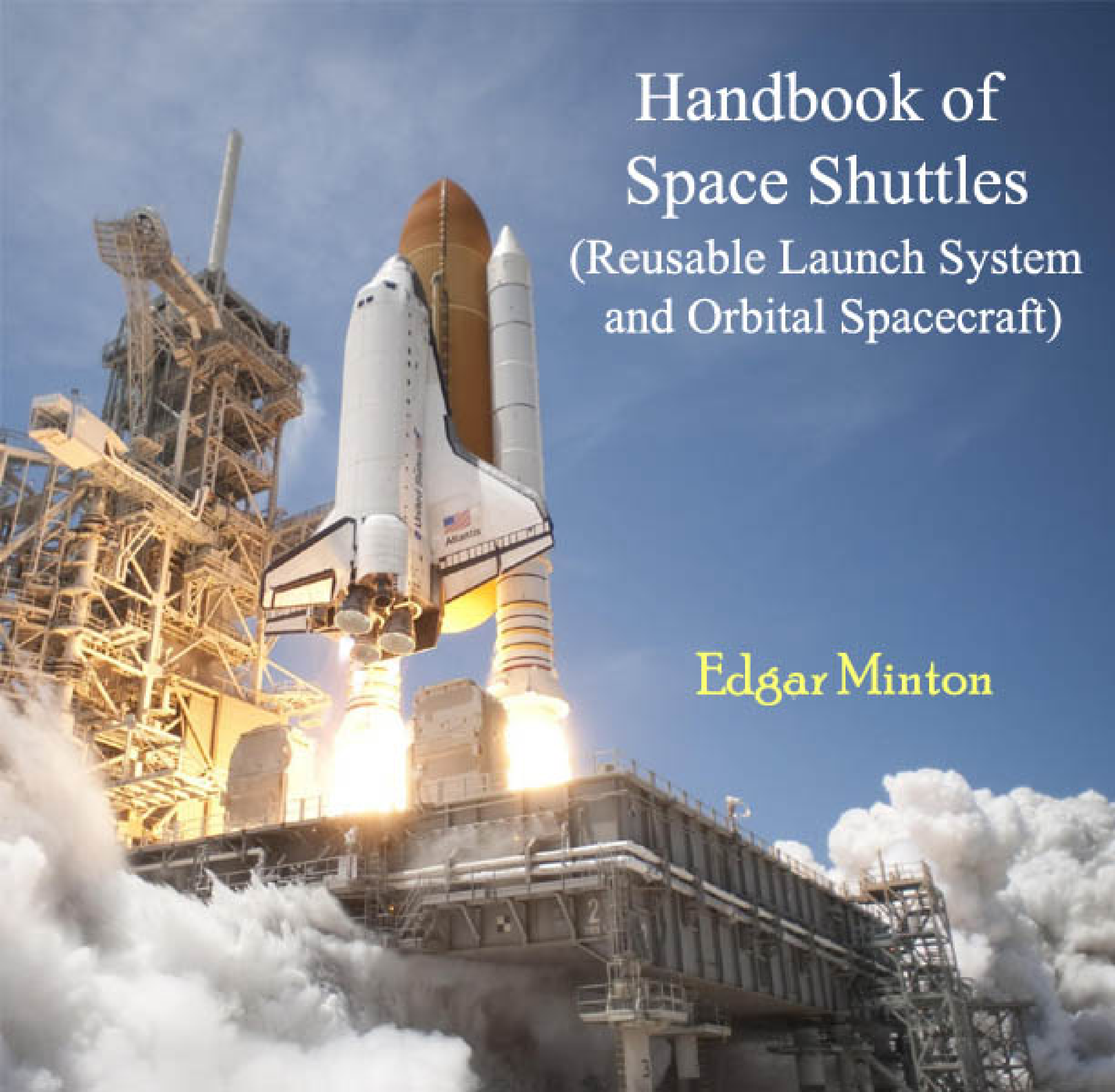
Handbook of Space Shuttles (Reusable Launch System and Orbital Spacecraft)

Edgar Minton



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Space Shuttle

Space Transportation System

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

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

Mass	4,470,000 lbm (2,030 t)
Capacity	
Payload to LEO	24,400 kg (53,600 lb)
Payload to GTO	3,810 kg (8,390 lbm)
Payload to Polar orbit	12,700 kg (28,000 lb)
Launch history	
Status	Active
Launch sites	LC-39, Kennedy Space Center SLC-6, Vandenberg AFB (unused)
Total launches	132
Successes	130
Failures	2 (launch failure, *Challenger*), (re-entry failure, *Columbia*)
Maiden flight	April 12, 1981
Notable payloads	Tracking and Data Relay Satellites Spacelab Great Observatories (including Hubble) Galileo, Magellan, Ulysses Mir Docking Module ISS components
Boosters (Stage 0) - Solid Rocket Boosters	
№ boosters	2
Engines	1 solid
Thrust	2,800,000 lbf each, sea level liftoff (12.5 MN)
Specific impulse	269 s
Burn time	124 s
Fuel	solid
First stage - External Tank	
Engines	3 SSMEs located on Orbiter
Thrust	1,225,704 lbf total, sea level liftoff (5.45220 MN)
Specific impulse	455 s
Burn time	480 s
Fuel	LOX/LH2
Second stage - Orbiter	
Engines	2 OME
Thrust	53.4 kN combined total vacuum thrust (12,000 lbf)
Specific impulse	316 s
Burn time	1250 s
Fuel	MMH/N_2O_4

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

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

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

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

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

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

Early history

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

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

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

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

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

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

Description

STS-1 on the launch pad (1981)

The Space Shuttle is the first orbital spacecraft designed for reuse. It carries different payloads to low Earth orbit, provides crew rotation for the International Space Station (ISS), and performs servicing missions. The orbiter can also recover satellites and other payloads from orbit and return them to Earth. Each Shuttle was designed for a projected lifespan of 100 launches or ten years of operational life, although this was later extended. The person in charge of designing the STS was Maxime Faget, who had also overseen the Mercury, Gemini, and Apollo spacecraft designs. The crucial factor in the size and shape of the Shuttle Orbiter was the requirement that it be able to accommodate the largest planned commercial and classified satellites, and have the cross-range recovery range to meet the requirement for classified USAF missions for a once-around abort from a launch to a polar orbit. Factors involved in opting for solid rockets and an expendable fuel tank included the desire of the Pentagon to obtain a high-capacity payload vehicle for satellite deployment, and the desire of the Nixon administration to reduce the costs of space exploration by developing a spacecraft with reusable components.

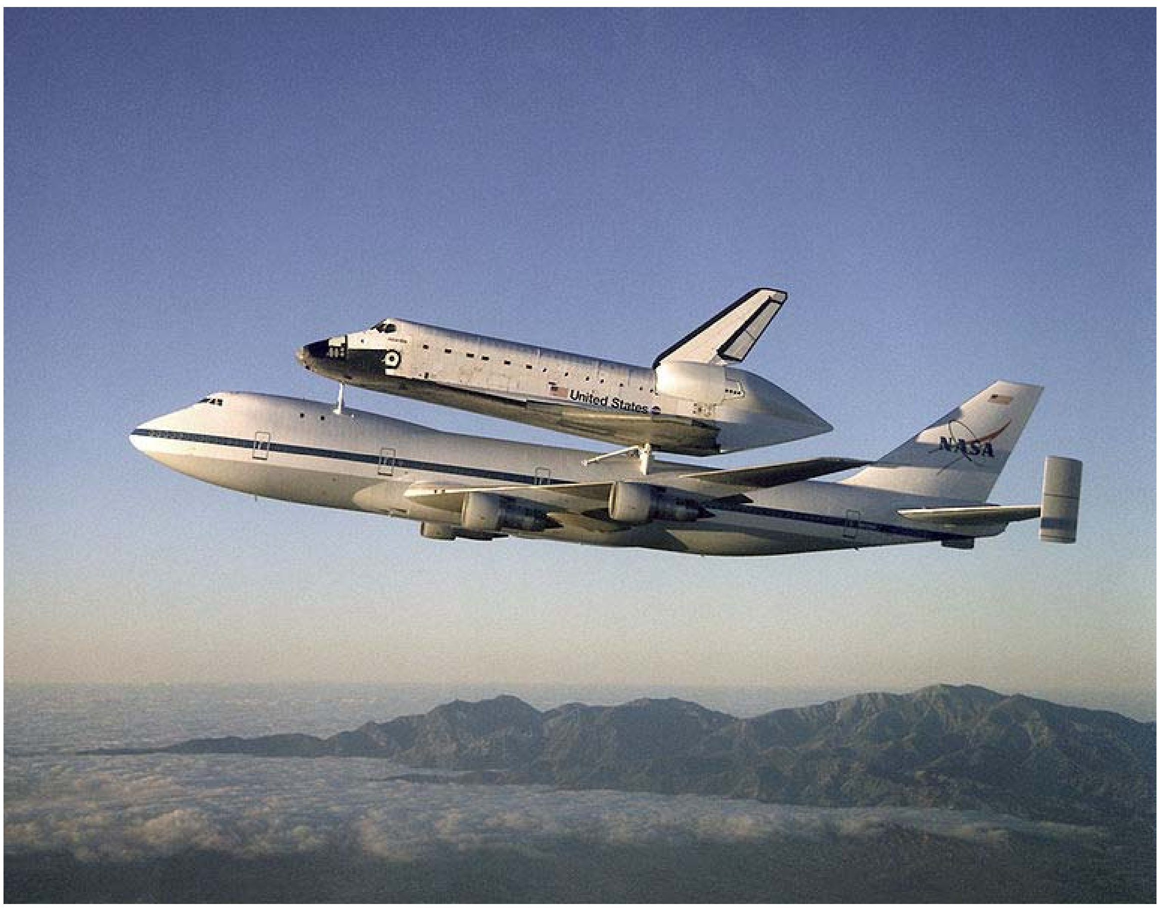
Each Space Shuttle is a reusable launch system that is composed of three main assemblies: the reusable Orbiter Vehicle (OV), the expendable external tank (ET), and the two reusable solid rocket boosters (SRBs). Only the orbiter enters orbit shortly after the tank and boosters are jettisoned. The vehicle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

Six airworthy orbiters have been built; the first, *Enterprise* (OV-101), was not built for orbital space flight, and was used only for testing glide and landing. Five space-worthy orbiters were built: *Columbia* (OV-102), *Challenger* (OV-099), *Discovery* (OV-103), *Atlantis* (OV-104), and *Endeavour* (OV-105). *Enterprise* was originally intended to be made fully space-worthy after use for the approach and landing test (ALT) program, but it was found more economical to upgrade the structural test article STA-099 into orbiter *Challenger* (OV-099). *Challenger* disintegrated 73 seconds after launch in 1986, and *Endeavour* was built as a replacement for Challenger from structural spare components.

Columbia broke apart during re-entry in 2003. Building Space Shuttle Endeavour cost about US$1.7 billion. One Space Shuttle launch costs around $450 million.

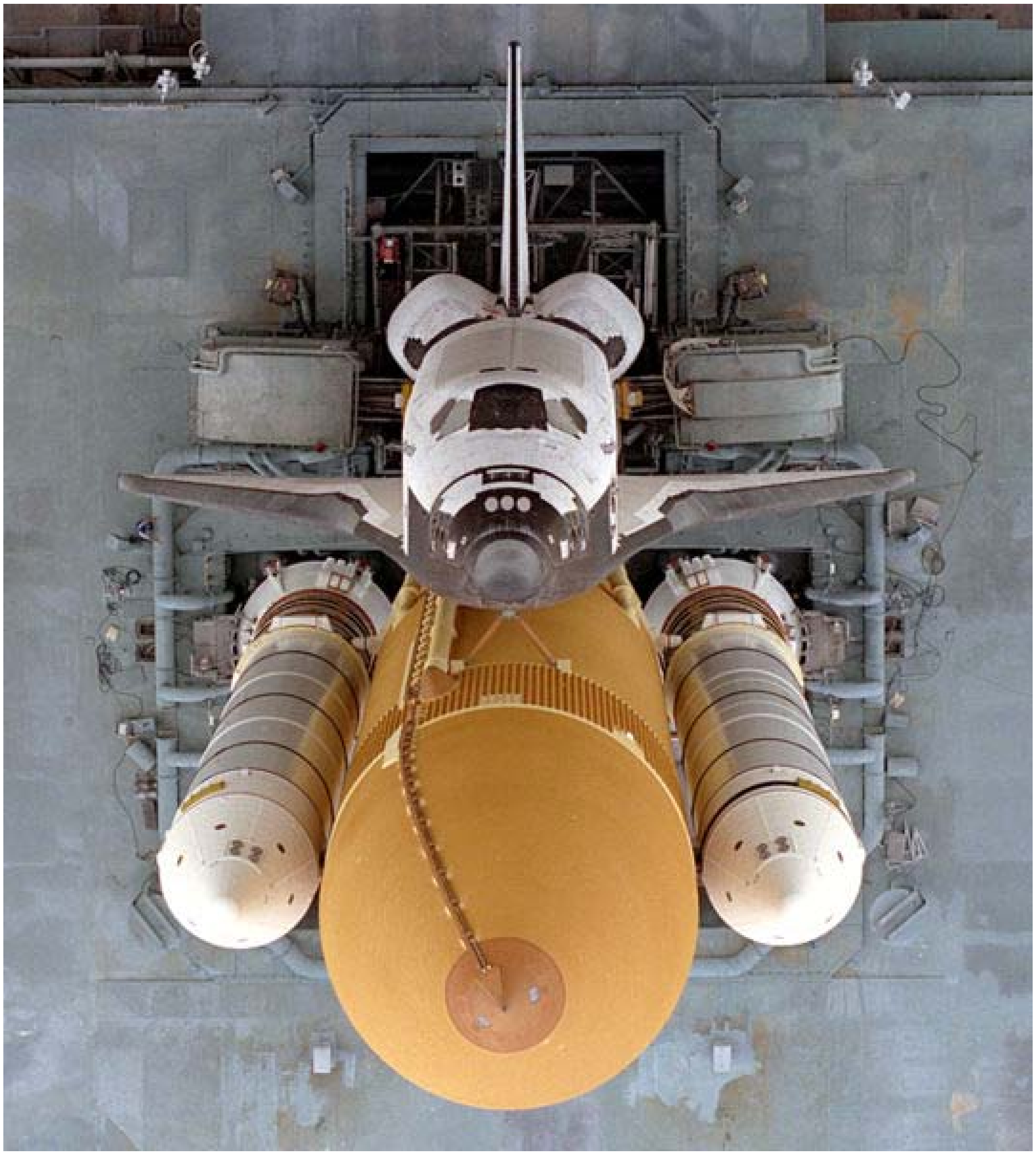
Roger A. Pielke, Jr. has estimated that the Space Shuttle program has cost about US$170 billion (2008 dollars) through early 2008. This works out to an average cost per flight of about US$1.5 billion. However, two missions were paid for by Germany, Spacelab D1 and D2 (D for *Deutschland*) with a payload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

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



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

Space Shuttle *Endeavour* being transported by a Boeing 747.



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

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

Orbiter vehicle

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

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

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

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

External tank

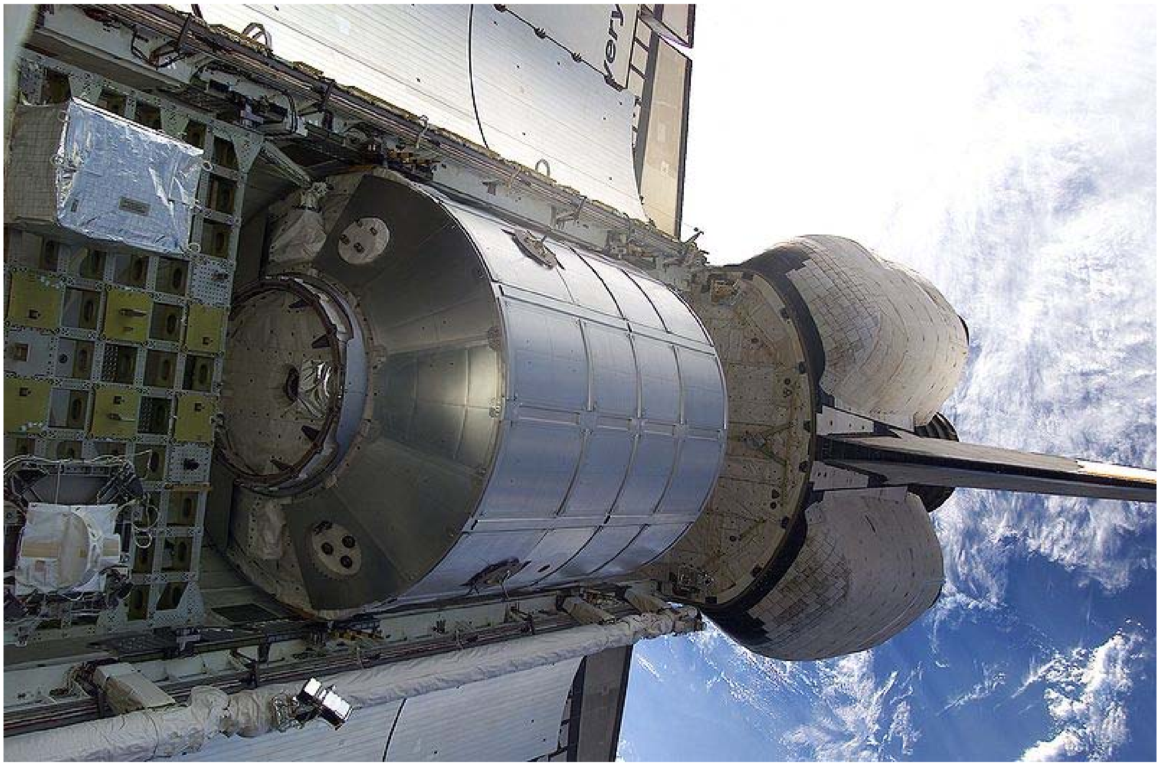
The main function of the Space Shuttle external tank is to supply the liquid oxygen and hydrogen fuel to the Space Shuttle main engines. It is also the backbone of the launch vehicle providing attachment points for the two Solid Rocket Boosters and the Orbiter. The external tank is the only part of the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

Solid Rocket Boosters

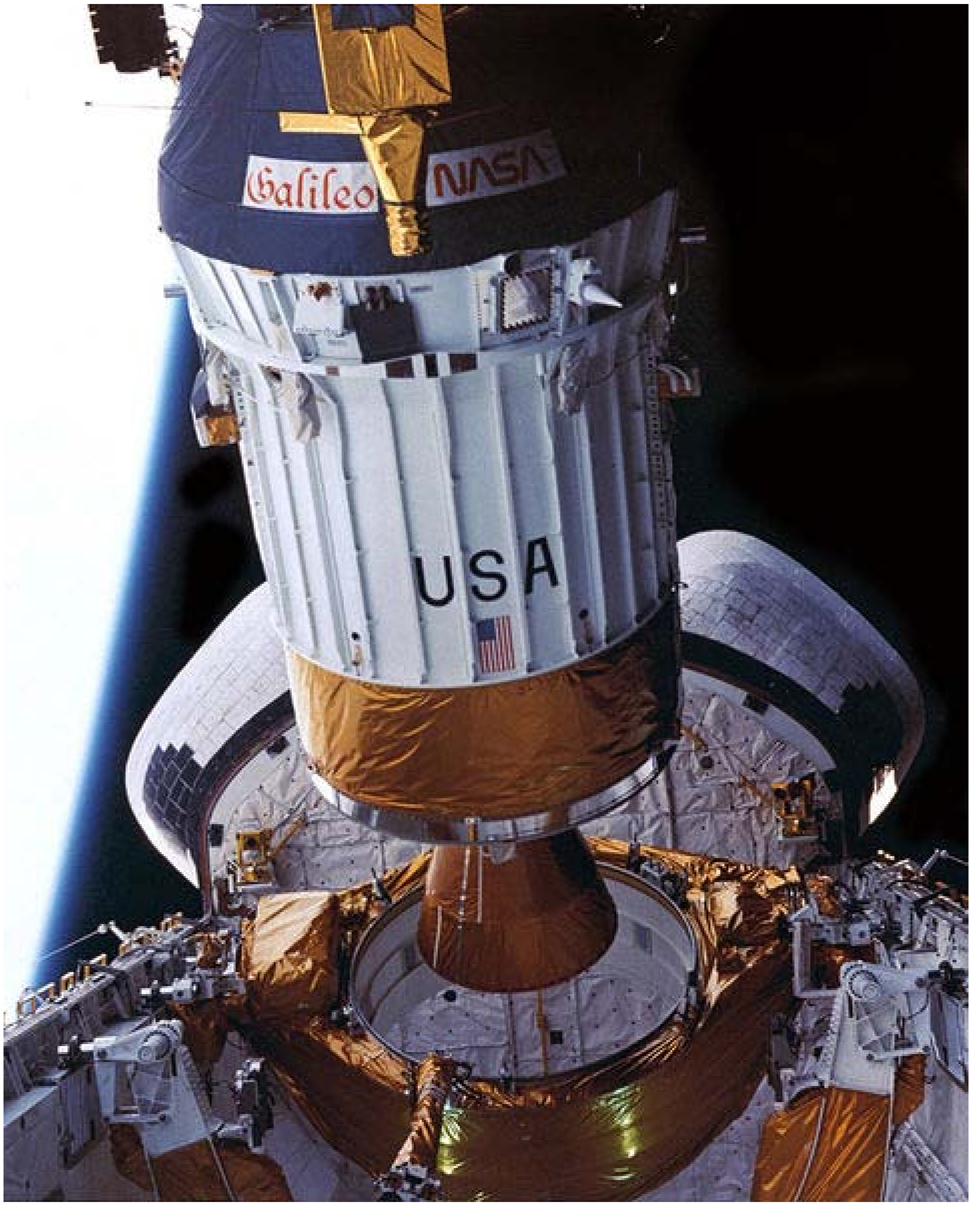
Two solid rocket boosters (SRBs) each provide 12.5 million newtons (2.8 million lbf) of thrust at liftoff, which is 83% of the total thrust needed for liftoff. The SRBs are jettisoned two minutes after launch at a height of about 150,000 feet (46 km), and then deploy parachutes and land in the ocean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

Orbiter add-ons

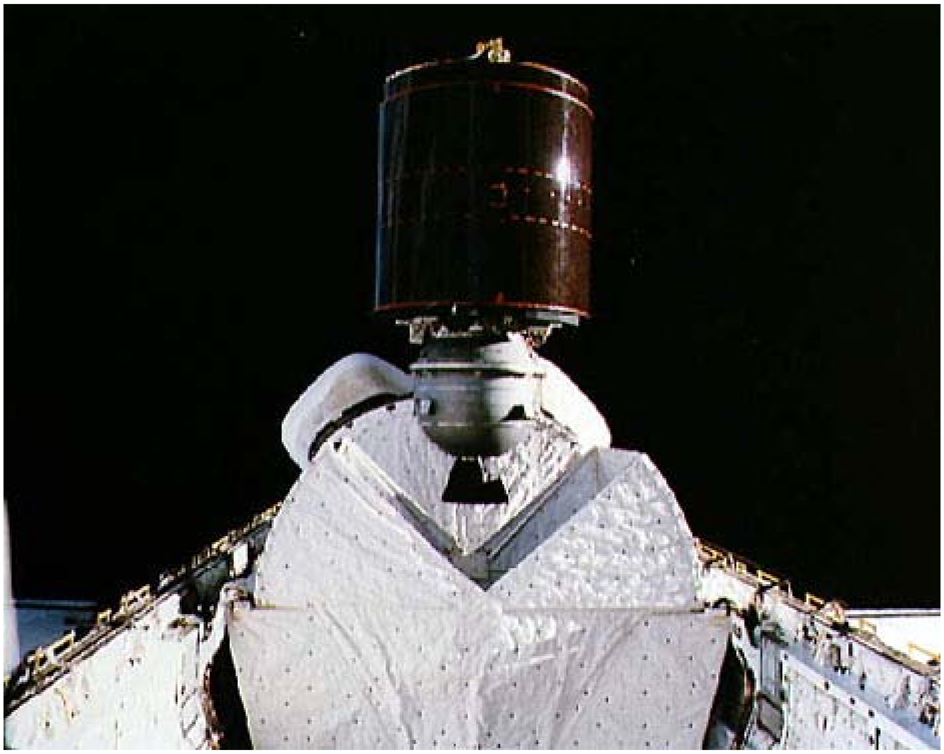
The orbiter can be used in conjunction with a variety of add-ons depending on the mission. This has included orbital laboratories (Spacelab, Spacehab), boosters for launching payloads farther into space (Inertial Upper Stage, Payload Assist Module), and other functions, such as provided by Extended Duration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



MPLM *Leonardo*



IUS deploying with Galileo



PAM-D with satellite

EDO being installed

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

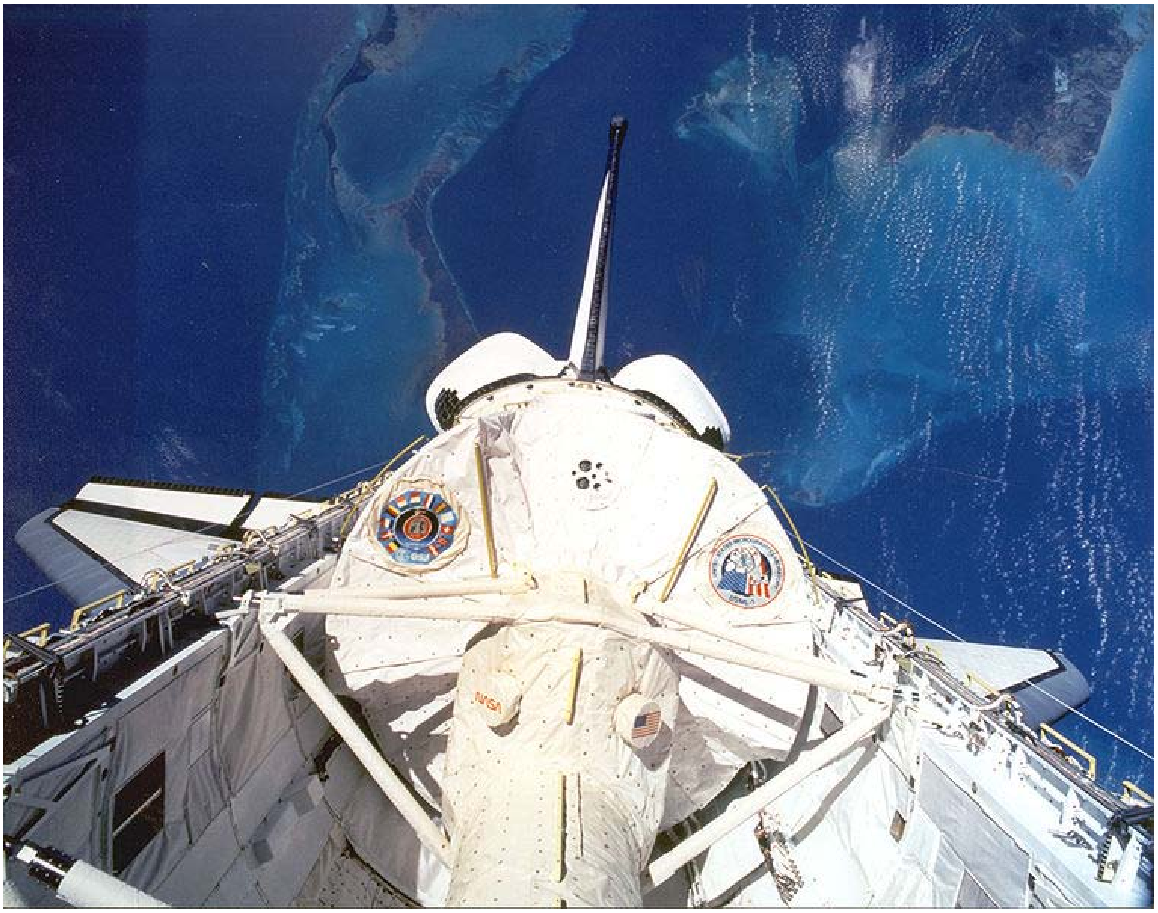
Atlantis deploys the landing gear before landing on a selected runway just like a common aircraft.

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.

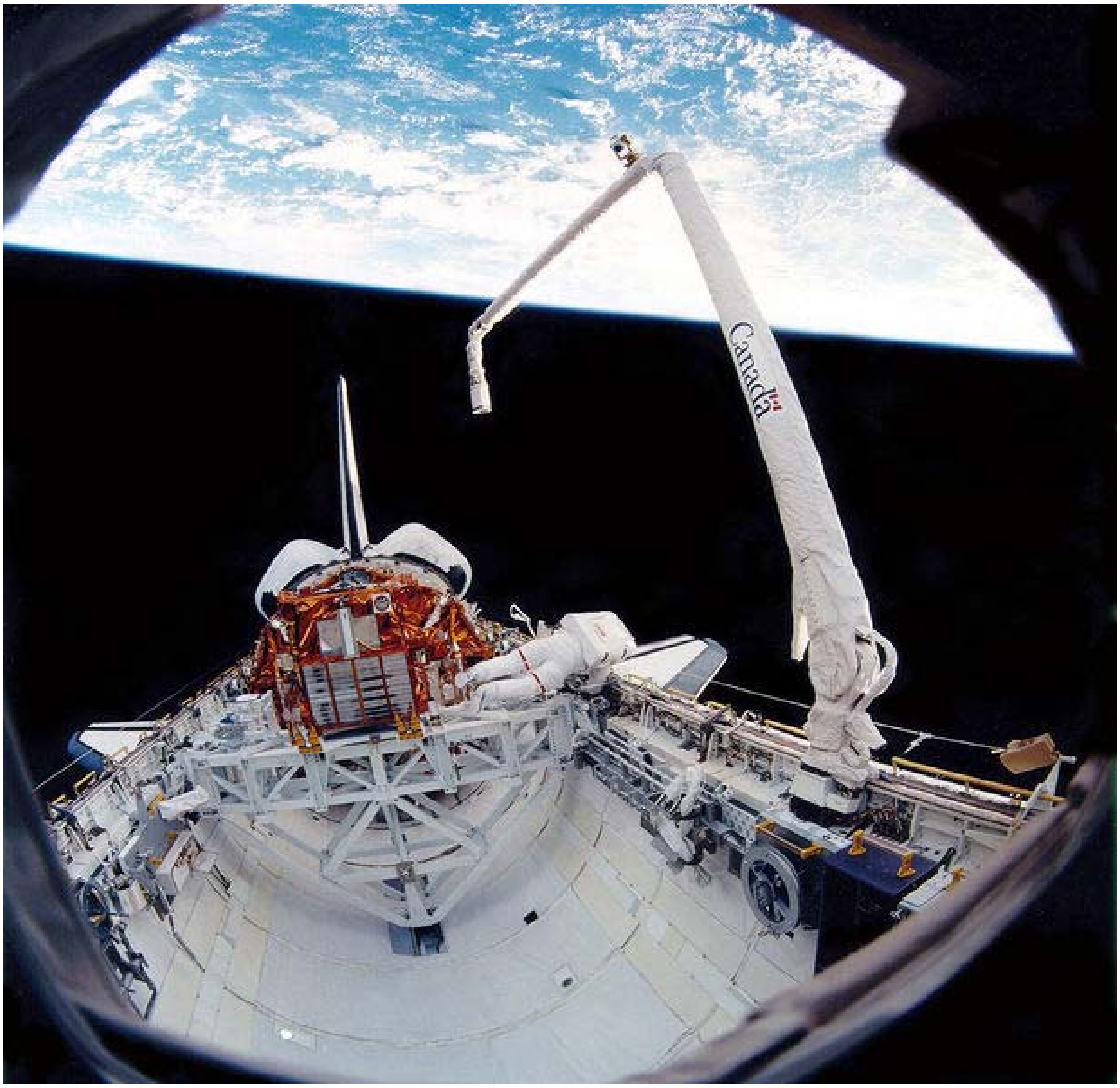
A primary concern with digital fly-by-wire systems is reliability. Much research went into the shuttle computer system. The shuttle uses five identical redundant IBM 32-bit general purpose computers (GPCs), model AP-101, constituting a type of embedded system. Four computers run specialized software 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.

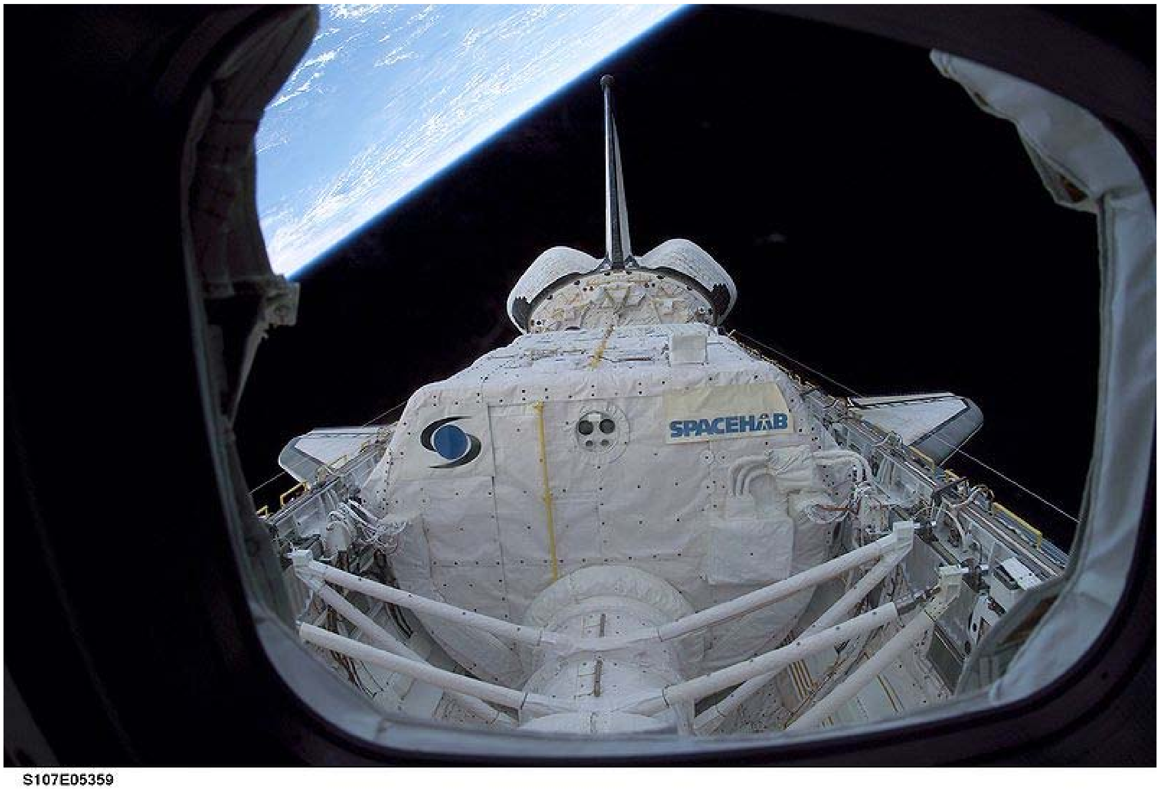
The four general-purpose computers operate essentially in lockstep, checking each other. If one computer fails, the three functioning computers "vote" it out of the system. This isolates it from vehicle control. If a second computer of the three remaining fails, the two functioning computers vote it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



Spacelab in orbit



RMS (Canadarm)



Spacehab

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

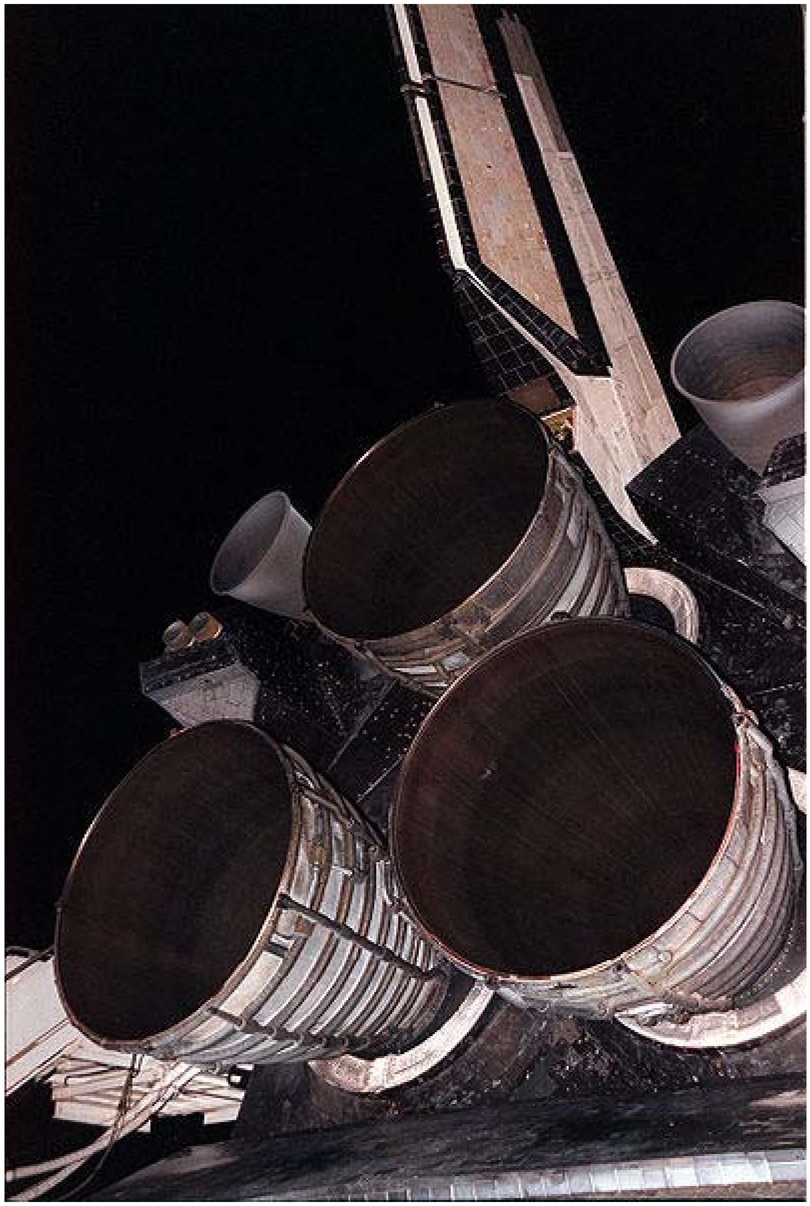
During STS-101, *Atlantis* was the first shuttle to fly with a glass cockpit.

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.

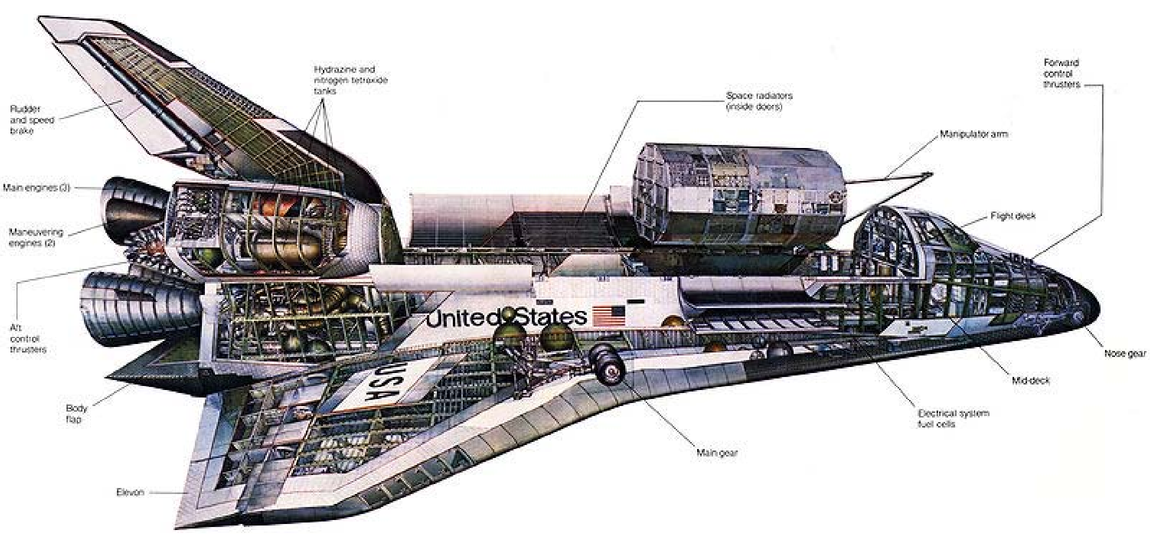
STS-70 was delayed in 1995, when woodpeckers bored holes in the foam insulation of *Discovery*'s external tank. Since then, NASA has installed commercial plastic owl decoys and inflatable owl balloons which must be removed prior to launch. The delicate nature of the foam insulation has been the cause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

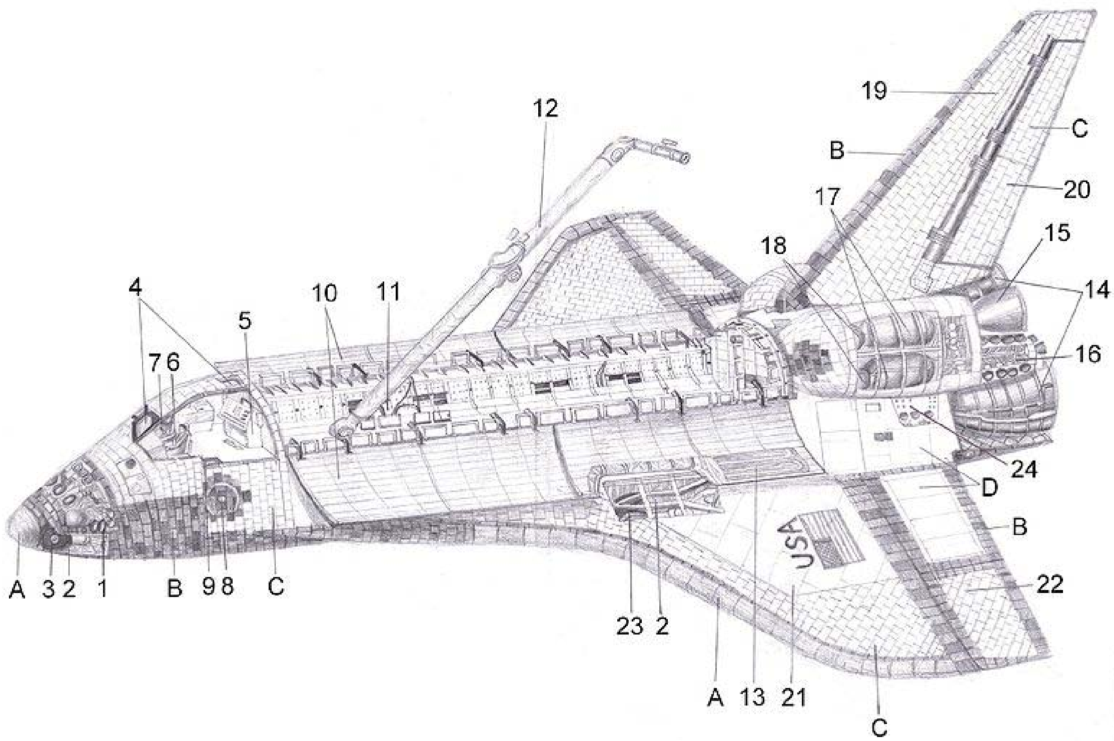
On the first four shuttle missions, astronauts wore modified U.S. Air Force high-altitude full-pressure suits, which included a full-pressure helmet during ascent and descent. From the fifth flight, STS-5, until the loss of *Challenger*, one-piece light blue nomex flight suits and partial-pressure helmets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

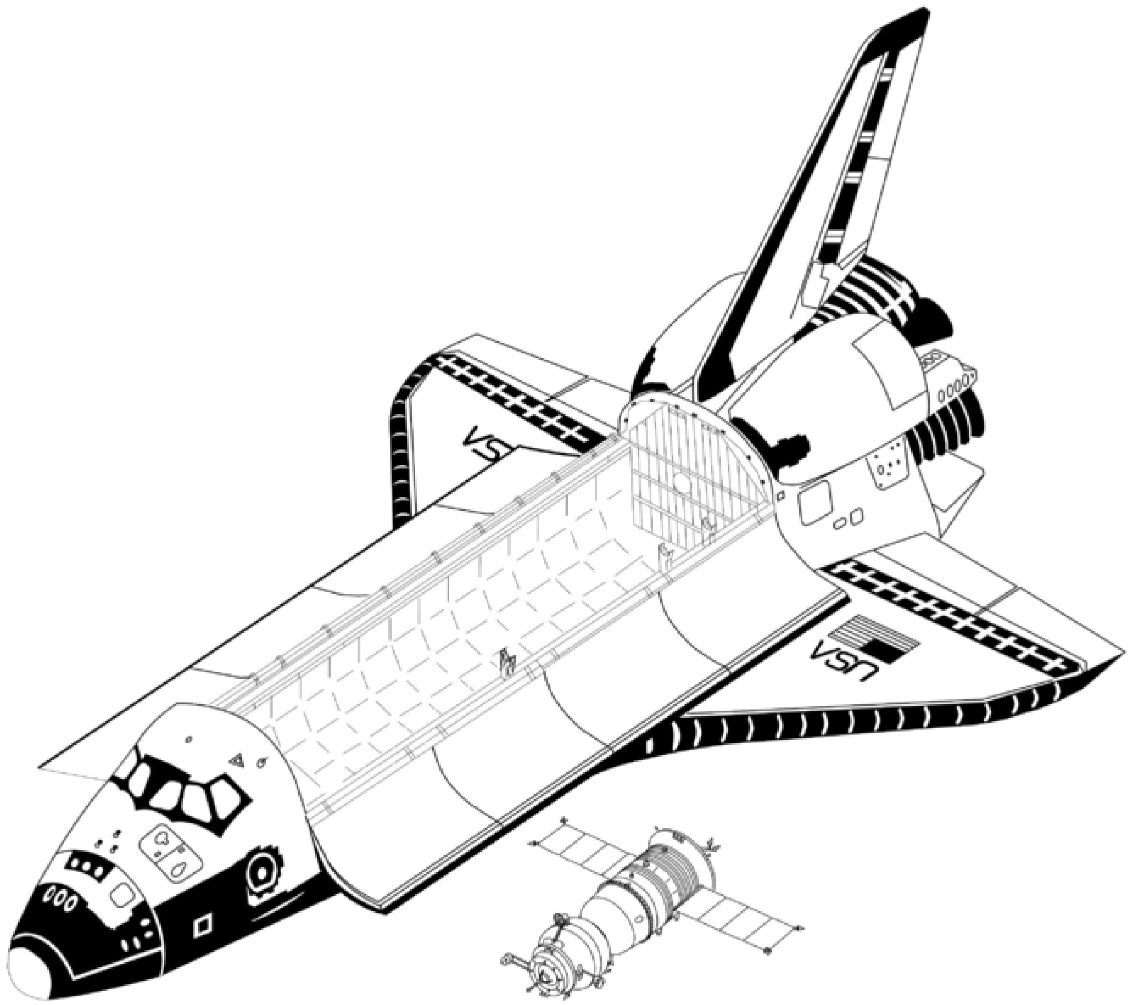


Space Shuttle orbiter illustration



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/N2O4

- Crew: Varies.

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

External tank specifications (for SLWT)

- Length: 46.9 m (154 ft)
- Diameter: 8.4 m (28 ft)
- Propellant volume: 2,025 m^3 (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)

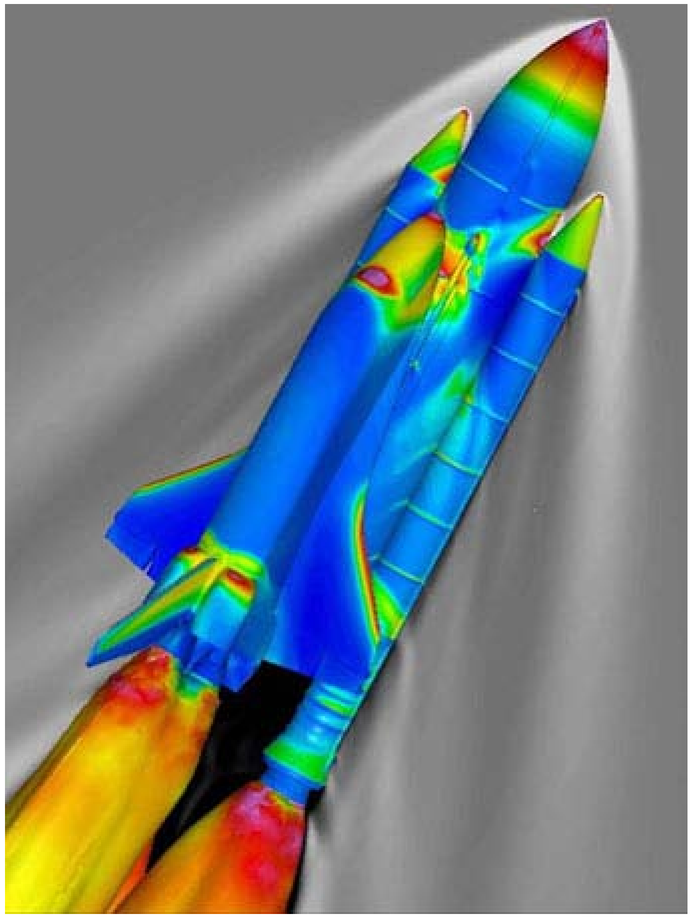
Mission profile

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^3) 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^2), largely for astronaut comfort.

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

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

In orbit

Atlantis and *Harmony* — spring 2010

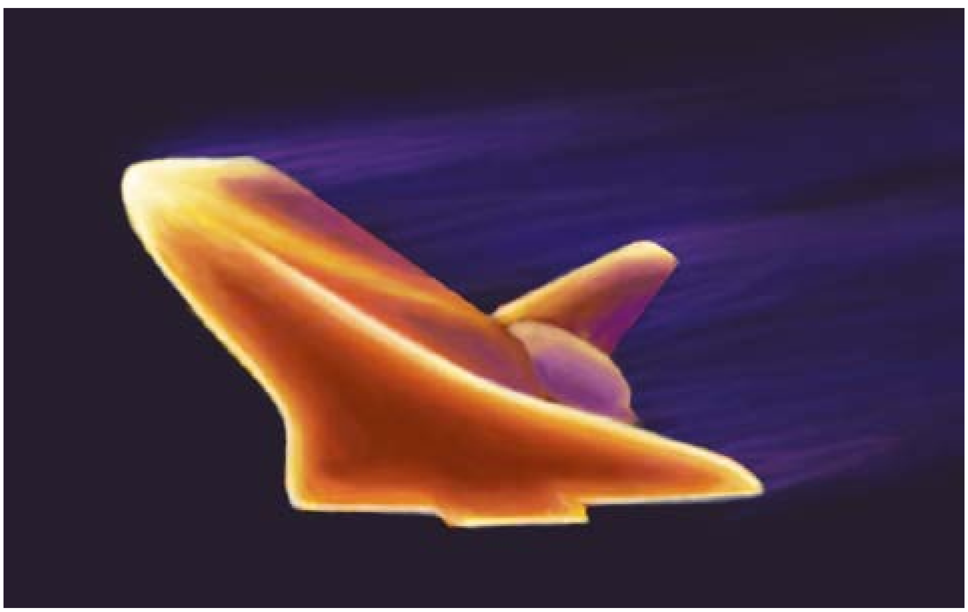
Once in orbit, the shuttle does any number of tasks, and usually some combination. In the 1980s and 1990s, many flights involved space science missions on the NASA/ESA Spacelab, or launching various types of satellites and science probes. By the 1990s and 2000s the focus shifted more to servicing space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

Re-entry and landing

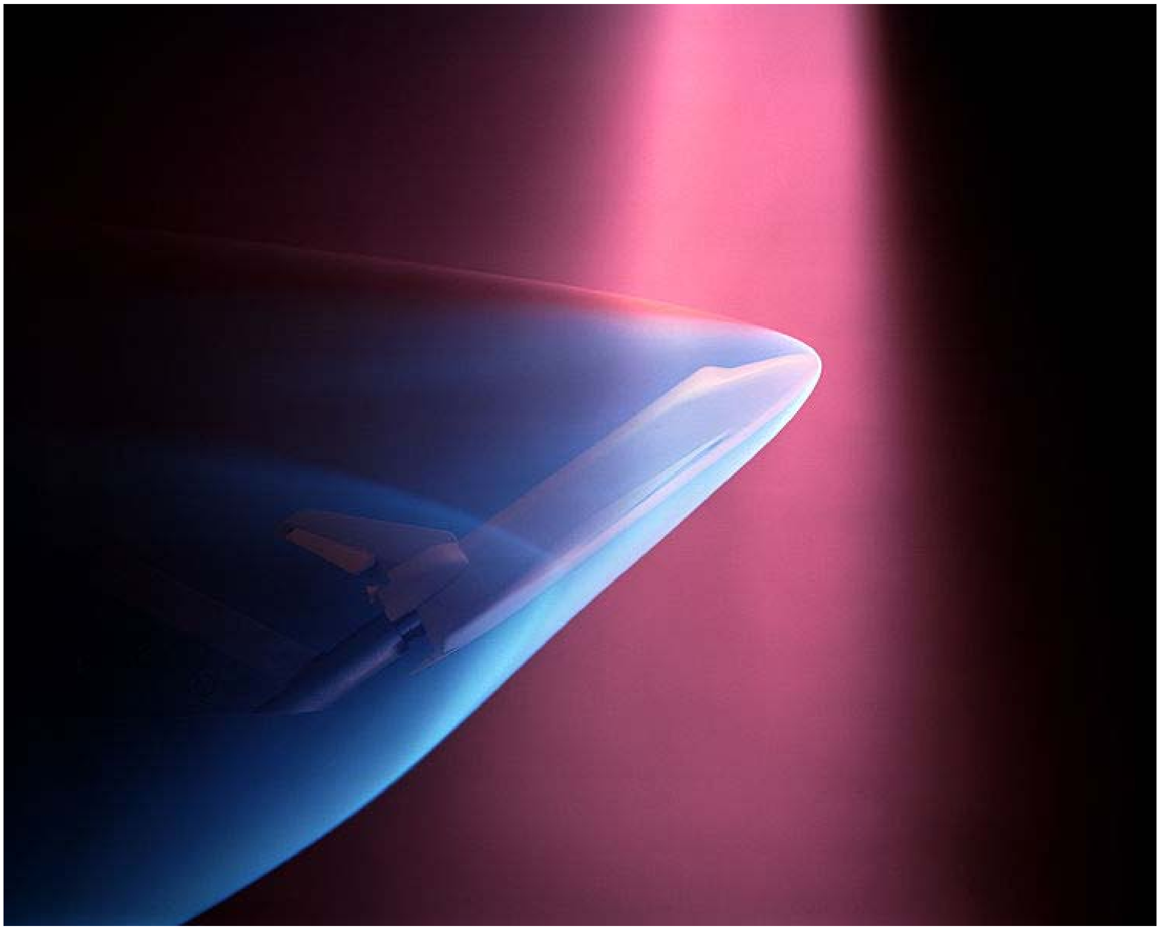
Almost the entire Space Shuttle re-entry procedure, except for lowering the landing gear and deploying the air data probes, is normally performed under computer control. However, the re-entry can be flown entirely manually if an emergency arises. The approach and landing phase can be controlled by the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

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

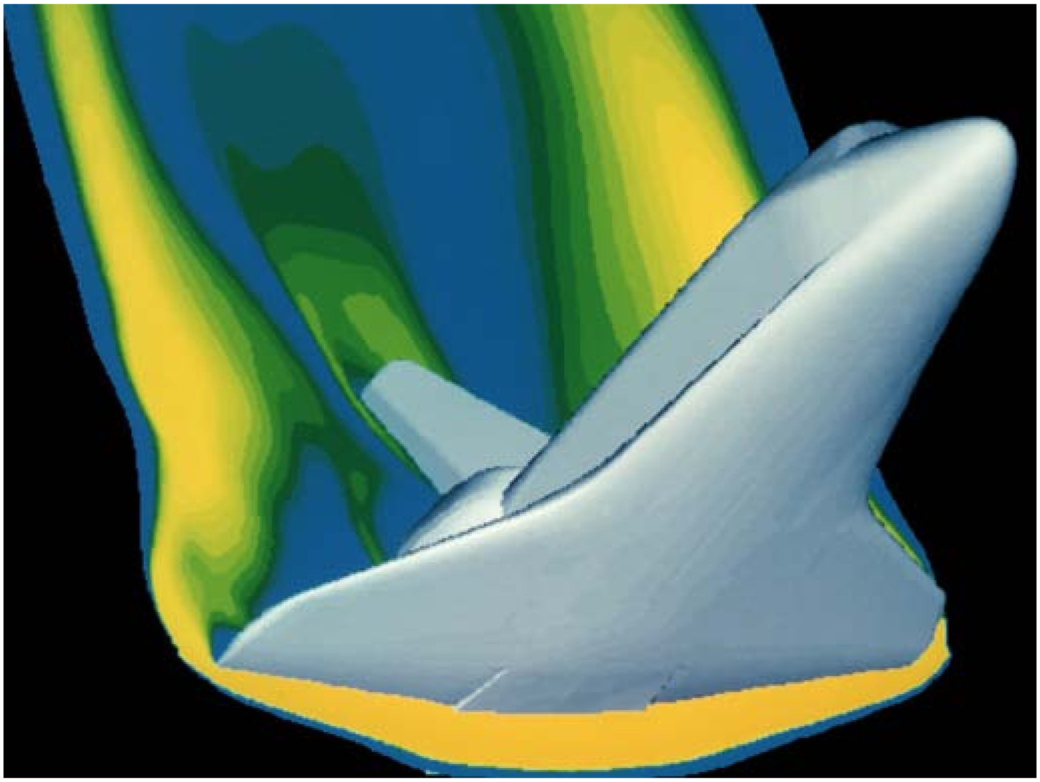
The vehicle starts encountering more significant air density in the lower thermosphere at about 400,000 ft (120 km), at around Mach 25, 8,200 m/s (30,000 km/h; 18,000 mph). The vehicle is controlled by a combination of RCS thrusters and control surfaces, to fly at a 40 degree nose-up attitude, producing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



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



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



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

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

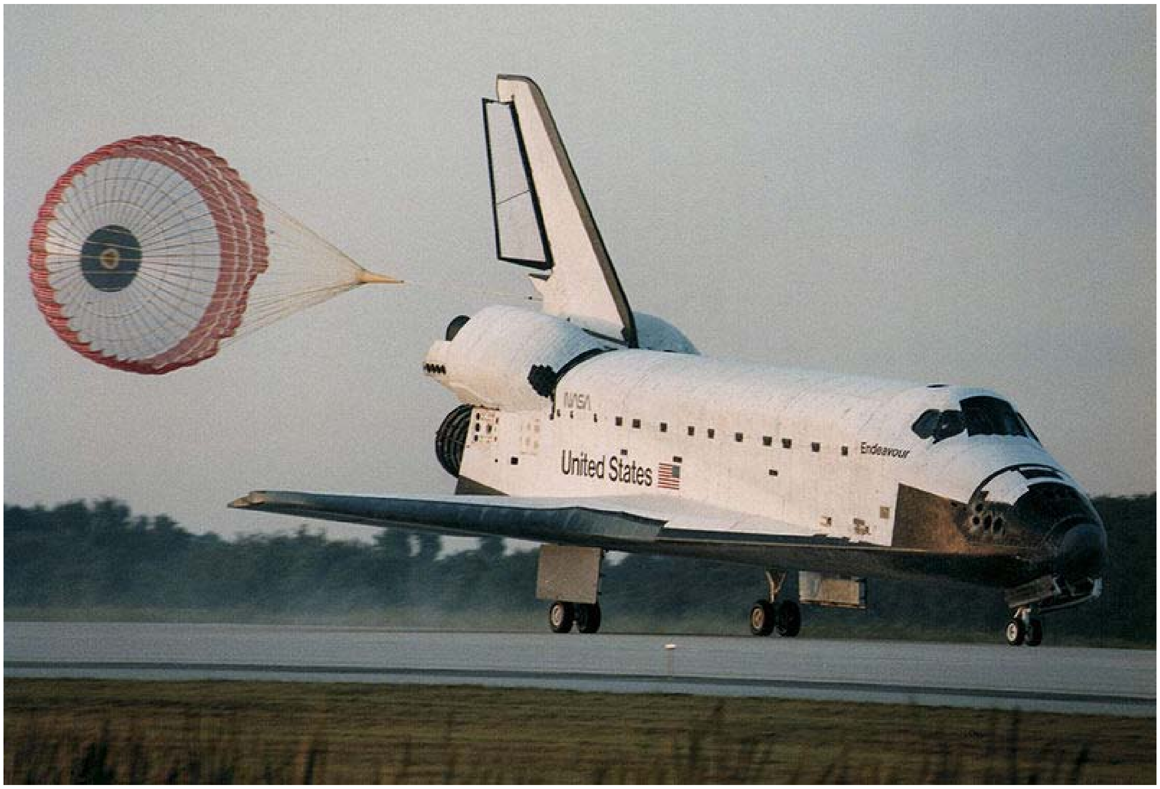
In the lower atmosphere, the orbiter flies much like a conventional glider, except for a much higher descent rate, over 50 m/s (180 km/h; 110 mph). At approximately Mach 3, two air data probes, located on the left and right sides of the orbiter's forward lower fuselage, are deployed to sense air pressure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

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

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

Discovery touches down at the end of STS-95.

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



Endeavour brake chute deploys after touching down

Discovery after landing on Earth for crew disembarkment

Landing sites

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

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

Risk contributors

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

- (1) Micro-Meteoroid Orbital Debris (MMOD) strikes
- (2) Space Shuttle Main Engine (SSME)-induced or SSME catastrophic failure

- (3) ascent debris strikes to TPS leading to LOCV on orbit or entry
- (4) crew error during entry
- (5) RSRM-induced RSRM catastrophic failure (RSRM are the Solid Rocket Boosters)
- (6) COPV failure (COPV are tanks inside the orbiter that hold gas at high pressure)

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

Fleet history

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

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

Space Shuttle major events

Date	Orbiter	Major event / remarks
February 18, 1977	*Enterprise*	First flight; Attached to Shuttle Carrier Aircraft throughout flight.
August 12, 1977	*Enterprise*	First free flight; Tailcone on; lakebed landing.
October 26, 1977	*Enterprise*	Final *Enterprise* free flight; First landing on Edwards AFB concrete runway.
April 12, 1981	*Columbia*	First *Columbia* flight, first orbital test flight; STS-1
November 11, 1982	*Columbia*	First operational flight of the Space Shuttle, first mission to carry four astronauts; STS-5
April 4, 1983	*Challenger*	First *Challenger* flight; STS-6
August 30, 1984	*Discovery*	First *Discovery* flight; STS-41-D
October 3, 1985	*Atlantis*	First *Atlantis* flight; STS-51-J
January 28, 1986	*Challenger*	Disaster starting 73 seconds after launch; STS-51-L; all seven crew members died.
September 29, 1988	*Discovery*	First post-*Challenger* mission; STS-26
May 4, 1989	*Atlantis*	The first Space Shuttle mission to launch a space probe, Magellan; STS-30
April 24, 1990	*Discovery*	Launch of the Hubble Space Telescope; STS-31
May 7, 1992	*Endeavour*	First *Endeavour* flight; STS-49
November 19, 1996	*Columbia*	Longest Shuttle mission to date at 17 days, 15 hours; STS-80
February 1, 2003	*Columbia*	Disintegrated during re-entry; STS-107; all seven crew members died.
July 25, 2005	*Discovery*	First post-*Columbia* mission; STS-114
May 14, 2010	*Atlantis*	Last planned *Atlantis* flight; STS-132
		Planned fleet events
February 24, 2011	*Discovery*	Last planned *Discovery* flight; STS-133; anticipated launch date
April 19, 2011	*Endeavour*	Last planned *Endeavour* flight; last planned flight of the *Space Shuttle program*; STS-134 To use the last built external tank ET-138.
June 28, 2011	*Atlantis*	Last anticipated *Atlantis* 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. The last scheduled flight of Atlantis before it is retired.

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

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

Final locations of retired orbiters

Space Shuttle Program commemorative patch

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

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

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

Space Shuttle successors and legacy

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

Successor cancelled

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

Commercial replacement vehicles and services

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

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

Technology transfer

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

Launch vehicles

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

Next-generation orbiters

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

Chapter- 2

Space Shuttle Atlantis

Atlantis
OV-104

Atlantis at the launch of STS-122 to rendezvous with the Space Station.

OV designation	OV-104
Country	United States
Contract award	January 29, 1979
Named after	RV *Atlantis*
Status	Active
First flight	STS-51-J

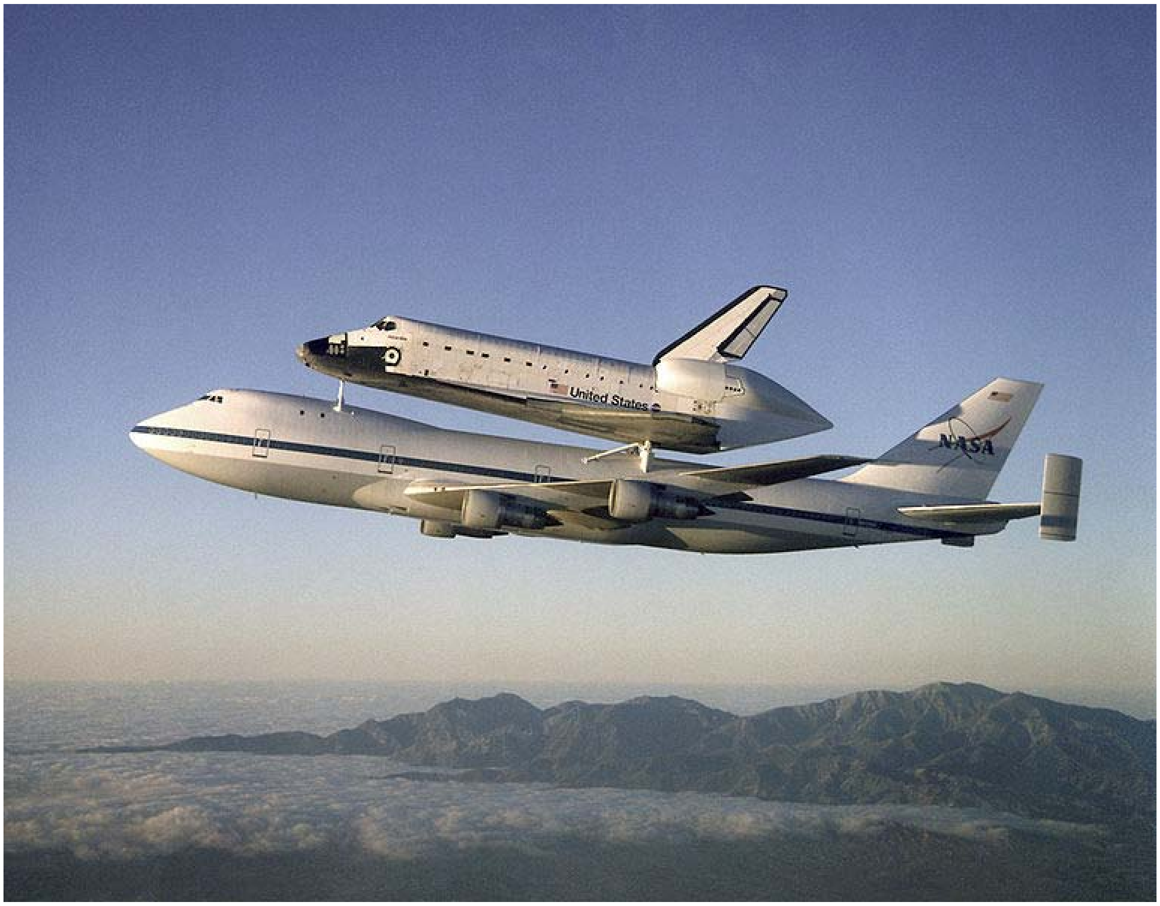
	October 3–7, 1985
Last flight	STS-132 May 14–26, 2010
Number of missions	32
Crews	191
Time spent in space	293 days, 18 hours, 29 minutes, 37 seconds as of STS-132
Number of orbits	4,648
Distance travelled	120,650,907 miles (194,168,813 km) as of STS-132
Satellites deployed	14
Mir dockings	7
ISS dockings	11

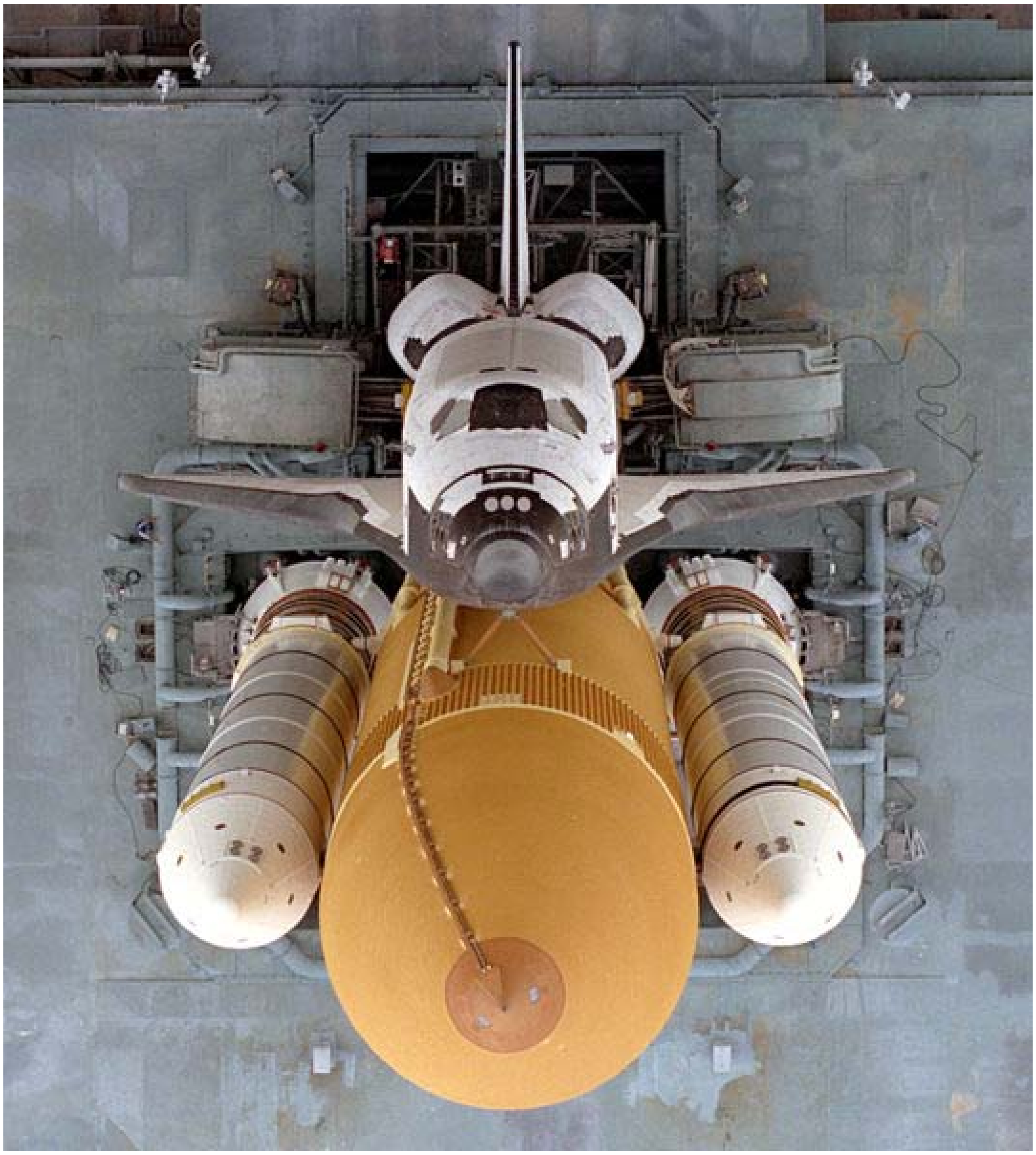
The **Space Shuttle *Atlantis*** (Orbiter Vehicle Designation: **OV-104**) is one of the three operational Space Shuttle orbiters in the Space Shuttle fleet belonging to the National Aeronautics and Space Administration (NASA), the spaceflight and space exploration agency of the United States (the other two operational Space Shuttles are the *Discovery* and the *Endeavour*). The *Atlantis* was the fourth operational (and the next-to-the-last) Space Shuttle to be constructed by the Rockwell International company in Southern California, and she was delivered to the John F. Kennedy Space Center in eastern Florida in April 1985. Atlantis is the only orbiter which lacks the ability to draw power from the International Space Station while docked there, it must continue to provide its own power through fuel cells.

In early 2008, the NASA Administrator, with the approval of the President and the United States Congress, decided to continue with the *Atlantis* making space flights until sometime in 2010, the tentatively predetermined end of the Space Shuttle's spaceflight program. This reversed a previous decision to retire *Atlantis* in 2008.

Space Shuttle *Atlantis* after it undocked from the Space Station on September 17, 2006.

The Space Shuttle *Atlantis* landing in 1997, at the end of STS-86.


Atlantis on top of the *Shuttle Carrier Aircraft* in 1998.


An overhead view of Atlantis as it sits atop the Mobile Launcher Platform before STS-79.

After its 32nd flight (STS-132), Atlantis has orbited the Earth more than 4600 times, traveling over 120 million miles in space, or more than 500 times the distance from the Earth to the Moon. One additional 5 million mile flight is planned (STS-135).

History

Atlantis heads toward Earth orbit at the beginning of STS-129.

Atlantis is named after RV *Atlantis*, a two-masted sailing ship that operated as the primary research vessel for the Woods Hole Oceanographic Institution from 1930 to 1966. The 460-ton ketch carried a crew of 17 and had room for 5 scientists. The former RV *Atlantis* is now commissioned as an oceanographic research vessel in the Argentine Naval Prefecture under the name *Dr. Bernardo Houssay* and finishing a lengthy period of restoration.

Construction milestones

January 29, 1979	Contract Award - Rockwell International Space Transportation Systems Division in Downey, California
March 30, 1980	Start structural assembly of crew module
November 23, 1981	Start structural assembly of aft-fuselage
June 13, 1983	Wings arrive at Palmdale from Grumman
December 2, 1983	Start of final assembly
April 10, 1984	Completed final assembly
March 6, 1985	Rollout from Palmdale
April 3, 1985	Overland transport from Palmdale to Edwards
April 9, 1985	Delivery to Kennedy Space Center
September 5, 1985	Flight Readiness Firing

Notable missions

Atlantis docked to the Space Station during STS-132 mission.

Space Shuttle *Atlantis* lifted off on its maiden voyage on October 3, 1985, on mission STS-51-J, the second dedicated Department of Defense flight. It flew one other mission, STS-61-B, the second night launch in the shuttle program, before the Space Shuttle Challenger disaster temporarily grounded the shuttle fleet in 1986. *Atlantis* was used for ten flights between 1988 and 1992. Two of these, both flown in 1989, deployed the planetary probes Magellan to Venus (on STS-30) and Galileo to Jupiter (on STS-34). With STS-30 *Atlantis* became the first shuttle to launch an interplanetary probe. During another mission, STS-37 flown in 1991, *Atlantis* deployed the Compton Gamma Ray Observatory. Beginning in 1995 with STS-71, *Atlantis* made seven straight flights to the former Russian space station Mir as part of the Shuttle-Mir Program. STS-71 marked a number of historic firsts in human spaceflight: 100th U.S. manned space flight; first U.S. shuttle-Russian Space Station Mir docking and joint on-orbit operations; and first on-orbit changeout of shuttle crew. When linked, *Atlantis* and *Mir* together formed the largest spacecraft in orbit at the time.

Shuttle *Atlantis* has also delivered several vital components for the construction of the International Space Station (ISS). During the February 2001 mission STS-98 to the ISS, *Atlantis* delivered the Destiny Module, the primary operating facility for U.S. research payloads aboard the ISS. The five hour 25 minute third spacewalk performed by astronauts Robert Curbeam and Thomas Jones during STS-98 marked NASA's 100th extra vehicular activity in space. The Quest Joint Airlock, was flown and installed to the ISS by *Atlantis* during the mission STS-104 in July 2001. The successful installation of the airlock gave on-board space station crews the ability to stage repair and maintenance spacewalks outside the ISS using U.S. EMU or Russian Orlan space suits. The first mission flown by *Atlantis* after the Space Shuttle Columbia disaster was STS-115, conducted during September 2006. The mission carried the P3/P4 truss segments and solar arrays to the ISS. On ISS assembly flight STS-122 in February 2008, *Atlantis* delivered the Columbus laboratory to the ISS. Columbus laboratory is the largest single contribution to the ISS made by the European Space Agency (ESA).

Space Shuttle Atlantis's last scheduled liftoff, STS-132 (480p / HD / 1080p)

In May 2009 *Atlantis* flew a seven member crew to the Hubble Space Telescope for its Servicing Mission 4, STS-125. The mission was a success, with the crew completing five space walks totaling 37 hours to install new cameras, batteries, a gyroscope and other components to the telescope.

Among the five space shuttles flown into space, *Atlantis* has conducted a subsequent mission in the shortest time after the previous mission when it launched in November, 1985 on STS-61-B, only 50 days after its previous mission, STS-51-J.

The longest mission flown using shuttle *Atlantis* was STS-117 and lasted almost 14 days in June 2007. During STS-117, Atlantis' crew added a new starboard truss segment and solar array pair (the S3/S4 truss), folded the P6 array in preparation for its relocation and performed four spacewalks. *Atlantis* was not equipped to take advantage of the Station-to-Shuttle Power Transfer System so missions could not be extended by making use of power provided by ISS.

During the STS-129 post-flight interview on 16 November 2009 shuttle launch director Mike Leinbach said that *Atlantis* officially beat shuttle *Discovery* on the record low amount of Interim Problem Reports, with a total of just 54 listed since returning from the STS-125. He continued to add "It is due to the team and the hardware processing. They just did a great job. The record will probably never be broken again in the history of the Space Shuttle Program, so congratulations to them". However, during the STS-132 post-launch interview on 14 May 2010, shuttle launch director Mike Leinbach said that *Atlantis* beat its previous record low amount of Interim Problem Reports, with a total of 46 listed between STS-129 and STS-132.

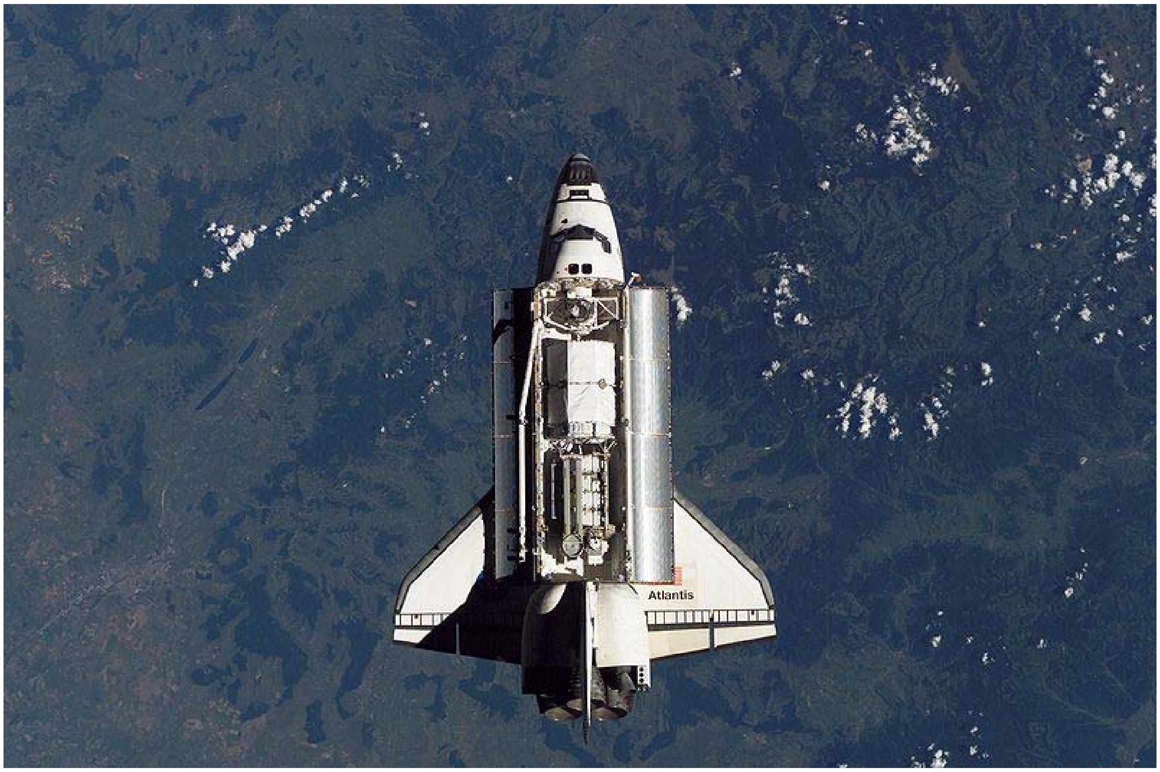
Orbiter Maintenance Down Periods

To date *Atlantis* has gone through two overhauls of scheduled Orbiter Maintenance Down Periods (OMDPs) during her operational history.

Atlantis arrived at Palmdale, California in October 1992 for OMDP-1. During that visit 165 modifications were made over the next 20 months. These included the installation of a drag chute, new plumbing lines to configure the orbiter for extended duration, more than 800 new heat tiles and blankets and new insulation for main landing gear and structural modifications to the airframe.

Atlantis and its STS-125 crew head toward Earth orbit and rendezvous with the Hubble Space Telescope.


Underside view of Atlantis during STS-117 as it approached the International Space Station and performed a back-flip.



An overhead image of Atlantis during STS-115, as recorded by an Expedition 13 crew member on board the International Space Station


Atlantis carrying the S1 Truss segment on mission STS-112.

On November 5, 1997, *Atlantis* again arrived at Palmdale for OMDP-2 which was completed on September 24, 1998. The 130 modifications carried out during OMDP-2 included glass cockpit displays, replacement of TACAN navigation with GPS and ISS airlock and docking installation. Several weight reduction modifications were also performed on the orbiter including replacement of Advanced Flexible Reusable Surface Insulation (AFRSI) insulation blankets on upper surfaces with FRSI. Moreover lightweight crew seats were installed and the Extended Duration Orbiter (EDO) package installed on OMDP-1 was removed to lighten *Atlantis* to better serve its prime mission of servicing the ISS.

During the stand down period post Columbia accident, Atlantis went through over 75 modifications to the orbiter ranging from very minor bolt change-outs to window change-outs and different fluid systems.

Planned decommissioning

NASA had planned to withdraw *Atlantis* from service in 2008, as the orbiter would have been due to undergo its third scheduled OMDP. However, because of the final retirement of the shuttle fleet in 2010, this was deemed uneconomical. It was planned that *Atlantis* would be kept in near flight condition to be used as a parts hulk for *Discovery* and *Endeavour*. However, with the significant planned flight schedule up to 2010, the decision was taken to extend the time between OMDPs, allowing Atlantis to be retained for operations. *Atlantis* has been swapped for one flight of each *Discovery* and *Endeavour* in the current flight manifest. *Atlantis* has completed its last flight, STS-132, prior to the end of the shuttle program. The extension of the Shuttle Program into 2011 has led to *Atlantis* being manifested to fly STS-135, which is now intended as the final Space Shuttle mission in June 2011.

Once *Atlantis* is finally decommissioned, it will be one of two orbiters to be given as museum donations, the other being *Endeavour* (*Discovery* will go to the Steven F. Udvar-Hazy Center of the National Air and Space Museum). The National Museum of the United States Air Force at Wright-Patterson Air Force Base in Ohio has declared an interest in obtaining an orbiter to exhibit, and is especially keen on securing *Atlantis*, owing to her history as the main orbiter used for USAF and DoD missions.

Crews

Crewmembers for the historic final Hubble Servicing Mission, STS-125 pose for a photo on the flight deck of Atlantis.

A total of 155 unique individuals have flown with Space Shuttle *Atlantis* over the course of her 32 missions. Because the shuttle sometimes flew crew members arriving and departing Mir and the ISS, not all of them launched and landed on *Atlantis*.

Astronaut Clayton Anderson, ESA astronaut Leopold Eyharts and Russian cosmonauts Nikolai Budarin and Anatoly Solovyev only launched on *Atlantis*. Similarly, astronauts Nicole Stott, Daniel Tani and Sunita Williams, as well as cosmonauts Vladimir Dezhurov and Gennady Strekalov only landed with *Atlantis*. Only 146 men and women both launched and landed aboard *Atlantis*.

Some of those people however, flew with *Atlantis* more than once. Taking them into account, 203 total seats were filled over *Atlantis*' 32 missions. Astronaut Jerry Ross holds the record for the most flights aboard *Atlantis* at five.

Astronaut Rodolfo Neri Vela who flew aboard Atlantis on STS-61-B mission in 1985 became the first and so far only Mexican to have traveled to space. ESA astronaut Dirk Frimout who flew on STS-45 as a payload specialist was the first Belgian in space. STS-46 mission specialist Claude Nicollier was the first astronaut from Switzerland. On the same flight, astronaut Franco Malerba became the first citizen of Italy to travel to space.

Remaining assigned missions

- STS-335 – Launch on Need (Rescue Shuttle for STS-134, should the need arise)

Problems

Composite overwrapped pressure vessels

NASA announced in 2007 that 24 helium and nitrogen gas tanks in *Atlantis* are older than their designed lifetime. These composite overwrapped pressure vessels (COPV) were designed for a 10 year life and later cleared for an additional 10 years; they exceeded this life in 2005. NASA said it cannot guarantee any longer that the vessels on *Atlantis* will not burst or explode under full pressure. Failure of these tanks could damage parts of the shuttle and even wound or kill ground personnel. An in-flight failure of a pressure vessel could even result in the loss of the orbiter and its crew. NASA analyses originally assumed that the vessels would leak before they burst, but new tests showed that they could in fact burst before leaking.

Because the original vendor was no longer in business, and a new manufacturer could not be qualified before 2010, when the shuttles are scheduled to be retired, NASA decided to continue operations with the existing tanks. Therefore, to reduce the risk of failure and the cumulative effects of load, the vessels will be maintained at 80 percent of the operating pressure as late in the launch countdown as possible, and the launch pad will be cleared of all but essential personnel when pressure is increased to 100 percent. The new launch procedure will be employed during the remaining *Atlantis* launches if no other resolution is found. *Atlantis* will have to fly at least once under this requirement.

However, since the problem was discovered, two of the COPV's have been replaced. The two COPV's were deemed to have the highest risk of failure.

Knob

After the STS-125 mission, a work light knob was discovered jammed in the space between one of Atlantis's front interior windows and the Orbiter dashboard structure. The knob was believed to have entered the space during flight, when the pressurized Orbiter was expanded to its maximum size. Then, once back on Earth, the Orbiter contracted, jamming the knob in place. Leaving "as-is" was considered unsafe for flight, and some options for removal (including window replacement) would have included a 6 month delay of Atlantis's next mission (planned to be STS-129). Had the removal of the knob been unsuccessful, the worst-case scenario is that Atlantis could have been retired from flight, leaving Discovery and Endeavour to complete the manifest alone. On 29 June 2009, Atlantis was pressurised to 17 psi/120 kPa (3psi-delta), which forced the Orbiter to expand slightly. The knob was then frozen with dry ice, and was successfully removed. Small areas of damage to the window were discovered where the edges of the knob had been embedded into the pane. Subsequent investigation of the window damage discovered a maximum defect depth of approximately 0.0003 in/0.0076 mm, less than the reportable depth threshold of 0.0015 in/0.038 mm and not serious enough to warrant the pane's replacement.

Chapter- 3

Space Shuttle Challenger

Challenger
OV-099

Challenger launches, STS-7

OV designation	OV-099
Country	United States
Contract award	July 26, 1972
Named after	HMS *Challenger*
Status	destroyed January 28, 1986

First flight	STS-6 April 4, 1983 – April 9, 1983
Last flight	STS-51-L January 28, 1986
Number of missions	10
Time spent in space	62 days 07:56:22
Number of orbits	995
Distance travelled	25,803,939 miles
Satellites deployed	10

Space Shuttle *Challenger* (NASA Orbiter Vehicle Designation: **OV-099**) was NASA's second Space Shuttle orbiter to be put into service, *Columbia* having been the first. The shuttle was built by Rockwell Internationa's Space Transportation Systems Division in Downey, California. Its maiden flight was on April 4, 1983, and it completed nine missions before breaking apart 73 seconds after the launch of its tenth mission, STS-51-L on January 28, 1986, resulting in the death of all seven crew members. The accident led to a two-and-a-half year grounding of the shuttle fleet, with missions resuming in 1988 with the launch of Space Shuttle *Discovery* on STS-26. *Challenger* itself was replaced by the Space Shuttle *Endeavour*, which first launched in 1992. *Endeavour* was constructed from spare parts originally meant for *Challenger* and the other shuttles in the fleet.

History

Challenger was named after two previous vessels: HMS *Challenger*, a British corvette that was the command ship for the Challenger Expedition, a pioneering global marine research expedition undertaken from 1872 through 1876; and the Apollo 17 lunar module *Challenger*, which landed on the Moon in 1972.

Construction

Because of the low production of orbiters, the Space Shuttle program decided to build a vehicle as a Structural Test Article, STA-099, that could later be converted to a flight vehicle. In order to prevent damage during structural testing, qualification tests were performed to a factor of safety of 1.2 times the design limit loads. The qualification tests were used to validate computational models, and compliance with the required 1.4 factor of safety was shown by analysis.

NASA planned to refit the prototype orbiter *Enterprise* (OV-101), used for flight testing, as the second operational orbiter. However, design changes made during construction of the first orbiter, *Columbia* (OV-102), would have required extensive rework. Because

STA-099's qualification testing prevented damage, NASA found that rebuilding STA-099 as OV-099 would be less expensive than refitting *Enterprise.*

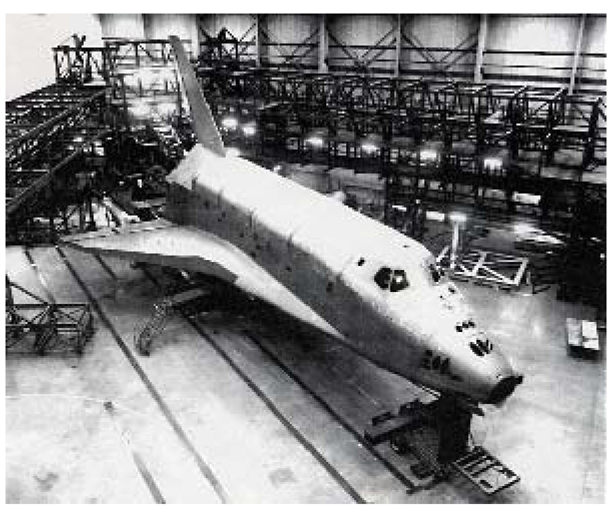
Challenger (and the orbiters built after it) had fewer tiles in its Thermal Protection System than Columbia. Most of the tiles on the payload bay doors, upper wing surface, and rear fuselage surface were replaced with DuPont white nomex felt insulation. This modification allowed *Challenger* to carry 2,500 lb (1,100 kg) more payload than *Columbia. Challenger* was also the first orbiter to have a head-up display system for use in the descent phase of a mission.

Flights and modifications

After its first flight in April 1983, *Challenger* quickly became the workhorse of NASA's Space Shuttle fleet, flying far more missions per year than *Columbia.* In 1983 and 1984, *Challenger* flew on 85% of all Space Shuttle missions. Even when the orbiters *Discovery* and *Atlantis* joined the fleet, *Challenger* remained in heavy use with three missions a year from 1983 to 1985. *Challenger,* along with *Discovery,* was modified at Kennedy Space Center to be able to carry the Centaur-G upper stage in its payload bay. Had STS-51-L been successful, *Challenger'*s next mission would have been the deployment of the Ulysses probe with the Centaur to study the polar regions of the Sun.

*Challenger'*s many spaceflight accomplishments included the first American woman, African-American, and Canadian in space; three Spacelab missions; and the first night launch and night landing of a Space Shuttle. *Challenger* was also the first space shuttle to be destroyed in an accident during a mission. The collected debris of the vessel are currently stored in decommissioned missile silos at Cape Canaveral Air Force Station. From time to time, further pieces of debris from the orbiter wash up on the Florida coast. When this happens, they are collected and transported to the silos for storage. Because of its early loss, *Challenger* was the only space shuttle that never wore the NASA "meatball" logo.

Challenger's rollout from Orbiter Processing
Facility (OPF) to the Vehicle Assembly Building (VAB). Photo 1983-8-25 courtesy of NASA.



Challenger while in service as structural test article STA-099.

#	Date	Designation	Launch pad	Landing location	Notes	Mission duration
1	April 4, 1983	STS-6	LC-39A	Edwards Air Force Base	Deployed TDRS-A. First spacewalk during a space shuttle mission.	5 days, 00 hours, 23 minutes, 42 seconds
2	June 18, 1983	STS-7	LC-39A	Edwards Air Force Base	Sally Ride becomes first American woman in space. Deployed two communications satellites.	6 days, 02 hours, 23 minutes, 59 seconds
3	August 30, 1983	STS-8	LC-39A	Edwards Air Force Base	Guion Bluford becomes first African-American in space First shuttle night launch and night landing. Deployed Insat-1B. Carried 260,000 envelopes stamped to commemorate the 25th Anniversary of NASA.	6 days, 01 hours, 08 minutes, 43 seconds
4	February 3, 1984	STS-41-B	LC-39A	Kennedy Space Center	First untethered spacewalk. Deployed two communications satellites, unsuccessfully.	7 days, 23 hours, 15 minutes, 55 seconds
5	April 6, 1984	STS-41-C	LC-39A	Edwards Air Force Base	Solar Maximum Mission service mission.	6 days, 23 hours, 40 minutes, 07 seconds
6	October 5, 1984	STS-41-G	LC-39A	Kennedy Space Center	First mission to carry two women. Marc Garneau becomes first Canadian in space. Kathryn D. Sullivan becomes first American	8 days, 05 hours, 23 minutes, 33 seconds

					woman to make a spacewalk. Deployed Earth Radiation Budget Satellite.	
7	April 29, 1985	STS-51-B	LC-39A	Edwards Air Force Base	Carried Spacelab-3.	7 days, 00 hours, 08 minutes, 46 seconds
8	July 29, 1985	STS-51-F	LC-39A	Edwards Air Force Base	Carried Spacelab-2.	7 days, 22 hours, 45 minutes, 26 seconds
9	October 30, 1985	STS-61-A	LC-39A	Edwards Air Force Base	Carried German Spacelab D-1. Wubbo Ockels becomes the first Dutchman in space	7 days, 00 hours, 44 minutes, 51 seconds
10	January 28, 1986	STS-51-L	LC-39B	Did not land (Planned to land at Kennedy Space Center).	Shuttle disintegrated after launch, killing all seven astronauts on board. Was to have deployed TDRS-B.	0 days, 00 hours, 01 minute, 13 seconds

Mission insignias

Mission insignia for Challenger flights				
				
STS 6	**STS 7**	**STS 8**	**STS 41-B**	**STS 41-C**
				
STS-41-G	**STS-51-B**	**STS-51-F**	**STS-61-A**	**STS-51-L**

Loss of Challenger

The crew of the *Challenger*'s final flight.

Challenger was destroyed as it broke up in mid-flight in the second minute of its tenth mission, on January 28, 1986 at 11:38:00 a.m. Eastern Standard Time. The breakup was ultimately due to the failure of an O-ring on its right solid-fuel rocket booster (SRB). The O-rings are used to seal the joints between the multiple segments of the SRBs. The failure was due to a variety of factors, including unusually low temperatures prior to liftoff. The failure allowed a plume of flame to leak out of the SRB and impinge on both the external fuel tank (ET) and the SRB aft attachment strut. This caused both structural failure of the ET, and pivoting of the SRB into the orbiter and ET. Damage near the bottom of the ET resulted in the complete loss of the aft dome of the lower tank and a rapid release of hydrogen, creating a forward thrust of about 2.8 million pounds and pushing the tank up into the intertank structure which connects the liquid hydrogen tank and liquid oxygen tank. This was followed by an almost explosive burning of the hydrogen combined with oxygen leaking from the intertank. Challenger's reaction control system then ruptured, resulting in the burning of its hypergolic propellants. The orbiter, traveling at about Mach 1.92, was forced into an attitude that caused it to endure extreme aerodynamic loads, with the resulting stresses causing it to break apart.

All seven crew members died in the disaster. Christa McAuliffe, who was selected to be the first teacher in space, was one of the crew members of this mission.

Chapter- 4

Space Shuttle Columbia

Columbia
OV-102

Columbia being transported to launch pad 39A prior to launching on STS-107

OV designation	OV-102
Country	United States
Contract award	July 26, 1972
Named after	Robert Gray's *Columbia Rediviva*
Status	Destroyed February 1, 2003
First flight	STS-1 April 12, 1981 - April 14, 1981
Last flight	STS-107 January 16, 2003 – February 1, 2003
Number of missions	28
Crews	160
Time spent in space	300 days 17:40:22
Number of orbits	4,808

Distance travelled	201,497,772 km (125,204,911 miles)
Satellites deployed	8

Space Shuttle *Columbia* (NASA Orbiter Vehicle Designation: **OV-102**) was the first spaceworthy Space Shuttle in NASA's orbital fleet. First launched on the STS-1 mission, the first of the Space Shuttle program, it completed 27 missions before being destroyed during re-entry on February 1, 2003 near the end of its 28th, STS-107. All seven crew members were killed. Following an independent investigation into the cause of the accident, NASA decided to retire the Shuttle orbiter fleet in 2010 in favor of the Constellation program and its manned Orion spacecraft. However, President Obama signed the NASA Authorization Act 2010 on October 11 which officially brought the Constellation program to an end.

History

Construction began on *Columbia* in 1975 at Rockwell International's (formerly North American Aviation/North American Rockwell, now Boeing North America) principal assembly facility in Palmdale, California, a suburb of Los Angeles. *Columbia* was named after the Boston-based sloop *Columbia* captained by Robert Gray, who in the 1790s explored the Pacific Northwest (including going upstream on its namesake river between Washington and Oregon) and which became the first American vessel to circumnavigate the globe. It is also named after the Command Module of Apollo 11, the first manned landing on another celestial body. After construction, the orbiter arrived at Kennedy Space Center on March 25, 1979, to prepare for its first launch. On March 19, 1981, during preparations for a ground test, two workers were asphyxiated while working in Columbia's nitrogen-purged aft engine compartment, resulting in their deaths.

The first flight of *Columbia* (STS-1) was commanded by John Young, a Gemini and Apollo veteran who was the ninth person to walk on the Moon in 1972, and piloted by Robert Crippen, a rookie astronaut originally selected to fly on the military's Manned Orbital Laboratory (MOL) spacecraft, but transferred to NASA after its cancellation, and served as a support crew member for the Skylab and Apollo-Soyuz missions.

Columbia was successfully launched on April 12, 1981, the 20th anniversary of the first human spaceflight (Vostok 1), and returned on April 14, 1981, after orbiting the Earth 36 times, landing on the dry lakebed runway at Edwards Air Force Base in California. *Columbia* then undertook three further research missions to test its technical characteristics and performance. Its first operational mission, with a four-man crew, was STS-5, which launched on November 11, 1982. At this point *Columbia* was joined by *Challenger*, which performed the next three shuttle missions, while *Columbia* underwent modifications for the first Spacelab mission.

Columbia astronauts Thomas K. Mattingly and Pilot Henry Hartsfield salute President Ronald Reagan, standing beside his wife, Nancy, upon landing in 1982.

In 1983, *Columbia*, under the command of John Young for his sixth spaceflight, undertook its second operational mission (STS-9), in which the Spacelab science laboratory and a six-person crew was carried, including the first non-American astronaut on a space shuttle, Ulf Merbold. After the flight, *Columbia* spent the next three years at the Rockwell Palmdale facility, undergoing modifications that removed the Orbiter Test Flight hardware and bringing it up to similar specifications as that of its sister Orbiters. At that time the shuttle fleet was expanded to include *Discovery* and *Atlantis*.

Columbia returned to space on January 12, 1986, with the launch of STS-61-C. The mission's crew included Dr. Franklin Chang-Diaz, as well as the first sitting member of the House of Representatives to venture into space, Bill Nelson.

The next shuttle mission was undertaken by *Challenger*. It was launched on January 28, 1986, ten days after STS-61-C had landed. The mission ended in disaster 73 seconds after launch. In the aftermath NASA's shuttle timetable was disrupted, and *Columbia* was not flown again until 1989 (on STS-28), after which it resumed normal service as part of the shuttle fleet.

STS-93, launched on July 23, 1999, was commanded by Lt. Col. Eileen Collins, the first female Commander of a U.S. spacecraft.

Prototype orbiter

Columbia launching during STS-1. *Columbia's* distinctive black chines and "USA" painted on the starboard wing are visible. *Columbia* was the only orbiter launched with a white external tank.

As the second orbiter to be constructed, yet the first to be able to fly into space, *Columbia* was roughly 8,000 lb (3,600 kg) heavier than subsequent orbiters such as *Endeavour*, which were of a slightly different design, and had benefited from advances in materials technology. In part this was due to heavier wing and fuselage spars, the weight of early test instrumentation that remained fitted to the avionics suite, and an internal airlock that, originally fitted into the other orbiters, were later removed for an external airlock to facilitate Shuttle/Mir and Shuttle/International Space Station dockings. This retention of an internal airlock allowed NASA to use *Columbia* for the STS-109 Hubble Space Telescope servicing mission, along with the Spacehab double module used on STS-107. Due to *Columbia's* heavier weight, it was less ideal for NASA to use it for missions to the

International Space Station, though modifications were done to the Shuttle at last refit incase the Shuttle was needed for such tasks. Had *Columbia* not been destroyed, it would have been fitted with the external airlock/docking adapter for mission STS-118, an International Space Station assembly mission, in November 2003. *Columbia* was scheduled for this mission due to *Discovery* being out of service for its Orbital Maintenance Down Period and the ISS assembly schedule could not be adhered to with just *Endeavour* and *Atlantis*.

Despite refinements to the launcher's thermal protection system and other enhancements, *Columbia* would never weigh as little unloaded as the other orbiters in the fleet. The next-oldest shuttle, *Challenger*, was also relatively heavy, although 2,200 lb (1,000 kg) lighter than *Columbia*.

Externally, *Columbia* was the first orbiter in the fleet that originally had a mostly all-tile thermal protection system (TPS) with nomex Fiberous Reuseable Surface Insulation (FRSI) blankets in some areas on the wings and fuselage. This was later modified to incorporate thicker Advanced Fiberous Reuseable Insulation (AFRSI) blankets on the fuselage and upper wing surfaces as well after their successful use on shuttle *Discovery* and *Atlantis*. The work was performed during *Columbia's* first retrofitting and the post-*Challenger* stand-down. Also unique to *Columbia* were the black "chines" on the upper surfaces of the shuttle's forward wing. These black areas were added because the first shuttle's designers did not know how reentry heating would affect the craft's upper wing surfaces. The "chines" allowed *Columbia* to be easily recognized at a distance, as opposed to the subsequent orbiters.

Until its last refit, *Columbia* was the only operational orbiter with wing markings consisting of an American flag on the port (left) wing and the letters "USA" on the starboard (right) wing. *Challenger*, *Discovery*, *Atlantis*, *Endeavour*, and even the *Enterprise* all, until 1998, bore markings consisting of the letters "USA" afore an American flag on the left wing, and the pre-1998 NASA "worm" logo afore the respective orbiter's name on the right wing. From its last refit to its destruction, *Columbia* bore markings identical to those of its operational sister orbiters — the NASA "meatball" logo on the left wing and the American flag afore the orbiter's name on the right; only *Columbia's* distinctive wing "chines" remained.

Another unique external feature, termed the "SILTS" pod, was located on the top of *Columbia's* tailfin, and was installed after STS-9 to acquire infrared and other thermal data. Though the pod's equipment was removed after initial tests, NASA decided to leave it in place, mainly to save costs, along with the agency's plans to use it for future experiments. The tailfin was later modified to incorporate the drag chute first used on *Endeavour* in 1992.

Columbia on the launch pad before its first mission.

Columbia was originally fitted with Lockheed Martin-built ejection seats identical to those found on the SR-71 Blackbird. These seats were active for the four orbital test flights, but were deactivated after STS-4 and were removed entirely after STS-9. *Columbia* was also the only orbiter not delivered with head-up displays for the Commander and Pilot, although these were incorporated after STS-9. Like its sister ships, *Columbia* was eventually retrofitted (at its last refit) with the new MEDS "glass cockpit" display and lightweight seats.

After the STS-118 mission, *Columbia's* career would have started to wind down. The shuttle was planned to service the Hubble Space Telescope two more times, once in 2004, and again in 2005, but no more missions were planned for it again until 2009 when, on STS-144, it would retrieve the Hubble Space Telescope from orbit and bring it back to Earth. Following the *Columbia* accident, NASA flew the STS-125 mission, using the *Atlantis* to perform the final service mission (incorporating the planned fourth and fifth servicing missions), and in the process, installed a "Soft Capture Docking Mechanism," based on the docking adapter to be used on the Orion spacecraft, for an eventual atmospheric reentry and breakup, as this would occur after the retirement of the Space Shuttle fleet in 2010.

Columbia was also scheduled to launch the X-38 V-201 Crew Return Vehicle prototype as the next mission after STS-118, until the cancellation of the project in 2002.

Flights

Space Shuttle *Columbia* flew 28 flights, spent 300.74 days in space, completed 4,808 orbits, and flew 125,204,911 miles (201,497,772 km) in total, including its final mission.

Columbia was the only shuttle to have been spaceworthy during the Shuttle-Mir and International Space Station programs and yet to have never visited either Mir or ISS. In contrast, *Discovery*, *Atlantis*, and *Endeavour* have all visited both stations at least once, as *Columbia* was not suited for high-inclination missions. *Challenger* was destroyed before the Shuttle-Mir Program began, and *Enterprise* never flew in space.

#	Date	Designation	Launch pad	Landing location	Notes
1	1981, April 12	STS-1	39-A	Edwards Air Force Base	First shuttle mission. Launch witnessed by the band Rush; inspired the song "Countdown" on their 1982 album *Signals*.
2	1981, November 12	STS-2	39-A	Edwards Air Force Base	First re-use of manned space vehicle
3	1982, March 22	STS-3	39-A	White Sands Space Harbor	First mission with an unpainted External tank. Only time that a space shuttle has landed at the White Sands Space Harbor. This launch was dedicated by Ronald Reagan to "the people of Afghanistan".
4	1982, June 27	STS-4	39-A	Edwards Air Force Base	Last shuttle R&D flight
5	1982, November 11	STS-5	39-A	Edwards Air Force Base	First four-person crew, first deployment of commercial satellite.
6	1983 November 28	STS-9	39-A	Edwards Air Force Base	First six-person crew, first Spacelab.
7	1986, January 12	STS-61-C	39-A	Edwards Air Force Base	Representative Bill Nelson (D-FL) on board/ final successful shuttle flight before Challenger disaster
8	1989, August	STS-28	39-B	Edwards Air	Launched KH-11

	8			Force Base	reconnaissance satellite
9	1990, January 9	STS-32	39-A	Edwards Air Force Base	Retrieved Long Duration Exposure Facility
10	1990, December 2	STS-35	39-B	Edwards Air Force Base	Carried multiple X-ray & UV telescopes
11	1991, June 5	STS-40	39-B	Edwards Air Force Base	5th Spacelab - Life Sciences-1
12	1992, June 25	STS-50	39-A	Kennedy Space Center	U.S. Microgravity Laboratory 1 (USML-1)
13	1992, October 22	STS-52	39-B	Kennedy Space Center	Deployed Laser Geodynamic Satellite II
14	1993, April 26	STS-55	39-A	Edwards Air Force Base	German Spacelab D-2 Microgravity Research
15	1993, October 18	STS-58	39-B	Edwards Air Force Base	Spacelab Life Sciences
16	1994, March 4	STS-62	39-B	Kennedy Space Center	United States Microgravity Payload-2 (USMP-2)
17	1994, July 8	STS-65	39-A	Kennedy Space Center	International Microgravity Laboratory (IML-2)
18	1995, October 20	STS-73	39-B	Kennedy Space Center	United States Microgravity Laboratory (USML-2)
19	1996, February 22	STS-75	39-B	Kennedy Space Center	Tethered Satellite System Reflight (TSS-1R)
20	1996, June 20	STS-78	39-B	Kennedy Space Center	Life and Microgravity Spacelab (LMS)
21	1996, November 19	STS-80	39-B	Kennedy Space Center	3rd flight of Wake Shield Facility (WSF)/ longest Shuttle flight as of 2006
22	1997, April 4	STS-83	39-A	Kennedy Space Center	Microgravity Science Laboratory (MSL)- cut short
23	1997, July 1	STS-94	39-A	Kennedy Space Center	Microgravity Science Laboratory (MSL)- reflight
24	1997, November 19	STS-87	39-B	Kennedy Space Center	United States Microgravity Payload (USMP-4)
25	1998, April 13	STS-90	39-B	Kennedy Space Center	Neurolab - Spacelab
26	1999, July 23	STS-93	39-B	Kennedy Space Center	Deployed Chandra X-ray Observatory
27	2002, March 1	STS-109	39-A	Kennedy Space Center	Hubble Space Telescope service mission (HSM-3B)

28	2003, January 16	STS-107	39-A	Did not land (Planned to land at Kennedy Space Center)	A multi-disciplinary microgravity and Earth science research mission. Shuttle destroyed during re-entry on February 1, 2003 and all seven astronauts on board died.

Final mission and destruction

Columbia was destroyed at about 0900 EST on February 1, 2003 while re-entering the atmosphere after a 16-day scientific mission. The Columbia Accident Investigation Board determined that a hole was punctured in the leading edge on one of *Columbia's* wings, made of a carbon-carbon composite. The hole had formed when a piece of insulating foam from the external fuel tank peeled off during the launch 16 days earlier and struck the shuttle's wing. During the intense heat of re-entry, hot gases penetrated the interior of the wing, destroying the support structure and causing the rest of the shuttle to break apart. The nearly 84,000 pieces of collected debris of the vessel are stored in a 16th floor office suite in the Vehicle Assembly Building at the Kennedy Space Center. The collection was opened to the media once and has since been open only to researchers. Unlike Space Shuttle Challenger, which had a replacement orbiter built, Columbia did not have a replacement orbiter built.

Tribute

The shuttle's final crew was honored in 2003 when the USGS's Board of Geographic Names approved the name Columbia Point for a 13,980-foot (4,260 m) mountain in Colorado's Sangre de Cristo Mountains, less than a half-mile from Challenger Point, a peak named after America's other lost shuttle. The Columbia Hills on Mars were also named in honor of the crew, and a host of other memorials were dedicated in various forms.

Fans of the original *Star Trek* television series were largely responsible for NASA naming the first Space Shuttle *Enterprise.* In the television series *Star Trek: Enterprise* both the first and second starships of the human-built NX-Class, registry numbers NX-01 & NX-02 respectively, were named in honor of pre-existing NASA space shuttles. The second vessel's name was first revealed in the season 3 episode "E^2" to be *Columbia*, in honor of the space shuttle *Columbia* following its destruction on February 1, 2003. Uniforms on NX-02 *Columbia* bear a crew patch depicting 7 stars, in honor of the astronauts who died in the shuttle accident.

The space shuttle Columbia makes a cameo role in the Japanese anime Cowboy Bebop, episode 'Wild Horses'. Coincidently, crashing after re-entry (though not burning up), due to the heat resistant tiles peeling off.

Chapter- 5

Space Shuttle Discovery

Discovery
OV-103

Space Shuttle *Discovery* launches from launch pad 39A on mission STS-124.

OV designation	OV-103
Country	United States
Contract award	January 29, 1979
Named after	RRS *Discovery*
Status	Active

First flight	STS-41-D August 30, 1984 – September 5, 1984
Last flight	STS-131 April 05, 2010 - April 20, 2010
Number of missions	38
Crews	246
Time spent in space	351 days, 17 hours, 50 minutes, 41 seconds
Number of orbits	5,628
Distance travelled	142,917,535 mi (230,003,477 km)
Satellites deployed	31 (including Hubble Space Telescope)
Mir dockings	1
ISS dockings	11

Space Shuttle *Discovery* (Orbiter Vehicle Designation: **OV-103**) is one of the three currently operational orbiters in the Space Shuttle fleet of NASA, the space agency of the United States. (The other two are *Atlantis* and *Endeavour*.) When first flown in 1984, *Discovery* became the third operational orbiter, and is now the oldest orbiter in service. *Discovery* has performed both research and International Space Station (ISS) assembly missions.

History

The spacecraft takes its name from four British ships of exploration named *Discovery*, primarily HMS *Discovery*, one of the ships commanded by Captain James Cook during his third and final major voyage, 1776–1779. Others include Henry Hudson's *Discovery*, which he used in 1610–1611 to search for a Northwest Passage; the HMS *Discovery*, one of the ships which took Captain George Nares' British Arctic Expedition of 1875–1876 to the North Pole; and RRS *Discovery*, a Royal Geographical Society research vessel which, under the command of Captain Robert Falcon Scott and Ernest Shackleton, was the main ship of the 1901–1904 "Discovery Expedition" to Antarctica which is still preserved as a museum.

The launch of STS-41-D, Discovery’s first mission.


STS-121 launched on Independence Day, the first shuttle to launch on July 4.

STS-119 on the morning of March 11, 2009.

Discovery sits atop a Boeing 747 as it touches down.

Discovery was the shuttle that launched the Hubble Space Telescope. The second and third Hubble service missions were also conducted by *Discovery*. It has also launched the Ulysses probe and three TDRS satellites. *Discovery* has been chosen twice as the return to flight orbiter, first in 1988 as the return to flight orbiter after the 1986 *Challenger* disaster, and then for the twin return to flight missions in July 2005 and July 2006 after the 2003 *Columbia* disaster. *Discovery* also carried Project Mercury astronaut John Glenn, who was 77 at the time, back into space during STS-95 on October 29, 1998, making him the oldest human being to venture into space.

Had the planned STS-62-A mission from Vandenberg Air Force Base in 1986 for the United States Department of Defense gone ahead, *Discovery* would have flown it.

Construction milestones

- January 29, 1979: Contract Award to Rockwell International's Space Transportation Systems Division in Downey, California
- August 27, 1979: Start long lead fabrication of Crew Module
- June 20, 1980: Start fabrication lower fuselage
- November 10, 1980: Start structural assembly of aft-fuselage
- December 8, 1980: Start initial system installation aft fuselage
- March 2, 1981: Start fabrication/assembly of payload bay doors
- October 26, 1981: Start initial system installation, crew module, Downey
- January 4, 1982: Start initial system installation upper forward fuselage
- March 16, 1982: Midfuselage on dock, Palmdale
- March 30, 1982: Elevons on dock, Palmdale
- April 30, 1982: Wings arrive at Palmdale from Grumman
- April 30, 1982: Lower forward fuselage on dock, Palmdale
- July 16, 1982: Upper forward fuselage on dock, Palmdale
- August 5, 1982: Vertical stabilizer on dock, Palmdale
- September 3, 1982: Start of Final Assembly
- October 15, 1982: Body flap on dock, Palmdale
- January 11, 1983: Aft fuselage on dock, Palmdale
- February 25, 1983: Complete final assembly and closeout installation, Palmdale
- February 28, 1983: Start initial subsystems test, power-on, Palmdale
- May 13, 1983: Complete initial subsystems testing
- July 26, 1983: Complete subsystems testing
- August 12, 1983: Completed Final Acceptance
- October 16, 1983: Rollout from Palmdale
- November 5, 1983: Overland transport from Palmdale to Edwards
- November 9, 1983: Delivery to Kennedy Space Center
- June 2, 1984: Flight Readiness Firing
- August 30, 1984: First Flight (41-D)

Upgrades and features

Discovery benefited from lessons learned in the construction and testing of Enterprise, Columbia and Challenger. At rollout, its weight was some 6,870 pounds less than Columbia.

Beginning in the fall of 1995, the orbiter underwent a nine-month Orbiter Maintenance Down Period (OMDP) in Palmdale California. The vehicle was outfitted with a 5th set of cryogenic tanks and an external airlock to support missions to the International Space Station. It returned to the Kennedy Space Center, riding piggy-back on a modified Boeing 747, in June 1996.

Discovery performing the Rendezvous pitch maneuver prior to docking with the International Space Station.


The Space Shuttle *Discovery* soon after landing on earth.

Modified Boeing 747 carrying Discovery.

Following STS-105, Discovery became the first of the orbiter fleet to undergo Orbiter Major Modification (OMM) period at the Kennedy Space Center. Work began in September 2002, and along with the scheduled upgrades, additional safety modifications were added as part of the preparations for Return to Flight.

Flights

Discovery has flown 38 flights, completed 5,247 orbits, and has spent 322 days in orbit. *Discovery* is the orbiter fleet leader, having flown more flights than any other orbiter in the fleet, including four in 1985 alone. *Discovery* flew all three "return to flight" missions after the *Challenger* and *Columbia* disasters: STS-26 in 1988, STS-114 in 2005, and STS-121 in 2006. *Discovery* is scheduled to fly the second to last space shuttle mission STS-133 currently targeted to launch no earlier than (NET) Feb. 24, 2011.

- STS-41-D: First flight
- STS-51-D: Carried first incumbent United States member of Congress into space, Senator Jake Garn (R–Utah)
- STS-26: Return to space after *Challenger* disaster (STS-51-L)
- STS-31: Launch of Hubble Space Telescope
- STS-60: First Russian launched in an American spacecraft (Sergei Krikalev)

- STS-95: Second flight of John Glenn, oldest man in space and third incumbent member of Congress to enter space
- STS-92: The 100th Space Shuttle mission
- STS-114: Return to space after *Columbia* disaster (STS-107)
- STS-116: First night time launch of a shuttle since the *Columbia* disaster. Last Shuttle launch from LC-39B
- STS-131: Longest mission for this orbiter

Flights listing

#	Date	Designation	Notes	Length of journey
1	1984 August 30	STS-41-D	First Discovery mission: Launched two communications satellites, including LEASAT F2.	6 days, 00 hours, 56 minutes, 04 seconds
2	1984 November 8	STS-51-A	Launched two and rescued two communications satellites including LEASAT F1.	7 days, 23 hours, 44 minutes, 56 seconds
3	1985 January 24	STS-51-C	Launched DOD Magnum ELINT satellite.	3 days, 01 hours, 33 minutes, 23 seconds-
4	1985 April 12	STS-51-D	Launched two communications satellites including LEASAT F3.	6 days, 23 hours, 55 minutes, 23 seconds
5	1985 June 17	STS-51-G	Launched two communications satellites, Sultan Salman al-Saud becomes first Saudi Arabian in space.	7 days, 01 hours, 38 minutes, 52 seconds
6	1985 August 27	STS-51-I	Launched two communications satellites including LEASAT F4. Recovered, repaired, and redeployed LEASAT F3.	7 days, 02 hours, 17 minutes, 42 seconds
7	1988 September 29	STS-26	Return to flight after Space Shuttle Challenger disaster, launched TDRS.	4 days, 01 hours, 00 minutes, 11 seconds
8	1989 March 13	STS-29	Launched TDRS.	4 days, 23 hours, 38 minutes, 52

				seconds
9	1989 November 22	STS-33	Launched DOD Magnum ELINT satellite.	5 days, 00 hours, 06 minutes, 49 seconds
10	1990 April 24	STS-31	Launch of Hubble Space Telescope (HST).	5 days, 01 hours, 16 minutes, 06 seconds
11	1990 October 6	STS-41	Launch of Ulysses.	4 days, 02 hours, 10 minutes, 04 seconds
12	1991 April 28	STS-39	Launched DOD Air Force Program-675 (AFP675) satellite.	8 days, 07 hours, 22 minutes, 23 seconds
13	1991 September 12	STS-48	Upper Atmosphere Research Satellite (UARS).	5 days, 08 hours, 27 minutes, 38 seconds
14	1992 January 22	STS-42	International Microgravity Laboratory-1 (IML-1).	8 days, 01 hours, 14 minutes, 44 seconds
15	1992 December 2	STS-53	Department of Defense payload.	7 days, 07 hours, 19 minutes, 47 seconds
16	1993 April 8	STS-56	Atmospheric Laboratory (ATLAS-2).	9 days, 06 hours, 08 minutes, 24 seconds
17	1993 September 12	STS-51	Advanced Communications Technology Satellite (ACTS).	9 days, 20 hours, 11 minutes, 11 seconds
18	1994 February 3	STS-60	Wake Shield Facility (WSF).	7 days, 06 hours, 08 minutes, 36 seconds
19	1994	STS-64	LIDAR In-Space Technology	10 days, 22

	September 9		Experiment (LITE).	hours, 49 minutes, 57 seconds
20	1995 February 3	STS-63	Rendezvous with Mir space station.	8 days, 06 hours, 29 minutes, 36 seconds
21	1995 July 13	STS-70	7th Tracking and Data Relay Satellite (TDRS).	8 days, 22 hours, 20 minutes, 05 seconds
22	1997 February 11	STS-82	Servicing Hubble Space Telescope (HST) (HSM-2).	9 days, 23 hours, 38 minutes, 09 seconds
23	1997 August 7	STS-85	Cryogenic Infrared Spectrometers and Telescopes.	11 days, 20 hours, 28 minutes, 07 seconds
24	1998 June 2	STS-91	Final Shuttle/Mir Docking Mission.	9 days, 19 hours, 55 minutes, 01 seconds
25	1998 October 29	STS-95	SPACEHAB, second flight of John Glenn, Pedro Duque becomes first Spaniard in space.	8 days, 21 hours, 44 minutes, 56 seconds
26	1999 May 27	STS-96	Resupply mission for the International Space Station.	9 days, 19 hours, 13 minutes, 57 seconds
27	1999 December 19	STS-103	Servicing Hubble Space Telescope (HST) (HSM-3A).	7 days, 23 hours, 11 minutes, 34 seconds
28	2000 October 11	STS-92	International Space Station Assembly Flight (carried and assembled the Z1 truss); 100th Shuttle mission.	12 days, 21 hours, 43 minutes, 47 seconds
29	2001 March 8	STS-102	International Space Station crew rotation flight (Expedition 1 and Expedition 2)	12 days, 19 hours, 51 minutes, 57 seconds

30	2001 August 10	STS-105	International Space Station crew and supplies delivery (Expedition 2 and Expedition 3)	11 days 21 hours, 13 minutes, 52 seconds
31	2005 July 26	STS-114	Return to flight since Space Shuttle Columbia disaster; International Space Station (ISS) supplies delivery, new safety procedures testing and evaluation, Multi-Purpose Logistics Module (MPLM) *Raffaello*.	13 days, 21 hours, 33 minutes, 00 seconds
32	2006 July 4	STS-121	Second return to flight since Space Shuttle Columbia disaster; International Space Station (ISS) supplies delivery, test new safety and repair techniques.	12 days, 18 hours, 37 minutes, 54 seconds
33	2006 December 9	STS-116	ISS crew rotation and assembly (carries and assembles the P5 truss segment); Last flight to launch on pad 39-B; First night launch since Space Shuttle Columbia disaster.	12 days, 20 hours, 44 minutes, 16 seconds
34	2007 October 23	STS-120	ISS crew rotation and assembly (carries and assembles the Harmony module).	15 days, 02 hours, 23 minutes, 55 seconds
35	2008 May 31	STS-124	ISS crew rotation and assembly (carries and assembles the Kibō JEM PM module).	13 days, 18 hours, 13 minutes, 07 seconds
36	2009 March 15	STS-119	International Space Station crew rotation and assembly of a fourth starboard truss segment (ITS S6) and a fourth set of solar arrays and batteries. Also replaced a failed unit for a system that converts urine to drinking water.	12 days, 19 hours, 29 minutes, 33 seconds
37	2009 August 28	STS-128	International Space Station crew rotation and ISS resupply using the Leonardo Multi-Purpose Logistics Module. Also carried the C.O.L.B.E.R.T treadmill named after Stephen Colbert	13 days 20 hours, 54 minutes, 40 seconds
38	2010 April 5	STS-131	ISS resupply using the Leonardo Multi-Purpose Logistics Module. The mission also marked the 1st time that 4 women were in space & the 1st time that 2	15 days 2 hours, 47 minutes, 10 seconds‡

			Japanese astronauts were together in space.	
39	2011 February 24	STS-133	The mission, currently set for launch at 4:50 p.m. EST on February 24, will carry the Pressurized Multipurpose Module (PMM) Leonardo and the ELC-4 to the ISS. Final mission for Discovery and is no longer last scheduled flight of the Space Shuttle Program.	11 days (Planned)

‡ Longest shuttle mission for *Discovery*
+ Targeted date as mission has yet to launch
– shortest shuttle mission for *Discovery*

Planned decommissioning

According to the current schedule, *Discovery* will be decommissioned in 2011. *Discovery* will be the third from last space shuttle to fly when it is launched on the STS-133 mission.

NASA has offered *Discovery* to the Smithsonian Institution's National Air and Space Museum for public display and preservation as part of the national collection after the orbiter has been retired.

Chapter- 6

Space Shuttle Endeavour

Endeavour
OV-105

Space Shuttle *Endeavour* on launch pad 39A prior to mission STS-127, July 15, 2009.

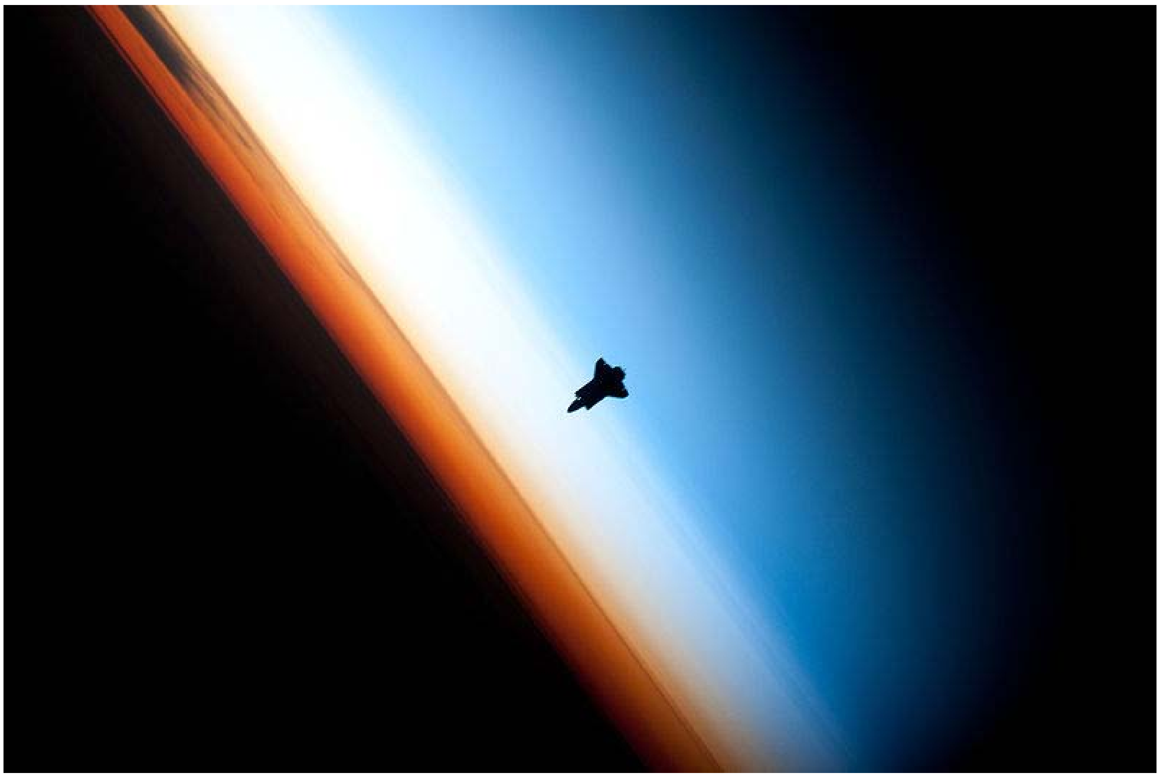
OV designation	OV-105
Country	United States
Contract award	July 31, 1987
Named after	HMS *Endeavour*
Status	Active
First flight	STS-49 May 7, 1992 - May 16, 1992

Last flight	STS-130 February 8–21, 2010
Number of missions	24
Crews	148
Time spent in space	280 days, 9 hours, 39 minutes, 44 seconds
Number of orbits	4,429
Distance travelled	166,003,247 km (103,149,636 mi)
Satellites deployed	3
Mir dockings	1
ISS dockings	10

Endeavour as photographed from the International Space Station as it approached the station during STS-118.

Space Shuttle *Endeavour* (Orbiter Vehicle Designation: **OV-105**) is one of three currently operational orbiters in the Space Shuttle fleet of NASA, the space agency of the United States. (The other two are *Discovery* and *Atlantis*.) *Endeavour* is the fifth and final spaceworthy NASA space shuttle to be built, constructed as a replacement for *Challenger*. *Endeavour* first flew in May 1992 on mission STS-49 and was scheduled for decommissioning in 2010. Before its decommissioning, NASA expects to use *Endeavour* for the STS-134 mission, which will make it the last shuttle to fly a mission for the Space Shuttle Program. However, should the proposed STS-135 mission be approved, *Atlantis* will be the final shuttle to fly.

History



Endeavour straddling the stratosphere and mesosphere.

The United States Congress authorized the construction of *Endeavour* in 1987 to replace *Challenger*, which was lost in an accident in 1986. Structural spares from the construction of *Discovery* and *Atlantis*, two of the three remaining operating shuttles at the time, were used in its assembly. The decision to build *Endeavour* was favored over refitting *Enterprise* on cost grounds.

The orbiter is named after the British HMS *Endeavour*, the ship which took Captain James Cook on his first voyage of discovery (1768–1771). This is why the name is spelled in the British English manner, rather than the American English ("Endeavor"). This has caused confusion, most notably when NASA themselves misspelled a sign on the launch pad in 2007. The name also honored *Endeavour*, the Command Module of Apollo 15.

Endeavour was named through a national competition involving students in elementary and secondary schools. Entries included an essay about the name, the story behind it and why it was appropriate for a NASA shuttle, and the project that supported the name. *Endeavour* was the most popular entry, accounting for almost one-third of the state-level winners. The national winners were Senatobia Middle School in Senatobia, Mississippi, in the elementary division and Tallulah Falls School in Tallulah Falls, Georgia, in the upper school division. They were honored at several ceremonies in Washington, D.C., including a White House ceremony where then-President George H.W. Bush presented awards to each school.

Endeavour was delivered by Rockwell International Space Transportation Systems Division in May 1991 and first launched a year later, in May 1992, on STS-49. Rockwell International claimed that it had made no profit on Space Shuttle *Endeavour*, despite construction costing US$2.2 billion. On its first mission, it captured and redeployed the stranded *INTELSAT VI* communications satellite. The African-American woman, Mae Jemison, was brought into space on the mission STS-47 on September 12, 1992.

In 1993, it made the first service mission to the Hubble Space Telescope. *Endeavour* was withdrawn from service for eight months in 1997 for a retrofit, including installation of a new airlock. In December 1998, it delivered the Unity Module to the International Space Station.

Endeavour completed its latest Orbiter Major Modification period, which began in December 2003, and ended on October 6, 2005. During this time, the Orbiter received major hardware upgrades, including a new, multi-functional, electronic display system, often referred to as glass cockpit, and an advanced GPS receiver, along with safety upgrades recommended by the Columbia Accident Investigation Board (CAIB) for shuttle return to flight after the disintegration of sister-ship *Columbia* during re-entry on February 1, 2003.

The STS-118 mission, the first for *Endeavour* following a lengthy refit, included astronaut Barbara Morgan, formerly assigned to the Educator Astronaut program, but now a full member of the Astronaut Corps, as part of the crew. Morgan was the backup for Christa McAuliffe on the ill-fated STS-51-L mission.

Upgrades and features

Endeavour mounted on a Shuttle Carrier Aircraft.

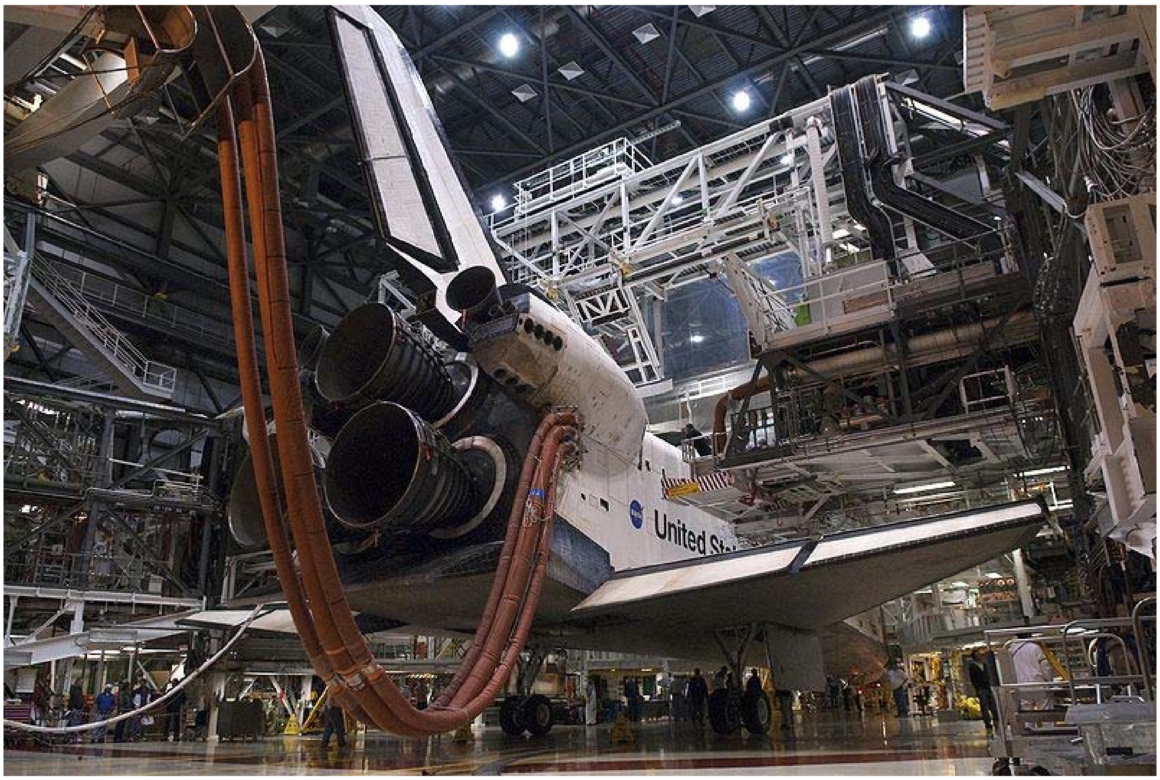
As it was constructed later, *Endeavour* was built with new hardware designed to improve and expand orbiter capabilities. Most of this equipment was later incorporated into the other three orbiters during out-of-service major inspection and modification programs. *Endeavour*'s upgrades include:

- A 40-foot (12 m) diameter drag chute that is expected to reduce the orbiter's rollout distance by 1,000 to 2,000 feet (300 to 610 m).
- The plumbing and electrical connections needed for Extended Duration Orbiter (EDO) modifications to allow up to 28-day missions (although a 28-day mission has never yet been attempted; the current record is 17 days, which was set by *Columbia*).
- Updated avionics systems that include advanced general purpose computers, improved inertial measurement units and tactical air navigation systems, enhanced master events controllers and multiplexer-demultiplexers, a solid-state star tracker and improved nose wheel steering mechanisms.
- An improved version of the Auxiliary Power Units (APUs) that provide power to operate the Shuttle's hydraulic systems.

Modifications resulting from a 2005-2006 refit of *Endeavour* include:

- The *Station-to-Shuttle Power Transfer System* (SSPTS), which converts 8 kilowatts of DC power from the ISS main voltage of 120VDC to the orbiter bus voltage of 28VDC. This upgrade will allow *Endeavour* to remain on-orbit while docked at ISS for an additional 3- to 4-day duration. The corresponding power equipment was added to the ISS during the STS-116 station assembly mission, and *Endeavour* flew with SSPTS capability during STS-118.

Planned decommissioning



Platforms around Endeavour in Orbiter Processing Facility-2.

Endeavour was originally scheduled to be decommissioned in 2010 after 18 years of service, but on July 1, 2010, NASA released a statement saying the shuttle *Endeavour* mission was rescheduled for February 27, 2011, instead of late November, 2010.

"The target dates were adjusted because critical payload hardware for STS-133 will not be ready in time to support the previously planned September 16 launch," NASA said in a statement. With the Discovery launch moving to November, the *Endeavour* mission "cannot fly as planned, so the next available launch window is in February 2011," NASA said, adding that the launch dates are subject to change.

Endeavour's final flight was originally scheduled for July 29, 2010, but was postponed. *Discovery* was going to be the last of the Space Shuttle program, on the STS-133 mission to the International Space Station, which will carry the next to final components in the ISS assembly sequence, the EXPRESS Logistics Carrier ELC5 and ELC1, to orbit. However, in 2008 one more mission (STS-134) was funded, and so *Endeavour* was then slated to be the final Orbiter to fly. However, one final mission, STS-135, has also been added to the schedule and has been allocated to *Atlantis* for June 2011.

NASA has offered the three remaining orbiters for museum donation once they are withdrawn from service. *Discovery* may go the Steven F. Udvar-Hazy Center of the National Air and Space Museum but this decision has not yet been finalized.

More than twenty organizations have submitted proposals to NASA for the display of an Orbiter. March Field Air Museum in Riverside, California has stated a preference to receive *Endeavour*, due to the local connection of astronaut Tracy Caldwell, who grew up in Beaumont and flew on *Endeavour* during mission STS-118. Another organization seeking an Orbiter, and with a direct connection to *Endeavour*, is the forthcoming Brazos Valley Museum of Science and History. The Museum is endorsed in its efforts by President George H. W. Bush during whose terms as Vice President, and then President *Endeavour* was commissioned and first flown.

Flights

#	Launch date	Designation	Launch pad	Landing location	Notes
1	1992-05-07	STS-49	39-B	Edwards Air Force Base	First flight of *Endeavour*: Capture and redeploy Intelsat VI. First three-man EVA, longest US EVA since Apollo 17.
2	1992-09-12	STS-47	39-B	Kennedy Space Center	Spacelab mission J
3	1993-01-13	STS-54	39-B	Kennedy	Deploy TDRS-F
4	1993-06-21	STS-57	39-B	Kennedy	Spacelab experiments. Retrieve European Retrievable Carrier

5	1993-12-02	STS-61	39-B	Kennedy	First Hubble Space Telescope service mission (HSM-1)
6	1994-04-09	STS-59	39-A	Edwards	Space Radar Laboratory experiments
7	1994-09-30	STS-68	39-A	Edwards	Space Radar Laboratory experiments
8	1995-03-02	STS-67	39-A	Edwards	Spacelab Astro-2 experiments
9	1995-09-07	STS-69	39-A	Kennedy	Wake Shield Facility and other experiments
10	1996-01-11	STS-72	39-B	Kennedy	Retrieve Japanese Space Flyer Unit
11	1996-05-19	STS-77	39-B	Kennedy	Spacelab experiments
12	1998-01-22	STS-89	39-A	Kennedy	Rendezvous with Mir space station and astronaut exchange
13	1998-12-04	STS-88	39-A	Kennedy	International Space Station assembly mission (assembled the Unity Module (Node 1), first American component of the ISS)
14	2000-02-11	STS-99	39-A	Kennedy	Shuttle Radar Topography Mission experiments
15	2000-	STS-97	39-B	Kennedy	International Space Station assembly

	11-30				mission (P6 truss segment)
16	2001-04-19	STS-100	39-A	Edwards	International Space Station assembly mission (Canadarm2 robotic arm and hand)
17	2001-12-05	STS-108	39-B	Kennedy	International Space Station rendezvous and astronaut exchange (Expedition 3/Expedition 4)
18	2002-06-05	STS-111	39-A	Edwards	International Space Station rendezvous and astronaut exchange (Expedition 4/Expedition 5)
19	2002-11-23	STS-113	39-A	Kennedy	International Space Station assembly mission and astronaut exchange/final successful shuttle flight before the Columbia disaster (Expedition 5/6 exchange; P1 truss segment assembly)
20	2007-08-08	STS-118	39-A	Kennedy	Four spacewalks conducted. Installation of the International Space Station S5 Truss, of the Integrated Truss Structure. Carried a SPACEHAB module carrying 5,000 pounds of supplies and equipment to the International Space Station. Crew included the Educator Astronaut Barbara Morgan. Thermal tiles protecting the underside of the vehicle were damaged during launch. NASA decided not to fix this damage in-flight as it was not believed to be serious enough to result in loss of vehicle or crew. The craft landed a day early due to the possibility that Hurricane Dean would force Mission Control to evacuate.
21	2008-	STS-123	39-A	Kennedy	International Space Station assembly mission which delivered the first

	03-11				element of Japan's Kibo module along with the Canadian Special Purpose Dexterous Manipulator robotic arm, and the Spacelab Pallet-Deployable 1.
22	2008-11-14	STS-126	39-A	Edwards	International Space Station assembly mission that brought equipment and supplies in the Multi-Purpose Logistics Module *Leonardo*, and Expedition 18 crew rotation, Sandra Magnus replaced Gregory Chamitoff. *Endeavour* was the only orbiter to land on the temporary Runway 4 at Edwards AFB, as the refurbished main runway will be operational from STS-119 onwards.
23	2009-07-15	STS-127	39-A	Kennedy	International Space Station assembly mission which delivered the last two elements of Japan's *Kibo* Module along with the Spacelab Pallet-Deployable 2, and an Integrated Cargo Carrier-Vertical Light Deployable.
24	2010-02-08	STS-130	39-A	Kennedy	International Space Station assembly mission which delivered the Node 3 and the Cupola observatory to the station. This brought the ISS to 98 percent completion.
25	19 April 2011*	STS-134	39-A	Kennedy	International Space Station assembly mission which will deliver the Alpha Magnetic Spectrometer and the ELC-3 to the space station. This will be the final mission of Endeavour. Originally thought to be the last space shuttle program flight, one additional flight of Atlantis in June 2011 is now planned.

‡ Longest shuttle mission for *Endeavour*
+ Targeted date as mission has yet to launch
* No Earlier Than (Tentative)

Chapter- 7

Space Shuttle Enterprise

Enterprise
OV-101

Enterprise at SLC-6 at Vandenberg AFB

OV designation	OV-101
Country	United States
Contract award	July 26, 1972
Named after	USS *Enterprise* (NCC-1701)
Status	Retired, on display at Smithsonian Institution, Steven F. Udvar-Hazy Center

First flight	Taxi test February 15, 1977
Last flight	Free flight October 26, 1977
Time spent in space	Never flew in space

The **Space Shuttle *Enterprise*** (NASA Orbiter Vehicle Designation: **OV-101**) was the first Space Shuttle orbiter. It was built for NASA as part of the Space Shuttle program to perform test flights in the atmosphere. It was constructed without engines or a functional heat shield, and was therefore not capable of spaceflight.

Originally, *Enterprise* had been intended to be refitted for orbital flight, which would have made it the second space shuttle to fly after *Columbia*. However, during the construction of *Columbia*, details of the final design changed, particularly with regard to the weight of the fuselage and wings. Refitting *Enterprise* for spaceflight would have involved dismantling the orbiter and returning the sections to subcontractors across the country. As this was an expensive proposition, it was determined to be less costly to build *Challenger* around a body frame (STA-099) that had been created as a test article. Similarly, *Enterprise* was considered for refit to replace *Challenger* after the latter was destroyed, but *Endeavour* was built from structural spares instead.

Service

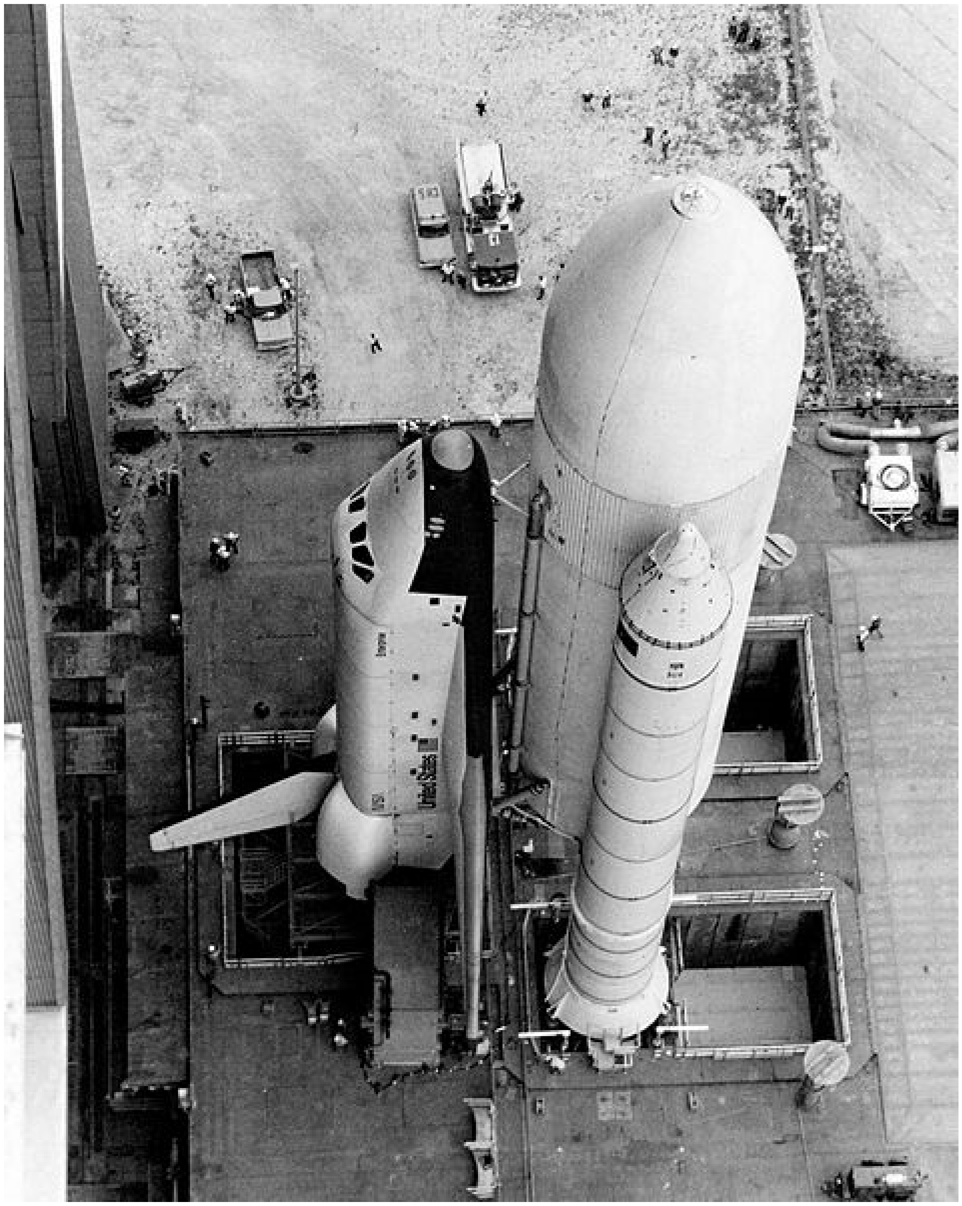
Construction began on the first orbiter on June 4, 1974. Designated OV-101, it was originally planned to be named *Constitution*. However, a write-in campaign caused it to be renamed after the Starship *Enterprise*, featured on the television show *Star Trek*.

The design of OV-101 was not the same as that planned for OV-102, the first flight model; the tail was constructed differently, and it did not have the interfaces to mount OMS pods. A large number of subsystems—ranging from main engines to radar equipment—were not installed on this vehicle, but the capacity to add them in the future was retained. Instead of a Thermal Protection System, its surface was primarily fiberglass.

Enterprise **ALT** Program Logo.

Enterprise rolls out of the Palmdale manufacturing facilities with *Star Trek* television cast members.

Space Shuttle *Enterprise* 747 separation.



Space shuttle Enterprise makes its first appearance mated to a supportive propellant containers/boosters cluster.

In mid-1976, the orbiter was used for ground vibration tests, allowing engineers to compare data from an actual flight vehicle with theoretical models.

On September 17, 1976, *Enterprise* was rolled out of Rockwell's plant at Palmdale, California. In recognition of its fictional namesake, *Star Trek* creator Gene Roddenberry and most of the principal cast of the original series of *Star Trek* were on hand at the dedication ceremony.

Approach and landing tests (ALT)

Enterprise as it banks on its second Approach and Landing Test, September 13, 1977.

On January 31, 1977, it was taken by road to Dryden Flight Research Center at Edwards Air Force Base, to begin operational testing.

While at NASA Dryden, *Enterprise* was used by NASA for a variety of ground and flight tests intended to validate aspects of the shuttle program. The initial nine-month testing period was referred to by the acronym **ALT**, for "Approach and Landing Test". These tests included a maiden "flight" on February 18, 1977 atop a Boeing 747 Shuttle Carrier Aircraft (SCA) to measure structural loads and ground handling and braking characteristics of the mated system. Ground tests of all orbiter subsystems were carried out to verify functionality prior to atmospheric flight.

The mated *Enterprise*/SCA combination was then subjected to five test flights with Enterprise unmanned and unactivated. The purpose of these test flights was to measure the flight characteristics of the mated combination. These tests were followed with three test flights with *Enterprise* manned to test the shuttle flight control systems.

Finally, *Enterprise* underwent five free flights where the craft separated from the SCA and was landed under astronaut control. These tests verified the flight characteristics of the orbiter design and were carried out under several aerodynamic and weight configurations.

On August 12, 1977, the space shuttle Enterprise flew on its own for the first time.

Preparation for STS-1

Enterprise visited pad 39-A in launch configuration 20 months before the first Shuttle launch.

Following the ALT program, *Enterprise* was ferried among several NASA facilities to configure the craft for vibration testing. In June 1979, it was mated with an external tank and solid rocket boosters (known as a boilerplate configuration) and tested in a launch configuration at Kennedy Space Center Launch Pad 39A.

Retirement

With the completion of critical testing, *Enterprise* was partially disassembled to allow certain components to be reused in other shuttles, then underwent an international tour visiting France, Germany, Italy, the United Kingdom, Canada, and the U.S. states of California, Alabama, and Louisiana (during the 1984 Louisiana World Exposition). It was also used to fit-check the never-used shuttle launch pad at Vandenberg AFB, California. Finally, on November 18, 1985, *Enterprise* was ferried to Washington, D.C., where it became property of the Smithsonian Institution.

Post-*Challenger*

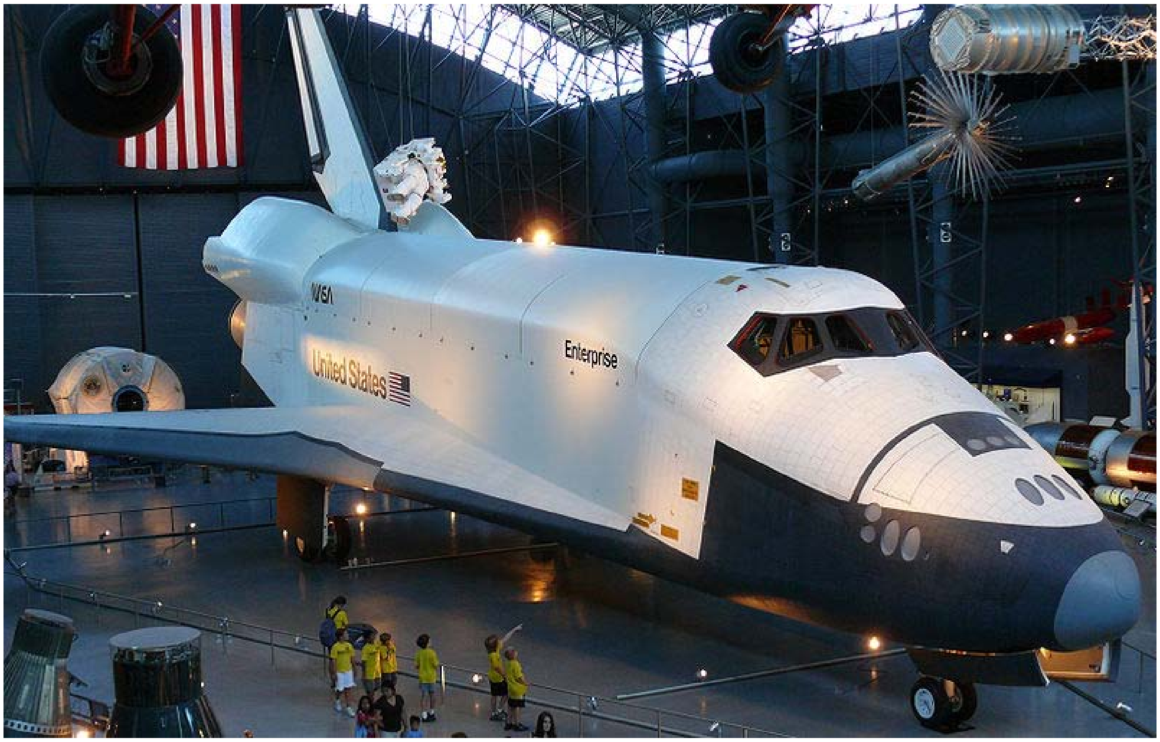
After the *Challenger* disaster, NASA had a choice of which shuttle to use as a replacement. Refitting *Enterprise* with all of the necessary equipment needed for it to be used in space was considered, but instead it was decided to use spares constructed at the same time as *Discovery* and *Atlantis* to build *Endeavour*.

Post-*Columbia*

In 2003, after the breakup of *Columbia* during re-entry, the Columbia Accident Investigation Board conducted tests at Southwest Research Institute, which used an air gun to shoot foam blocks of similar size, mass and speed to that which struck *Columbia* at a test structure which mechanically replicated the orbiter wing leading edge. They removed a fiberglass panel from *Enterprise*'s wing to perform analysis of the material and attached it to the test structure, then shot a foam block at it. While the panel was not broken as a result of the test, the impact was enough to permanently deform a seal. As the Reinforced Carbon-Carbon (RCC) panel on *Columbia* was 2.5 times weaker, this suggested that the RCC leading edge would have been shattered. Additional tests on the fiberglass were canceled in order not to risk damaging the test apparatus, and a panel from *Discovery* was tested to determine the effects of the foam on a similarly-aged RCC leading edge. On July 7, 2003 a foam impact test created a hole 41 cm by 42.5 cm (16.1 inches by 16.7 inches) in the protective RCC panel. The tests clearly demonstrated that a foam impact of the type *Columbia* sustained could seriously breach the protective RCC panels on the wing leading edge.

The board determined that the probable cause of the accident was that the foam impact caused a breach of a Reinforced Carbon-Carbon panel along the leading edge of *Columbia's* left wing, allowing hot gases generated during re-entry to enter the wing and cause structural collapse. This caused *Columbia* to spin out of control, breaking up with the loss of the entire crew.

Museum exhibit



Enterprise on display with IRBMs, ICBMs, and ABM equipment at the Steven F. Udvar-Hazy Center.

Enterprise was stored at the Smithsonian's hangar at Washington Dulles International Airport before it was restored and moved to the newly built Smithsonian's National Air and Space Museum's Steven F. Udvar-Hazy Center at Dulles International Airport, where it is the centerpiece of the space collection. Space Shuttle *Discovery* is expected to be added to the collection once the Shuttle fleet is retired. When that happens, *Enterprise* will likely be loaned out to other institutions. Engineers evaluated the vehicle in early 2010 and determined that it was safe to fly on the Shuttle Carrier Aircraft again.

Chapter- 8

Military Space Shuttle & Pathfinder

Military space shuttle

A **military space shuttle** would have been the military equivalent of NASA's space shuttle. Many experts believe that it is extremely unlikely that NASA, the United States Department of Defense or any other Federal agency could keep the existence of such a spacecraft secret, given the official knowledge that stated extensive technical support and launching establishment would be necessary to fly it.

However, early in the design phase of what eventually became the Space Shuttle, there were plans for the U.S. military to purchase some of the vehicles for its own purposes (mainly the servicing and crewing of proposed 'surveillance space stations'). The design requirements that thus emerged (in particular, the need for a longer-range glide capability, enabling the shuttle to land at specific U.S. Air Force bases), affected the eventual design of the vehicle, increasing its complexity. However, none of these 'Blue Shuttles' were ever built, and the U.S. military turned to increasingly sophisticated unmanned satellites as a more viable alternative.

Regular space shuttles have on occasion carried out missions for the military. It is noteworthy that NASA and the DoD agreed on delivering *Discovery* to Vandenberg AFB, first in May 1985 and then in September of that year. *Discovery* would have been dedicated for military and civilian flights from Vandenberg's SLC-6 launch complex. The schedule slipped until the *Challenger* Disaster in January 1986. In the wake of *Challenger*, on December 26, 1989 the Space Shuttle Program at Vandenberg was terminated by the USAF. Military Shuttle flights were conducted from Kennedy Space Center in Florida, the last dedicated mission being STS-53 in late 1992, deploying a military SDS B-3 communication satellite. Some military payloads have been flown on regular civilian Shuttle missions afterwards.

The Soviet Buran space shuttle was designed with military applications in mind as well. One of the main reasons for its creation was to counter the perceived military advantage that the NASA space shuttle gave the USA. On the first launch of Buran's energia booster the military Polyus satellite was launched.

There have been several abortive military programs to develop a form of space shuttle.

- X-20 Dyna-Soar - USAF program, canceled in 1963
- Project Hot Eagle - USMC program, proposed in 2002

There have been several programs speculated to exist inside the military world

- Blackstar (spaceplane)

Military space shuttles have, however, been featured in popular entertainment from time to time.

Pathfinder (Space Shuttle simulator)

Pathfinder

Pathfinder at the U.S. Space & Rocket Center in Alabama.

OV designation	OV-098
Country	United States
Status	Retired, on display at the U.S. Space & Rocket Center in Huntsville, Alabama.
Number of missions	6 (0 space missions)
Time spent in space	Not a space vehicle
Number of orbits	0

The **Space Shuttle Orbiter *Pathfinder*** (honorary Orbiter Vehicle Designation: OV-098) is a Space Shuttle test simulator made of steel and wood.

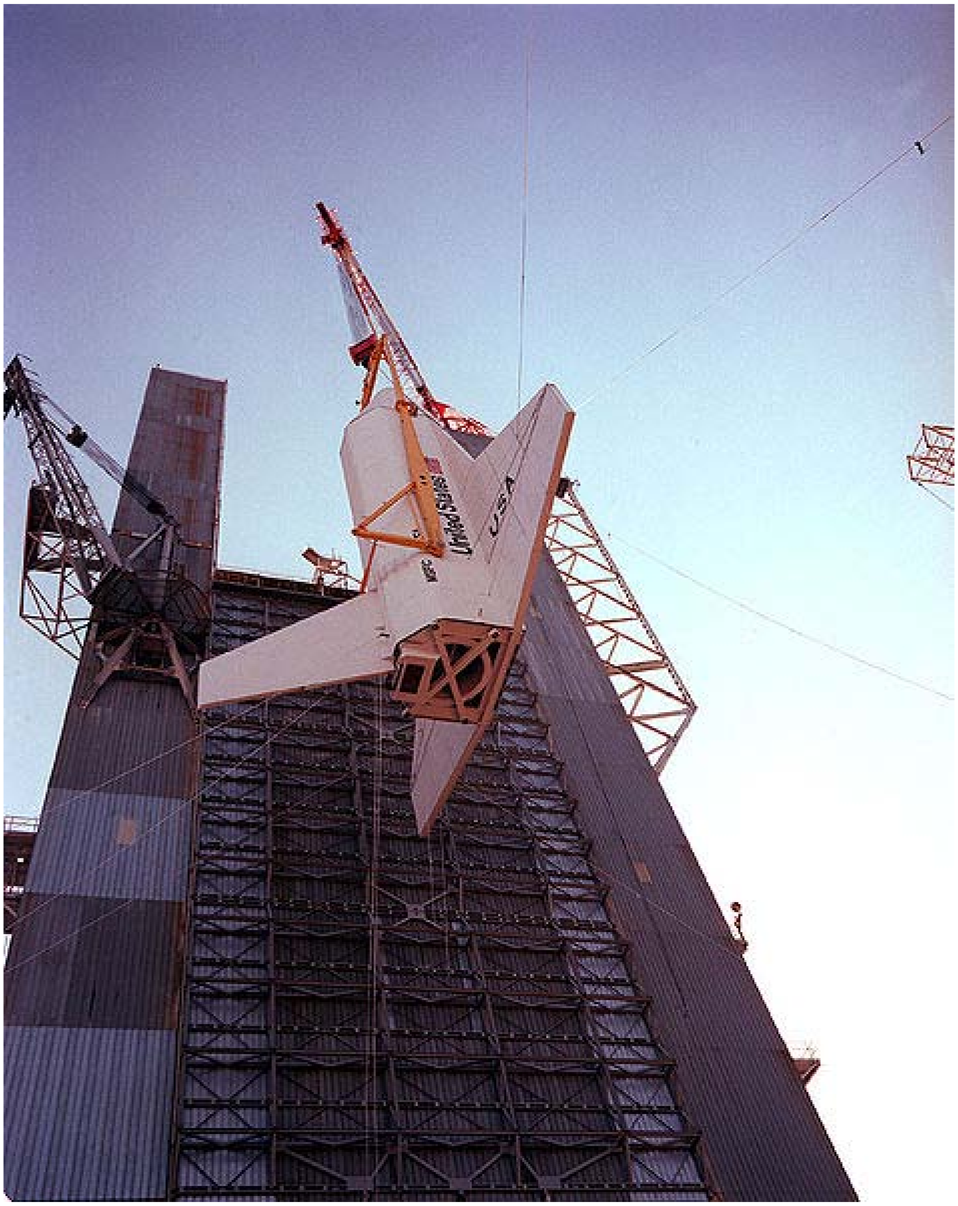
Activities

Originally unnamed, the simulator was built at the Marshall Space Flight Center in 1977 for use in activities such as checking roadway clearances, crane capabilities and fits within structures. It was later shipped by barge to the Kennedy Space Center and was used for ground crew testing in the Vehicle Assembly Building, Orbiter Processing Facility, and Shuttle Landing Facility. *Pathfinder* is approximately the same size, shape and weight of an actual Orbiter. The use of *Pathfinder* allowed facilities to be tested without requiring the use of the more delicate and expensive *Enterprise*.

Appearance

Pathfinder is noticeably shorter than actual shuttle orbiters. Places where this is most noticeable are where the forward section blends into the wings and where it attaches to the external tank. The Orbital Maneuvering System rocket engines are also considerably smaller (in ratio) than the actual orbiters.

Refurbishment



The Space Shuttle Orbiter simulator is hoisted into the dynamics test stand at NASA's Marshall Space Flight Center.

After it had sat in storage for many years, a Japanese organization funded the refurbishing of the steel mock-up to more closely resemble an actual Space Shuttle and named it *Pathfinder*. It was displayed at the "Great Space Shuttle Exposition" in Tokyo from June 1983 to August 1984.

U.S. Space & Rocket Center

Pathfinder has since been returned to the U.S. and is presently on display at the U.S. Space & Rocket Center in Huntsville, Alabama.

It is displayed as part of a complete Shuttle stack which comprises the Pathfinder, the MPTA-ET external tank, which was used for propulsion tests with MPTA-098, and two prototype Advanced Solid Rocket Booster casings, which were developed after the *Challenger* accident but never put into production.

In 1999, NASA removed the forward assemblies from each SRB attached to the *Pathfinder* stack. Although the SRBs are recovered and reused after each flight, several of the forward assemblies had been damaged or lost over the history of the Space Shuttle program necessitating the acquisition of those attached to the *Pathfinder* stack as spares.