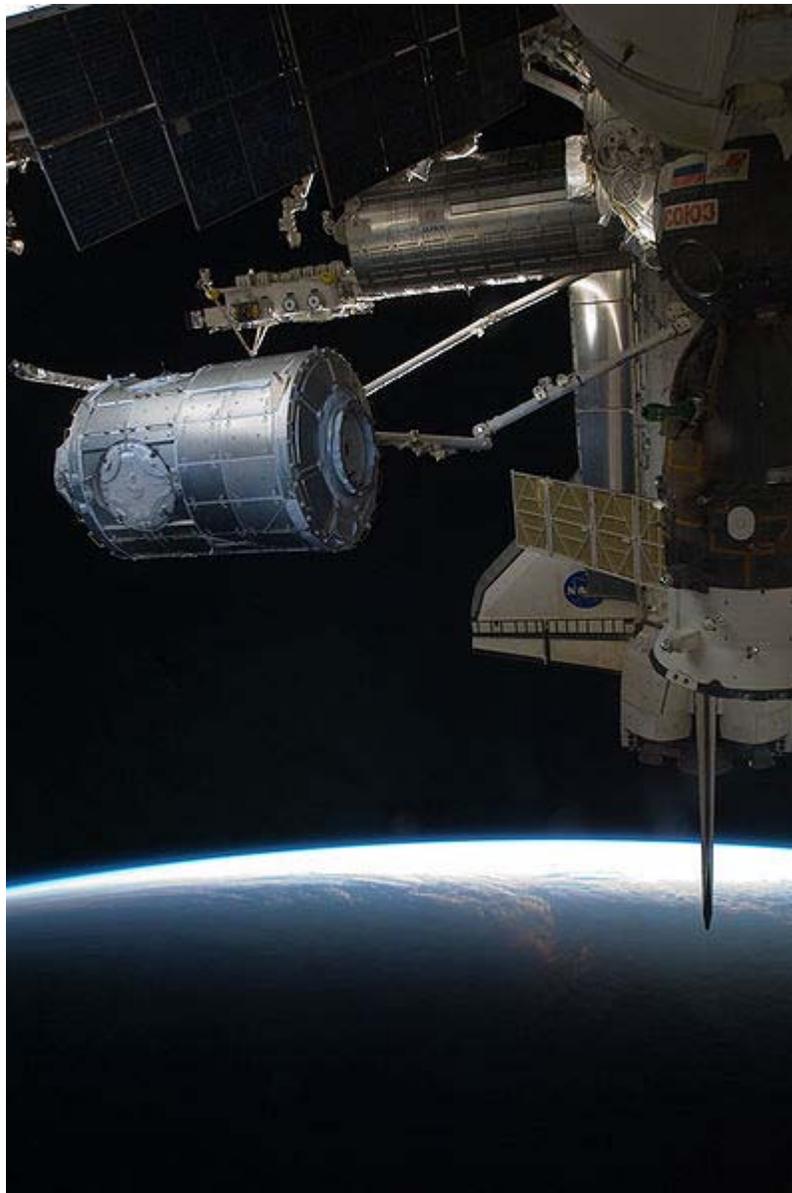
Tranquility was built within the ESA-NASA ISS bartering system. ESA committed to build and fund both *Harmony* and *Tranquility* as well as the ATV in order to use NASA ISS facilities, fly astronauts on the Shuttle and for other ISS services. ESA teamed up with the Italian Space Agency ASI to build both *Harmony* and *Tranquility* at Thales Alenia Space in Turin.

Tranquility provides six berthing locations with power, data and commanding, thermal and environmental control, and crew access for more attached habitable volumes or for crew transportation vehicles or stowage, or an appropriate combination of all of these.

One of the berthing locations is used by *Cupola*, which houses a Robotic Work Station inside it to assist in the assembly/maintenance of the ISS as well as offer a window for earth observations. *Tranquility* was launched with the Cupola attached to mating adapter earthward facing port. After mating *Tranquility* with the port Common Berthing Mechanism of *Unity*, the *Cupola* was transferred to the nadir facing port of *Tranquility* where it will stay. The module has three redundant ports that are currently not scheduled to be used. Because the current ISS configuration requires *Tranquility* to be docked to the port berthing location of *Unity*, the three unused berthing locations of *Tranquility* have been disabled and would mostly be blocked by the station's other segments in any event. The docking module PMA-3 has been relocated to the port berthing location of *Tranquility*. The move of PMA-3 to the port location of *Tranquility* was required because NASA decided to leave the MPLM Leonardo permanently attached to the ISS, which will be located at the nadir side of *Unity*.



The Tranquility node during pre-processing



Tranquility during its move from Endeavour to the install position on the Unity node



Cupola just after installation at Earth-facing port on Tranquility

In 2001, NASA considered changing the design of the module. This idea for an extended or "stretched" module, was a result of the deferral/deletion of the Habitation module. The stretched module would have held 16 racks compared with the baseline capacity of eight racks. This modification was not funded and the plans were abandoned.

Purpose

The module will contain the most advanced life support systems ever flown in space. These systems will recycle waste water for crew use and generate oxygen for the crew to breathe. In addition, *Tranquility* will contain an atmosphere revitalization system to

remove contaminants from the atmosphere and monitor/control the atmosphere constituents of the ISS. *Tranquility* will also contain a Waste and Hygiene Compartment (toilet) for supporting the on-board crew.

Tranquility will primarily be used for exercise, storage, and robotics work in connection with Cupola.

Status



Tranquility in the SSPF

Tranquility was located in the clean room at the Thales Alenia Space Turin site until 2009. It was shipped to Kennedy Space Center (KSC) on May 17 and arrived in Florida on May 20, 2009. It was officially welcomed to KSC on June 8, 2009.

Tranquility was launched on February 8, 2010 onboard the STS-130 mission flown by Endeavour. It was berthed to the port side of *Unity* on February 12, 2010.

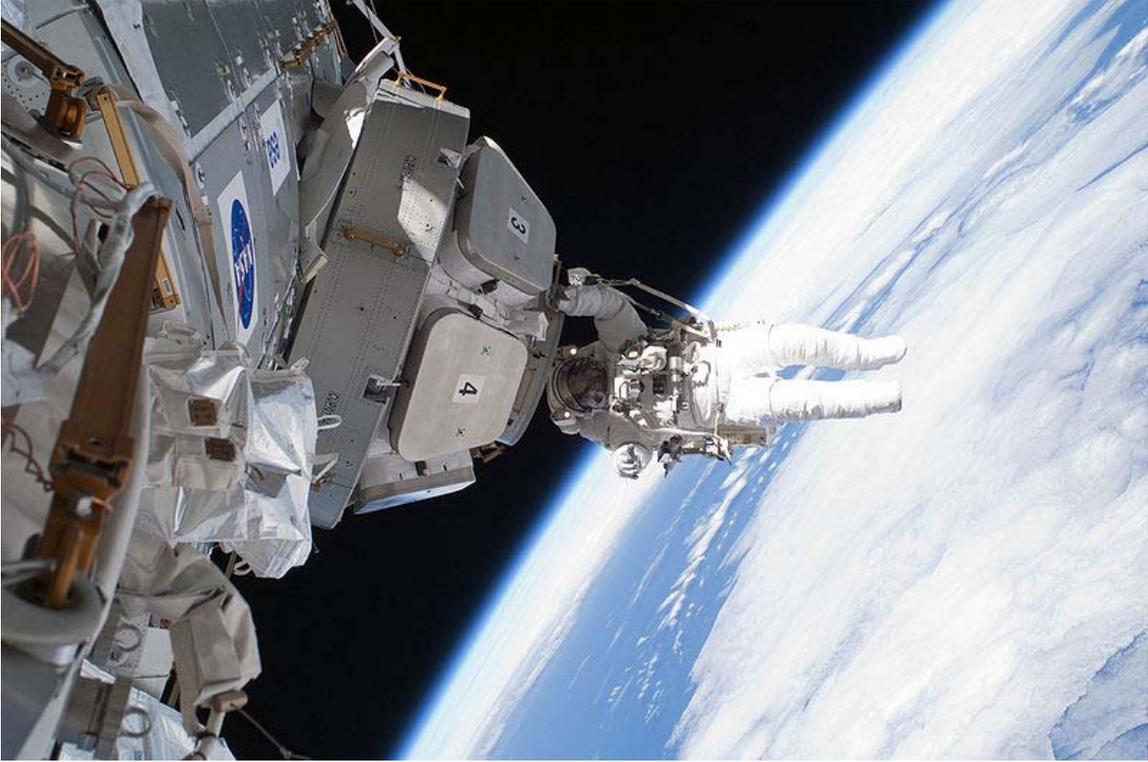
Naming contest

NASA held an online poll to name Node 3. Users were allowed to choose from among four provided names (Earthrise, Legacy, Serenity, and Venture), or to suggest their own. In early voting, fans of the science fiction TV series *Firefly* boosted "Serenity", also the

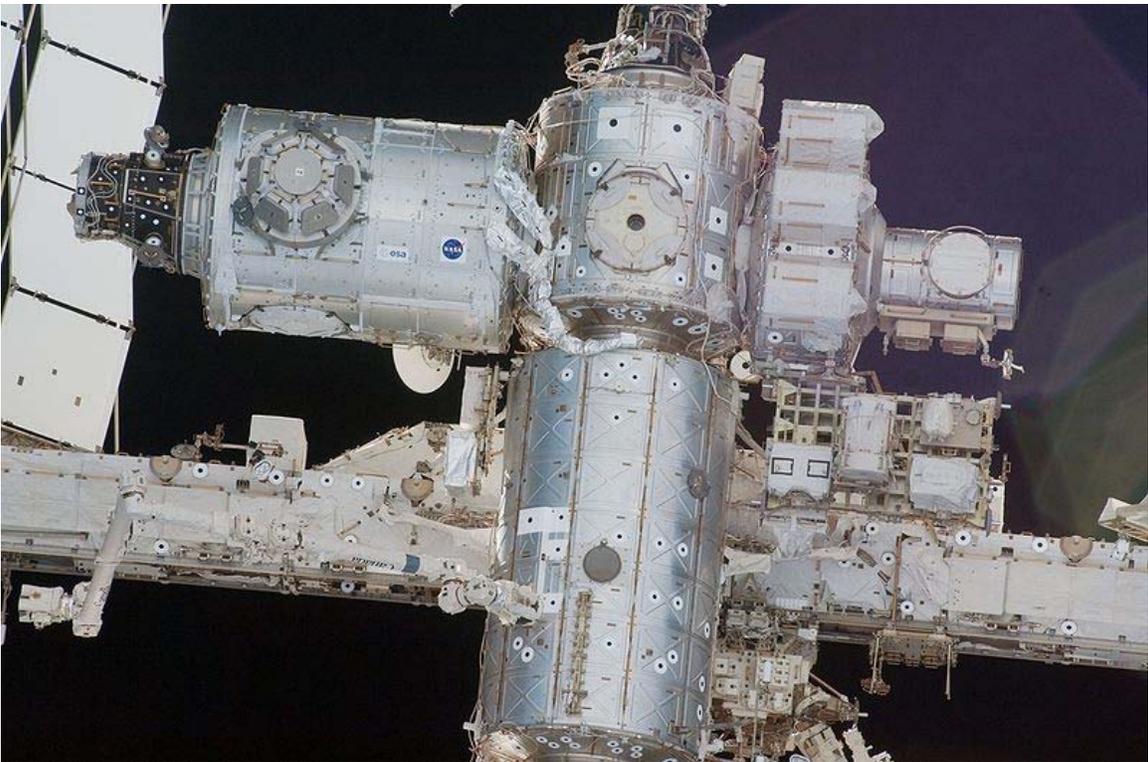
name of the show's film and eponymous spacecraft, to the top with 86%. On the March 3, 2009, episode of *The Colbert Report*, host Stephen Colbert instructed his viewers to suggest "Colbert" as the name for Node 3 in the online poll.



PMA-3 is moved to the end of Tranquility. Cupola is seen on top with its protective launch cover still attached.



Astronaut Nicholas Patrick hanging on to Cupola after insulation has been removed



Tranquility seen top left corner with Cupola and PMA-3

Following Colbert's call to have the node named after him, several other groups attempted to influence the vote. For example, a number of different environmental groups promoted the name "Amazonia", after the Amazon Rainforest. They argued that the name was more appropriate given that Node 3 will include the station's environmental control systems. Humorist Dave Barry urged readers of his blog to name the node "Buddy", which finished as the sixth most popular user-suggested name. Gaia Online asked its users to "Send Gaia to Space" by naming the node "Gaia", referring to the Greek goddess of the planet Earth, and "Gaia" finished third among the user-suggested names. Other popular user suggestions included "myYearbook", "SocialVibe", "Ubuntu", and the name of Scientology's galactic overlord: "Xenu".



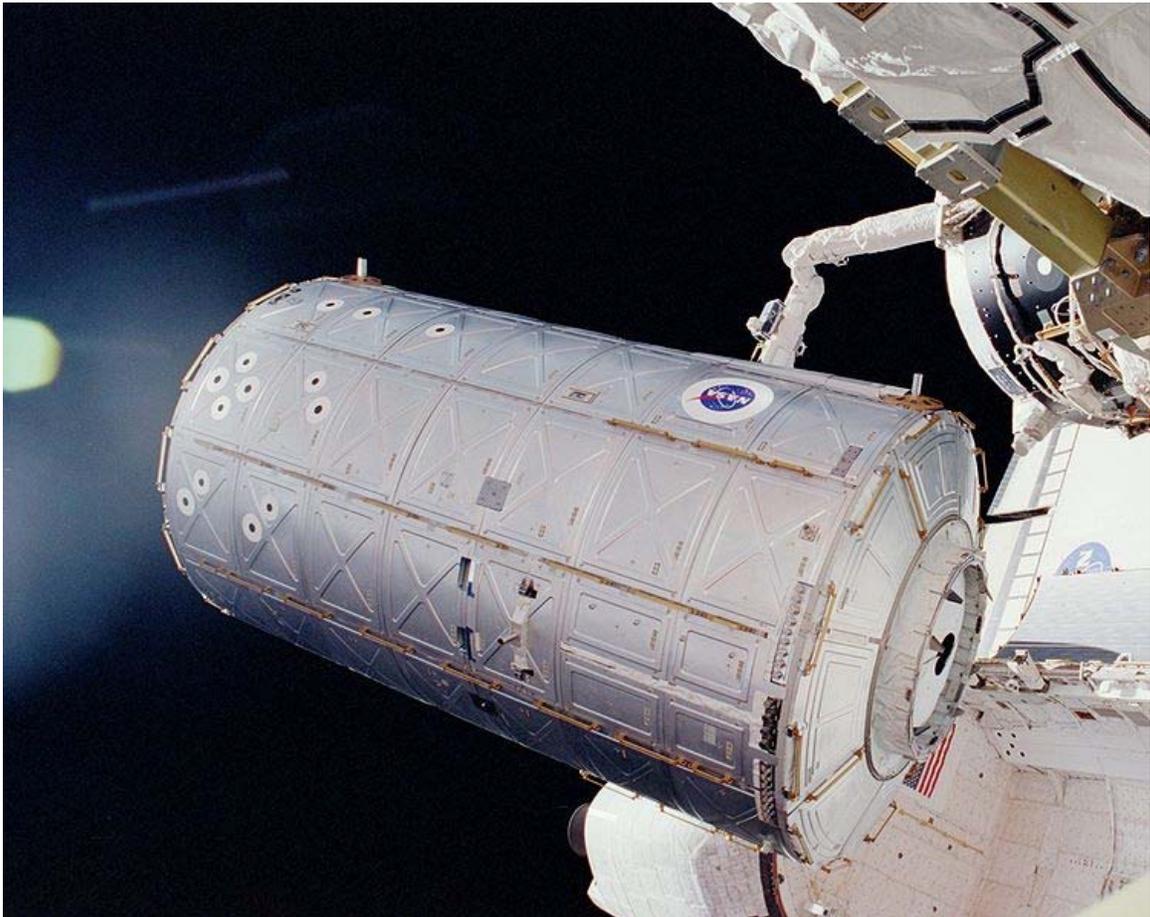
Colbert urging his viewers on the March 3, 2009 airing of *The Colbert Report* to vote for the node to be named after him.

On March 23, 2009, NASA announced that the overall vote winner was "Colbert", with 230,539 votes. Nearly 1.2 million votes were cast in total. "Serenity" was the top choice among the NASA-provided names, with 70% of the vote, but finished second overall, losing to "Colbert" by more than 40,000 votes. The naming contest rules, however, state that although the poll results will be taken into account, NASA has ultimate discretion in choosing an appropriate name for the node. On April 6, 2009, Stephen Colbert, in jest, threatened a lawsuit if the node was not named after him. In addition, United States Congressman Chaka Fattah stated that he believes that paying attention to democracy and voting results should not be limited to earthbound organizations so he planned to use congressional power to force NASA to honor the winning Colbert write-in votes.

On April 14, 2009, astronaut Suni Williams appeared on *The Colbert Report*, and announced the name of the node would be *Tranquility*. The name was chosen in honor of the 40th Anniversary of the first lunar landing of Apollo 11 on the Sea of Tranquility. However, the treadmill the astronauts use for exercise will be named "C.O.L.B.E.R.T." for "Combined Operational Load Bearing External Resistance Treadmill" and will be located in *Tranquility*. Colbert was thrilled and happily accepted this offer. The treadmill traveled to space aboard Space Shuttle mission STS-128 on August 28, 2009, for eventual installation in the *Tranquility* node during STS-130.

Chapter 10

Destiny



The *Destiny* Laboratory Module (NASA) being installed on the International Space Station.

The *Destiny* module is the primary operating facility for U.S. research payloads aboard the International Space Station (ISS). It was berthed to the *Unity* module and activated over a period of five days in February, 2001. *Destiny* is NASA's first permanent operating orbital research station since Skylab was vacated in February 1974.

The Boeing Company began construction of the 16 ton (14.5 tonne), state-of-the-art research laboratory in 1995 at the Marshall Space Flight Center in Huntsville, Alabama. *Destiny* was shipped to the Kennedy Space Center in Florida in 1998, and was turned over to NASA for pre-launch preparations in August 2000. It launched on February 7, 2001 aboard the Space Shuttle Atlantis on STS-98.

Astronauts work inside the pressurized facility to conduct research in numerous scientific fields. Scientists throughout the world will use the results to enhance their studies in medicine, engineering, biotechnology, physics, materials science, and Earth science.

Laboratory structure



Astronaut Susan J. Helms, Expedition Two flight engineer, views the Earth from the *Destiny* module window.

The aluminum U.S. laboratory module is 28 feet (8.5 m) long and 14 feet (4.3 m) wide. It comprises three cylindrical sections and two endcones that contain the hatch openings through which astronauts enter and exit the module. The aft port of *Destiny* is connected to the forward port of the *Unity* node, and the forward port of *Destiny* is connected to the aft port of the *Harmony* module. A 20-inch (510 mm)-diameter window is located on one side of the center module segment.

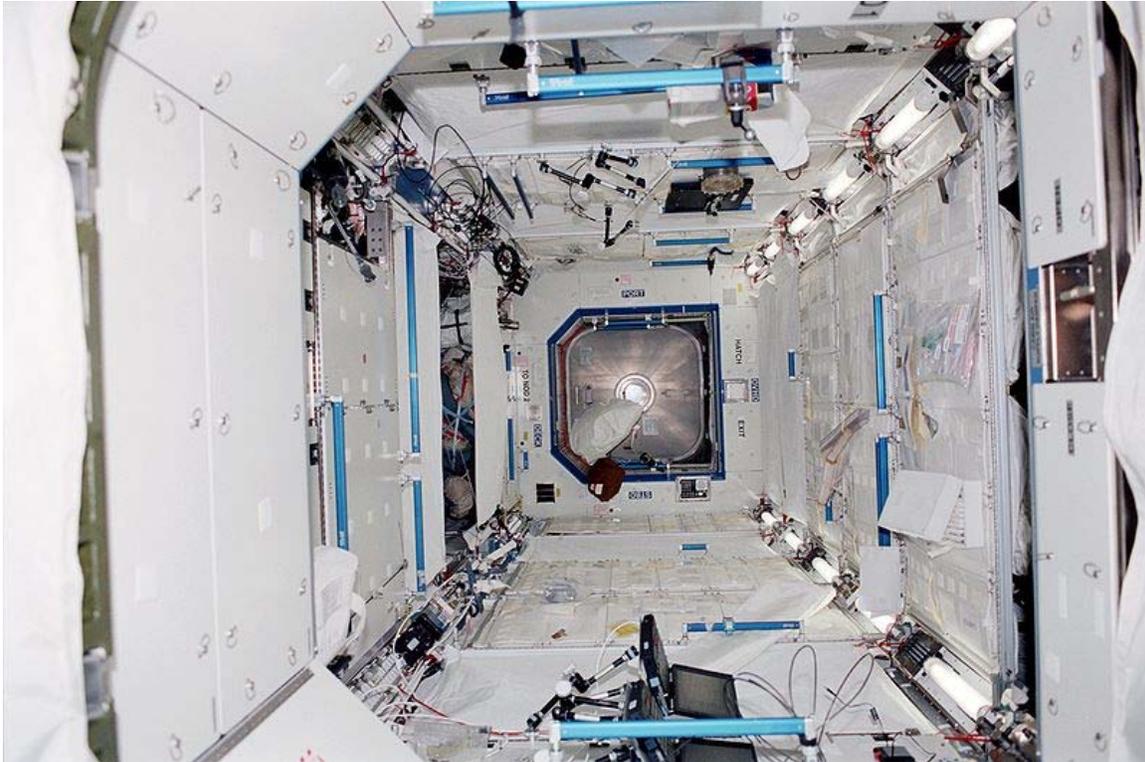
Each of the two berthing ports on *Destiny* contains a hatch. Both hatches are normally open, and remain open unless a situation arises requiring a module to be isolated. Each hatch has a window. The hatches can be opened or closed from either side. The hatches have a pressure interlock feature, which prevents the hatch from being opened if there is a negative pressure across the hatch (higher pressure on the outside of the hatch).

Destiny has a 20-inch (510 mm) optically pure, telescope-quality glass window located in an open rack bay used primarily for Earth science observations. Station crewmembers use very high quality video and still cameras at the window to record Earth's changing landscapes. A window shutter protects the window from potential micrometeoroid and orbital debris strikes during the life of the ISS. The crew manually opens the shutter to use the window.

Imagery captured from *Destiny's* window has given geologists and meteorologists the chance to study floods, avalanches, fires and ocean events such as plankton blooms in a way never seen before, as well as given international scientists the opportunity to study features such as glaciers, coral reefs, urban growth and wild fires.

Specifications

- Length: 8.53 m (28 ft)
- Diameter: 4.27 m (14 ft)
- Mass: 14,520 kg (32,000 lb)
- Pressurized Volume: 106 m³ (3,743.354 ft³)



The *Destiny* laboratory as it looked following installation in 2001

Equipment

Destiny arrived at the station pre-configured with five racks housing electrical and life support systems that provide electrical power, cooling water, air revitalization, and temperature and humidity control. Seven additional racks were flown to *Destiny* in the *Leonardo* Multi-Purpose Logistics Module by STS-102, and ten more were delivered on subsequent missions. *Destiny* can hold up to 13 payload racks with experiments in human life science, materials research, Earth observations and commercial applications. The laboratory has a total of 24 racks inside the laboratory, six on each side.



Astronaut Kenneth Cockrell, STS-98 commander, emerges from behind a rack curtain in *Destiny*.



Joan E. Higginbotham and Sunita L. Williams work the controls of the Space Station Remote Manipulator System in the *Destiny* laboratory.

As with the European and Japanese laboratories of the station, payloads inside *Destiny* are configured around International Standard Payload Racks (ISPRs), that can be removed or reconfigured for various experiments and equipment. Made out of a graphite composite shell, each rack weighs about 1,200 pounds (540 kg), and is about 73 inches high, and 42 inches (1,100 mm) wide. The eight rack bays are equipped with curtains that provide around 290 cubic feet (8.2 m³) of temporary stowage space when not occupied by experiments.

Internal to the laboratory are racks, rack stand-offs, and vestibule jumpers. The lab racks house the system hardware in removable modular units. The stand-offs provide space for electrical connections, data management systems cabling for computers, air conditioning ducts, thermal control tubes and more, all of which support the space station's equipment racks. The racks interface to the piping and wiring in the standoff via outlets and ports located in the standoffs at the base end of each rack location.

Jumpers in the vestibule, the area between *Unity* and *Destiny*, connect the piping and wiring between the two. Grounding straps between *Unity* and *Destiny* will be installed. One side of the grounding strap will be connected to the Active Common Berthing Mechanism (ACBM) on *Unity*, while the other end will be connected to the Passive Common Berthing Mechanism (PCBM) on *Destiny*.

Some of the mechanisms on *Destiny* are the CBMs (passive and active), hatches, and the laboratory window shutter. The ACBM is in the forward port of the laboratory. It is attached to the *Harmony* node. The PCBM on *Destiny* is located in the laboratory's aft port. The ACBM in *Unity's* forward port is latched to the laboratory's PCBM to berth *Destiny* to *Unity*.

Science equipment

Destiny also contains the Minus Eighty Degree Laboratory Freezer for ISS (MELFI), transported to the Space Station on STS-121. The freezer is used both to store samples and reagents on the station, and to transport them to and from the space station in a temperature controlled environment.

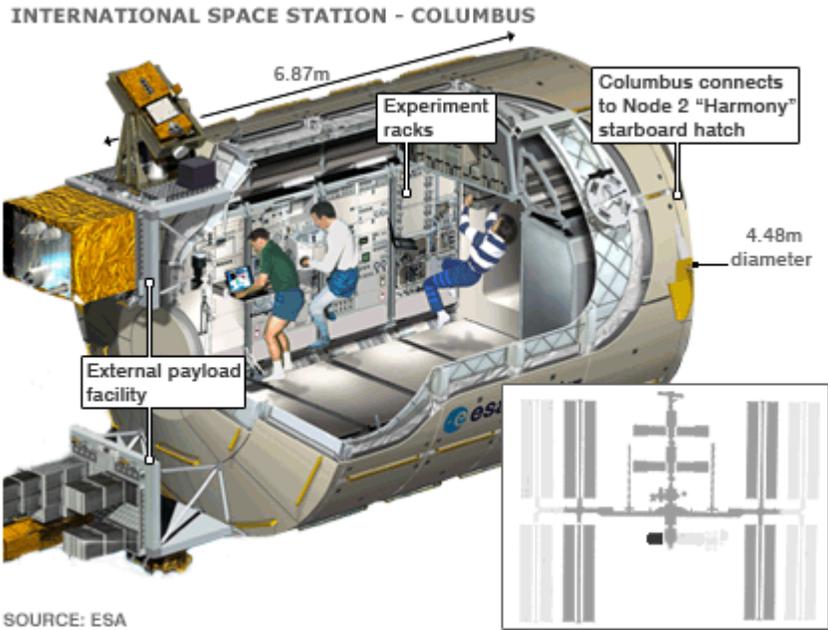
Currently installed at the main observation window of *Destiny* is the Agricultural Camera (AgCam). It is a multi-spectral imaging system built and primarily operated by students and faculty at the University of North Dakota. Its purpose is to take frequent images, in visible and infrared light, of vegetated areas on the Earth and promises to deliver a greater effectiveness for in-season agriculture applications research and operational decision support than current satellite systems such as Landsat.

Chapter 11

Columbus



The Columbus Module on the International Space Station



A cut-away illustration of the Columbus laboratory



Hans Schlegel is working on outfitting *Columbus*

Columbus is a science laboratory that is part of the International Space Station (ISS) and is the largest single contribution to the ISS made by the European Space Agency (ESA).

Like the *Harmony* and *Tranquility* modules, the *Columbus* laboratory was constructed in Turin, Italy by Rome based Alcatel Alenia Space with respect to structures and thermal control. The functional architecture (including software) of the lab was designed by EADS in Germany where it was also integrated before being flown to the Kennedy Space Center (KSC) in Florida in an Airbus Beluga. It was launched aboard Space Shuttle *Atlantis* on February 7, 2008 on flight STS-122. It is designed for ten years of operation. The module is controlled by the Columbus Control Centre, located at the German Space Operations Centre, part of the German Aerospace Center in Oberpfaffenhofen near Munich, Germany.

The European Space Agency has spent €1.4 billion (about US\$2 billion) on building *Columbus*, including the experiments that will fly in it and the ground control infrastructure necessary to operate them.





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Description

The laboratory is a cylindrical module with two end cones. It is 4,477 mm (15 ft) in external diameter and 6,871 mm (23 ft) in overall length, excluding the projecting external experiment racks. Its shape is very similar to that of the Multi-Purpose Logistics Modules (MPLMs), since both were designed to fit in the cargo bay of a Space Shuttle orbiter. The starboard end cone contains most of the laboratory's on-board computers. The port end cone contains the Common Berthing Mechanism.

Construction

ESA chose EADS Astrium Space Transportation as prime contractor for *Columbus*. The Columbus flight structure, the micro-meteorite protection system, the active and passive thermal control, the environmental control, the harness and all the related ground support equipment were designed and qualified by Alcatel Alenia Space in Turin, Italy as defined by the PICA - Principle; the related hardware was pre-integrated and sent as PICA in September 2001 to Bremen. The lab was then fully integrated and qualified on system level at the EADS Astrium Space Transportation facilities in Bremen, Germany.

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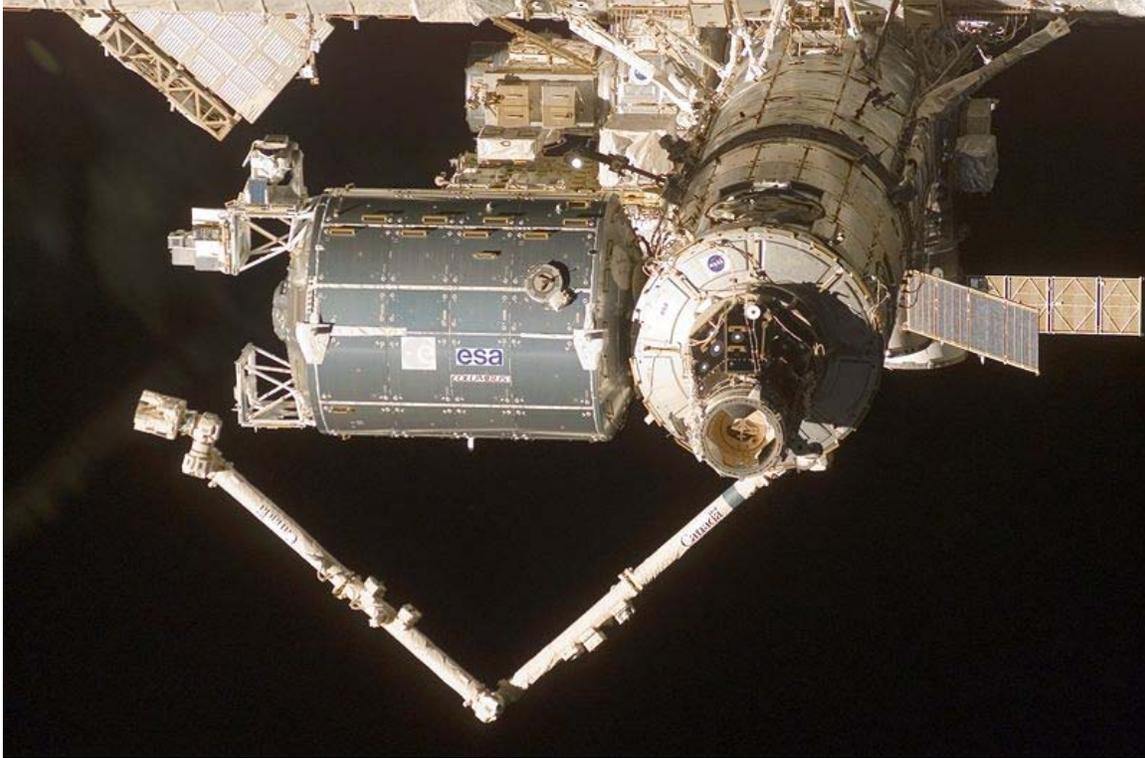


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Launch, berthing and outfitting



Columbus installed in *Atlantis's* payload bay in preparation for launch



Columbus docked to the starboard side of Harmony

In November 2007, *Columbus* was moved out of the KSC Space Station Processing Facility, and installed into the payload bay of the *Atlantis* orbiter for launch on ISS assembly flight 1E. During cryo-filling of the space shuttle External Tank (ET) with liquid hydrogen and liquid oxygen prior to the first launch attempt on December 6, 2007, two of four LH2 ECO sensors failed a test. Mission rules called for at least three of the four sensors to be in working order for a launch attempt to proceed. As a result of the failure, the Launch Director Doug Lyons postponed the launch, initially for 24 hours. This was later revised into a 72 hour delay, resulting in a next launch attempt set for Sunday December 9, 2007. This launch attempt was scrubbed when one of the ECO sensors again failed during fuelling.

The ECO sensors external connector was changed on the space shuttle external tank, causing a two month delay in the launch. Columbus was finally launched successfully on the third attempt at 2:45pm EST, February 7, 2008. Once at the station, Canadarm2 removed Columbus from the docked shuttle's cargo bay and attached it to the starboard hatch of *Harmony* (also known as Node 2), with the cylinder pointing outwards on February 11, 2008.

Research activities and payloads

Activities in the lab are controlled on the ground by the Columbus Control Centre (at DLR Oberpfaffenhofen in Germany) and by the associated User Support Operations Centres throughout Europe.

The laboratory can accommodate ten active International Standard Payload Racks (ISPRs) for science payloads. Agreements with NASA allocate to ESA 51% usage of the Columbus Laboratory. ESA is thus allocated five active rack locations, with the other five being allocated to NASA. Four active rack locations are on the forward side of the deck, four on the aft side, and two are in overhead locations. Three of the deck racks are filled with life support and cooling systems. The remaining deck rack and the two remaining overhead racks are storage racks.

In addition, four un-pressurized payload platforms can be attached outside the starboard cone, on the Columbus External Payload Facility (CEPF). Each external payload is mounted on an adaptor able to accommodate small instruments and experiments totalling up to 230 kilograms (507 lb).



External payloads SOLAR and EuTEF installed on LCC-lite cargo carrier prior to launch on shuttle mission STS-122.

The following European ISPRs have been initially installed inside Columbus:

1. Fluid Science Laboratory (FSL)
2. European Physiology Modules (EPM)
3. Biolab
4. European Drawer Rack (EDR)
5. European Storage Rack

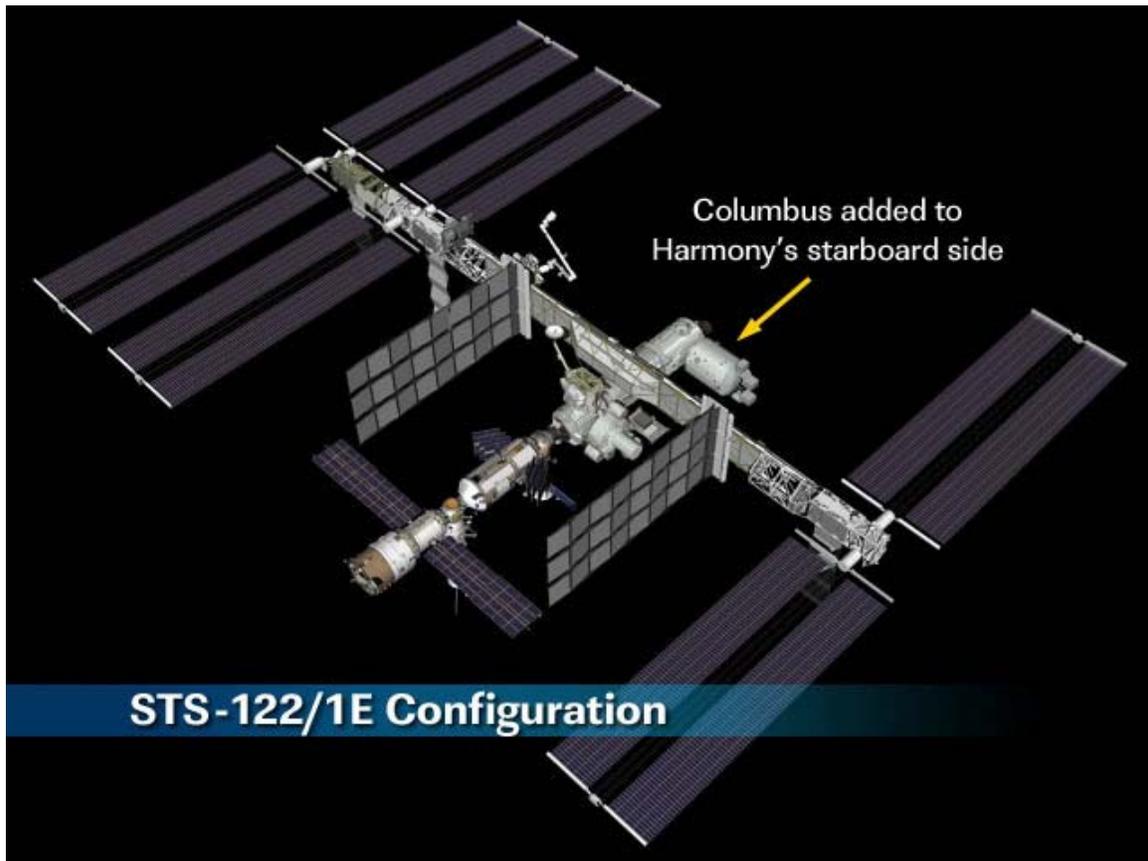
The first external payloads were mounted on Columbus by crew members of the mission STS-122 mission. The three payloads mounted are:

1. European Technology Exposure Facility (EuTEF) platform, which accommodates nine instruments: TRIBOLAB, PLEGPAY, MEDET, EUFIDE, DEBIE-2, FIPEX, EUTEMP, EXPOSE, DOSTEL, and the Earth Viewing Camera.
2. Solar Monitoring Observatory (SOLAR)
3. MISSE-6 (NASA payload)

Planned additional external payload:

1. Atomic Clock Ensemble in Space (ACES)
2. EXPORT
3. Atmosphere-Space Interaction Monitor (ASIM)

History



Columbus's position on the ISS

ESA's Board of Directors approved the Columbus program in 1985. From then on, numerous studies and proposals were made.

Like the MPLMs and the ATV resupply craft Columbus traces its origins to Spacelab.

Initially the Columbus program included three flight configurations: a *Man-tended Free-Flyer* (MTFF) element serviced by the Hermes shuttle and flying periodically to the station for maintenance and reconfiguration, an *Attached Pressurized Module* (APM), and a *Polar Platform* (PPF). For development cost saving and optimization of spares provisioning during the operational phase commonality was foreseen between the flight configurations and to the space station (e.g. same computers used for all three elements, video and comms units identical to station equipment).

When the complete phase C/D proposal (Fixed Price) was delivered end 1989 by the prime contractor MBB-ERNO it turned out that the costs were much higher than expected by ESA.



The Columbus logo

After several budget cuts (and cancellation of the CNES-led Hermes program), all that remained in the Columbus program was the APM, renamed to Columbus Orbital Facility (Note: later it was renamed to just *Columbus* being the present formal name); the polar platform was contracted separately with commonality to the French satellite HELIOS.

When only the APM was left in the program there were not enough tasks for the two main contributors Germany and Italy represented by MBB-ERNO and Alenia respectively. As compromise the PICA (Pre Integrated Columbus APM) - Principle was invented meaning a split systems engineering responsibility where Alenia as a Co-prime is responsible for the overall Columbus configuration, the mechanical and thermal/life support systems, HFE and harness design/manufacturing whereas EADS Astrium Space Transportation is responsible for the overall Columbus design and all Avionics systems including electrical harness design and software. Splitting off systems engineering responsibility and harness design under separate fixed-price contracts was found not to be advantageous with respect to efficiency and fast decision making as financial reasonings were pre-dominant in the last phase of development and verification.



Loading of Columbus at the Bremen airport into an Airbus Beluga

On May 27, 2006 Columbus was flown from Bremen, Germany to Kennedy Space Center on board an Airbus Beluga.

The structure used is based on the MPLM module built for NASA by Thales Alenia Space. In 2000 the pre-integrated module (structure including harness and tubing) was delivered to Bremen in Germany by the Co-prime contractor Alenia. The final integration and system testing was performed by the overall prime contractor EADS Astrium Space Transportation, after that the initial Payload was integrated and the overall complement checked-out.

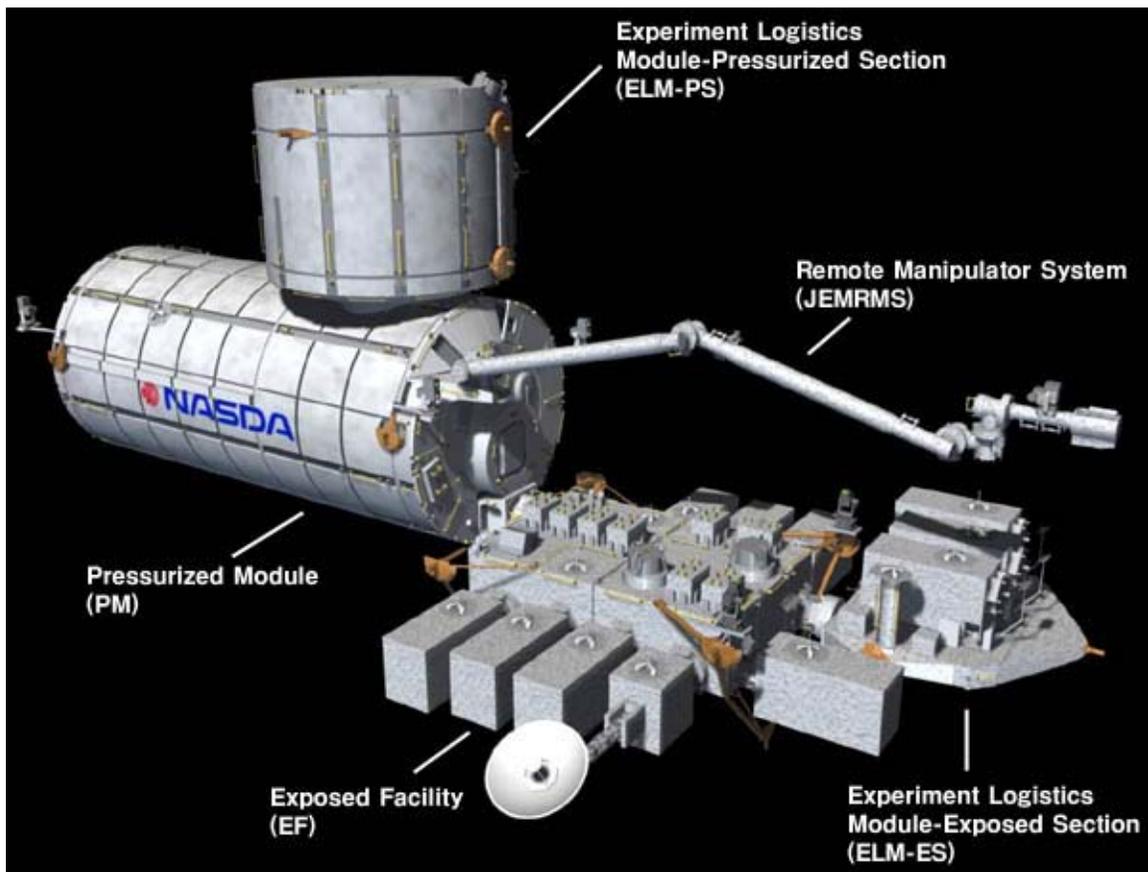
The final schedule was much longer than originally planned due to development problems (several caused by the complex responsibility splitting between the Co-prime and the Overall prime contractor) and design changes introduced by ESA but being affordable due to the Shuttle problems delaying the Columbus launch for several years. The main design change was the addition of the *External Payload Facility* (EPF), which was driven by the different European Payload organizations being more interested in outer space than internal experiments. Also the addition of a terminal for direct communications to/from ground, which could have been used also as back-up for the *ISS* system, was studied but not implemented for cost reasons.

Specifications

- Length: 7 m (23 ft)
- Diameter: 4.5 m (15 ft)
- Total mass: 10,300 kg (22,708 lb)
- Total payload mass 2,500 kg (5,512 lb)
- Total on-orbit mass 12,800 kg (28,219 lb)

Chapter 12

Japanese Experiment Module



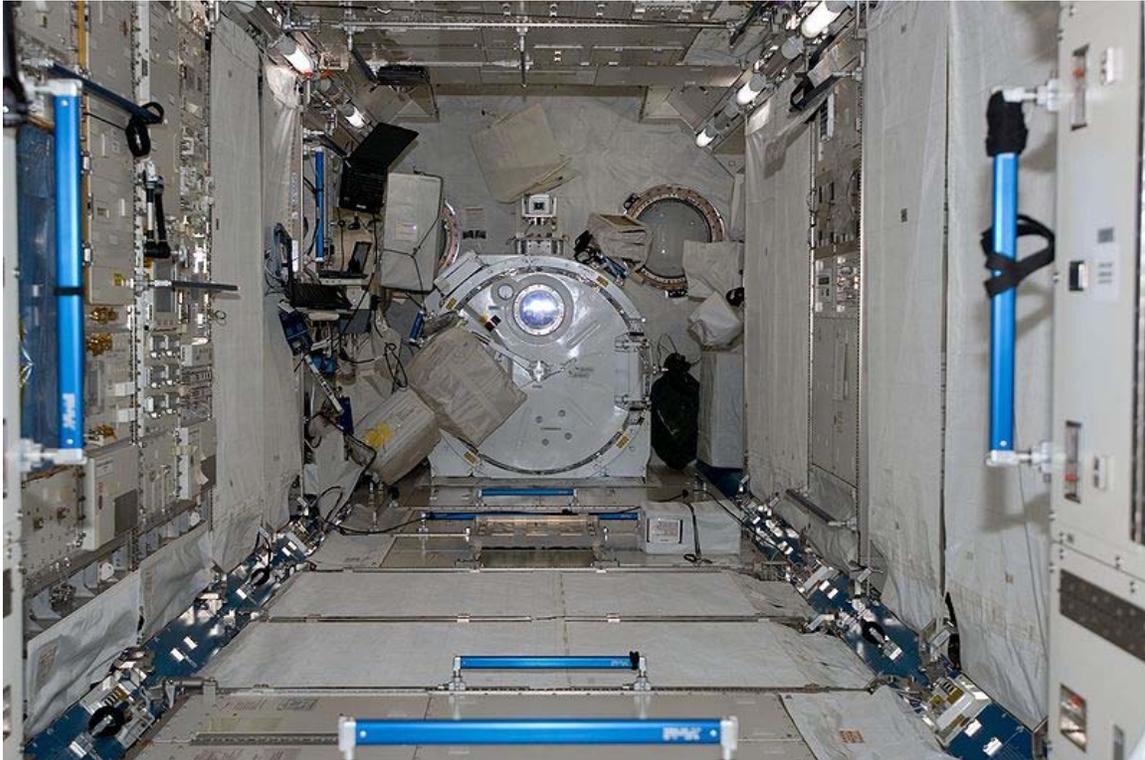
ISS JAXA JEM module

The **Japanese Experiment Module (JEM)**, also known with the nickname **Kibo** (きぼう *Kibō*[?], Hope), is a Japanese science module for the International Space Station (ISS) developed by JAXA. It is the largest single ISS module. The first two pieces of the module were launched on space shuttle missions STS-123 and STS-124. The third and final components were launched on STS-127.

Components

Kibō consists of four primary components:

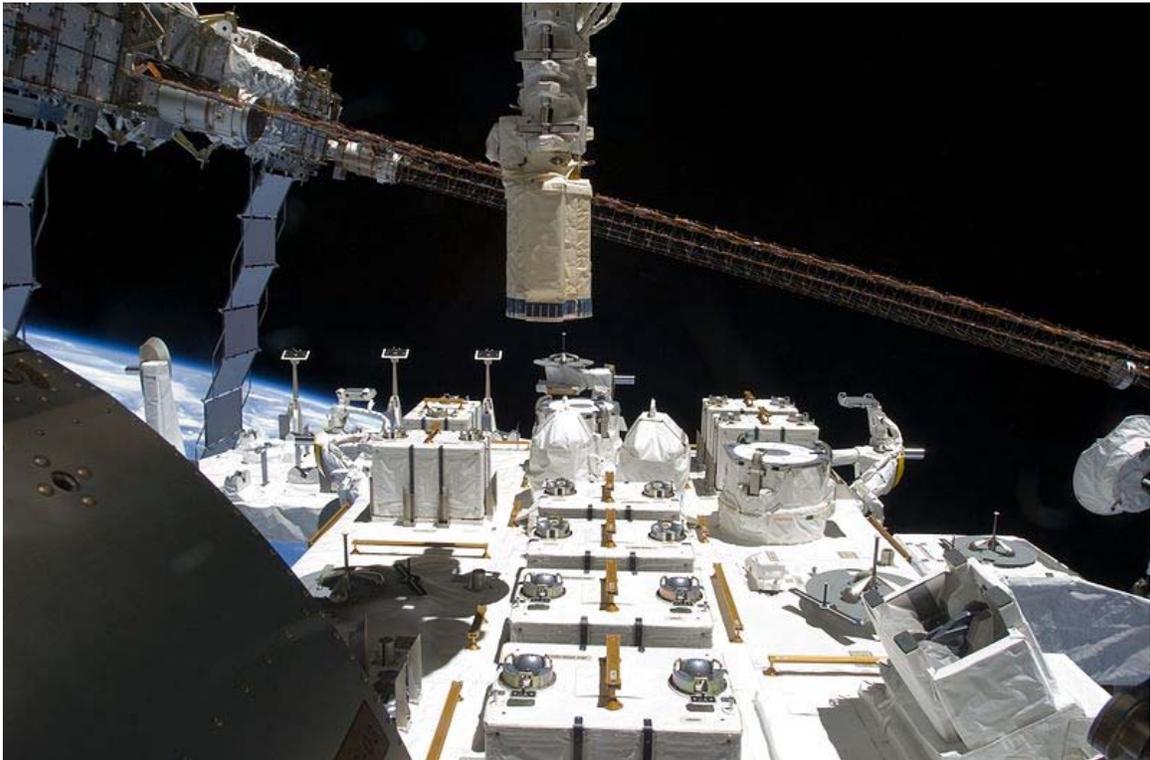
Pressurized Module



The interior of the Pressurized Module

The *Pressurized Module* (PM) is the core component connected to the port hatch of the Node 2 Module. It is a cylindrical shape and contains twenty-three International Standard Payload Racks (ISPRs), ten of which are dedicated to science experiments while the remaining 13 are dedicated to Kibo's systems and storage. The racks will be placed 6-6-6-5 among the four walls of the module. The end of the JEM-PM has an airlock and two window hatches. The three components: Exposed Facility, Experiment Logistics Module and the Remote manipulator all connect to the pressurized module.

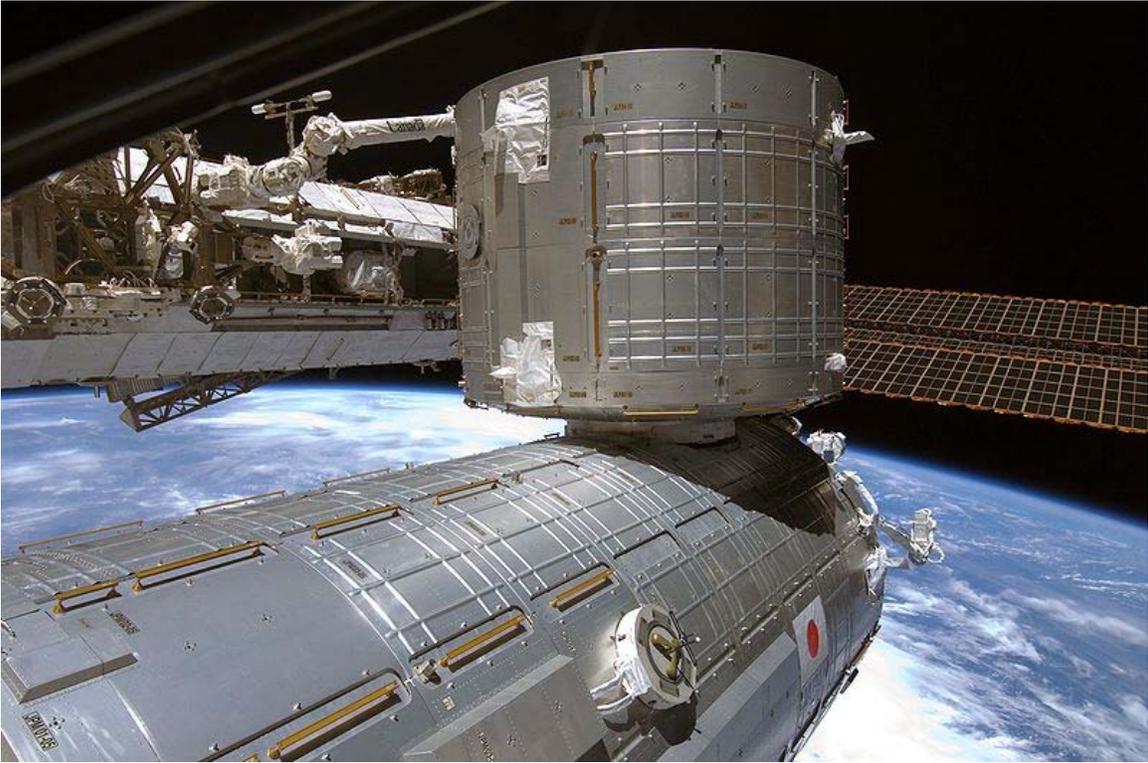
Exposed Facility



The Exposed facility as seen from Kibo

The *Exposed Facility* (EF), also known as "Terrace", is located outside the port cone of the PM (which is equipped with an airlocked hatch). The EF has 12 EFU (Exposed Facility Unit) Ports that attach to PIU (Payload Interface Unit) Connectors on EF-EEUs (EF-Equipment Exchange Units). All experiment payloads are fully exposed to the space environment. For Proper functioning of these experiments, the payload requires an ORU (Orbital Replacement Unit) which consists of the EPS (Electrical Power System), CT (Communications & Tracking) and the TCS (Thermal Control System). Of the 12 ORUs, 8 are replaceable by the JEMRMS while the other 4 are EVA replaceable.

Experiment Logistics Module



The exterior of the Experiment Logistics Module, Pressurized Section (top) and the Pressurized Module (bottom).

The *Experiment Logistics Module* (ELM), is now on orbit and includes two sections:

- The Japanese Experiment Logistics Module, Pressurized Section (ELM-PS) — also called the JLP — is a pressurized addition to the PM. The module is a storage facility that provides storage space for experiment payloads, samples and spare items.
- The unpressurized (external) section (ELM-ES) will serve the EF. It is intended as a storage and transportation module.

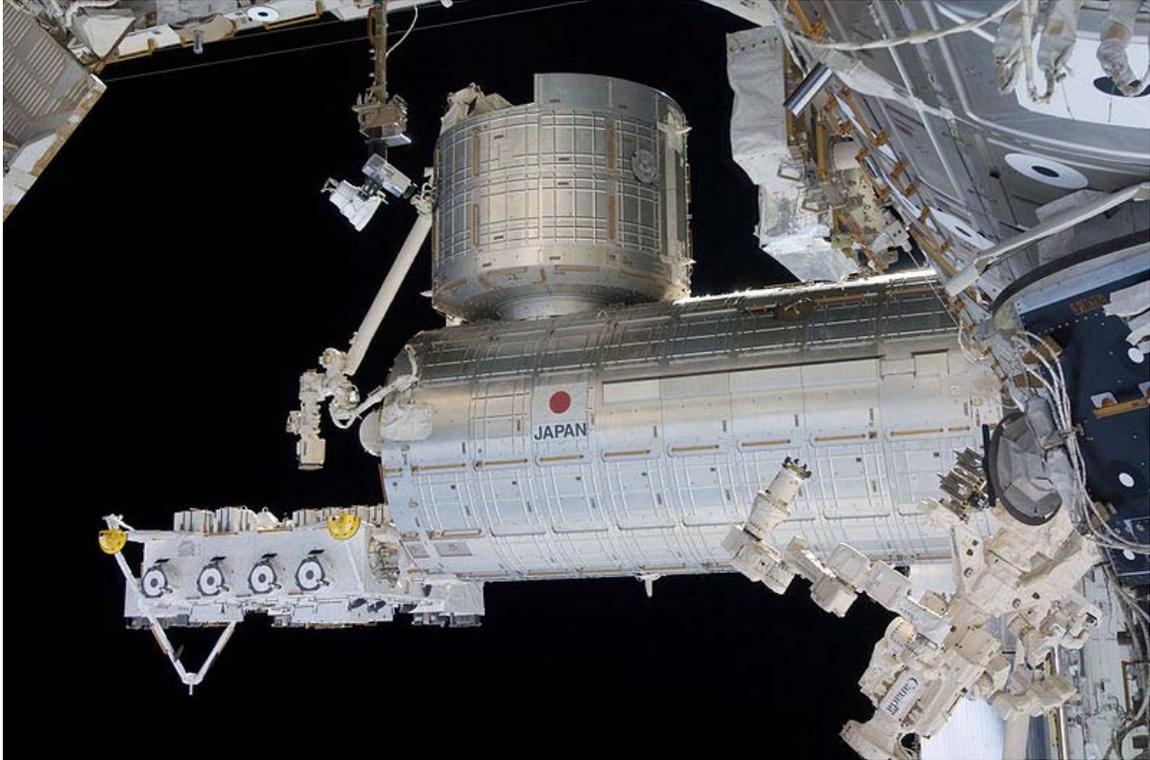
Remote Manipulator System



Technicians work on the Remote Manipulator System in the Kennedy Space Center

The *Remote Manipulator System* (JEMRMS) is a robotic arm, mounted at the port cone of the PM, intended to service the EF and to move equipment from and to ELM. The RMS control console was launched in the ELM-PS. The main arm was launched with the PM. The "Small Fine Arm", which attaches to the end effector of the main arm, was launched aboard HTV-1.

Launch sequence



A view of the completed Kibo module

NASA launched the JEM complex over three flights:

- On 12 March 2007 the *Experiment Logistics Module Pressurized Section* (ELM-PS) arrived in Kennedy Space Center (KSC) from Japan. It was stored in the Space Station Processing Facility until launched into orbit aboard Space Shuttle *Endeavour* as part of the STS-123 mission. At first the ELM-PS was connected to a temporary location into Harmony Module (Node 2) and later, on 6 June 2008, was moved to its final destination into the PM's upper section.
- On 30 May 2003 the *Pressurized Module* (PM) arrived in KSC from Japan. It was stored in the Space Station Processing Facility until launched into orbit aboard Space Shuttle *Discovery* as part of the STS-124 mission. On 3 June 2008 the PM was connected to the Harmony Module.

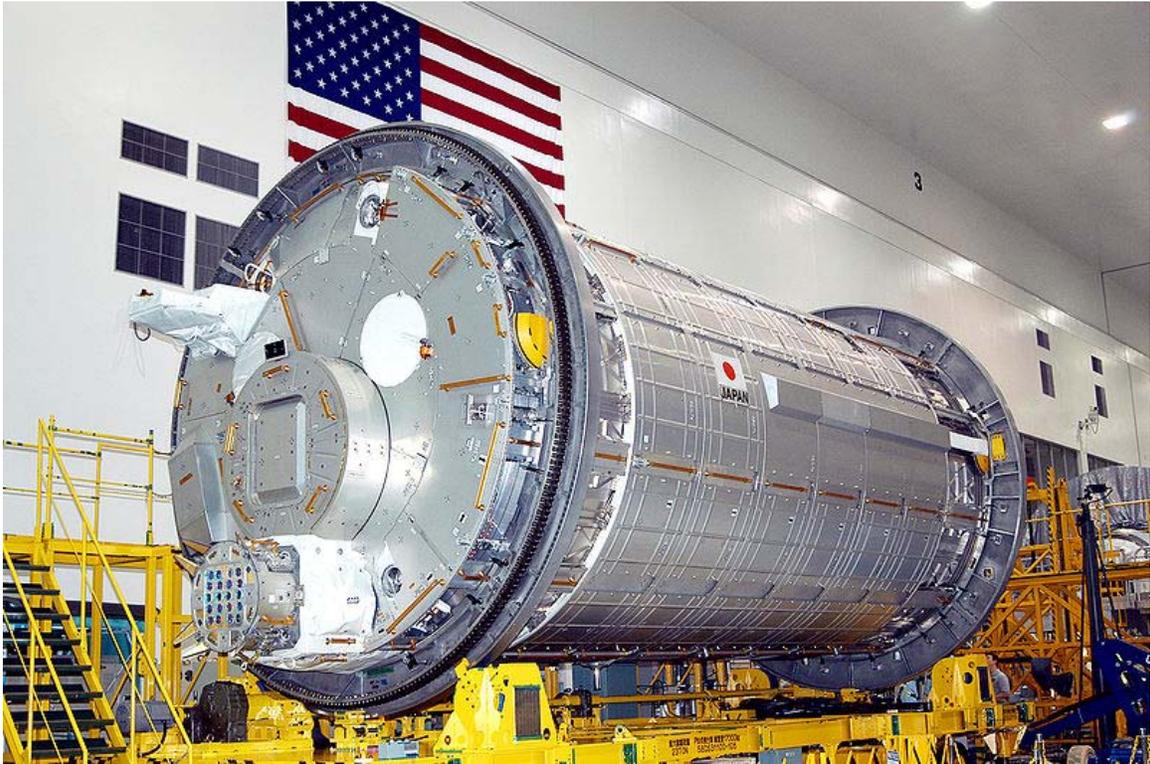


EF and ELM-ES arrive at KSC

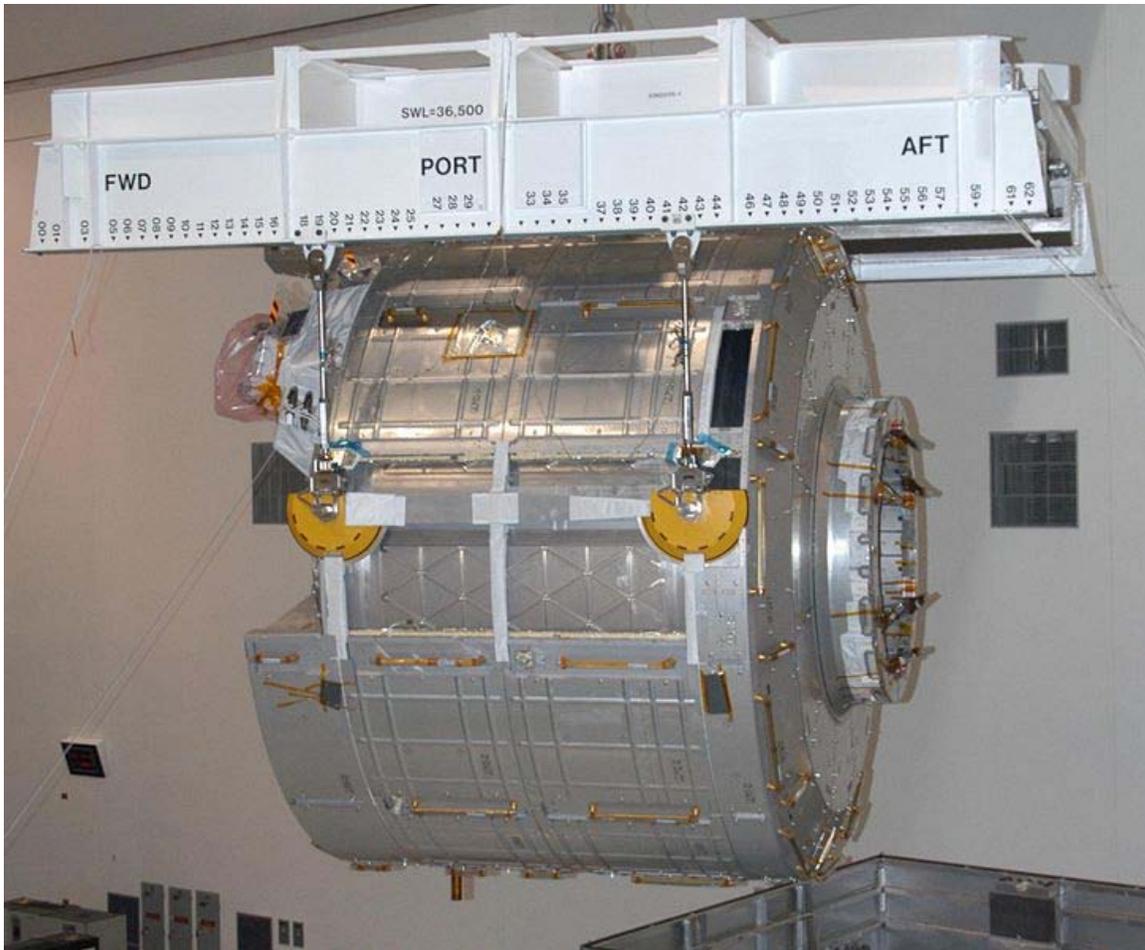
- The EF and ELM-ES arrived at KSC on 24 September 2008.

The *Exposed Facility* (EF) and ELM-ES were launched on STS-127, on 15 July 2009. The ELM-ES will be brought back to Earth at the end of the mission. The assembly of the EF was completed during the fifth spacewalk.

Specifications



JEM PM module in assembly



JEM ELM module in assembly

Kibō is the largest single ISS module.

- *Pressurized Module*
 - Length: 11.19 m (36.7 ft)
 - Diameter: 4.39 m (14.4 ft)
 - Mass: 14,800 kg (32,600 lb)
- *Experiment Logistics Module*
 - Length: 4.21 m (13.8 ft)
 - Diameter: 4.39 m (14.4 ft)
 - Mass: 8,386 kg (18,488 lb)

Current external experiments on Kibo

- **MAXI** X-ray astronomy from 0.5 to 30 keV
- **SMILES** observes and monitors very weak sub-millimeter wave emission lines of trace gas molecules in the stratosphere

- **SEDA-AP** (Space Environment Data Acquisition equipment-Attached Payload) measures neutrons, plasma, heavy ions, and high-energy light particles in ISS orbit.
- **HREP** (Hyperspectral Imager for the Coastal Ocean (HICO) & Remote Atmospheric & Ionospheric Detection System (RAIDS) Experimental Payload)

Planned external experiments on Kibo

- **CALET** Observation for high energy. Launch 2012 through H-II Transfer Vehicle, Mass: 2500 kg

Current internal experiments on Kibo

Japanese:

- **RYUTAI Rack** Fluid Physics Experiment Facility (FPEF), Solution Crystallization Observation Facility (SCOF), Protein Crystallization Research Facility (PCRF), Image Processing Unit (IPU)
- **SAIBO Rack** Cell Biology Experiment Facility (CBEF), Clean Bench (CB)

American:

- **EXPRESS Rack 4** Biotechnology Specimen Temperature Controller (BSTC), Gas Supply Module (GSM), Space Acceleration Measurement System-II (SAMS-II), Biotechnology Specimen Temperature Controller (BSTC)
- **EXPRESS Rack 5**
- **MELFI-1**

Planned internal experiments on Kibo

- **KOBAIRO Rack** Gradient Heating Furnace (GHF)
- **MPSR** Multi-Purpose Small payload Rack

Chapter 13

Rassvet



MRM1 Rassvet as seen from the Cupola module during STS-132

Rassvet (Russian: Рассвёт; lit. "dawn"), also known as the **Mini-Research Module 1 (MRM 1)** (Russian: Малый исследовательский модуль, МИМ 1) and formerly known as the **Docking Cargo Module (DCM)**, is a component of the International Space Station (ISS). *Rassvet* will be primarily used for cargo storage and as a docking port for visiting spacecraft. It was flown to the ISS on STS-132 aboard Space Shuttle *Atlantis* on May 14, 2010, and was connected to the ISS on May 18. The hatch connecting *Rassvet* with the ISS was opened on May 20.

On 28 June 2010 the Soyuz TMA-19 spacecraft performed the first docking with the module.

Details



Rassvet in the Space Station Processing Facility (SSPF) at Kennedy Space Center in Florida

Rassvet was docked to the nadir port of *Zarya* with help from the SSRMS. *Rassvet* carried externally attached outfitting equipment from NASA for the *Nauka* Multipurpose Laboratory Module (MLM), a spare elbow joint for the European Robotic Arm, and a radiator. Delivering *Rassvet* thus enabled NASA to fulfill its promise to ship 1.4 metric tons to equip the MLM.

Rassvet has two docking units: one to attach to the nadir port of the *Zarya* module, and one to provide a docking port for a Soyuz or Progress spacecraft. It implements the role of the Docking and Stowage Module from the original ISS design. Russia announced the cancellation of the last of the two planned Russian Research Modules when it announced the plans for *Rassvet*.

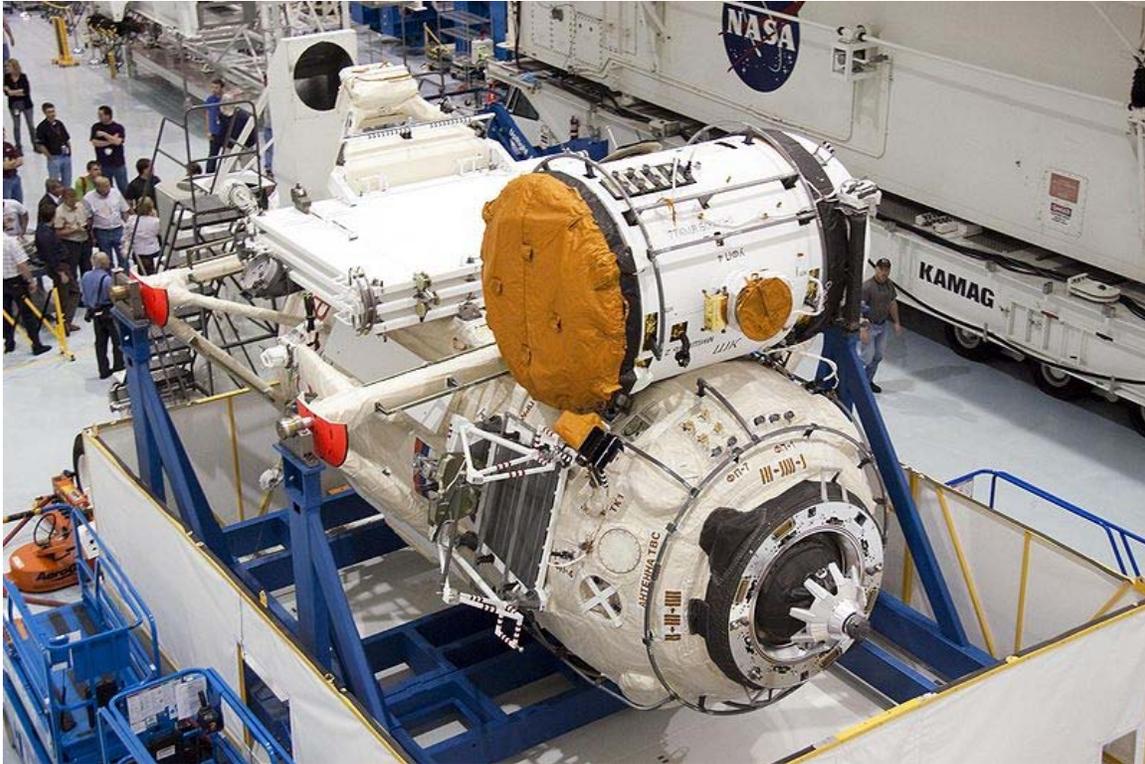
Initial planning

In the initial ISS plan there was a **Docking and Stowage Module (DSM)**. This module was a planned Russian element of the International Space Station that was intended to provide facilities for stowage and an additional docking port. The **Docking and Stowage Module** would have been used for additional stowage and to support Soyuz docking, and would have been launched to the International Space Station on a Proton launch vehicle. The DSM would have been mounted to *Zarya*'s nadir (Earth-facing) docking port. It was similar in size and shape to the *Zarya* module.



MRM1 at the Astrotech Facility





This ISS module was canceled due to budget constraints by Russia for some time, but according to the current schedule the design of the module is modified into the **Docking and Cargo Module** (MRM 1 *Rassvet*) that will connect to the same *Zarya* location and will provide stowage space and docking port. During the cancellation period it was a proposal that a **Multi Purpose Module (MPM)** called *Enterprise* should be docked at its location and afterwards the **Multipurpose Laboratory Module** was expected to be located there, but according to current plans *Enterprise* is not approved and MLM will be docked to *Zvezda's* nadir port instead.

Benefits

Rassvet came to exist out of two requirements that needed to be fulfilled by the ISS partners:

1. NASA is under contract to carry the MLM outfitting equipment into space.
2. The overlapping missions of the Progress, Soyuz, and ATV spacecraft highlight the need of having four Russian docking ports available on the ISS. The cancellation of both Russian Research Modules meant that the ISS would be left with just three such docking ports after the installation of the Pressurized Multipurpose Module, which makes the nadir port of *Zarya* unusable.

The new MRM solves both of these issues. NASA will not need to add another payload flight to accommodate the MLM outfitting equipment, as it can attach the hardware to the exterior of MRM 1; the ISS will have 4 docking ports available (the aft port of *Zvezda*,

the port of *Pirs* (later MLM) on the nadir port of *Zvezda*, the port of MRM 2 on the zenith port of *Zvezda*, and the port on MRM 1 on the nadir port of *Zarya*); and Russia's cancellation of the Research Module is of less consequence for the ISS program as a whole.

Design and construction



The Experiment Airlock of the Rassvet module

The module was designed and built by S.P. Korolev RSC Energia, from the already-made pressurized hull of the mock-up for dynamic tests of the canceled Science Power Platform .

On December 17, 2009 airplane AN-124 carrying the *Rassvet* Module and ground process equipment kit arrived at the Kennedy Space Center . Upon unloading, the equipment was delivered to prelaunch processing facility run by the Astrotech. Energia specialists and technicians continued their work at the SPPF facility of the Astrotech on the processing of the *Rassvet* Module and completed stand-alone electrical tests and leak tests of the module and the airlock. They also prepared the airlock and the radiative heat exchanger for installation onto *Rassvet*. The module was moved to NASA's Space Station Processing Facility on April 2, 2010. After completing the final touches, it was placed into the shuttle payload transporter on April 5, 2010. The payload canister containing the *Rassvet* Module arrived at Launch Pad 39A on April 15, 2010.

Engineers at Launch Pad 39A preparing space shuttle *Atlantis* had noticed paint peeling from the MRM 1 module. Although the problem was declared to have no impact on the operation of MRM 1, it holds a potential threat of releasing debris on orbit.

Basic specifications



The Soyuz TMA-19 spacecraft docks to the Rassvet Mini-Research Module 1

MRM 1 basic specifications:

Module launch mass	5075 kg
Total Launch mass	8015 kg
Maximum hull diameter	2.35 m
Hull length between docking assembly planes	6 m
Pressurized volume	17.4 m ³
Habitable volume	5.85 m ³

Chapter 14

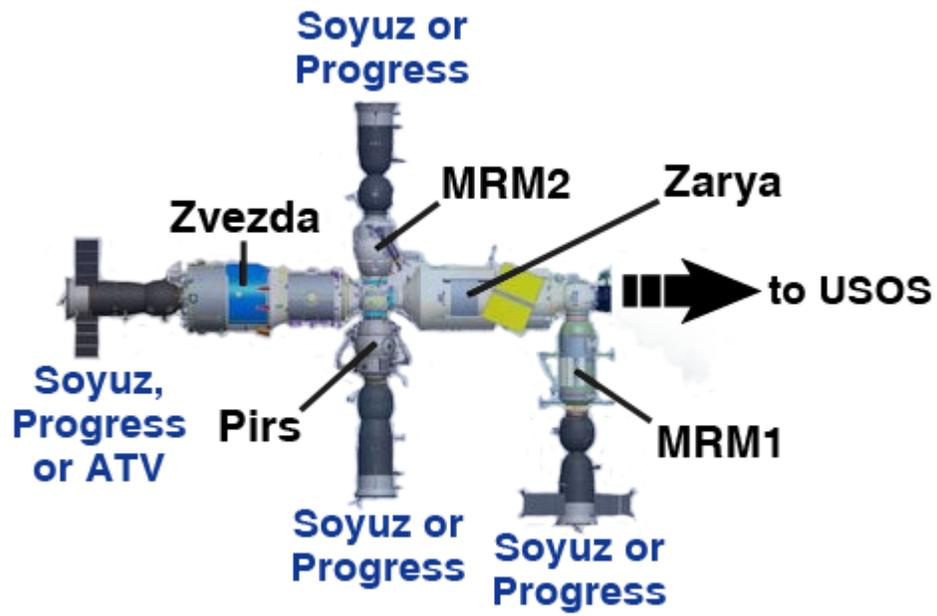
Poisk



Poisk docking module at the Space Station

Poisk (Russian: По́иск; lit. *Search*), also known as the **Mini-Research Module 2 (MRM 2)**, *Малый исследовательский модуль 2*, or *МИМ 2*, is a docking module of the International Space Station. Its original name was **Docking Module 2** (*Stykovochniy Otshek 2* (SO-2)), as it is almost identical to the Pirs Docking Compartment. *Poisk* was the first major Russian addition to the International Space Station since 2001.

Details



The location of MRM-2 on the Russian Orbital Segment



Poisk arrives at the ISS for docking in 2009

Poisk docked to the zenith port of the *Zvezda* module on November 12, 2009, and will serve as an additional docking port for Soyuz and Progress spacecraft and as an airlock for spacewalks. *Poisk* will also provide extra space for scientific experiments, and provide power-supply outlets and data-transmission interfaces for two external scientific payloads to be developed by the Russian Academy of Sciences.

Two spacewalks conducted from the ISS in June 2009, successfully completed activities anticipating *Poisk* module's future berthing.

On 5 June 2009, during Russian Orlan EVA-22 spacewalk Expedition 19/20 Commander Gennady Padalka and Flight Engineer Michael Barratt installed two Kurs docking antennas, a docking target and electrical connectors on the exterior of *Zvezda*'s Service Module.

On June 10, 2009, during Russian Orlan EVA-23 spacewalk Padalka and Barratt replaced a flat hatch cover in the forward section of *Zvezda* with a standard conical docking cone cover to allow for *Poisk*'s docking.

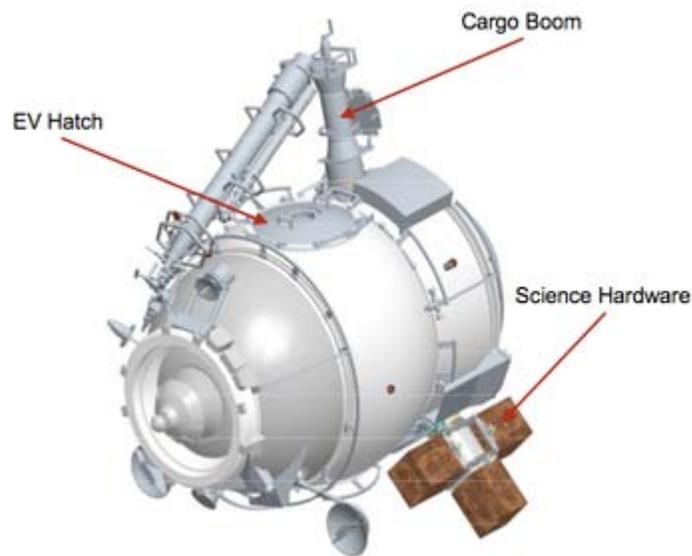


Diagram of the *Poisk* docking module



Astronaut Jeffrey Williams and cosmonaut Maksim Suraev inspecting the *Poisk* module



Poisk approaching the ISS for docking

On January 14, 2010, cosmonauts Oleg Kotov and Maksim Suraev conducted a spacewalk to outfit the *Poisk* module to prepare for receiving Soyuz and Progress ships in the future . They deployed antennas and a docking target, installed two handrails and plugged the new module's Kurs antennas into the Kurs docking system circuitry . The spacewalk lasted five hours and 44 minutes.

On January 21, 2010, the module was first used when cosmonaut Suraev and Expedition 22 Commander Jefferey Williams relocated their Soyuz TMA-16 spacecraft from the aft port of the *Zvezda* module to the zenith-facing port of the *Poisk* module . The Soyuz TMA-16 spacecraft undocked from the aft end of the *Zvezda* service module at 10:03 UTC and backed away to a distance of about 100 feet from the space station. Undocking occurred as the station flew about 213 miles high off the southwest coast of Africa. Redocking occurred at 10:24 UTC after Suraev fired the *Soyuz* maneuvering thrusters to fly halfway around the orbiting space station and line up with the *Poisk* module.

Design and construction

The module was designed and built by S.P. Korolev RSC Energia , the leading organization engaged in the development and operational use of the ISS Russian segment.

Launch in 2009



The propulsion compartment of the *Poisk* module departs the Space Station

The module was launched on November 10, 2009, 2:22 p.m. GMT attached to a modified Progress spacecraft, called Progress M-MIM2, on a Soyuz-U rocket from Launch Pad 1 at the Baikonur Cosmodrome in Kazakhstan. The occasion also marked the 1750th launch of a Soyuz rocket in its various configurations. About eight minutes after launch, the three-stage Soyuz rocket delivered *Poisk*, to a low-altitude injection orbit. According to NASA *Poisk* carried about 1800 pounds of cargo to the ISS including new Russian Orlan spacesuits, life support equipment, medical supplies and crew hygiene items.

The Progress space tug provided electrical power and propulsion for the *Poisk* module during its two-day journey to the space station. On 12 November, Progress began its automated final approach to the station on a Kurs rendezvous radar system and at 15:41 UTC *Poisk* docked to the *Zvezda* module's zenith port. The docking happened as the space station sailed more than 220 miles over northern Kazakhstan.

Cosmonauts Maksim Suraev and Roman Romanenko entered the module for the first time by opening the hatch leading into *Poisk* at 12:17 UTC on 13 November 2009.

The jettisoning of the Progress ship from the *Poisk* module happened around 8 December 2009. The Progress was destroyed during re-entry into the atmosphere.

Specifications



Poisk after arriving at the Space Station on November 12, 2009

Designation	240GK No. 2L
Launch mass	3670 kg ± 50 kg
Maximum hull diameter	2.55 m
Hull length between docking assembly planes	4.049 m
Pressurized volume	14.8 m ³
Habitable volume	10.7 m ³
Number of egress hatches (open inward)	2
Egress hatch diameter	1 m
Mass of delivered cargoes	up to 1000 kg

False depressurization alarm

False alarms woke the crews aboard space shuttle *Atlantis* and the Space Station at 01:36 UTC on 20 November 2009 and once again at 02:53 UTC on 21 November. An erroneous indication of a rapid depressurization led to the automatic shutdown of ventilation fans throughout the station, which stirred up dust and led to a false smoke detection alarm in the European Space Agency's Columbus laboratory. Mission control Capcom Frank Lien in Houston told Expedition 21 Commander Frank De Winne it might have originated with the *Poisk* module.

Visited spacecraft

The following Table shows the spacecraft that have linked up with the Poisk Module

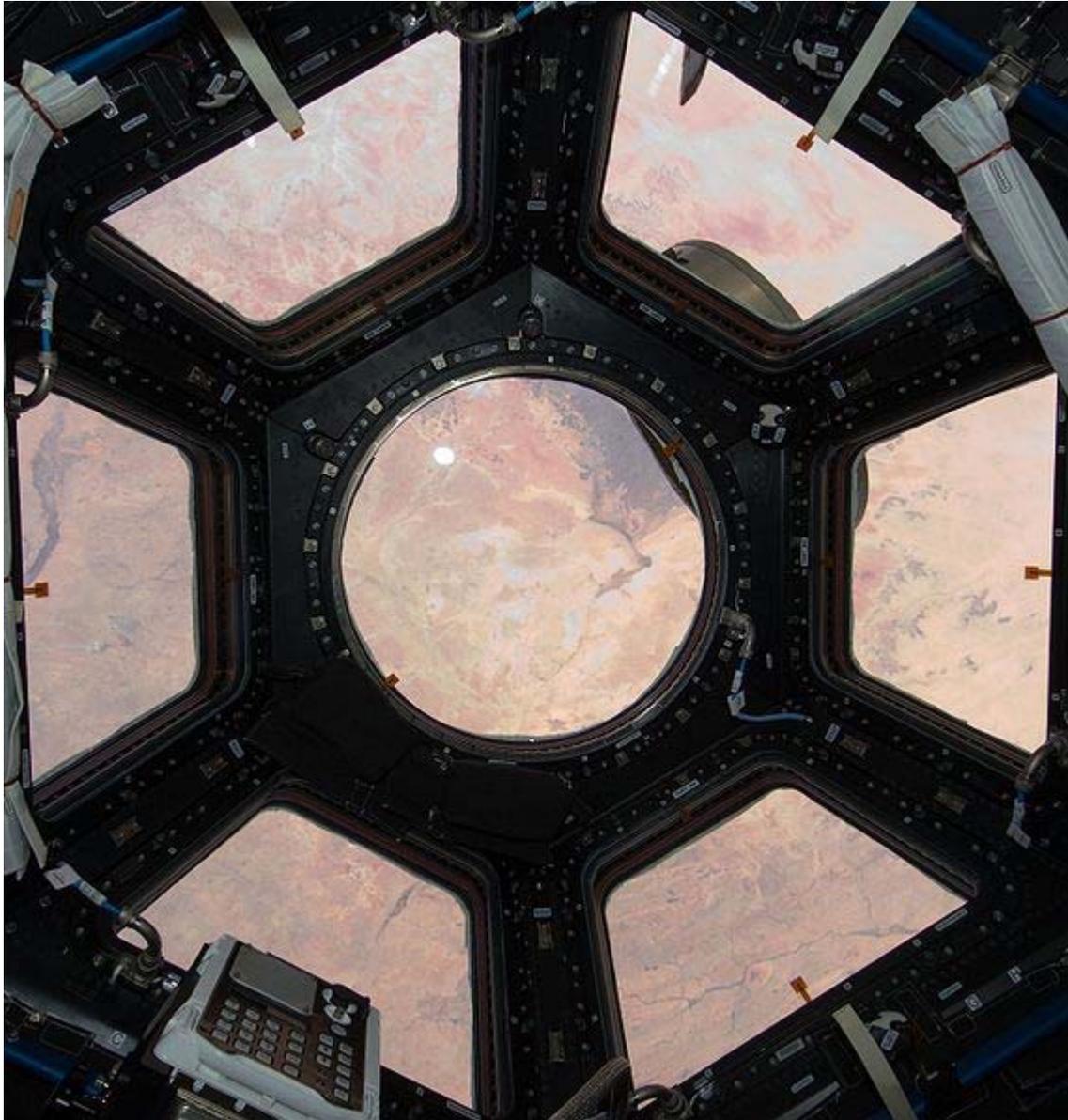
Spacecraft	Docking	Undocking
Soyuz TMA-16	January 21, 2010 5:24 a.m. EST	March 18, 2010 8:03 UTC
Soyuz TMA-18	April 4, 2010 5:25 UTC	September 25, 2010 02:02 UTC
Soyuz TMA-01M	October 10, 2010 00:01 UTC	March 16, 2011 Planned

Chapter 15

Cupola



Tracy Caldwell Dyson in the Cupola module of the International Space Station observing the Earth below.



The Sahara desert viewed through the Cupola with its shutters open

The **Cupola** is an ESA-built observatory module of the International Space Station (ISS). Its seven windows are used to conduct experiments, dockings and observations of Earth. It was launched aboard Space Shuttle mission STS-130 on 8 February 2010 and attached to the *Tranquility* (Node 3) module. With the Cupola attached, ISS assembly reached 85 percent completeness. The Cupola is the largest window ever used in space.

Overview



External view of the Cupola with window shutters open

The Cupola provides an observation and work area for the ISS crew giving visibility to support the control of the space station remote manipulator system and general external viewing of Earth, celestial objects and visiting vehicles. Its name derives from Italian word *cupola*, which means "dome". The Cupola project was started by NASA and Boeing, but canceled due to budget cuts. A barter agreement between NASA and the ESA resulted in the Cupola's development being resumed in 1998 by the ESA. It is extremely important to the ISS astronauts, as previously they have been confined to looking out of small portholes or at best the 20-inch (50 cm) window in the US *Destiny* laboratory. The Cupola is berthed onto the down-facing port of Node 3—the final of three modules, including Node 1 and Node 2.

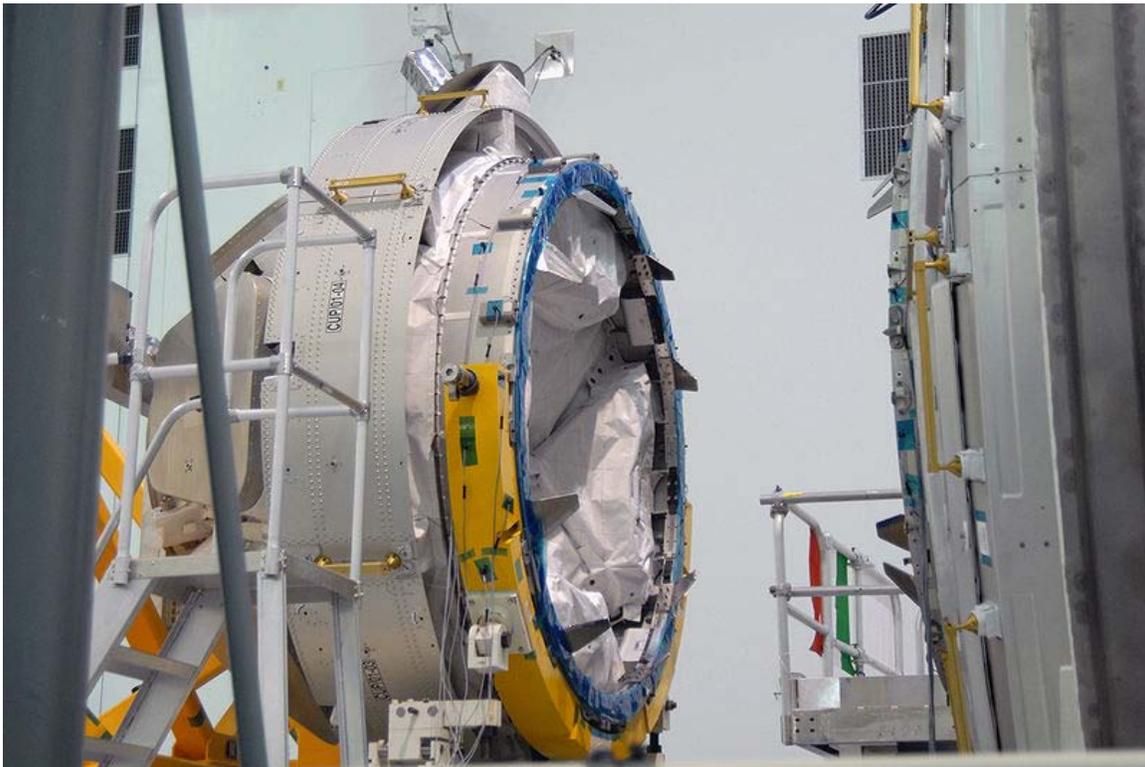
Design and construction



Doug Wheelock in the Cupola

The International Space Station Cupola was first conceived in 1987 by Space Station Man-Systems Architectural Control Manager Gary Kitmacher as a workstation for operating the station's robotic arm, maneuvering vehicles outside of the station, and observing and supporting spacewalks. He likened the use as similar to that of the Shuttle Orbiter Aft Flight Deck. There were to have been 2 Cupolas, one on either end of the racetrack shape formed by the station modules and nodes. It was initially named the "windowed workstation", to discriminate it from other computer-based workstations inside of the station and from which the crew could operate the station's systems. Once the idea was initially accepted, a number of people went to work. Human factors specialist Frances Mount began to develop the rationale and operational scenarios for the Cupola, and got considerable support from Chief Astronaut John Young and Shuttle Commander Gordon Fullerton. Charles Wheelwright, who had defined the specifications for every window on every prior US manned spacecraft, began to define the design specs of the Cupola windows. Laurie Weaver, who had just started with NASA as a co-op, began to work on a series of different configurations for the Cupola. She started with Kitmacher's idea based on the Shuttle Aft Flight Deck, in this case two Aft Flight Decks mounted back to back, placed atop a short cylinder. An inexpensive mock-up made of PVC tubes was built and tested underwater where critical dimensions could be measured to ensure that two crew members in zero-g would have adequate access. Then she built a series of small cardboard models, looking at a variety of different alternative shapes. The

different configurations and their positive and negative attributes were presented at a series of Crew Station Reviews over the next year in which participants rated each. The Cupola that evolved was octagonal in shape, with eight similar windows around the periphery, four quadrant windows overhead, and mounted on a cylinder. The module was designed to fully contain at least two crewmembers 'floating' side by side in zero-g neutral body posture. About this time, Kitmacher and Designer Jay Cory applied the term Cupola for the first time. Kitmacher wrote the requirements and the name into the Man-Systems Architectural Control Document and into the RFPs for Work Package 1 at MSFC and Work Package 2 at JSC. Later Kitmacher went on to lead the Man-Systems group leading the first lunar outpost and moonbase studies and the Cupola reappeared on several of his rover and module designs.



Cupola being aligned...



Cupola getting mated...



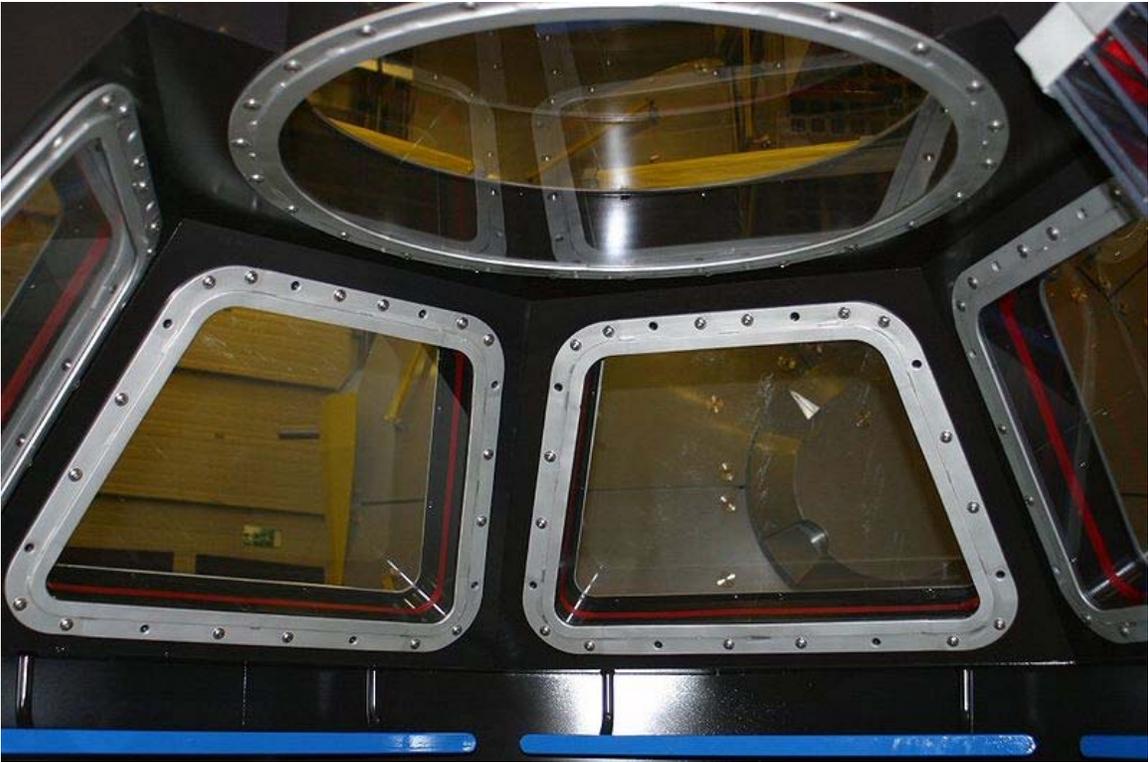
Cupola-artists rende...



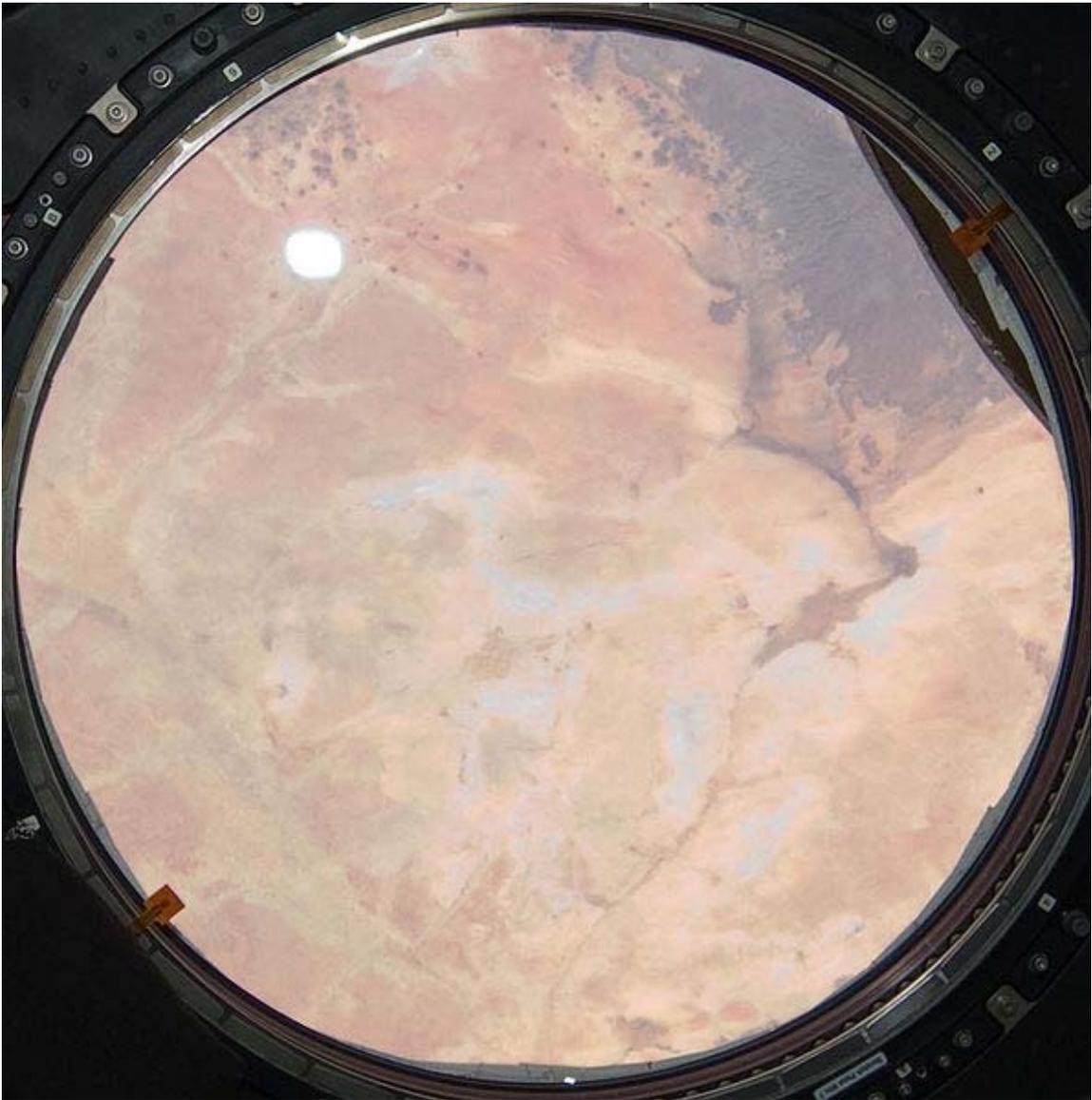
Cupola-close-up-iss0...



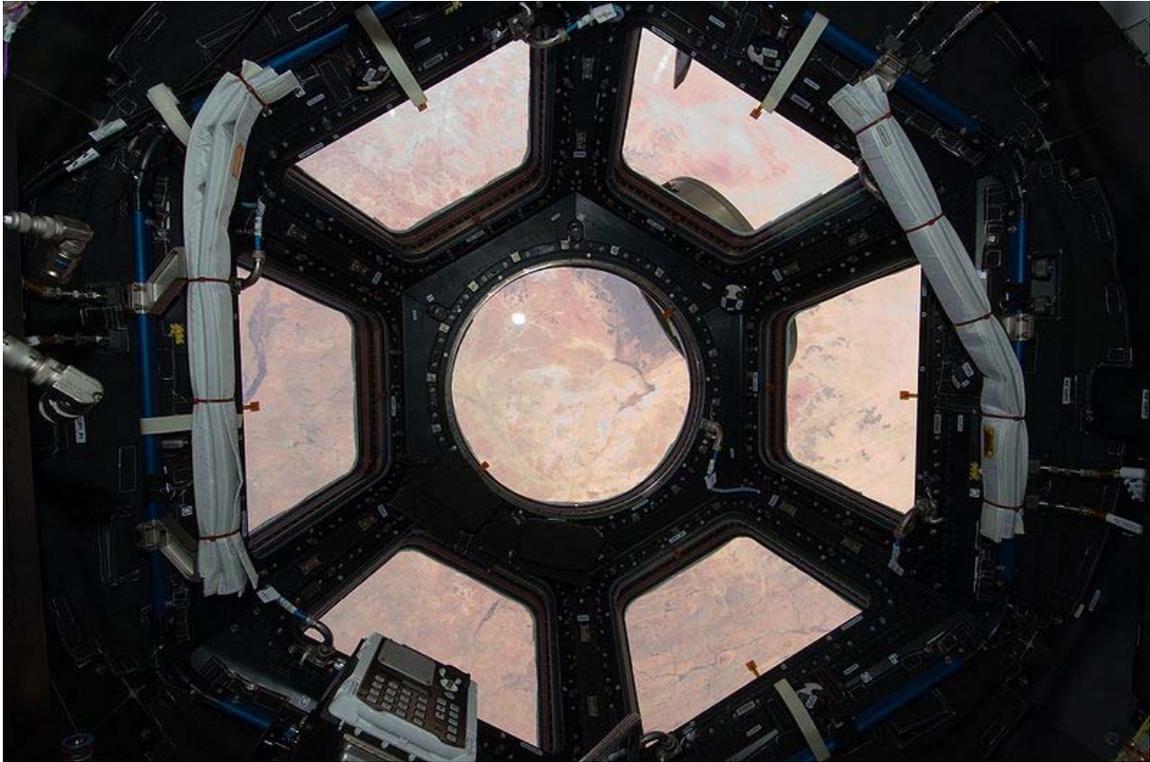
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Cupola ISS open shut...

Because of confusion between the responsibilities of the two contracts, both Boeing, which won Work Package 1, and McDonnell-Douglas, which won Work Package 2, bid to build the Cupola. The McDonnell-Douglas design was basically the same as NASA's but Boeing's was smaller; a hexagon, with a single large circular overhead window, and a much shorter cylinder; this design had been considered but previously discarded because it was unable to accommodate two crew members completely and would instead require the crew to dangle their legs and bodies in the Node to which the Cupola would be attached. This design was the one ultimately built. Components of the Cupola were initially fabricated in California, and the windows in New York in the late 1980s. But as budgets were cut, the Cupola was a favorite target. Several times it was fought back into the program only to be cut again as not technically required. More than once the responsibilities for fabrication were bartered to one international partner and then another in exchange for Shuttle launch services and resources that the US would provide on-board the station in orbit. The Cupola made the rounds to Brazil and then finally wound up with ESA and the Italians in 1998, who did complete it back in 2003. Even then the launch of the Cupola was repeatedly delayed until it finally made it into orbit in February, 2010.

With final design and assembly by the Italian contractor Alenia Spazio (now Thales Alenia Space), it is approximately 2 metres in diameter and 1.5 metres tall. It has six side windows and a top window, all of which are equipped with shutters to protect them from damage by micrometeorites and orbital debris. It features a thermal control system, audio, video and MIL-STD-1553 bus interfaces, as well as the connections needed for installing one of the two identical robotic workstations that control the Canadarm2 into it.

Installation



Astronaut Nicholas Patrick hanging on to Cupola

The Cupola was launched aboard the Space Shuttle on mission STS-130, on February 8, 2010. It was berthed to the forward port of the Tranquility module for launch, and was later transferred to the nadir-facing port of Tranquility by the Canadarm2, once Tranquility had been berthed to the Unity Module of the ISS. The installation of the Cupola, along with Tranquility, marks one of the last main components to be added to the International Space Station.

Specifications

- Overall Height: 1.5-metre (4.9 ft)
- Maximum Diameter: 2.95-metre (9.68 ft)
- Launch Mass: 1,805-kilogram (3,979 lb)
- On Orbit Mass: 1,880-kilogram (4,145 lb)

- Dome: Forged Al 2219-T851
 - Skirt: Al 2219-T851
 - Windows: Fused Silica and Borosilicate Glass
 - MDPS Shutters: Kevlar/Nextel sheets
 - Electrical Power: Node 120 V Interface
-
- Top Window: 80-centimetre (31 in) Diameter
 - Thermal Control: Goldised Kapton Multi-Layer Insulation Blanket