



# Support Vehicles of the International Space Station

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 m<sup>3</sup>)

**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

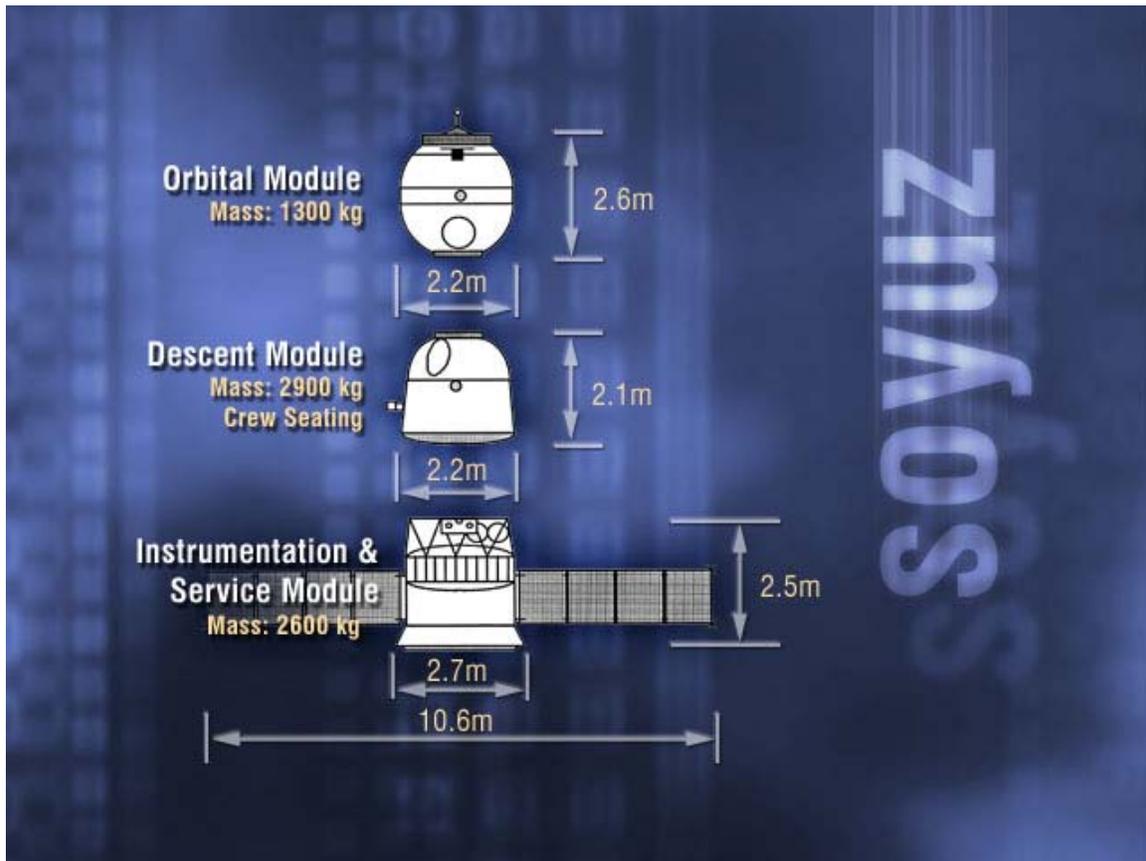


Diagram showing the three elements of the Soyuz-TMA spacecraft.

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

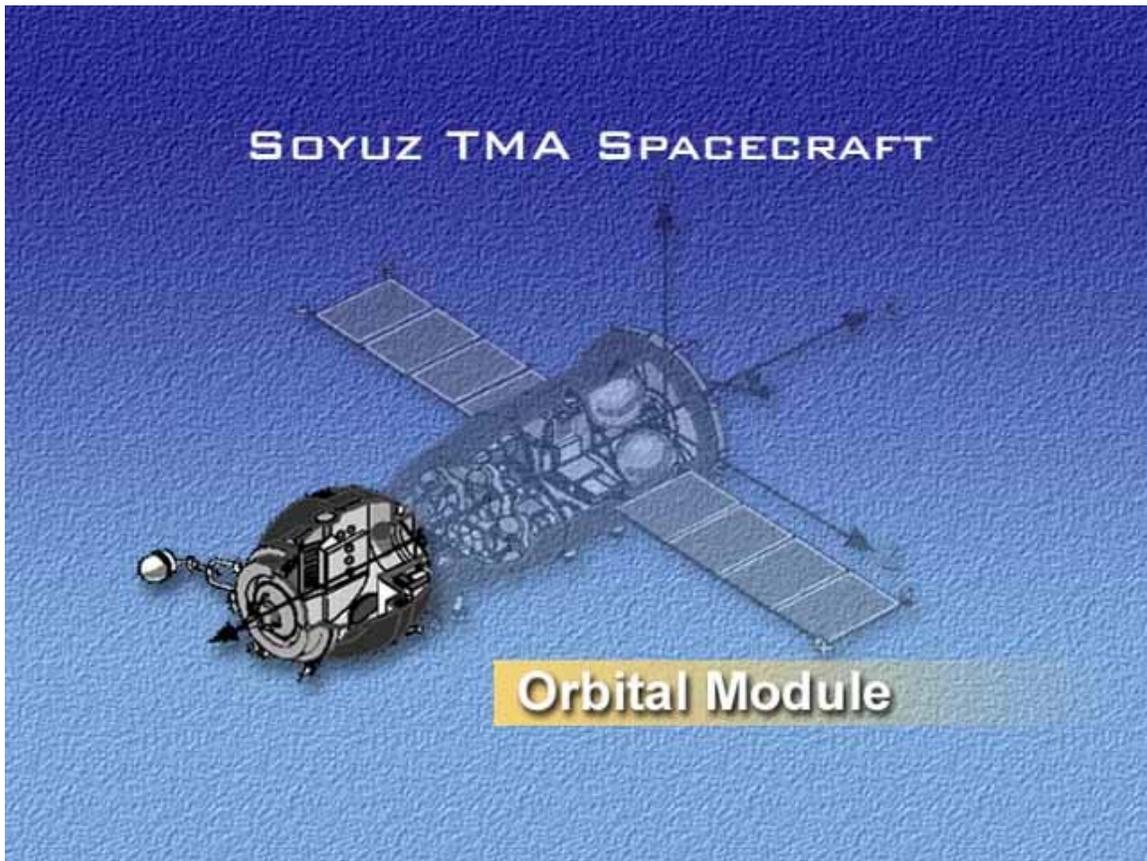
- A spheroid orbital module, which provides accommodation for the crew during their mission;
- A small aerodynamic reentry module, which returns the crew to Earth;
- A cylindrical service module with solar panels attached, which contains the instruments and engines.

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  $\text{KO}_2$  cylinders, which absorb most of the  $\text{CO}_2$  and water produced by the crew and regenerates the oxygen, and  $\text{LiOH}$  cylinders which absorb leftover  $\text{CO}_2$ .

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)*; Bytovoï 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

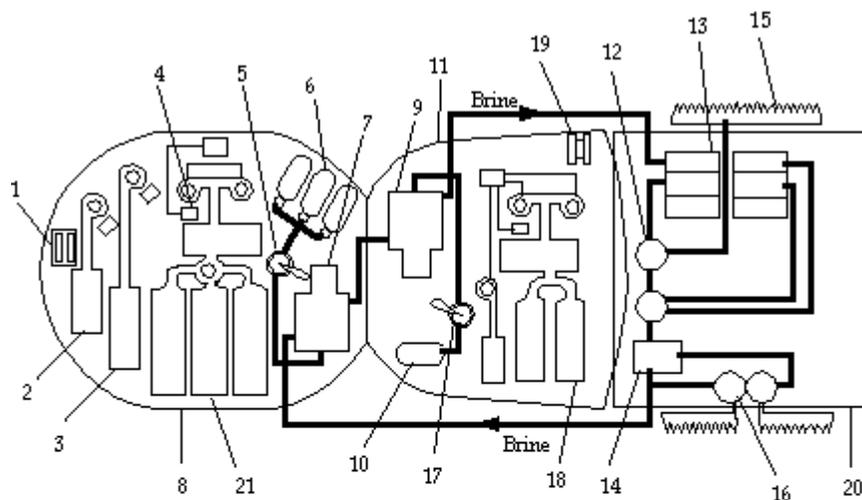
Because its modular construction differs from that of previous designs, the Soyuz has an unusual sequence of events prior to re-entry. The spacecraft is turned engine-forward and

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 <sub>2</sub> Removal                               | (12) Temperature Control Valves   |
| (3) KO <sub>2</sub> Oxygen Supply and Primary CO <sub>2</sub> 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 <sub>2</sub> O Storage Tanks   | (16) Sequencing Space Radiators   |
| (7) Condensing Heat Exchanger with wick-type H <sub>2</sub> O separator    | (17) Manual Pump  |
| (8) Flight Module  | (18) Trace Contaminant Control Bed  |
| (9) Condensing Heat Exchanger with wick-type H <sub>2</sub> O separator    | (19) Pressure Relief Valve  |
| (10) H <sub>2</sub> O Storage Tank   | (20) Equipment Module   |
|  | (21) KO <sub>2</sub> Beds for Oxygen Supply and Trace Contaminant Removal with Activated Charcoal and Bacteria Filter |

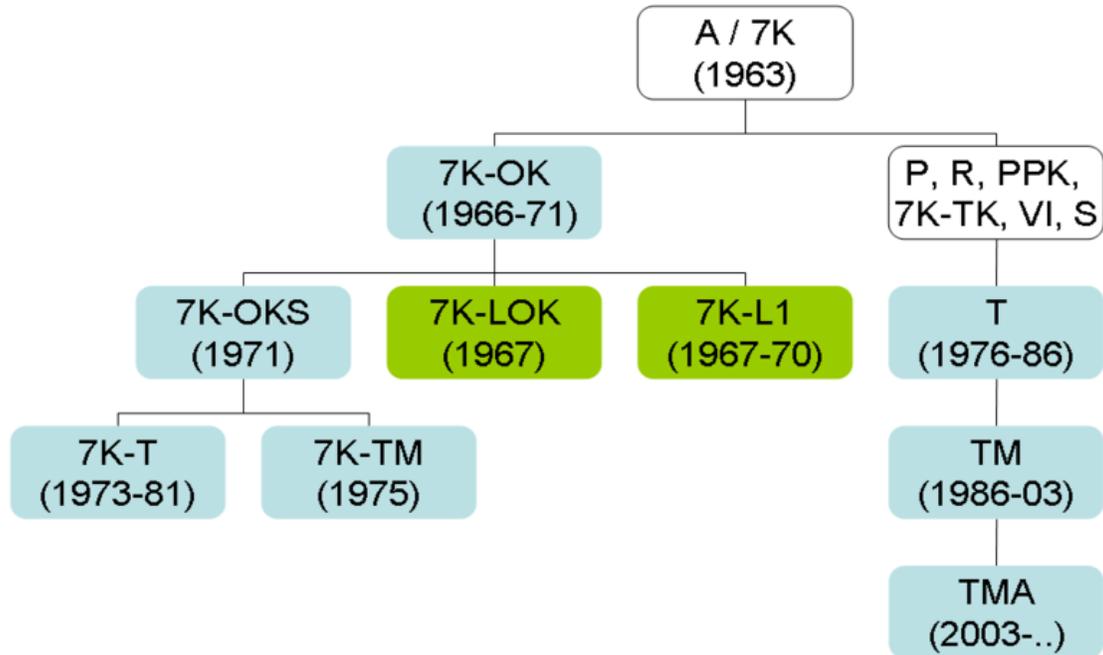
Soyuz diagram

- **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*

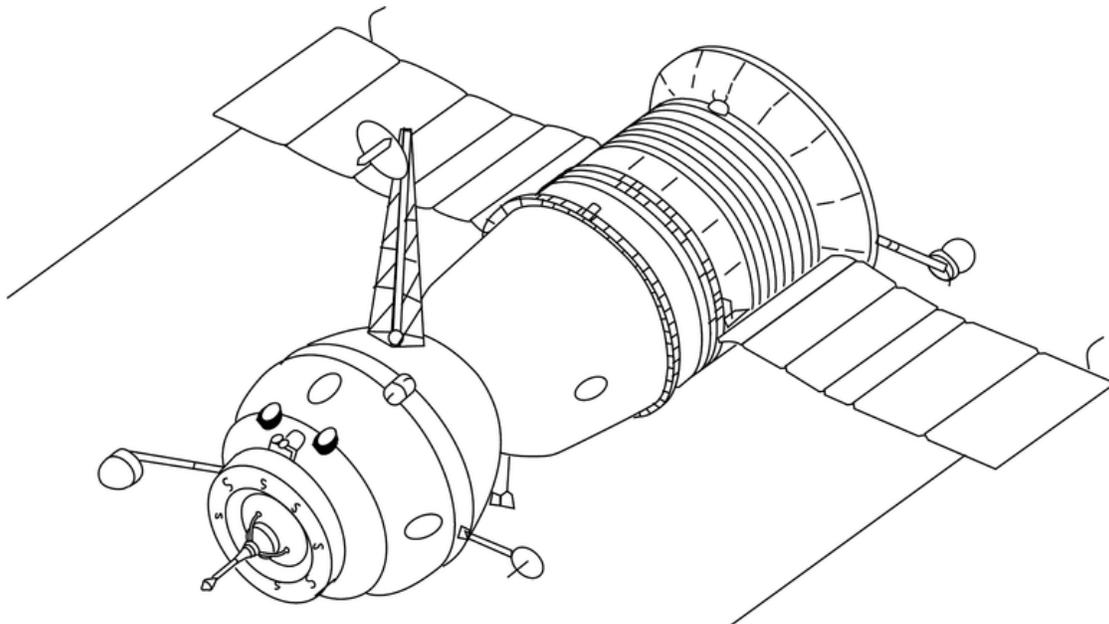
## Variants

### Soyuz spacecraft models

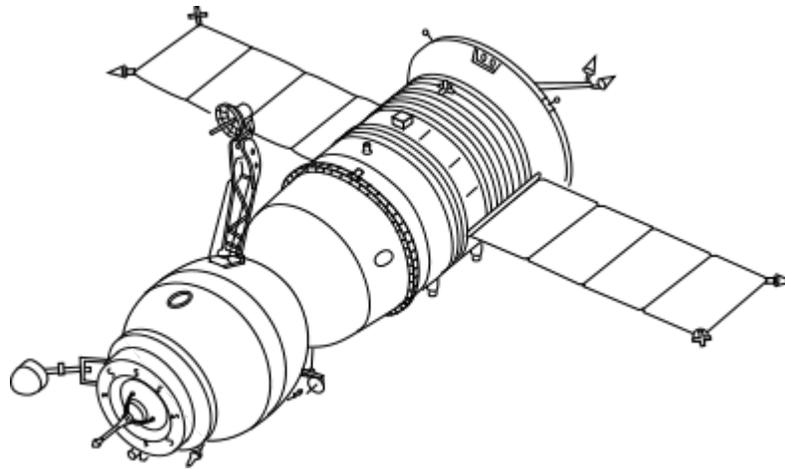


*White: proposed, green: lunar, blue: flown*

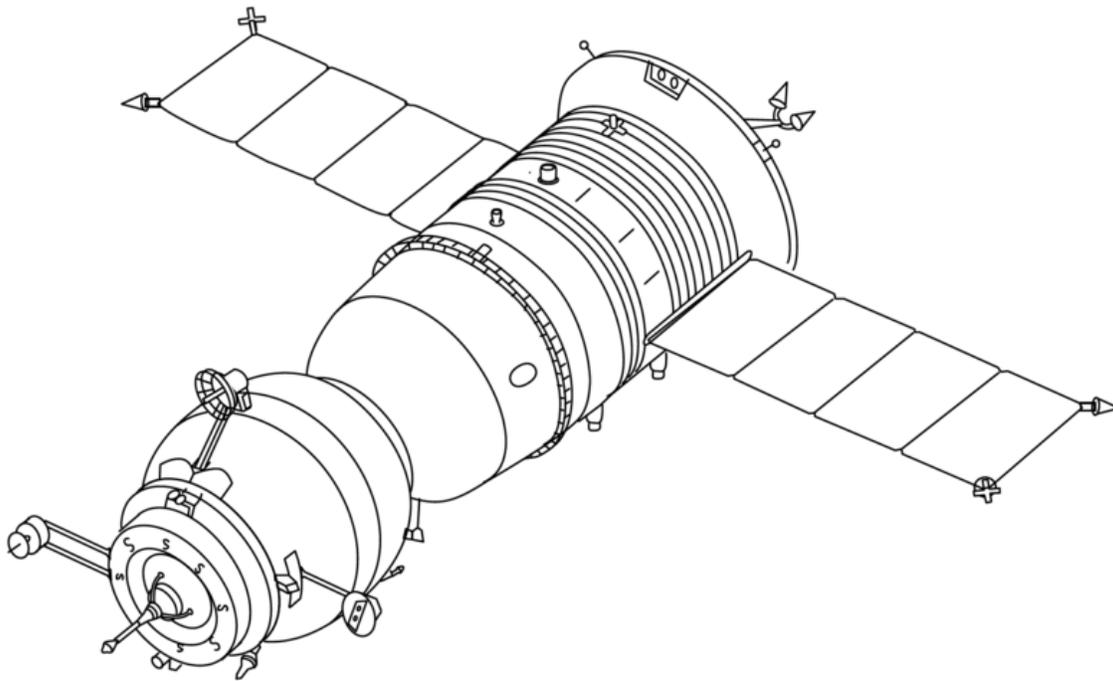
Soyuz family tree



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–....)
<b>Total</b>									
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
<b>Orbital Module (BO)</b>									
Mass	1 000	1 100	-	1 350	1 224	1 100	1 450	1 370	

(kg)								
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 <sup>3</sup> )	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 <sup>3</sup> )	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	
 A photograph of a Progress cargo spacecraft in orbit. The spacecraft is cylindrical with a white nose cone and two large solar panel arrays extending from the sides. It is set against a blue sky with white clouds.	
Progress cargo spacecraft	
Description	
<b>Role:</b>	Used to supply the International Space Station, originally used to supply Soviet and Russian space stations
<b>Crew:</b>	0
Dimensions	
<b>Height:</b>	7.23 m (23.72 ft)
<b>Diameter:</b>	2.72 m (8.92 ft)
<b>Volume:</b>	7.6 m <sup>3</sup> (268 ft <sup>3</sup> )
<b>Payload:</b>	2,350 kg (5,200 lb)
Performance	

<b>Endurance:</b>	6 months docked to station
-------------------	----------------------------

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:

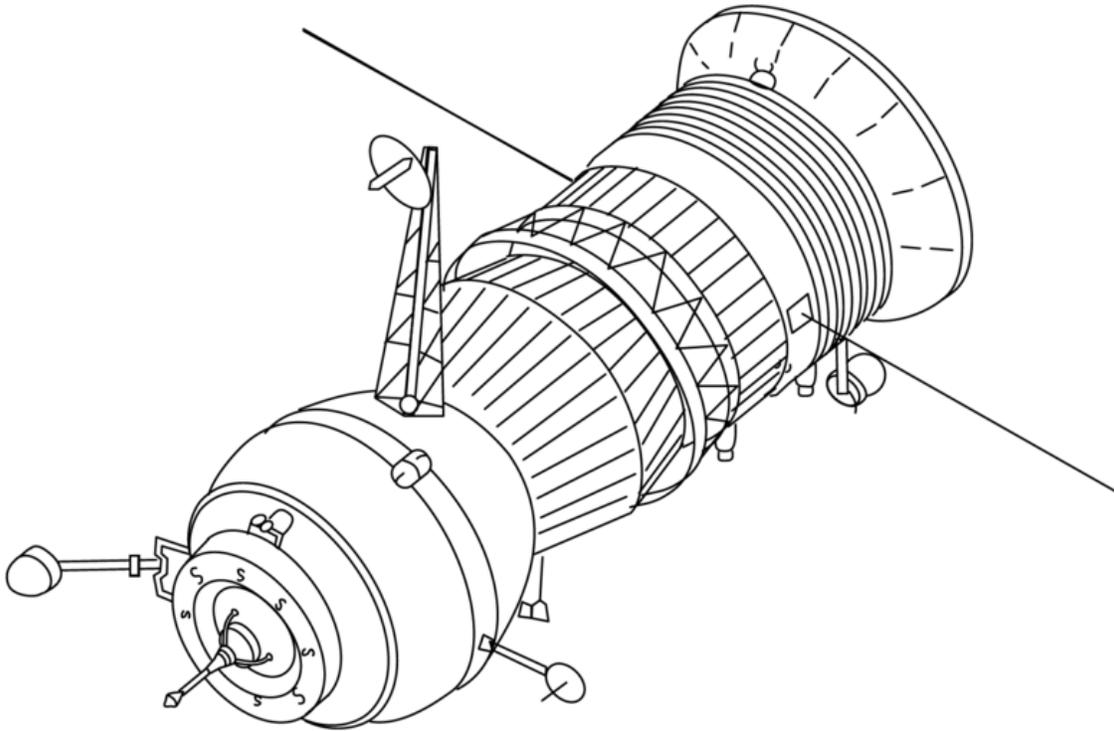
- A pressurized forward module. This carries the supplies for the crew such as scientific equipment, clothes, prepackaged and fresh food, and letters from home. The docking drogue is similar to that of the Soyuz but features ducting for the UDMH fuel and N<sub>2</sub>O<sub>4</sub> oxidiser.
- A fuel 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.

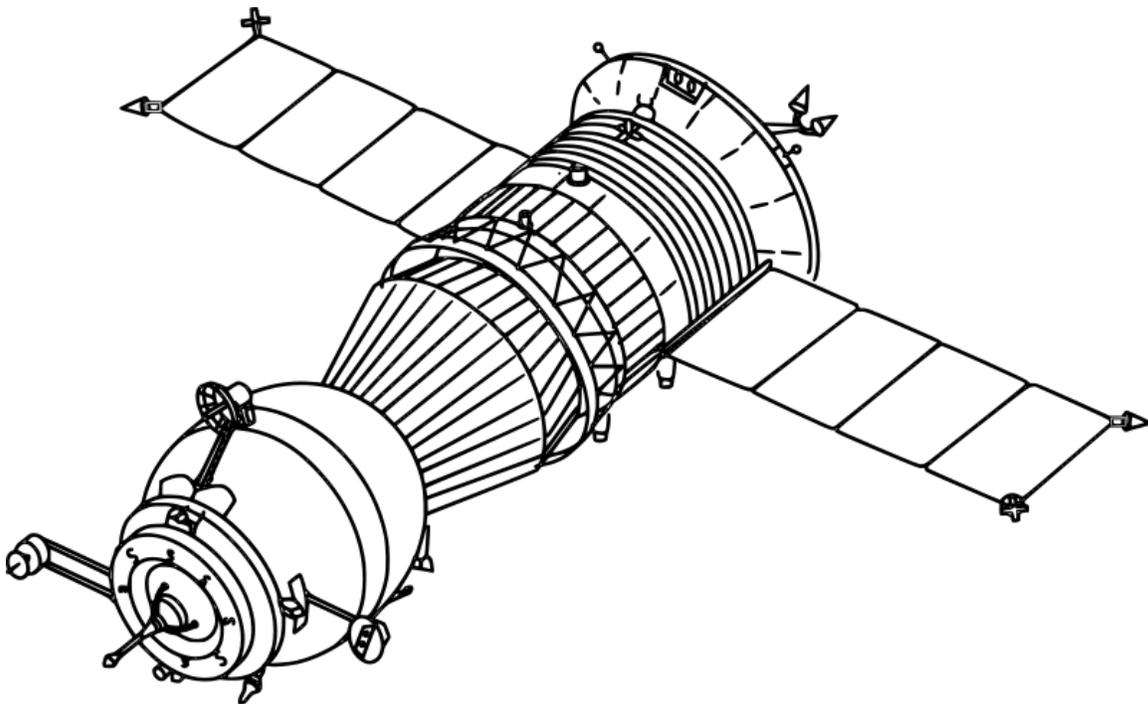
The bureau in charge of designing the freighter was TsKBEM (now RKK Energia). They began work on the design in mid-1973, assigning Progress the GRAU index 11F615A15. The design was complete by February 1974, and the first production model was ready for launch in November 1977. Progress 1 launched on 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 m<sup>3</sup>

### **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 m<sup>3</sup>
- 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

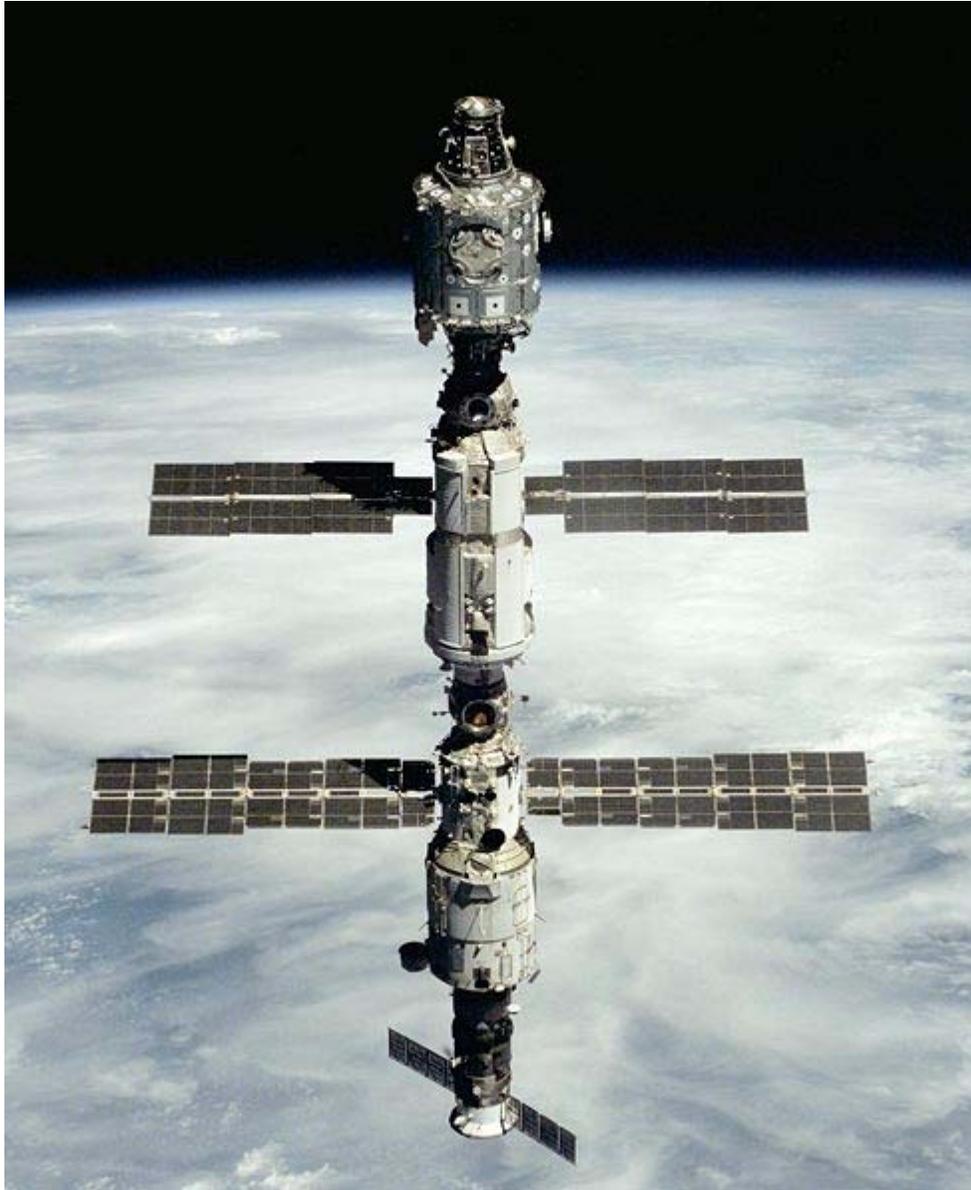
### **Progress M2**

**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.

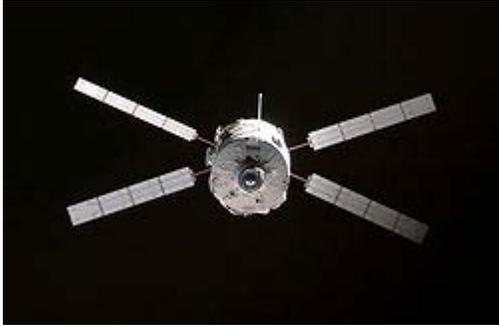
The European Space Agency (ESA) operates its own type of supply freighter, the Automated Transfer Vehicle (ATV). The first of these, named *Jules Verne*, was launched at 04:03 GMT on March 9, 2008. ATVs can carry up to 9 tonnes of cargo into space, roughly three times as much as the Progress, and will 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	
 A photograph of the Automated Transfer Vehicle (ATV) in space. The vehicle is a cylindrical module with four large solar panel wings extending outwards. It is positioned against a black background.	
Description	
<b>Role:</b>	Supply the International Space Station with propellant, water, air, payload and experiments.
<b>Crew:</b>	Unmanned, but human-rated.
Dimensions	
<b>Height:</b>	10.3 m (34 ft)
<b>Diameter:</b>	4.5 m (15 ft)
<b>Launch Payload:</b>	7,667 kg (16,900 lb)
<b>Return Payload:</b>	None
<b>Mass at launch:</b>	20,750 kg
<b>Pressurized Volume:</b>	48 m <sup>3</sup>
Electrical Energy	
<b>Source:</b>	4 solar panel wings of 4

	panels each and 40Ah rechargeable batteries
<b>Size:</b>	total span 22,3 m
<b>Generated Power:</b>	3,800 W
<b>On-board engines</b>	
<b>Main engine:</b>	4 x 490N, Aerojet (GenCorp) Model R-4D-11
<b>Thrusters :</b>	28 x 220N for Altitude control & braking, Astrium Lampoldshausen
<b>Performance</b>	
<b>Endurance:</b>	Docked with the ISS for six months
<b>Apogee:</b>	400 km
<b>Perigee:</b>	300 km
<b>Inclination:</b>	51.6 degrees
<b>Launch</b>	
<b>Location:</b>	ESA's Guiana Space Centre, Kourou in French Guiana
<b>Site:</b>	ELA-3
<b>Booster:</b>	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 N<sub>2</sub>O<sub>4</sub> oxidizer) is of a different type from the *payload* Russian refueling propellant (UDMH fuel and N<sub>2</sub>O<sub>4</sub> 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



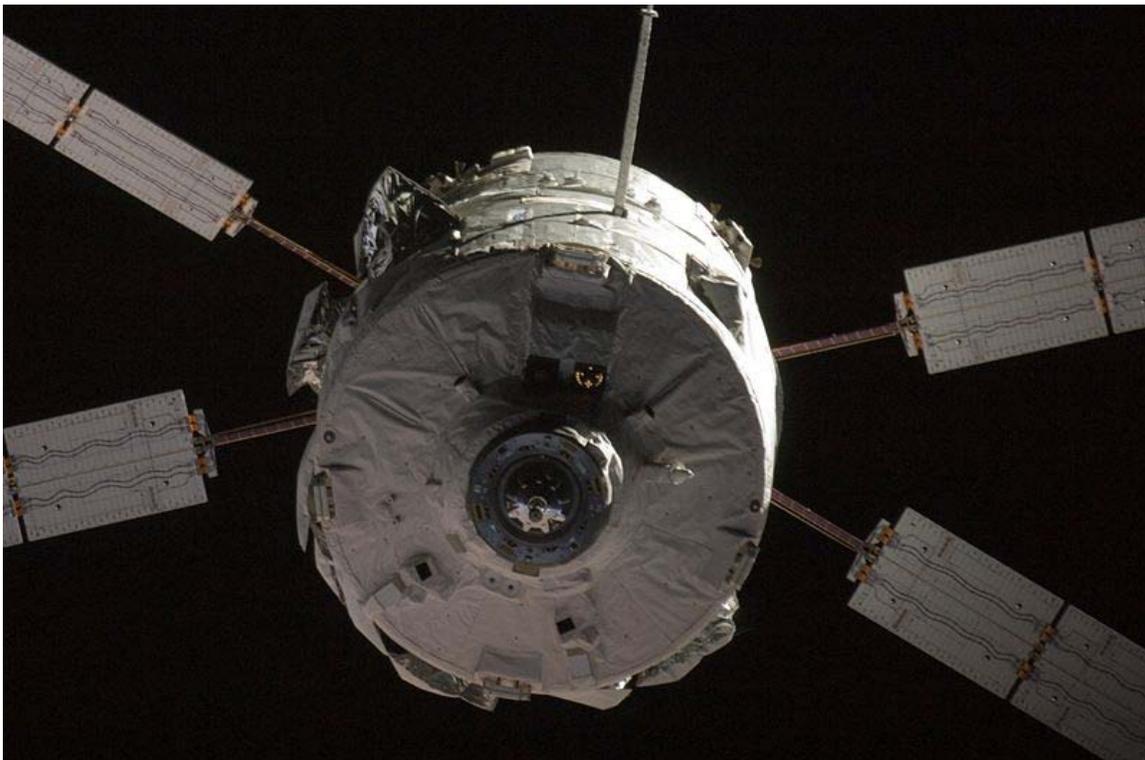
ATV *Jules Verne* as it re-enters Earth's atmosphere in a controlled burn-up after undocking from ISS.

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

<b>Designation</b>	<b>Name</b>	<b>Launch date</b>	<b>Result</b>	<b>Re-entry</b>
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**

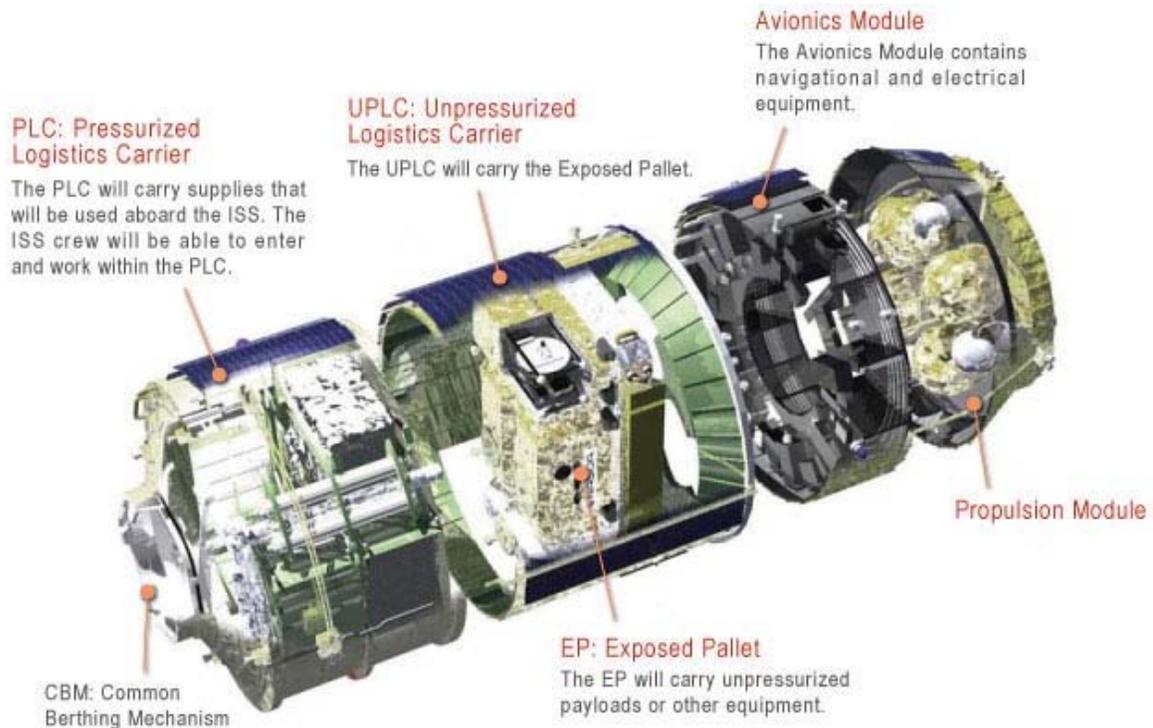
In November 2008, ESA ministers budgeted for a feasibility study into developing a re-entry capsule for the ATV, a requirement for developing either a cargo return capacity or a manned version of the ATV. ESA signed a €21 million study contract with EADS Astrium on 7 July 2009.

## Chapter- 4

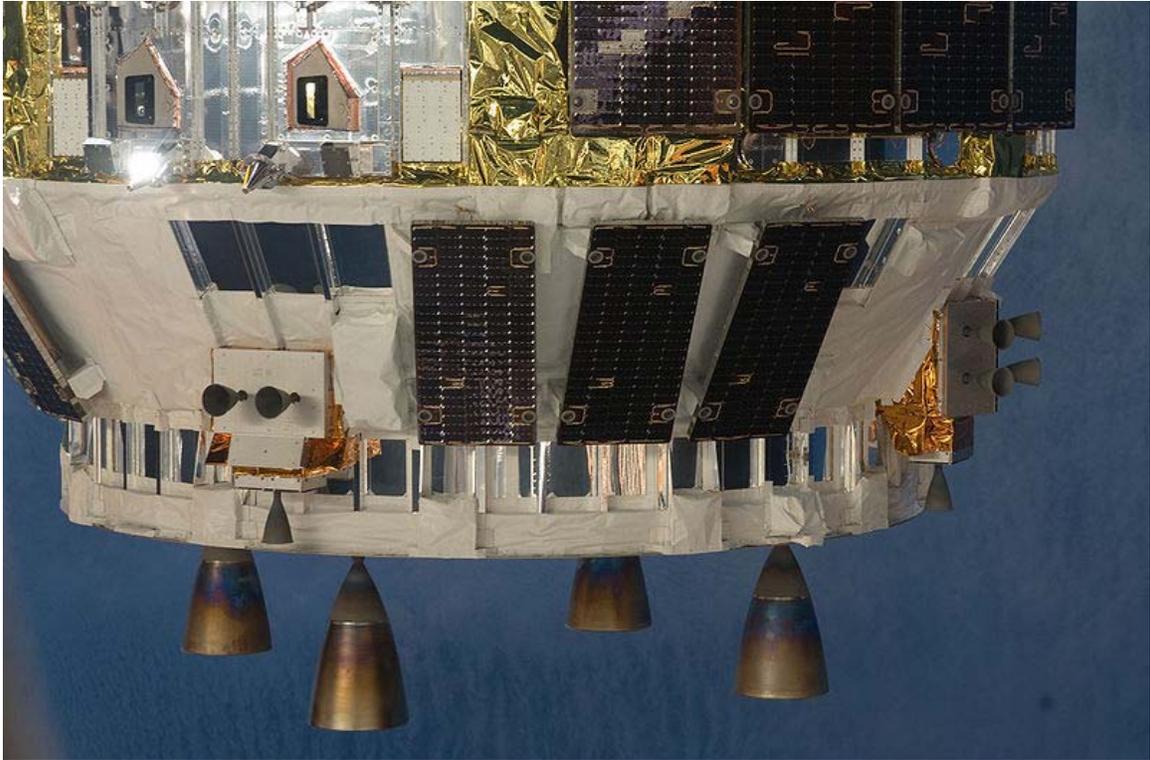
# H-II Transfer Vehicle

H-II Transfer Vehicle	
	
H-II Transfer Vehicle (HTV-1) approaching the ISS	
Description	
<b>Role:</b>	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.
<b>Crew:</b>	Unmanned
Dimensions	
<b>Height:</b>	10 m (including thrusters)
<b>Diameter:</b>	4.4 m
<b>Spacecraft weight:</b>	10,500 kg
<b>Total Launch Payload:</b>	6,000 kg
<b>Pressurized</b>	5,200 kg

<b>Payload:</b>	
<b>Unpressurized Payload:</b>	1,500 kg
<b>Return Payload:</b>	None
<b>Mass at launch:</b>	16.5 ton
<b>Pressurized Volume:</b>	
<b>Performance</b>	
<b>Endurance:</b>	Solo flight about 100 hours, stand-by more than a week, docked with the ISS about 30 days
<b>Apogee:</b>	460 km
<b>Perigee:</b>	350 km
<b>Inclination:</b>	51.6 degrees



Structure

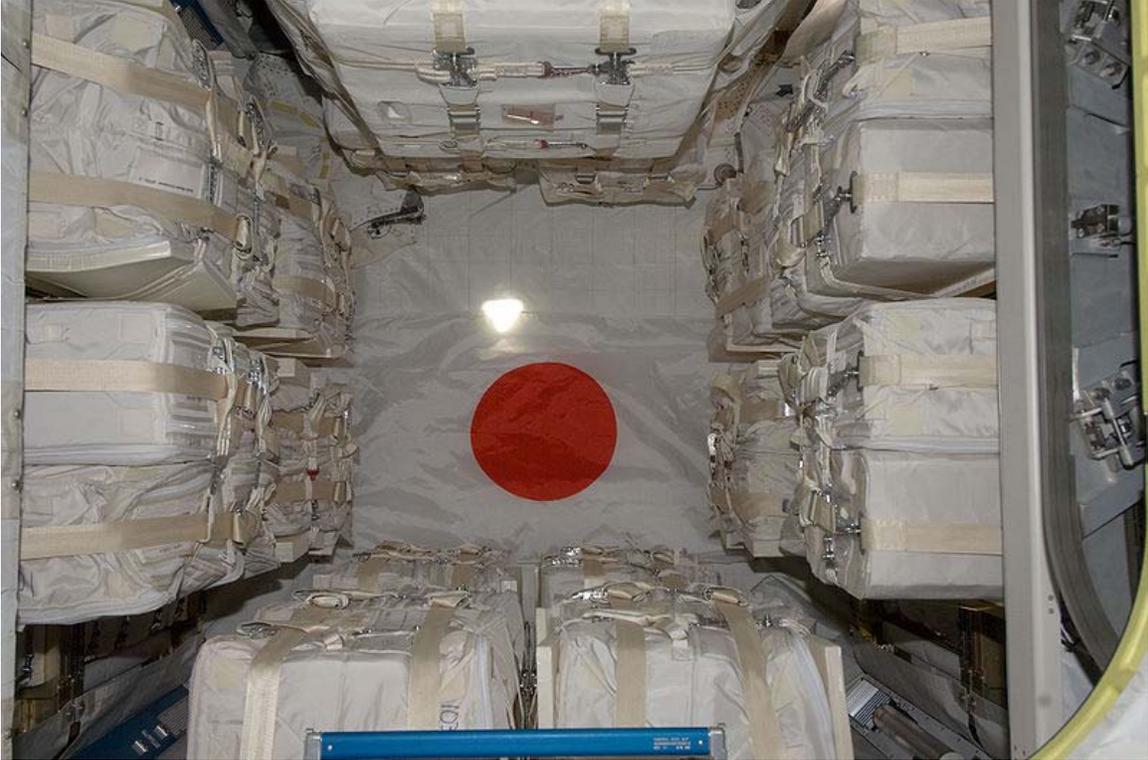


At the bottom the four main thrusters. Smaller attitude control thrusters can be seen at the right side of this view of HTV-1.

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.

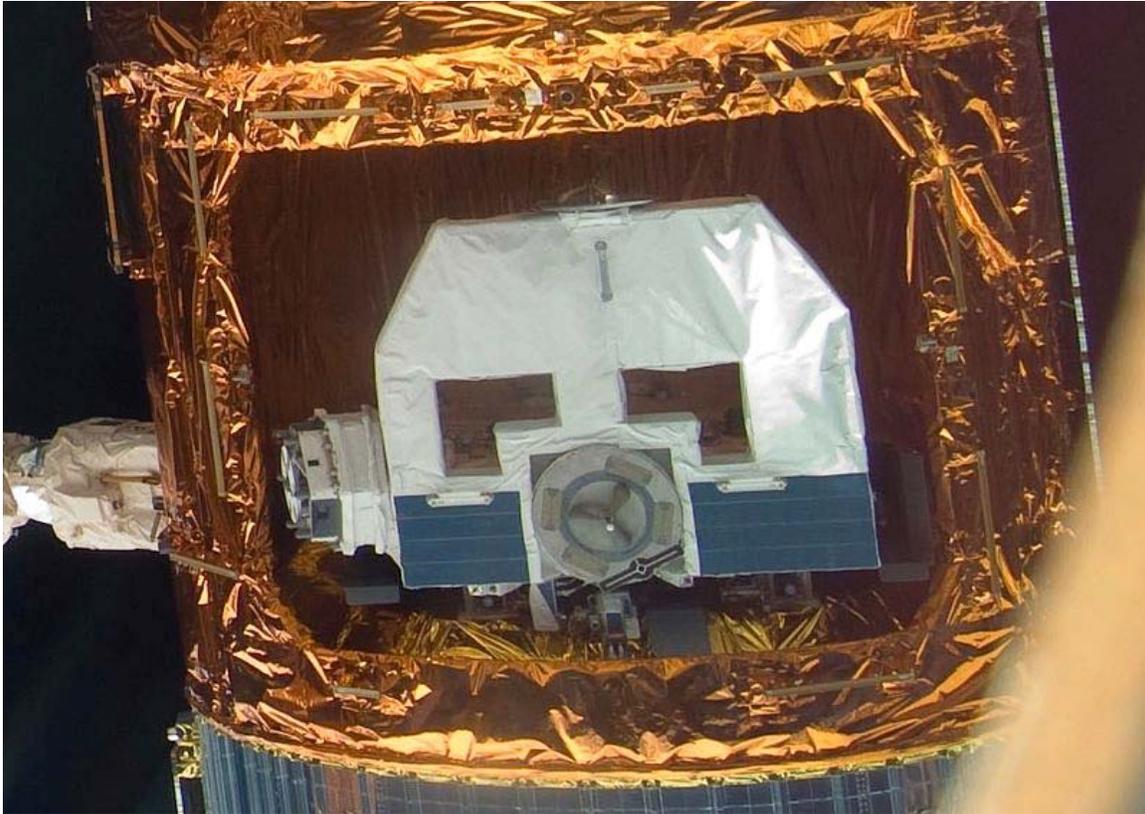
## Design

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.

<b>HTV</b>	<b>Launch date/time</b>	<b>Carrier rocket</b>	<b>Re-entry date/time</b>
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.

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

<b>Diameter</b>	28.5 ft (8.7 m)
<b>Mass</b>	4,470,000 lbm (2,030 t)
<b>Capacity</b>	
<b>Payload to LEO</b>	24,400 kg (53,600 lb)
<b>Payload to GTO</b>	3,810 kg (8,390 lbm)
<b>Payload to Polar orbit</b>	12,700 kg (28,000 lb)
<b>Launch history</b>	
<b>Status</b>	Active
<b>Launch sites</b>	LC-39, Kennedy Space Center SLC-6, Vandenberg AFB (unused)
<b>Total launches</b>	132
<b>Successes</b>	130
<b>Failures</b>	2 (launch failure, <i>Challenger</i> ), (re-entry failure, <i>Columbia</i> )
<b>Maiden flight</b>	April 12, 1981
	Tracking and Data Relay Satellites Spacelab
<b>Notable payloads</b>	Great Observatories (including Hubble) Galileo, Magellan, Ulysses Mir Docking Module ISS components
<b>Boosters (Stage 0) - Solid Rocket Boosters</b>	
<b>N<sup>o</sup> boosters</b>	2
<b>Engines</b>	1 solid
<b>Thrust</b>	2,800,000 lbf each, sea level liftoff (12.5 MN)
<b>Specific impulse</b>	269 s
<b>Burn time</b>	124 s
<b>Fuel</b>	solid
<b>First stage - External Tank</b>	
<b>Engines</b>	3 SSMEs located on Orbiter
<b>Thrust</b>	1,225,704 lbf total, sea level liftoff (5.45220 MN)
<b>Specific impulse</b>	455 s
<b>Burn time</b>	480 s
<b>Fuel</b>	LOX/LH2
<b>Second stage - Orbiter</b>	
<b>Engines</b>	2 OME
<b>Thrust</b>	53.4 kN combined total vacuum thrust (12,000 lbf)
<b>Specific impulse</b>	316 s
<b>Burn time</b>	1250 s
<b>Fuel</b>	MMH/N <sub>2</sub> O <sub>4</sub>

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

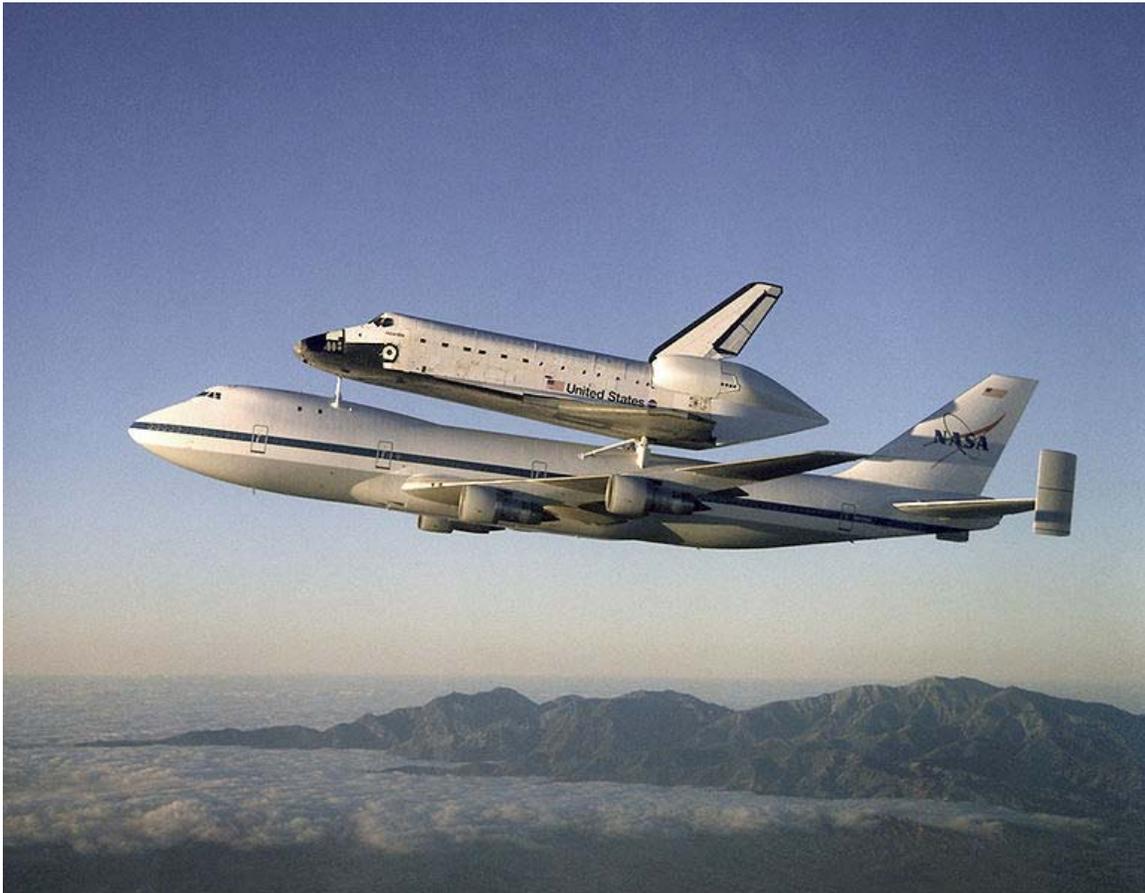
Each Space Shuttle is a reusable launch system that is composed of three main assemblies: the reusable Orbiter Vehicle (OV), the expendable external tank (ET), and the two reusable solid rocket boosters (SRBs). Only the orbiter enters orbit shortly after the tank and boosters are jettisoned. The vehicle 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.

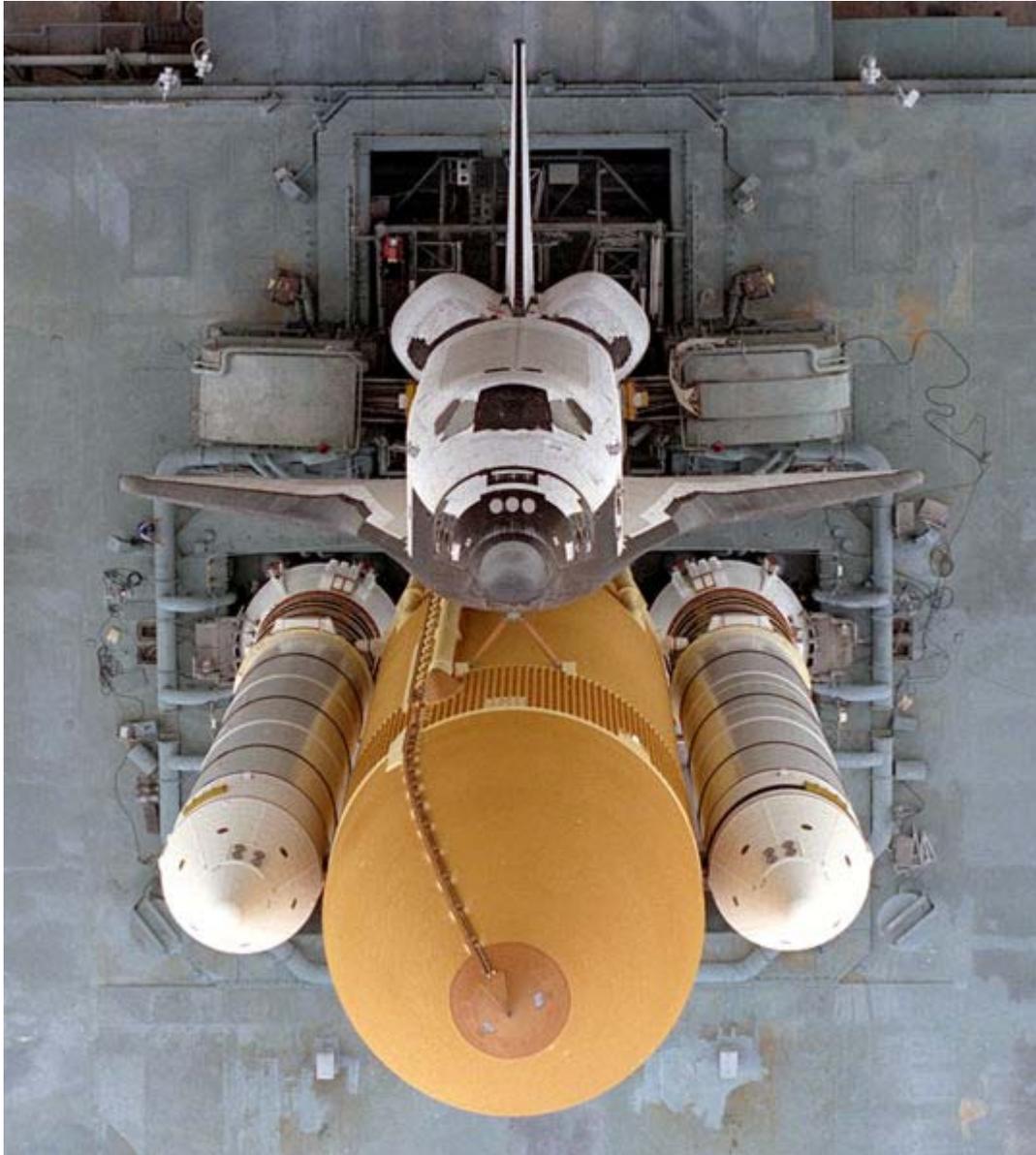
At times, the orbiter itself is referred to as the Space Shuttle. Technically, this is a slight misnomer, as the actual "Space Transportation System" (Space Shuttle) is the combination of the orbiter, the external tank, and the two solid rocket boosters. Combined, these are referred to as the "Stack"; 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 m<sup>3</sup>) 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**

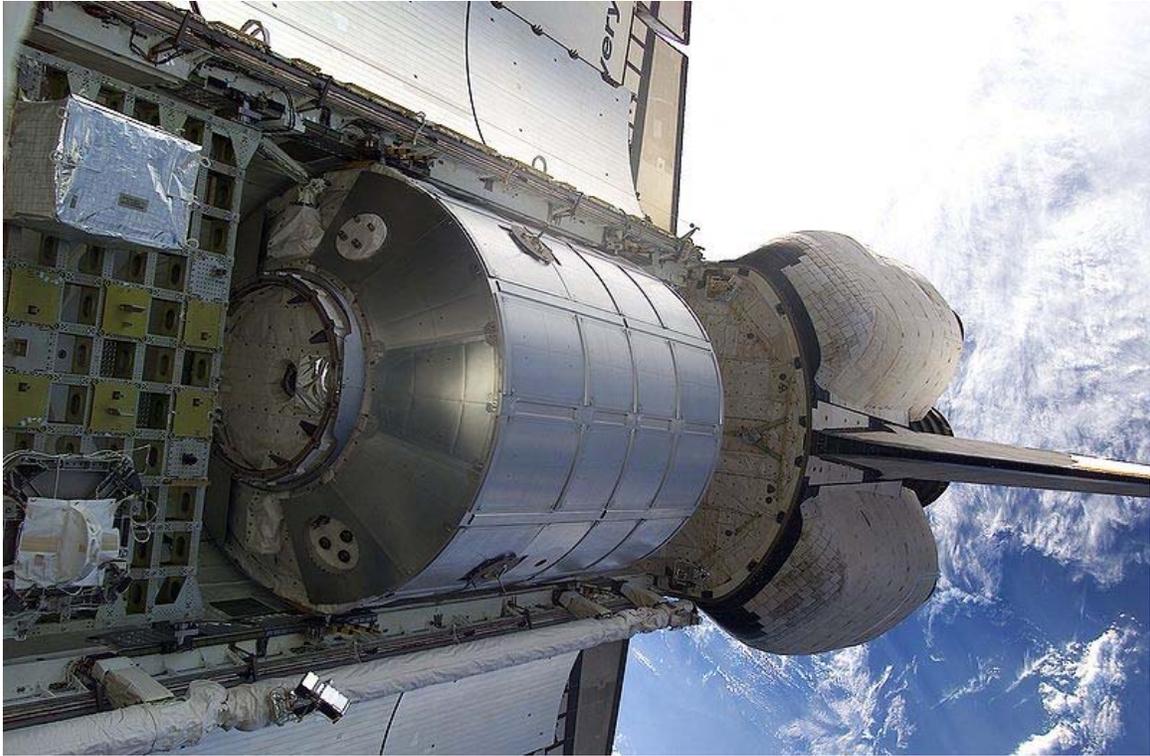
The main function of the Space Shuttle external tank is to supply the liquid oxygen and hydrogen fuel to the Space Shuttle main engines. It is also the backbone of the launch vehicle providing attachment points for the two Solid Rocket Boosters and the Orbiter. The external tank is the only part of the 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**

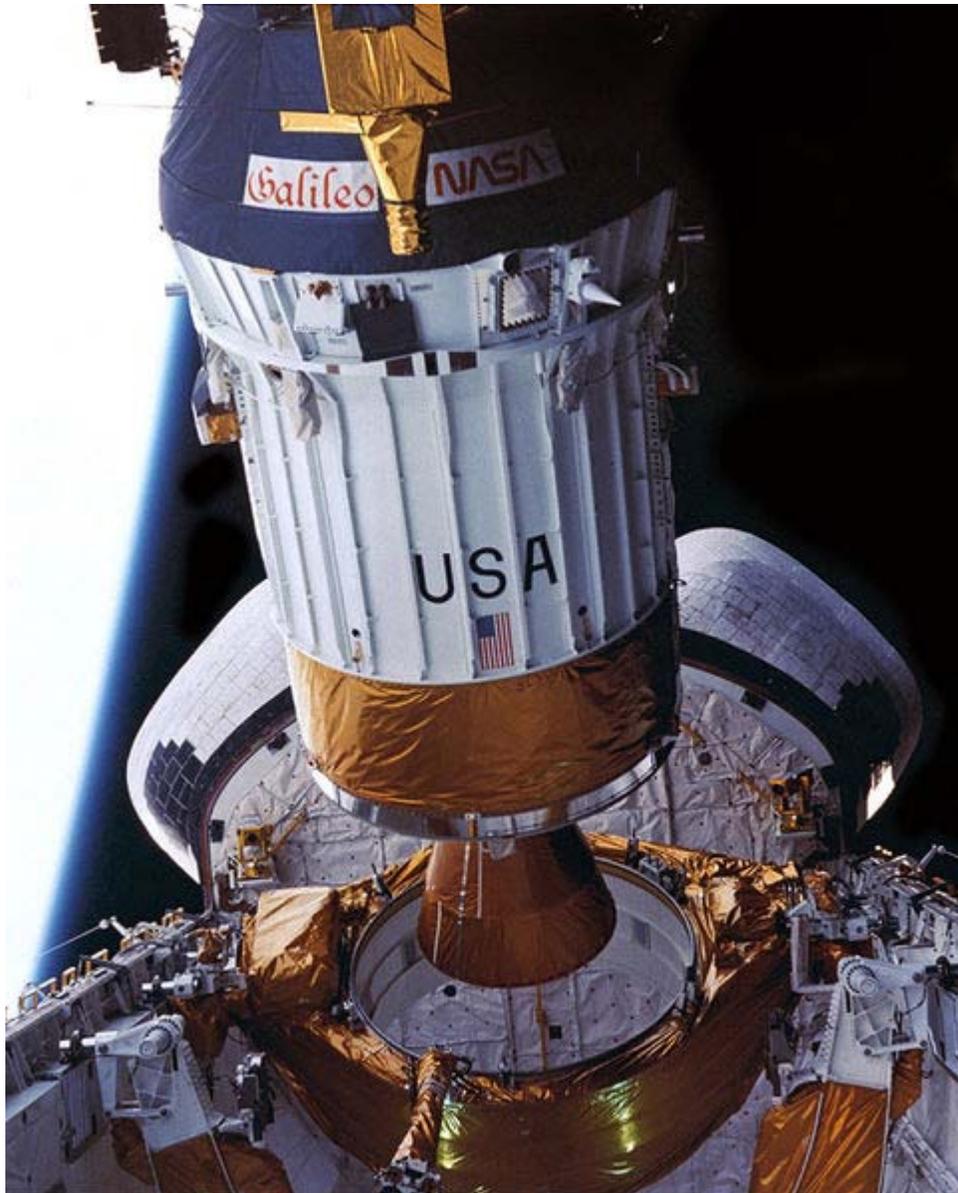
Two solid rocket boosters (SRBs) each provide 12.5 million newtons (2.8 million lbf) of thrust at liftoff, which is 83% of the total thrust needed for liftoff. The SRBs are jettisoned two minutes after launch at a height of about 150,000 feet (46 km), and then deploy parachutes and land in the ocean 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**

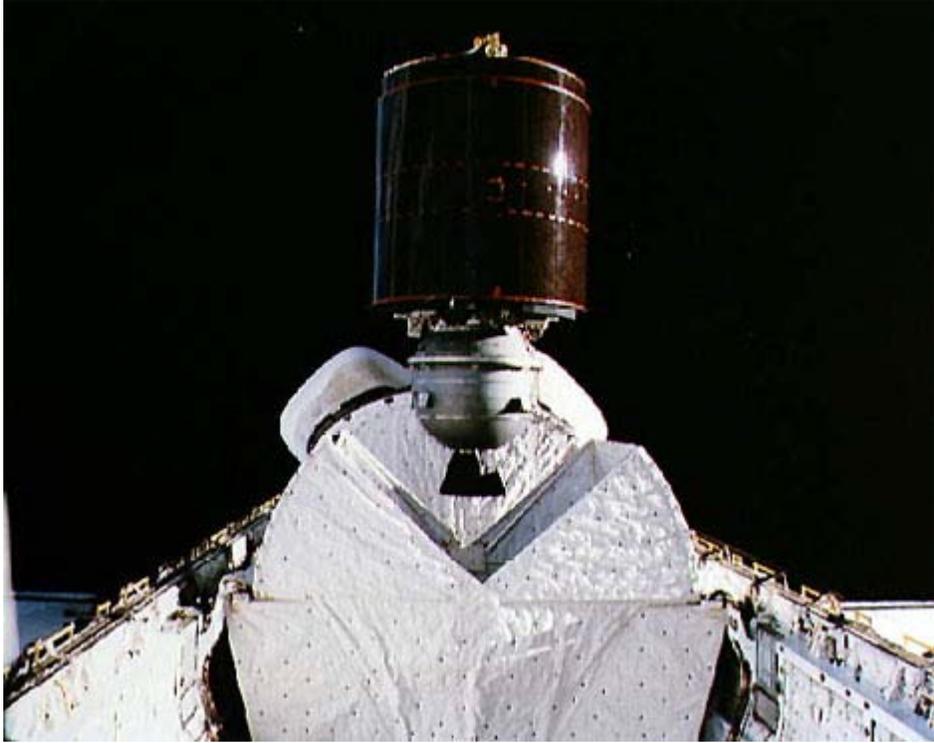
The orbiter can be used in conjunction with a variety of add-ons depending on the mission. This has included orbital laboratories (Spacelab, Spacehab), boosters for launching payloads farther into space (Inertial Upper Stage, Payload Assist Module), and other functions, such as provided by Extended Duration 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*



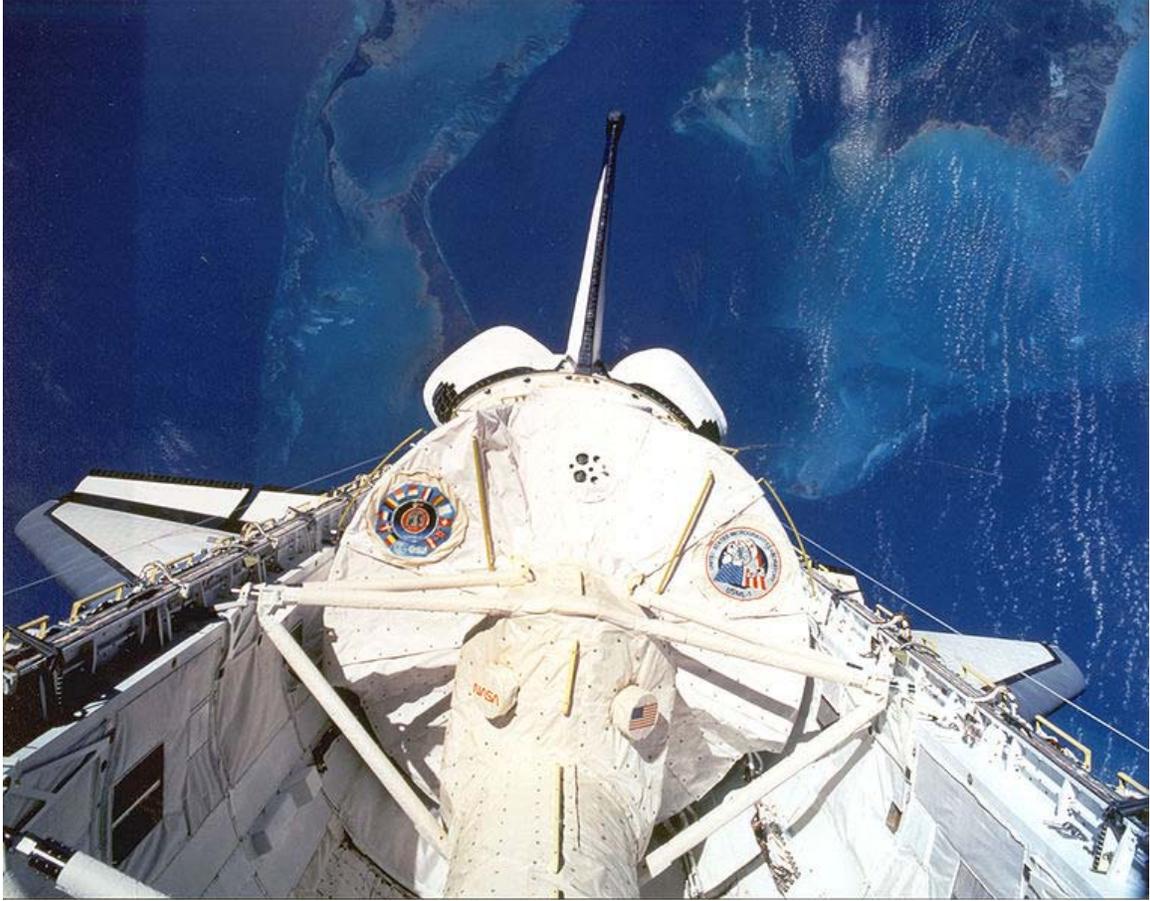
IUS deploying with Galileo



PAM-D with satellite



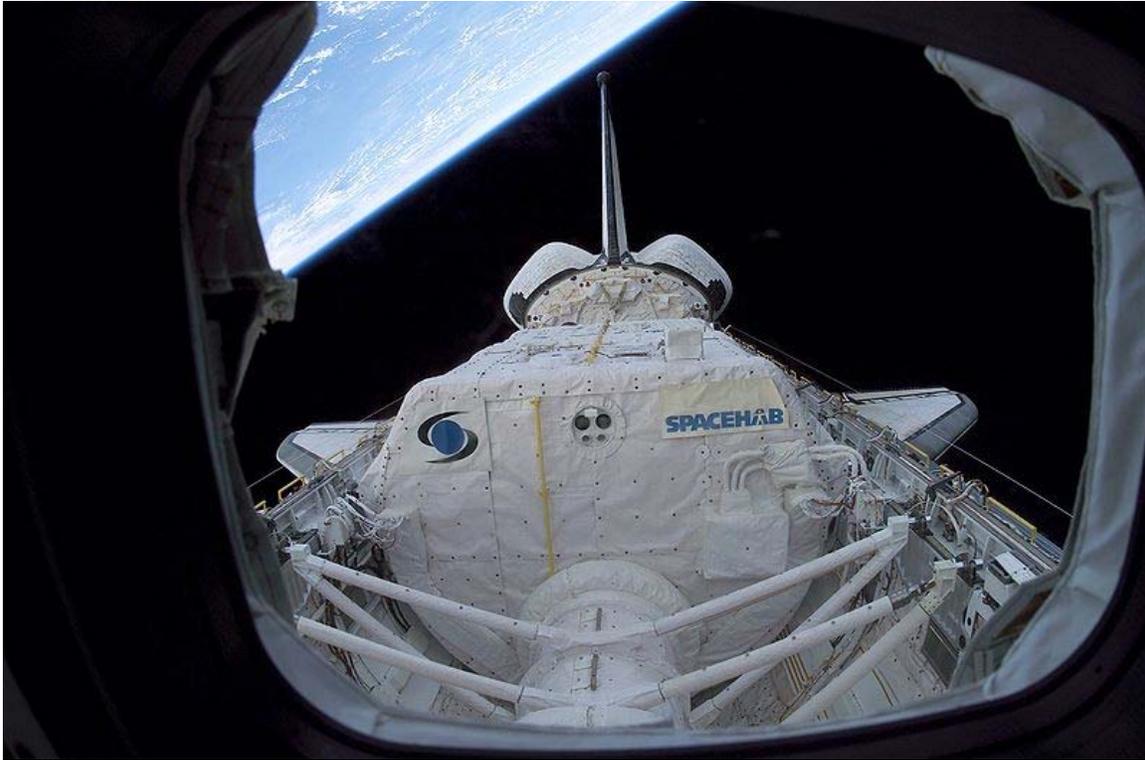
EDO being installed



Spacelab in orbit



RMS (Canadarm)



S107E05359

Spacehab

## **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.

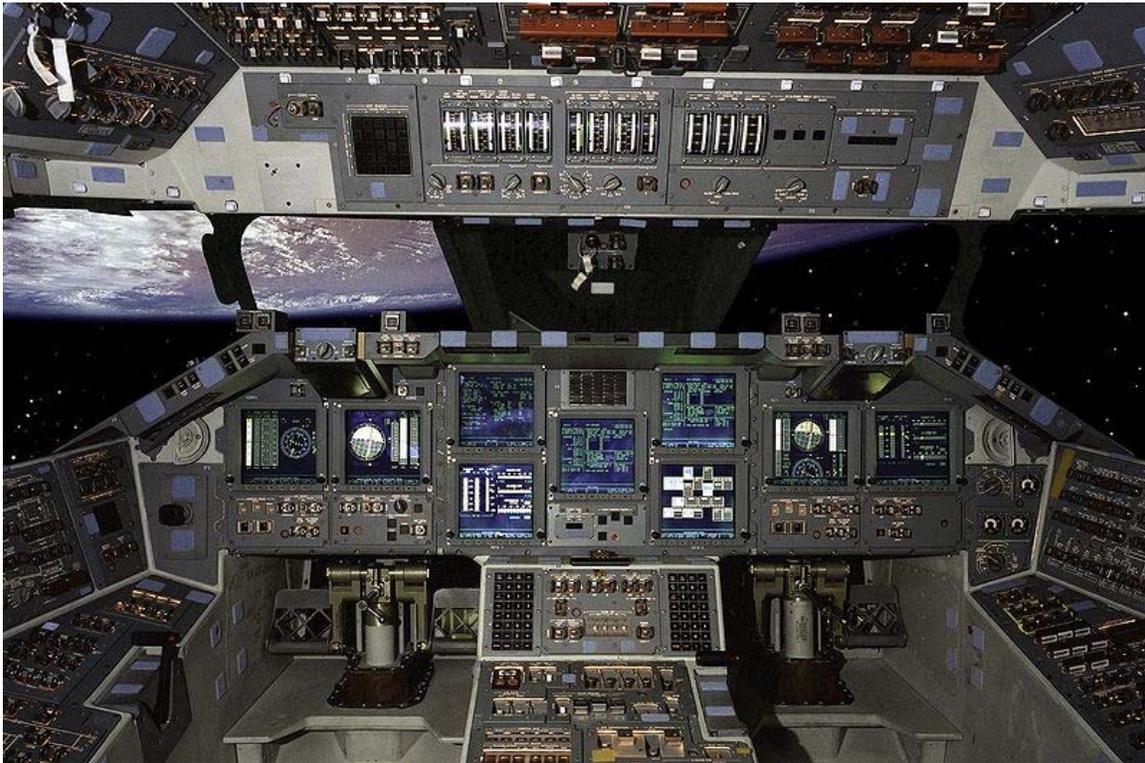


Space Shuttle program insignia

### **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.

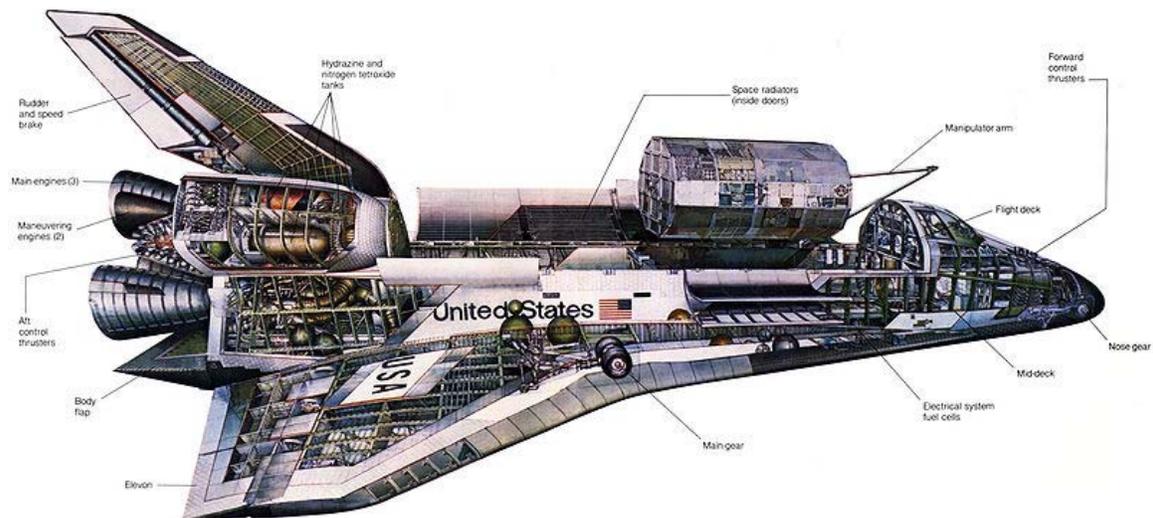
STS-70 was delayed in 1995, when woodpeckers bored holes in the foam insulation of *Discovery's* external tank. Since then, NASA has installed commercial plastic owl decoys and inflatable owl balloons which must be removed prior to launch. The delicate nature of the foam insulation has been the cause 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.

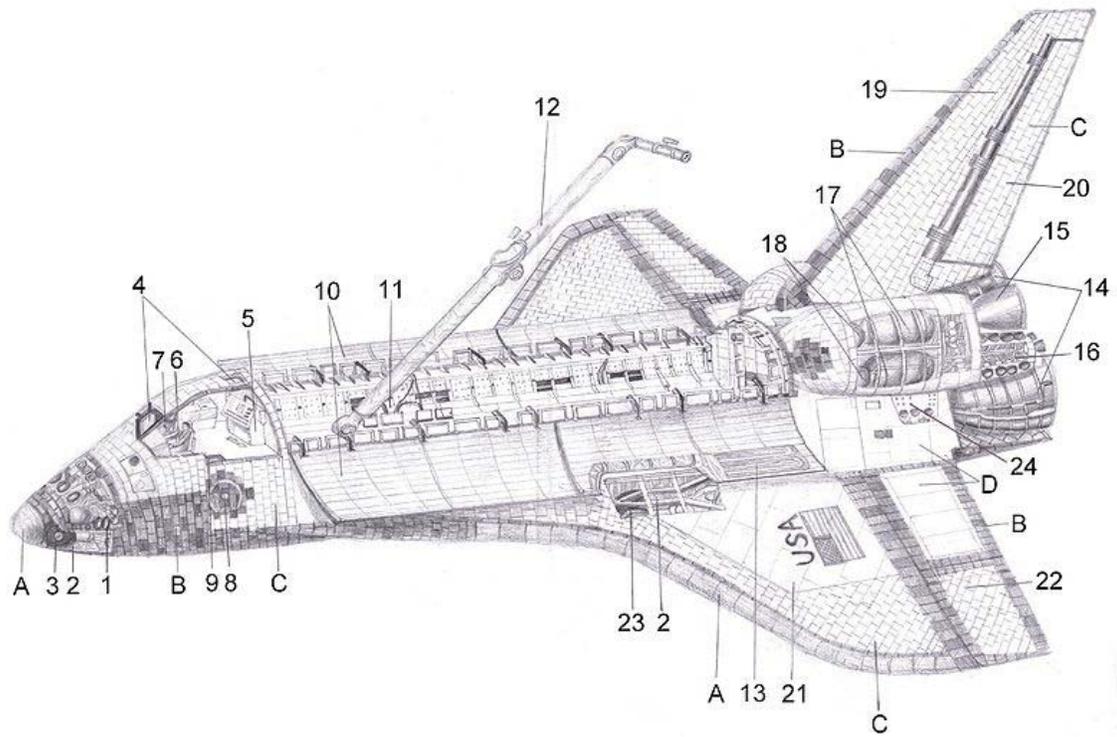
On the first four shuttle missions, astronauts wore modified U.S. Air Force high-altitude full-pressure suits, which included a full-pressure helmet during ascent and descent. From the fifth flight, STS-5, until the loss of *Challenger*, one-piece light blue nomex flight suits and partial-pressure helmets 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



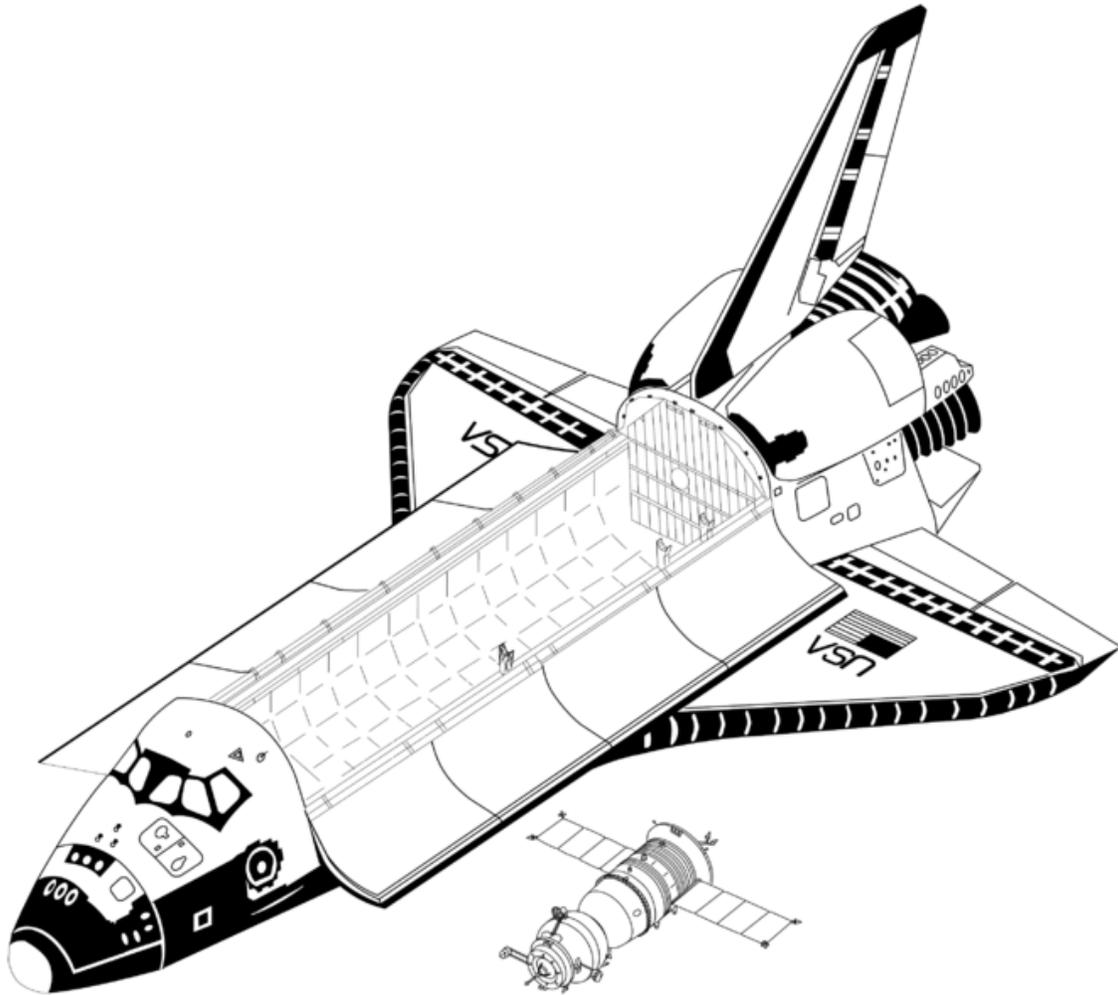
Space Shuttle orbiter illustration



Space Shuttle drawing



Space Shuttle wing cutaway



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/N<sub>2</sub>O<sub>4</sub>
- 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 m<sup>3</sup> (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



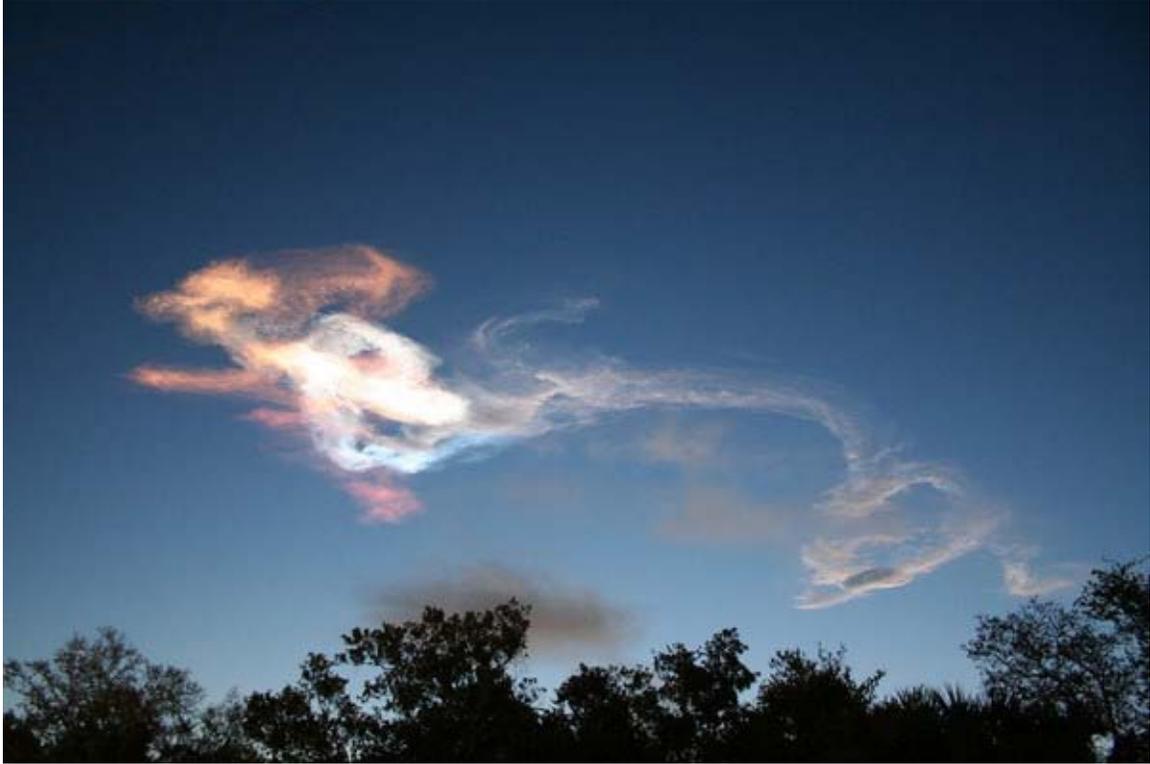
STS mission profile



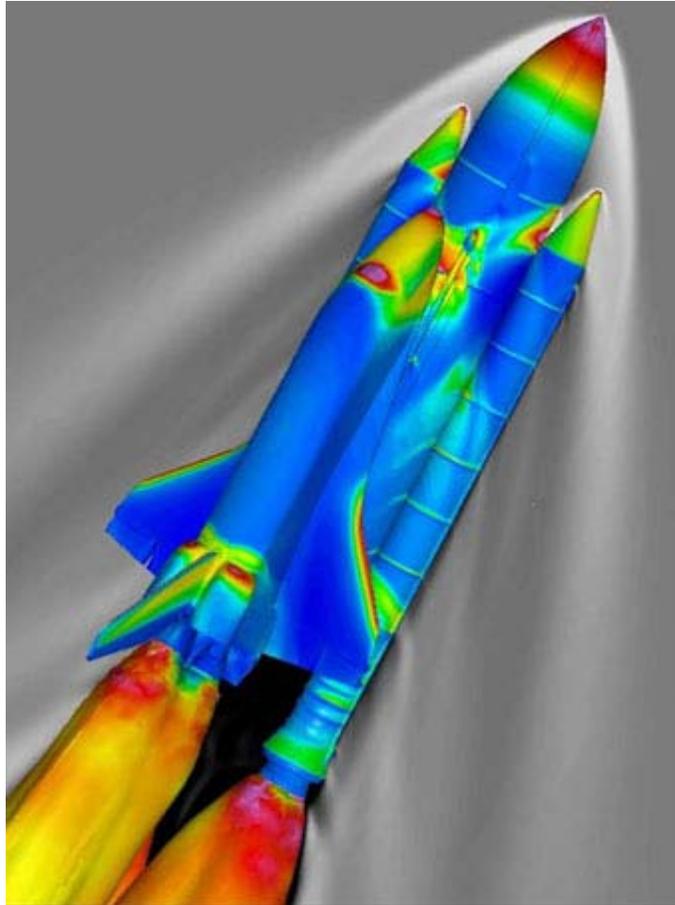
Two Space Shuttles sit at launch pads. This particular occasion is due to the final Hubble servicing mission, where the International Space Station is unreachable, which necessitates having a Shuttle on standby for a possible rescue mission.



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 m<sup>3</sup>) 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 RSLS 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.

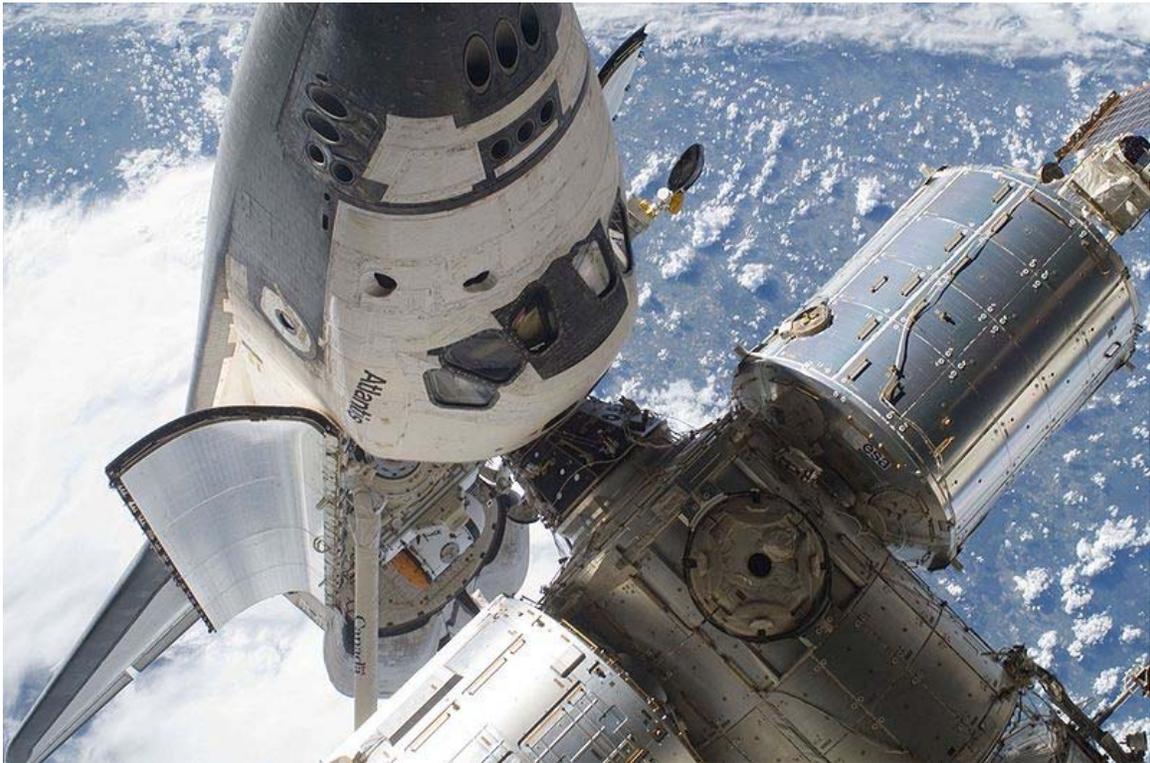
The vehicle continues to climb and takes on a somewhat nose-up angle to the horizon – it uses the main engines to gain and then maintain altitude while it accelerates horizontally towards orbit. At about five and three-quarter minutes into ascent, the orbiter's direct communication links with the ground 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<sup>2</sup>), 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.

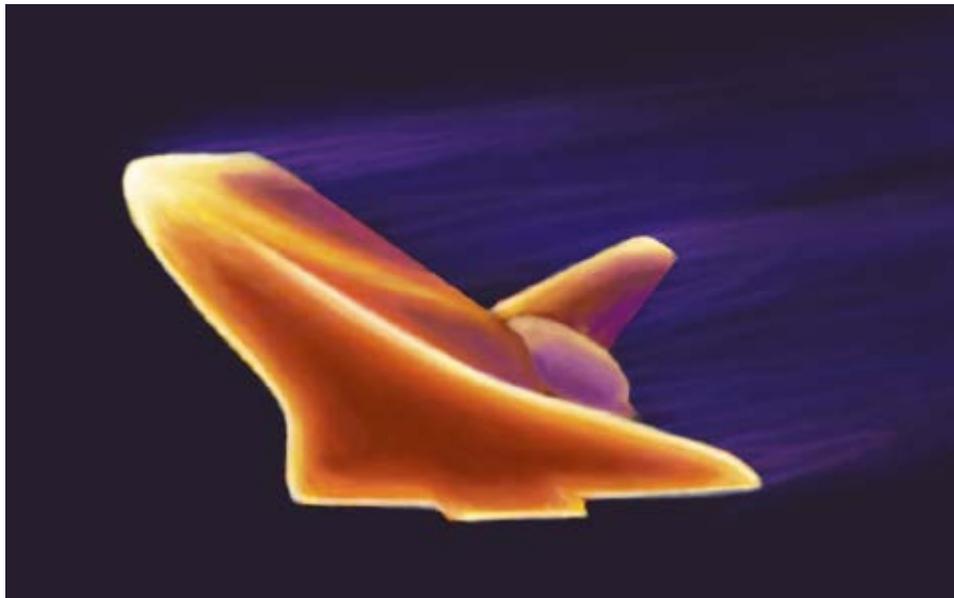
### **Re-entry and landing**

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.

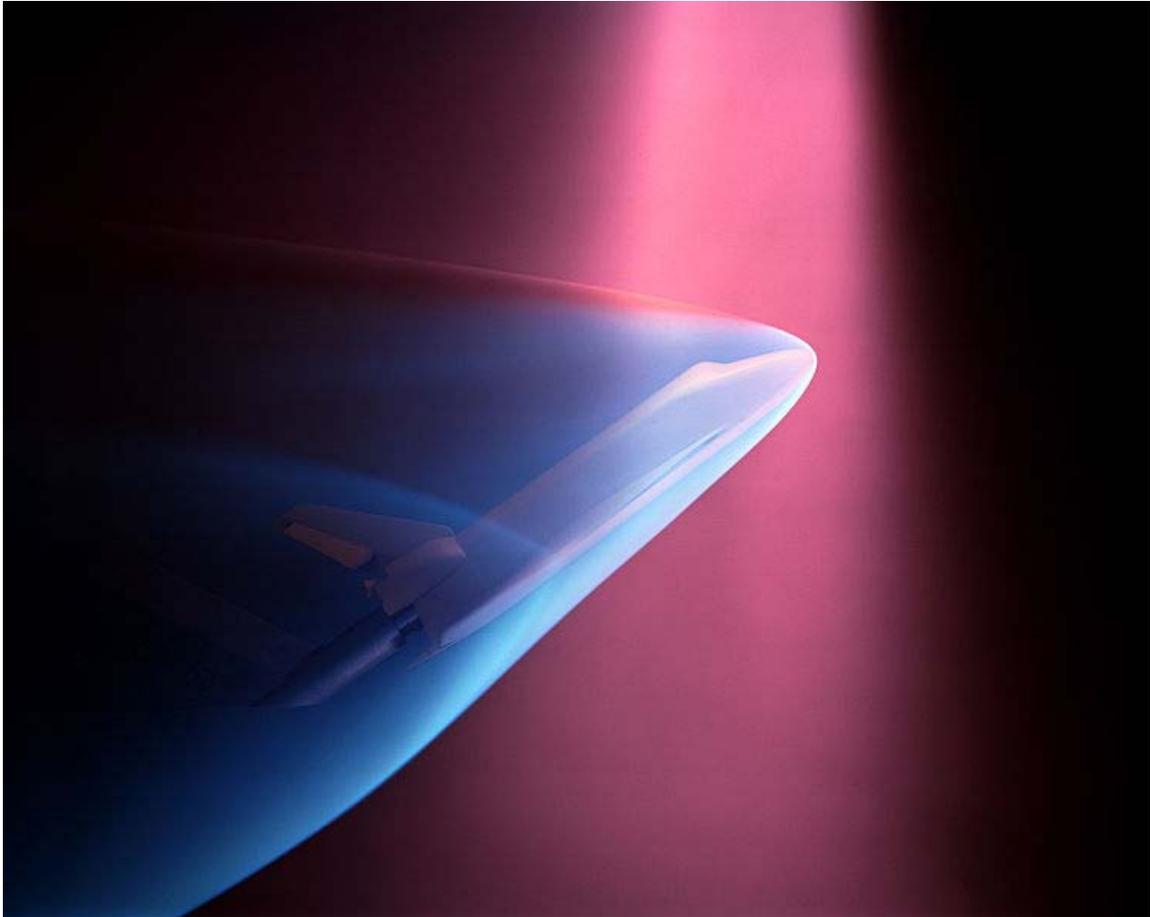
The vehicle begins re-entry by firing the Orbital maneuvering system engines, while flying upside down, backside first, in the opposite direction to orbital motion for approximately three minutes, which reduces the shuttle's velocity by about 200 mph (322 km/h). The resultant slowing of the Shuttle lowers 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.

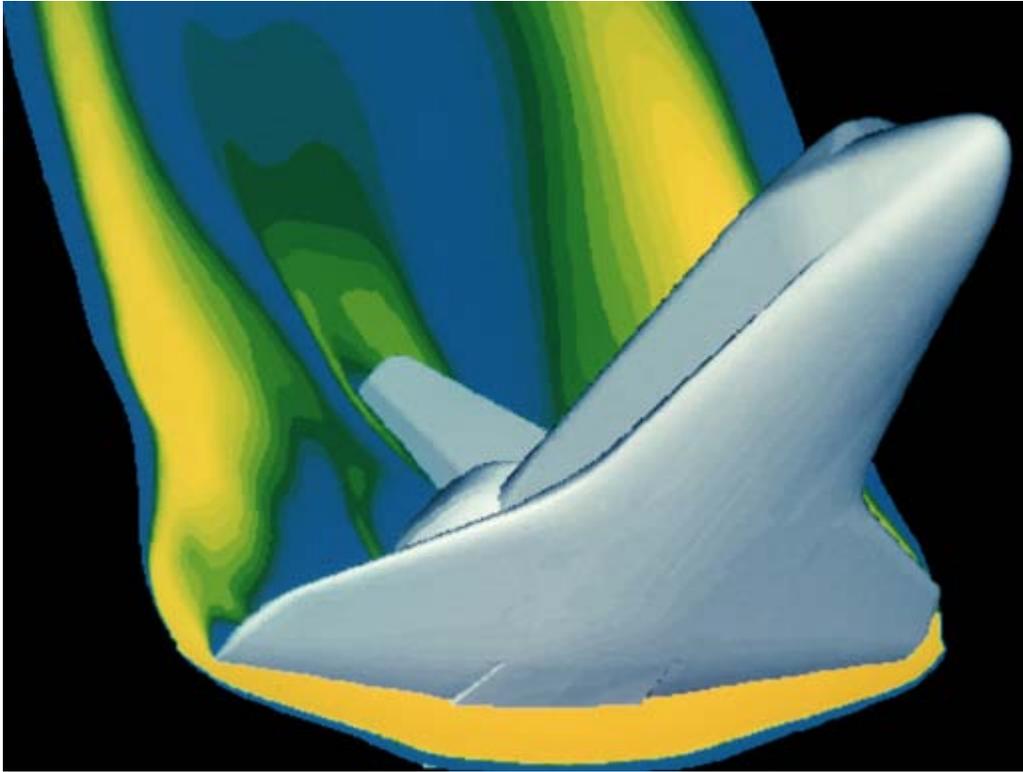
The vehicle starts encountering more significant air density in the lower thermosphere at about 400,000 ft (120 km), at around Mach 25, 8,200 m/s (30,000 km/h; 18,000 mph). The vehicle is controlled by a combination of RCS thrusters and control surfaces, to fly at a 40 degree nose-up attitude, producing 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, 1986	<i>Challenger</i>	Disaster starting 73 seconds after launch; STS-51-L; all seven 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.

## **In culture**

The Space Shuttle has played an important role in various works of fiction. Early examples include the 1979 James Bond film, *Moonraker*, where shuttles played a major role well before any were actually launched, Activision videogame *Space Shuttle: A Journey into Space* (1982) and G. Harry Stine's novel *Shuttle Down* (1981). In the 1986 family film *SpaceCamp*, the *Atlantis* accidentally launches into space with children as its crew. The 1998 film *Armageddon* portrays a combined crew of offshore oil rig workers and US military pilot two modified shuttles to avert the destruction of Earth by an asteroid, while retired American test pilots visit a Russian satellite in the Clint Eastwood adventure film *Space Cowboys* (2000). On television, the 1996 drama *The Cape* portrays the lives of a group of NASA astronauts as they prepare for and fly shuttle missions.

The Space Shuttle has also been the subject of toys and models, for example a large Lego Space Shuttle model was constructed by visitors at Kennedy Space Center.

## **U.S. Postage commemorations**

The U.S. Postal Service has released several postage issues that depict the Space Shuttle. The first such stamps were issued in 1981, and are on display at the National Postal Museum.

## Chapter- 6

# Dragon (Spacecraft)

### SpaceX Dragon spacecraft



#### Description

<b>Role:</b>	<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
<b>Crew:</b>	<i>Dragon Cargo:</i> 0 <i>Dragon Crew:</i> 7
<b>Carrier Rocket:</b>	Falcon 9

#### Dimensions

<b>Height:</b>	2.9 m	9.51 ft
<b>Diameter:</b>	3.6 m	11.8 ft
<b>Pressurized Volume:</b>	10 m <sup>3</sup>	353 cu ft
<b>Unpressurized</b>	14 m <sup>3</sup>	494 cu ft

**Volume:**

**Unpressurized  
Volume  
(with additional  
trunk extended):**      34 m<sup>3</sup>              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).

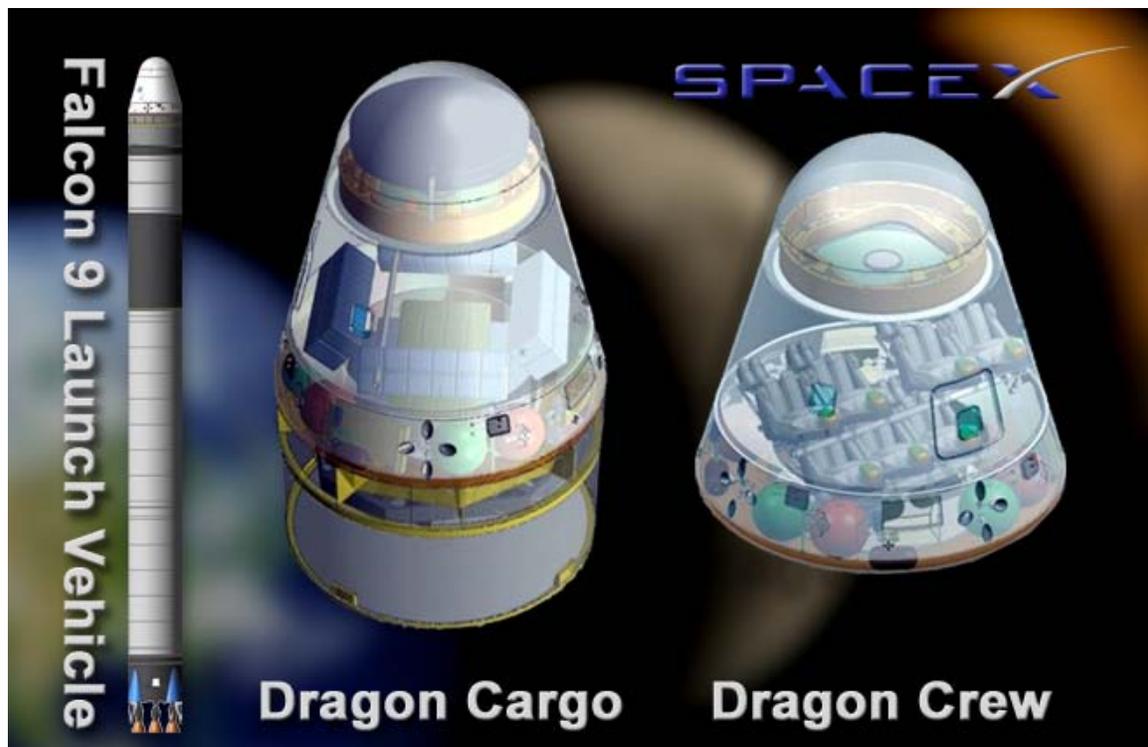
The Dragon capsule is launched atop a Falcon 9 rocket. SpaceX has built a full-sized prototype of the capsule and "thoroughly tested" its life support system.

## 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 m<sup>3</sup> (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 m<sup>3</sup> (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 m<sup>3</sup> (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 m<sup>3</sup> (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<sub>DC</sub> 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

# Orion

### Orion



An artist's rendering of the Orion spacecraft

### Description

<b>Role:</b>	Beyond LEO, back-up for commercial cargo and crew to the ISS
<b>Crew:</b>	4
<b>Carrier Rocket:</b>	Shuttle-Derived Launch Vehicle Current front- runner launch vehicle for the CEV
<b>Launch Date:</b>	2016

### Dimensions

**Height:**

**Diameter:** 5 m (16.5 ft)

**Pressurized Volume:** 19.55 m<sup>3</sup>

**Habitable Volume:** 8.95 m<sup>3</sup>

**Capsule Mass:** 8,913 kg  
(19,650 lb)

**Service Module Mass:** 12,337 kg  
(27,198 lb)

**Total Mass:** 21,250 kg  
(46,848 lb)

**Service Module  
Propellant Mass:** 7,907 kg  
(17,433 lb)

### Performance

**Total delta-v:** 1,595 m/s

**Endurance:** 210 days



Orion logo designed by Michael Okuda

**Orion** is a spacecraft which is being designed by Lockheed Martin for NASA, the space agency of the United States. Orion development began as part of the Constellation program, where Orion would fulfill the function of a Crew Exploration Vehicle.

Each Orion spacecraft is projected to carry a crew of four astronauts. The spacecraft was originally designed to be launched by the Ares I launch vehicle, for the Constellation Program. As of 11 October 2010, with the canceling of the Constellation Program the Orion vehicle is now planned to be launched on top of a Shuttle-Derived Heavy Lift Vehicle.

Orion would launch from Launch Complex 39 at Kennedy Space Center, the same launch complex used by the Space Shuttle and the Saturn V. While shuttle operations continued from launch pad 39A, 39B was readied for Ares launches. The first crewed Orion flight is anticipated in 2016. Subsequent flights would visit the International Space Station. If commercial orbital transportation services are unavailable, Orion would handle logistic flights to the station. After that, Orion may become a key component of human missions beyond low Earth orbit which may include missions to Lagrange points, Near-Earth objects, the Moon and Mars.

The federal government proposed cancellation of the Constellation program in February 2010 and was signed into law October 11. The bill is basically a retooling of the Constellation Program, moving the objective away from a moon base and more towards a NEO mission and an eventual Mars landing.

## History



Artist's rendering of the Orion spacecraft and Altair in lunar orbit

On January 14, 2004, President George W. Bush announced the Orion spacecraft, known then as the Crew Exploration Vehicle (CEV), as part of the Vision for Space Exploration:

Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, and to conduct the first manned mission no later than 2014. The Crew Exploration Vehicle will be capable of ferrying astronauts and scientists to the Space Station after the shuttle is retired. But the main purpose of this spacecraft will be to carry astronauts beyond our orbit to other worlds. This will be the first spacecraft of its kind since the Apollo Command Module.

The proposal to create the Orion spacecraft was partly a reaction to the Space Shuttle *Columbia* accident, the subsequent findings and report by the Columbia Accident Investigation Board (CAIB), and the White House's review of the American space program. The Orion spacecraft effectively replaced the conceptual Orbital Space Plane (OSP), which itself was proposed after the failure of the Lockheed Martin X-33 program to produce a replacement for the space shuttle.

The name is derived from the constellation of Orion, and was also used on the Apollo 16 Lunar Module that carried astronauts John W. Young and Charlie Duke to the lunar surface in April 1972.

After the replacement of Sean O'Keefe, NASA's procurement schedule and strategy completely changed, as described above. In July 2004, before he was named NASA administrator, Michael Griffin participated in a study called "Extending Human Presence Into the Solar System" for The Planetary Society, as a co-team leader. The study offers a strategy for carrying out Project Constellation in an affordable and achievable manner. Since Griffin was one of the leaders of the study, it can be assumed that he agrees with its conclusions, and the study may show insight into possible future developments of the CEV. Griffin's actions as administrator supported the goals of the plan.

According to the executive summary, the study was built around "a staged approach to human exploration beyond low Earth orbit (LEO)." It recommends that Project Constellation be carried out in three distinct stages. These are:

- Stage 1 – "Features the development of a new crew exploration vehicle (CEV), the completion of the International Space Station (ISS), and an early retirement of the shuttle orbiter. Orbiter retirement would be made as soon as the ISS U.S. Core is completed (perhaps only 6 or 7 flights) and the smallest number of additional flights necessary to satisfy our international partners' ISS requirements. Money saved by early orbiter retirement would be used to accelerate the CEV development schedule to minimize or eliminate any hiatus in U.S. capability to reach and return from LEO."
- Stage 2 – "Requires the development of additional assets, including an updated CEV capable of extended missions of many months in interplanetary space. Habitation, laboratory, consumables, and propulsion modules, to enable human flight to the vicinities of the Moon and Mars, the Lagrange points, and certain near-Earth asteroids."
- Stage 3 – "Development of human-rated planetary landers is completed in Stage 3, allowing human missions to the surface of the Moon and Mars beginning around 2020."

A number of changes to the original CEV acquisition strategy were explained in a NASA study called the Exploration Systems Architecture Study. The results were presented at a news conference held on September 19, 2005. The ESAS recommends strategies for flying the manned Orion by 2014, and endorses a Lunar Orbit Rendezvous approach to the Moon. The LEO versions of Orion was intended carry crews of four to six to the ISS.

The lunar version of the Orion would carry a crew of four and the Mars Orion would carry six. Cargo would also be carried aboard an unmanned version of Orion, similar to the Russian Progress cargo ships. The contractor for the Orion is Lockheed Martin, which was selected by NASA in September, 2006 and is the current contractor for the Space Shuttle's External Tank and the Atlas V EELV.

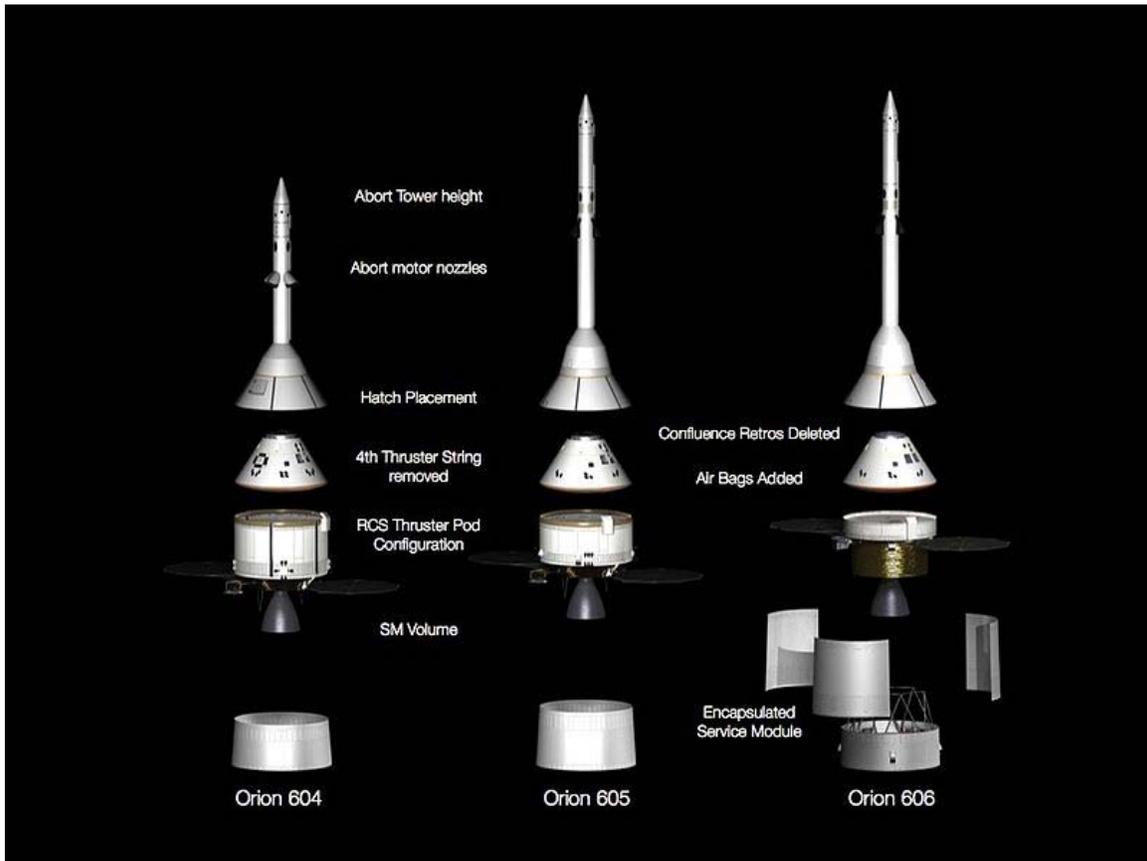
The Orion spacecraft (CEV) will be an Apollo-like capsule, not a lifting body or winged vehicle like the current Shuttle. Like the Apollo Command Module, Orion would be attached to a service module for life support and propulsion. It is intended to land in water but past versions had included plans for it to land on land. Landing on the west coast would allow the majority of the reentry path to be flown over the Pacific Ocean rather than populated areas. Orion will have an AVCOAT ablative heat shield that would be discarded after each use.

The Orion spacecraft (CEV) would weigh about 25 tons (23 tonnes) ... almost four times the mass of the Apollo Command Module at 6.4 tons (5.8 tonnes) ... and, with a diameter of 16.5 feet (5 metres) vice 12.8 feet (3.9 metres) provide 2.5 times greater volume.

Accelerated lunar mission development is slated to start by 2010, once the Shuttle is retired. The Lunar Surface Access Module (LSAM) and heavy-lift boosters would be developed in parallel and would both be ready for flight by 2018. The eventual goal is to achieve a lunar landing by 2020. The LSAM would be much larger than the Apollo Lunar Module and is anticipated to be capable of carrying up to around 23 tons (21 tonnes) of cargo to the lunar surface to support a lunar outpost (t.b.d.). This weight in cargo is greater than the mass of the entire Apollo Lunar Module.

Like the Apollo Lunar Module, the LSAM would include a descent stage for landing and an ascent stage for returning to orbit. The crew of four would ride in the ascent stage. The ascent stage would be powered by a methane/oxygen fuel for return to lunar orbit (later changed to liquid hydrogen and liquid oxygen, due to the infancy of oxygen/methane rocket propulsion). This would allow a derivative of the same lander to be used on later Mars missions, where methane propellant can be manufactured from the Martian soil in a process known as in-situ resource utilization (ISRU). The LSAM would support the crew of four on the lunar surface for about a week and use advanced roving vehicles to explore the lunar surface. The huge amount of cargo carried by the LSAM would be extremely beneficial for supporting a lunar base and for bringing large amounts of scientific equipment to the lunar surface.

## Design revisions and updates



Comparison of 604, 605 and 606 versions  
July 2006 design revisions

In late July 2006 NASA's second design review resulted in major changes to the spacecraft design. Originally, NASA wanted to use liquid methane (LCH<sub>4</sub>) as the SM fuel, but due to the infancy of oxygen/methane-powered rocket technologies and the need to launch the Orion by 2012, the switch to hypergolic propellants was mandated in late July 2006. This switch will allow NASA to man-rate the Orion and Ares I stack by no later than 2011, and eliminate one potential cause of the gap between the shuttle's retirement in 2010 and the first manned Orion flight.



607 version, with solar panels undeployed  
April 2007 contract revision

On April 20, 2007 NASA and Boeing signed a modification to the Orion contract. The updated contract adds two years to the Orion project design phase, adds two test flights of Orion's launch abort system, and deletes from the initial design phase production of a pressurized cargo carrier for the International Space Station.

May 2007 design update

An article in "Aerospace Daily & Defense Report" indicates that in the latest Orion design revision, called configuration "606" by Lockheed Martin, the service module will have exterior panels that are jettisoned shortly after the second stage engine of the Ares I ignites. This configuration will save 1,000 pounds of the mass compared with the prior "605" configuration.

August 2007 design update

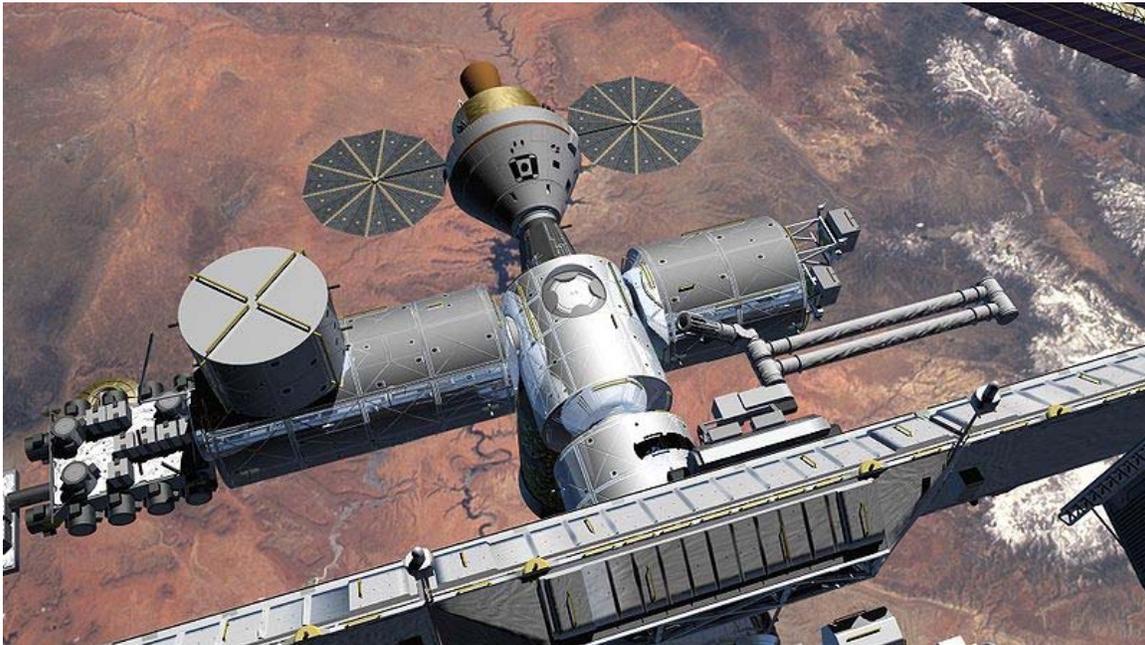
On August 5, a report surfaced stating that the airbag landing system was removed from the next Orion design cycle ("607") in a weight saving measure, opting to return to an Apollo-style splashdown for the vehicle's end of mission.

## **2009 Human Space Flight Plans Committee**

On September 8, 2009, the Human Space Flight Plans Committee was scheduled to release a report proposing a short list of different long term plans for the US Government's human space flight program. The review was commissioned by the Obama Administration to take into account several objectives. These include support for the International Space Station, development of missions beyond low Earth orbit (including the Moon) and use of commercial space industry. These objectives must fit within a defined budget profile.

Among the parameters to be considered in the course of the review are "crew and mission safety, life-cycle costs, development time, national space industrial base impacts, potential to spur innovation and encourage competition, and the implications and impacts of transitioning from current human space flight systems". The review considered the appropriate amounts of research and development and "complementary robotic activity necessary to support various human space flight activities". It also "[explores] options for extending International Space Station operations beyond 2016".

## **Funding and expected cost**



Artist's rendering of the Orion spacecraft docked to the International Space Station.

President Bush's budget request for Fiscal Year 2005 included "\$428 million for Project Constellation (\$6.6 billion over five years) to develop a new crew exploration vehicle". The budget for FY2005 was confirmed by the Congress in November 2004 with full funding for the CEV.

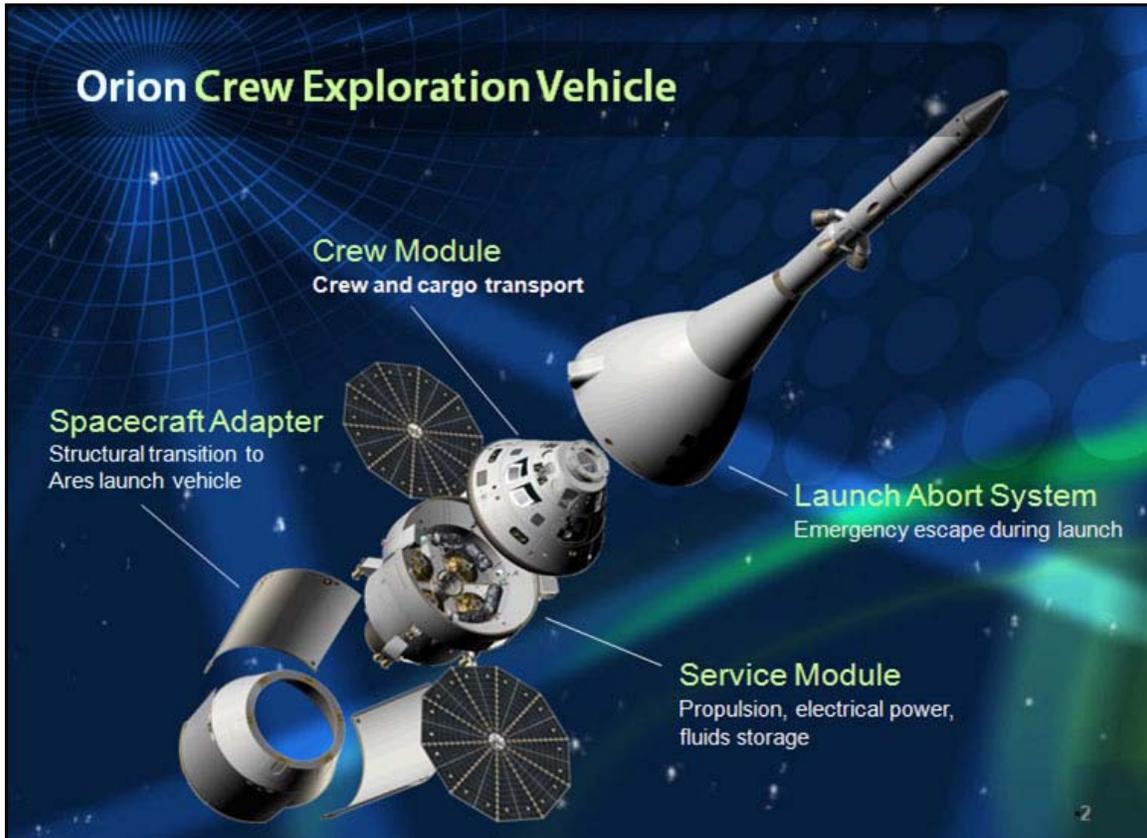
The FY2006 budget request includes \$753 million for continuing development of the CEV. As of 2005 the total development costs of the CEV are estimated at \$15 billion.

Lockheed Martin's contract for the initial "Schedule A" part of the Orion project, awarded on August 31, 2006 and running through 2013, is worth \$3.9 billion. Additional development options in the "Schedule B" part of the contract could be worth up to another \$3.5 billion.

Although to date the exploration systems have received full funding and a House endorsement, there was a possibility that rising shuttle Return To Flight costs would make funding of CEV development extremely difficult. There has been discussion of either obtaining a special supplemental from Congress to pay for the extra shuttle costs, or of involving private industry in CEV development and operations. The total funding of Project Constellation through 2025, inflation-adjusted and without any other increases to NASA's budget, is estimated at \$210 billion; the ESAS estimates the cost of the program through that date at being only \$7 billion more, at \$217 billion. This cost may in fact end up lower as it includes developing new engines for the EDS instead of the newer idea of using J-2 derivatives.

The White House's Augustine Commission estimated that after development of the Orion and its Ares I launch vehicle is completed, the system will have a recurring cost of nearly \$1 billion per flight.

# Design



The Orion spacecraft configuration including Launch Escape System/Boost Protective Cover and spacecraft adapter



The Crew Module

The **Orion Crew and Service Module** (CSM) stack consists of two main parts: a conical Crew Module (CM), and a cylindrical Service Module (SM) holding the spacecraft's propulsion system and expendable supplies. Both are based substantially on the Apollo Command and Service Modules (Apollo CSM) flown between 1967 and 1975, but include advances derived from the space shuttle program. "Going with known technology and known solutions lowers the risk," according to Neil Woodward, director of the integration office in the Exploration Systems Mission Directorate.

## **Crew Module**

The Orion CM will hold four to six crew members, compared to a maximum of three in the smaller Apollo CM or seven in the larger space shuttle. Despite its conceptual resemblance to the 1960s-era Apollo, Orion's CM will use several improved technologies, including:

- "Glass cockpit" digital control systems derived from that of the Boeing 787.
- An "autodock" feature, like those of Russian Progress spacecraft and the European Automated Transfer Vehicle, with provision for the flight crew to take over in an emergency. Previous American spacecraft (Gemini, Apollo, and Space Shuttle) have all required manual piloting for docking.
- Improved waste-management facilities, with a miniature camping-style toilet and the unisex "relief tube" used on the space shuttle (whose system was based on that used on Skylab) and the International Space Station (based on the Soyuz, Salyut, and Mir systems). This eliminates the use of the much-hated plastic "Apollo bags" used by the Apollo crews.
- A nitrogen/oxygen (N<sub>2</sub>/O<sub>2</sub>) mixed atmosphere at either sea level (101.3 kPa/14.69 psi) or slightly reduced (55.2 to 70.3 kPa/8.01 to 10.20 psi) pressure.
- Much more advanced computers than on previous manned spacecraft.



Orion crew module mock-up at Dryden Flight Research Lab

Another feature will be the partial reusability of the Orion CM. NASA aims to reuse each craft for up to ten flights, allowing it to build a fleet of both manned and unmanned Orion CMs. Both the CM and SM will be constructed of the aluminium lithium (Al/Li) alloy currently used on the shuttle's external tank, and the Delta IV and Atlas V rockets. The CM itself will be covered in the same Nomex felt-like thermal protection blankets used on non-critical parts on the shuttle such as the payload bay doors. The reusable recovery parachutes will be based on the parachutes used on both the Apollo spacecraft and the Space Shuttle Solid Rocket Boosters, and will also use the same Nomex cloth for construction. Water landings will be the exclusive means of recovery for the Orion CM.

To allow the Orion spacecraft to service the International Space Station, and to mate with other Constellation vehicles, it will use a new Low Impact Docking System, a simplified version of the universal docking ring currently used on the shuttle fleet, which itself was a Russian design that originated during the 1975 Apollo-Soyuz Test Project. Both the spacecraft and docking adapter will employ a Launch Escape System (LES) like that used in Mercury and Apollo, along with an Apollo-derived "Boost Protective Cover" (made of fiberglass), to protect the Orion CM from aerodynamic and impact stresses during the first 2½ minutes of ascent.

The Orion Crew Module (CM) is a 57.5° frustum shape, similar to that of the Apollo Command Module. As projected, the CM will be 5.02 meters (16 ft 6 in) in diameter and

3.3 meters (10 ft 10 in) in length, with a mass of about 8.5 metric tons (19,000 lb). It is to be built by the Lockheed Martin Corporation. It will have more than 2.5 times the volume of an Apollo capsule, which had an interior volume of 5.9 m<sup>3</sup> (210 cu ft), and will carry four to six astronauts. After extensive study, NASA has selected the Avcoat ablator system for the Orion crew module. Avcoat, which is composed of silica fibers with a resin in a honeycomb made of fiberglass and phenolic resin, was previously used on the Apollo missions and on select areas of the space shuttle for early flights.

### **Service module**



This concept image shows the Ares I crew launch vehicle during ascent.

The service module designed for Orion will serve as the primary power and propulsion component of the spacecraft system, and like its predecessors, will be discarded at the

end of each mission. Roughly cylindrical in shape, the Orion service module, like the crew module, will be constructed of Al-Li alloy (to keep weight down), and will feature a pair of deployable circular solar panels, similar in design to the panels used on the Mars Phoenix lander. The panels, the first to be used on a U.S. manned spacecraft (except for a 10-year period, the Soviet/Russian Soyuz spacecraft has used them since the first mission in 1967), will allow NASA to eliminate the need to carry malfunction-prone fuel cells, and its associated hardware (mainly LH<sub>2</sub> tanks) from the service module, resulting in a shorter, yet more maneuverable spacecraft. Successful initial testing of an Orion solar array design using full-scale "UltraFlex wing" hardware was reported in October, 2008.

The spacecraft's main propulsion system is an Aerojet AJ-10 rocket engine, derived from the second stage of the Delta II rocket, powered by hypergolic fuels, that are kept in helium pressured fuel cells. The SM Reaction Control System (RCS), the spacecraft's maneuvering thrusters (originally based on the Apollo "quad" system, but currently resembles that used on Gemini), will also be pressure-fed, and will use the same propellants. NASA believes the SM RCS would be able to act as a backup for a trans-Earth injection (TEI) burn in case the main SM engine fails.

A pair of LOX tanks (similar to those used in the Apollo SM) will provide, along with small tanks of nitrogen, the crew with breathing air at sea-level or "cruising altitude" pressure (10.2 to 14.7 psi), with a small "surge tank" providing necessary life support during reentry and touchdown. Lithium hydroxide (LiOH) cartridges will recycle the spacecraft's environmental system by "scrubbing" the carbon dioxide (CO<sub>2</sub>) exhaled by the astronauts from ship's air and adding fresh oxygen and nitrogen, which is then cycled back out into the system loop. Because of the switch from fuel cells to solar panels, the service module will have an onboard water tank which will provide drinking water for the crew, and (when mixed with glycol), cooling water for the spacecraft's electronics. Unlike the practice during Apollo of dumping both water and urine overboard during the flight, the Orion will have an onboard recycling system, identical to that used on the International Space Station, that will convert both waste water and urine into both drinking and cooling water.

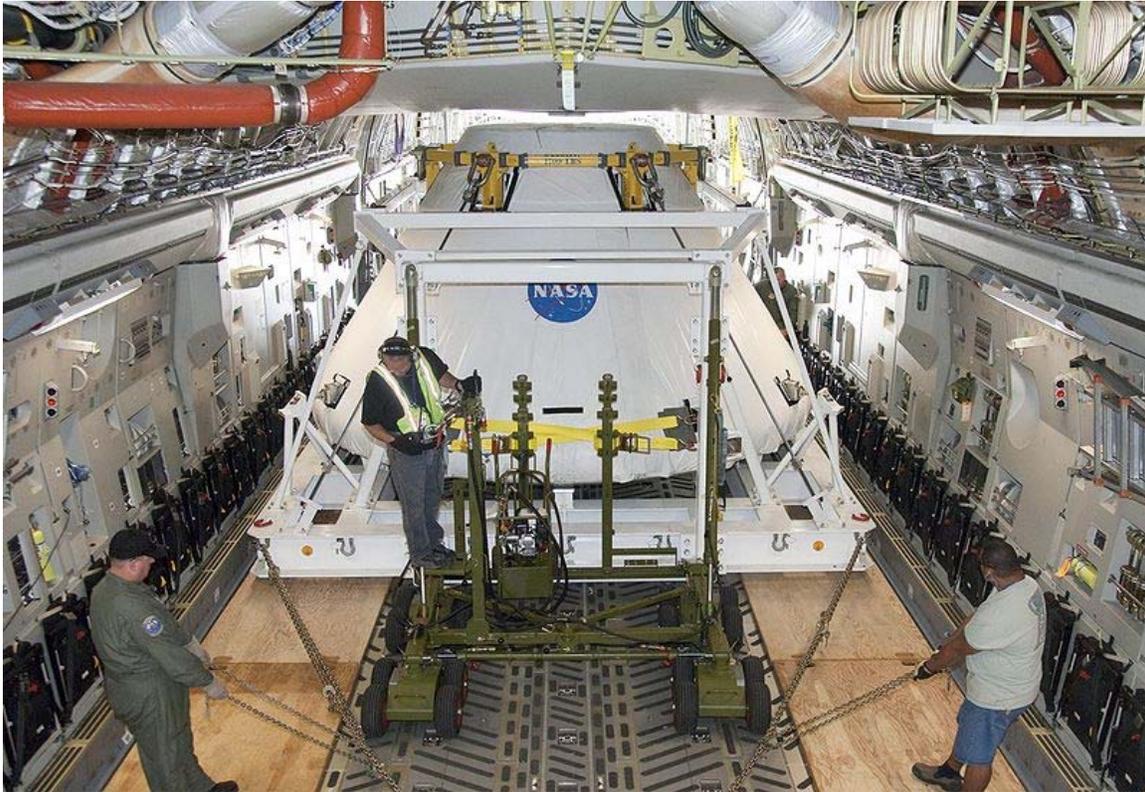
The Service Module also mounts the spacecraft's waste heat management system (its radiators) and the aforementioned solar panels. These panels, along with backup batteries located in the Orion CM, will provide in-flight power to the ship's systems. The voltage, 28 volts DC, is similar to that used on the Apollo spacecraft during flight.

Like the Orion crew module, the Orion service module will be encapsulated by a fiberglass shroud that would be jettisoned at the same time as the LES/Boost Protective Cover, which would take place roughly 2½ minutes after launch (30 seconds after the solid rocket first stage is jettisoned). Prior to the "Orion 606" redesign, the Orion SM resembled a squat, enlarged version of the Apollo Service Module. The new "Orion 606" SM design retains the 5-meter width for the attachments of the Orion SM with the Orion CM, but utilizes a Soyuz-like service module design that allows Lockheed Martin to make the vehicle lighter in weight and permitting the attachment of the circular solar

panels at the module's mid-points, like that of the Soyuz, instead of at the base near the spacecraft/rocket adapter, which may subject the panels to damage.

The Orion service module (SM) is projected comprising a cylindrical shape, having a diameter of 5.03 m (16 ft 6 in) and an overall length (including thruster) of 4.78 m (15 ft 8 in). With solar panels extended, span is either 17.00 m (55.77 ft) or 55.00 ft (16.76 m). The projected empty mass is 3,700 kg (8,000 lb), fuel capacity is 8,300 kg (18,000 lb).

### **Launch Abort System**



Technicians carefully position an Orion flight test crew module to be airlifted. This module will be used for the Orion Launch Abort System Pad Abort-1 flight test.



The reentry of the Orion Crew Module.

In the event of an emergency on the launch pad or during ascent, a launch escape system called the Launch Abort System (LAS) will separate the Crew Module from the launch vehicle using a solid rocket-powered launch abort motor (AM), which is more powerful than the Atlas 109-D booster that launched astronaut John Glenn into orbit in 1962. There are two other propulsion systems in the LAS stack: the attitude control motor (ACM) and the jettison motor (JM). On July 10, 2007, Orbital Sciences, the prime contractor for the LAS, awarded Alliant Techsystems (ATK) a \$62.5 million sub-contract to, "design, develop, produce, test and deliver the launch abort motor." ATK, which has the prime contract for the first stage of the Ares I rocket, intends to use an innovative "reverse flow" design for the motor. On July 9, 2008 NASA announced that ATK has completed a vertical test stand at a facility in Promontory, Utah to test launch abort motors for the Orion spacecraft. Another long-time space motor contractor, Aerojet, was awarded the jettison motor design and development contract for the LAS. As of September 2008 Aerojet has, along with team members Orbital Sciences, Lockheed Martin and NASA, successfully demonstrated two full-scale test firings of the jettison motor. This motor is important to every flight in that it functions to pull the LAS tower away from the vehicle after a successful launch. The motor also functions in the same manner for an abort scenario.

Another idea, recently floated by NASA, would see the LAS tower being replaced with the so-called Max Launch Abort System (MLAS), in which four existing solid-rocket motors, integrated into the boost protective cover and placed at 90° intervals, would fire and pull the Orion crew module away from an Ares I rocket in the event of a launchpad or in-flight abort during the first 2½ minutes of launch. If implemented in place of the LAS, the MLAS would allow NASA to reduce further weight of the Orion/Ares I stack (which has been described by critics as being overweight) and the design, which is shaped like a bullet, would reduce stresses on both the spacecraft and the launch vehicle, as well as reducing the overall height by 20–25 feet.

## Abort tests

ATK successfully completed the first Orion launch-abort test on November 20, 2008. The abort motor will provide 500,000 lbf (2,200 kN) of thrust for an emergency on the launch pad or during the first 300,000 feet (91 km) of the rocket's climb to orbit. The test firing was the first time a motor with reverse flow propulsion technology at this scale has been tested.

This abort test firing brought together a series of motor and component tests conducted in 2008 as a preparation for the next major milestone, a full-size mock-up or boilerplate test scheduled for the spring of 2009.

## Pathfinder



Orion Launch Abort Simulator is completed at NASA's Langley Research Center

On March 2, 2009, the LAS Pathfinder began its transfer from the Langley Research Center to the White Sands Missile Range, New Mexico, for launch tests. The Pathfinder is a combination of the Orion Boilerplate and LAS module. The 45 ft (14 m)-long rocket assembly will begin its first Pad Abort 1 Test on the Missile Range.

## **Criticism**

### **Acquisition strategy**

The Space Frontier Foundation has asserted that the \$3.9 billion initial phase of the Orion contract essentially duplicates the functionality of NASA's \$500 million Commercial Orbital Transportation Services (COTS) program. Additionally, NASA's contract with Lockheed Martin is a cost-plus contract, a contracting method which has been criticized for being prone to cost overruns and delays, while contractors in the COTS only receive payment for successes. The U.S. Government Accountability Office (GAO) is also critical of NASA, saying, "NASA's current acquisition strategy for the CEV places the project at risk of significant cost overruns, schedule delays, and performance shortfalls because it commits the government to a long-term product development effort before establishing a sound business case."

## **Testing**

### **Environmental testing**

NASA will perform environmental testing of Orion from 2007 to 2011 at the Glenn Research Center Plum Brook Station in Sandusky, Ohio. The Center's Space Power Facility is the world's largest thermal vacuum chamber.

## Abort Flight Test (AFT)



Test-firing of Orion LAS jettison motor



NASA and Department of Defense personnel familiarize themselves with a Navy-built, 18,000-pound Orion mock-up in a test pool at the Naval Surface Warfare Center's Carderock Division in West Bethesda, Md.

NASA will perform a series of six Abort Flight Tests between the fall of 2008 and the end of 2011 at the United States Army's White Sands Missile Range (WSMR), New Mexico. The Orion AFT subproject includes two pad abort tests and four ascent abort tests. Three of the four ascent aborts are planned to be flown from a special test launch vehicle, the Orion Abort Test Booster, the fourth one being performed with Ares I-Y. The Orion Abort Flight Tests are similar in nature to the Little Joe II tests performed at WSMR between September 1963 and January 1966 in support of the development of the Apollo program's Launch Escape System. The LAS Pathfinder boilerplate is being used.

### **Post-landing Orion Recovery Test (PORT)**

The PORT Test is to determine and evaluate what kind of motions the astronaut crew can expect after landing. This will include conditions outside the capsule for the recovery team. The evaluation process will support NASA's design of landing recovery operations including equipment, ship and crew necessities.

The Port Test will use a full-scale boilerplate of NASA's Orion crew module and will be tested in water under simulated and real weather conditions. Tests began March 23, 2009 with a Navy-built, 18,000-pound boilerplate. It will be placed in a test pool at the Naval Surface Warfare Center's Carderock Division in West Bethesda, Md. Full sea testing will

begin April 6, 2009, in a special location off the coast of NASA's Kennedy Space Center with media coverage.

## Schedule

NASA hopes to follow this schedule in development of the Orion:

- 2006–2007 — Engineering review of selected design
- May 6, 2010 — PA-1 (Pad Abort-1) unmanned pad abort test.
- 2009 (Sep) — AA-1 (Ascent Abort-1) unmanned ascent abort test (transonic)
- 2010 (Spring) — PA-2 unmanned pad abort test
- 2010 (August) — AA-2 unmanned ascent abort test (Max Q)
- 2011 (February) — AA-3 unmanned ascent abort test (low-altitude tumble test)
- 2012 (September) — Ares I-Y unmanned ascent abort test (high altitude)
- 2014 — First unmanned flight of Orion in Earth orbit
- **2015 — First manned flight of Orion in Earth orbit.**
- 2015–2018 — First unmanned flight of Altair.
- 2016–2018 First manned flight of Altair.
- **2019 First manned lunar landing with Orion/Altair system.**
- 2020 Review of Mars missions
- 2031 The Mission to Mars has tentative dates

NASA initially established that it would initiate a phased retirement of the space shuttle, which would have begun with the retirement of one orbiter, *Atlantis*, in 2008. This decision was later changed; all three remaining shuttles would keep flying until 2010. In the meantime, NASA engineers would work to upgrade the current launch facilities to work with the next generation shuttle-derived launch vehicles. Such a plan would allow lunar mission development to begin much earlier than currently planned, as additional funding will be available earlier.

## Existing craft and mockup models (as of April 2009)

This is a list of the mockups that look like a whole crew module or other major component of Orion. There are other simulators that are just cockpits and smaller components, but those may be even more difficult to keep current. The flight crew module will be predominantly white (as opposed to silver).

- **Lockheed Martin**
  - Houston: Exploration Development Laboratory has a Low-Fidelity Crew Module Human Engineering Mockup
  - Kennedy Space Center Operations & Checkout Facility: full scale Crew Module Pathfinder
  - Michoud: Crew Module Ground Test Article is currently being built
- **Orbital, Dulles**

- Launch Abort System Inert Vehicle
- **ATK**
  - Launch Abort System Abort Motor
- **United Space Alliance**
  - 1/10th scale crew module for buoyancy testing with Texas A&M-Galveston
  - KSC: crew module wire frame mockup in the Human Engineering Modeling & Performance Lab
- **Johnson Space Center**
  - Bldg 9: Medium Fidelity Crew Module
  - PORT – Post-landing Orion Recovery Test (full scale) – currently at KSC, was built at Navy Carderock facility
  - WEST – Water Egress Survival Trainer (1/4 scale) – Houston
- **Dryden Flight Research Center**
  - Pad Abort 1 Flight Test Crew Module
- **White Sands Missile Range**
  - Launch Abort System Pathfinder
  - Pad Abort 1 Crew Module Pathfinder Mockup

## **Project Constellation nomenclature**

- **Orion** – Crew/Service Module (CSM) manned/unmanned multi-role spacecraft.
- **Altair** – Lunar Surface Access Module (LSAM), the manned/unmanned lunar logistics vehicle.
- **Ares I** – ("The Stick") Medium-lift crew/cargo launch vehicle.
- **Ares IV** – Medium-heavy lift launch vehicle announced in February, 2007.
- **Ares V** – Heavy-lift cargo launch vehicle.

## Chapter- 8

# Cygnus & CST-100

## Cygnus (spacecraft)

Cygnus spacecraft		
		
Artist's rendering of the Cygnus spacecraft		
Description		
<b>Role:</b>	Under development To be used to supply the International Space Station after retirement of the Shuttle	
<b>Crew:</b>	0	
<b>Carrier Rocket:</b>	Taurus II	
Dimensions		
<b>Height:</b>	3.07 m /3.07 m	10.07 ft / 10.07 ft
<b>Diameter:</b>	3.07 m	10.07 ft /

	/3.07 m	10.07 ft
<b>Weight:</b>		
<b>Volume:</b>	18.9 m <sup>3</sup> / 26.2 m <sup>3</sup>	
<b>Launch Payload:</b>	2,000 kg/ 2,700 kg	4,400 lb/ 5,950 lb
<b>Disposal Payload:</b>	1,200 kg	2,600 lb
<b>Performance</b>		
<b>Endurance:</b>	Yet to be specified	

The **Cygnus spacecraft** is an unmanned resupply spacecraft being developed by Orbital Sciences Corporation and Thales Alenia Space as part of NASA's COTS project. They are designed to transport supplies to the International Space Station (ISS) after the retirement of the Space Shuttle. Since August 2000 unmanned ISS resupply missions have been regularly flown by Russian Progress spacecraft, and by one flight of the European Automated Transfer Vehicle and two flights of the Japanese H-II Transfer Vehicle. With the Cygnus spacecraft, NASA seeks to increase its partnerships with domestic commercial aviation and aeronautics industry.

## Development

With Rocketplane Kistler unable to meet funding obligations for its K-1 launch vehicle under the terms of the COTS agreement, NASA decided on October 18, 2007 to terminate its contract with Rocketplane Kistler and re-award its contract after a competition. On February 19, 2008 NASA announced that it had chosen Orbital Sciences as the new winner.

On December 23, 2008, NASA awarded Orbital Sciences a \$1.9 billion contract under the Commercial Resupply Services plan. Under this contract, Orbital Sciences will deliver up to 20 tons of cargo to the ISS through 2016 in eight Cygnus spacecraft flights.

In April 2010 Orbital displayed a full-scale model of the Cygnus cargo delivery spacecraft at the National Space Symposium (NSS) in Colorado Springs, CO.

The first Cygnus demonstration flight was originally expected in late 2010, launched by a Taurus II rocket. This has now been postponed to May or June 2011.

## Design

The Cygnus spacecraft consists of two basic components: the service module and the cargo module. The service module is based on Orbital's STAR spacecraft bus as well as components from the development of the Dawn spacecraft. It is currently expected to have a gross mass of 1,800 kg with propulsion provided by thrusters using the hypergolic propellants hydrazine and nitrogen tetroxide and is capable of producing up to 4 kW of electrical power via two gallium arsenide solar arrays. On November 12, 2009, Dutch Space announced it will provide solar arrays for nine Cygnus spacecraft under a contract valued at more than \$35 million.

There are two types of cargo modules slated for use with the spacecraft. The first type is a pressurized cargo module based on the Italian-built Multi-Purpose Logistics Module. This version is expected to have a gross mass of 3,500 kg, a payload mass of 2,000 kg and a total pressurized volume of 18.7 m<sup>3</sup>. The second type is based on a variant of NASA's ExPRESS Logistics Carrier. This variant will also have a gross mass of 3,500 kg with an expected payload mass of 2,000 kg, depending on the configuration being used, and an expected total cargo volume of 18.1 m<sup>3</sup>. The spacecraft will dock with the International Space Station by maneuvering close to the space station where the Canadarm2 robotic arm will grapple the spacecraft and attach it to a Common Berthing Mechanism on the Harmony module in a similar fashion to the Japanese H-II Transfer Vehicle. Neither cargo module provides return capability but modules can be loaded with obsolete equipment and trash for destructive reentry similar to Russian Progress modules.

A Cygnus variant with a robotic arm is being considered. Such a variant would be a space tug suitable for supporting the International Space Station, other space stations and propellant depots.

# CST-100

## CST-100



Promotional image released by Boeing.

<b>Operator</b>	Boeing, Bigelow Aerospace
<b>Mission type</b>	Crew Transfer Vehicle
<b>Carrier rocket</b>	EELV, Falcon 9

The **CST-100** crew capsule is a spacecraft design proposed by Boeing in collaboration with Bigelow Aerospace as their entry for NASA's Commercial Crew Development (CCDev) program. Its primary mission would be to transport crew to the International Space Station, and to private space stations such as the proposed Commercial Space Station from Bigelow Aerospace.

Outwardly it would look much like the Orion, a spacecraft being built for NASA by Lockheed Martin. The exact dimensions have not been released, but the capsule would be larger than the Apollo command module and smaller than the Orion capsule. It would only be used for transport to and from low Earth orbit, so that there would be no need for the deep space infrastructure present in the Orion. The CST-100 would be able to support larger crews of up to 7 people as the result of greater habitable interior volume and the reduced weight of equipment needed to support an exclusively low-Earth-orbit configuration. It is designed to be able to remain on-orbit for up to seven months and for reusability for up to ten missions.

NASA has awarded Boeing \$18 million for preliminary development of the spacecraft under its CCDev program.

The CST-100 would be compatible with multiple launch vehicles, including the Atlas V, Delta IV, and Falcon 9.

## **Future**

Receiving the full fixed-price payments for the CCDev Space Act Agreement requires the following milestones to be met in 2010:

- trade study and down-select between pusher-type and tractor-style LAS (Launch Abort System)
- system definition review
- Abort System Hardware Demonstration Test
- Base Heat Shield Fabrication Demonstration
- Avionics Systems Integration Facility demonstration
- CM Pressure Shell Fabrication Demonstration
- Landing System Demonstration (drop test and water uprighting test)
- Life Support Air Revitalization demonstration
- Autonomous Rendezvous and Docking (AR&D) hardware/software demonstration
- Crew Module Mockup demonstration.

The future of the CST-100 is surrounded by uncertainty. Boeing has stated the capsule could be operational in 2015 if the go-ahead was given soon, but also indicated they would only proceed with development of the CST-100 if NASA goes ahead with the commercial crew transport initiative that was announced by the Obama administration in its FY11 budget request. Boeing executive Roger Krone stated that NASA investment would allow Boeing to close the business case, while this would be very difficult without NASA. In addition a second destination besides the ISS would be needed to close the business case and Krone said that cooperation with Bigelow was crucial for this.

## **Technology partners**

- Bigelow Aerospace
- Aerojet
- Airborne Systems
- Alliant Techsystems
- Spincraft

## **Design heritage**

The design will draw upon Boeing's experience with NASA's Apollo, Space Shuttle and ISS programs as well as the Orbital Express project sponsored by the Department of Defense.

The CST-100 has no Orion heritage, but it is sometimes confused with the earlier and similar Orion-derived Orion Lite proposal that Bigelow was reportedly working on with technical assistance from Lockheed Martin. It will use the Androgynous Peripheral

Attach System for docking and use the Boeing Lightweight Ablator (BLA) for its heatshield.

## **Name**

The initial Boeing press releases did not state a name for the CST-100. The name CST-100 was first revealed to the public by Bigelow Aerospace CEO Robert Bigelow, who referred to the capsule as the CST-100 in June, 2010. The letters CST stand for Crew Space Transportation and the number 100 in the name stands for 100 km, the height of the Kármán line, which defines the boundary of space.