Space Shuttle

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*"STS" redirects here. For other uses, see*[*STS (disambiguation)*](http://en.wikipedia.org/wiki/STS_(disambiguation))*.*

*This article is about the NASA Space Transportation System vehicle. For the associated NASA STS program, see*[*Space Shuttle program*](http://en.wikipedia.org/wiki/Space_Shuttle_program)*. For other shuttles and aerospace vehicles, see [Spaceplane](http://en.wikipedia.org/wiki/Spaceplane" \o "Spaceplane).*

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| --- | --- |
| **Space Shuttle** | |
| [STS120LaunchHiRes-edit1.jpg](http://en.wikipedia.org/wiki/File:STS120LaunchHiRes-edit1.jpg) [*Discovery*](http://en.wikipedia.org/wiki/Space_Shuttle_Discovery) lifts off at the start of [STS-120](http://en.wikipedia.org/wiki/STS-120). | |
| **Function** | Manned orbital launch and reentry |
| **Manufacturer** | [United Space Alliance](http://en.wikipedia.org/wiki/United_Space_Alliance) [Thiokol](http://en.wikipedia.org/wiki/Thiokol)/[Alliant Techsystems](http://en.wikipedia.org/wiki/Alliant_Techsystems) (SRBs) [Lockheed Martin](http://en.wikipedia.org/wiki/Lockheed_Martin)/[Martin Marietta](http://en.wikipedia.org/wiki/Martin_Marietta) (ET) [Boeing](http://en.wikipedia.org/wiki/Boeing)/[Rockwell](http://en.wikipedia.org/wiki/Rockwell_International) (orbiter) |
| **Country of origin** | United States of America |
| **Size** | |
| **Height** | 56.1 m (184.2 ft) |
| **Diameter** | 8.7 m (28.5 ft) |
| **Mass** | 2,030 t (4,470,000 lbm) |
| **Stages** | 2 |
| **Capacity** | |
| [**Payload**](http://en.wikipedia.org/wiki/Payload_(air_and_space_craft))**to**[**LEO**](http://en.wikipedia.org/wiki/Low_Earth_orbit) | 24,400 kg (53,600 lb) |
| **Payload to** [**GTO**](http://en.wikipedia.org/wiki/Geostationary_transfer_orbit) | 3,810 kg (8,390 lbm) |
| **Payload to** [**Polar orbit**](http://en.wikipedia.org/wiki/Polar_orbit) | 12,700 kg (28,000 lb) |
| **Payload to Landing**[[1]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-woodcock-1) | 14,400 kg (32,000 lb[[1]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-woodcock-1)) |
| **Launch history** | |
| **Status** | Retired |
| **Launch sites** | [LC-39](http://en.wikipedia.org/wiki/Kennedy_Space_Center_Launch_Complex_39), [Kennedy Space Center](http://en.wikipedia.org/wiki/Kennedy_Space_Center) [SLC-6](http://en.wikipedia.org/wiki/Vandenberg_AFB_Space_Launch_Complex_6), [Vandenberg AFB](http://en.wikipedia.org/wiki/Vandenberg_Air_Force_Base) (unused) |
| **Total launches** | 135 |
| **Successes** | 134 successful launches 133 successful re-entries |
| **Failures** | 2 ([launch failure](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster), [*Challenger*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger); [re-entry failure](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia_disaster), [*Columbia*](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia)) |
| **First flight** | [April 12, 1981](http://en.wikipedia.org/wiki/STS-1) |
| **Last flight** | [July 21, 2011](http://en.wikipedia.org/wiki/STS-135) |
| **Notable payloads** | [Tracking and Data Relay Satellites](http://en.wikipedia.org/wiki/Tracking_and_Data_Relay_Satellite) [Spacelab](http://en.wikipedia.org/wiki/Spacelab) [Great Observatories](http://en.wikipedia.org/wiki/Great_Observatories_program) (including [Hubble](http://en.wikipedia.org/wiki/Hubble_Space_Telescope)) [Galileo](http://en.wikipedia.org/wiki/Galileo_spacecraft), [Magellan](http://en.wikipedia.org/wiki/Magellan_probe), [Ulysses](http://en.wikipedia.org/wiki/Ulysses_(spacecraft)) [Mir Docking Module](http://en.wikipedia.org/wiki/Mir_Docking_Module) [ISS components](http://en.wikipedia.org/wiki/ISS_assembly_sequence) |
| **Boosters (Stage 0) -**[**Solid Rocket Boosters**](http://en.wikipedia.org/wiki/Space_Shuttle_Solid_Rocket_Booster) | |
| **No. boosters** | 2 |
| **Engines** | 1 [solid](http://en.wikipedia.org/wiki/Solid-fuel_rocket) |
| **Thrust** | 12.5 [MN](http://en.wikipedia.org/wiki/Meganewton) each, sea level liftoff (2,800,000 [lbf](http://en.wikipedia.org/wiki/Pound_force" \o "Pound force)) |
| [**Specific impulse**](http://en.wikipedia.org/wiki/Specific_impulse) | 269 s |
| **Burn time** | 124 s |
| **Fuel** | solid |
| **First stage -**[**Orbiter**](http://en.wikipedia.org/wiki/Space_Shuttle_Orbiter)**plus**[**External Tank**](http://en.wikipedia.org/wiki/Shuttle_External_Tank) | |
| **Engines** | 3 [SSMEs](http://en.wikipedia.org/wiki/Space_Shuttle_Main_Engine) located on Orbiter |
| **Thrust** | 5.45220 MN total, sea level liftoff (1,225,704 lbf) |
| [**Specific impulse**](http://en.wikipedia.org/wiki/Specific_impulse) | 455 s |
| **Burn time** | 480 s |
| **Fuel** | [LOX](http://en.wikipedia.org/wiki/Liquid_oxygen)/[LH2](http://en.wikipedia.org/wiki/Liquid_hydrogen) |

The **Space Shuttle** was a crewed, partially reusable [low Earth orbital](http://en.wikipedia.org/wiki/Low_Earth_orbit) [spacecraft](http://en.wikipedia.org/wiki/Spacecraft) operated by the U.S. [National Aeronautics and Space Administration](http://en.wikipedia.org/wiki/National_Aeronautics_and_Space_Administration) (NASA). Its official program name was *Space Transportation System*, taken from a 1969 plan for [a system of reusable spacecraft](http://en.wikipedia.org/wiki/Space_Transportation_System) of which it was the only item funded for development.[[2]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-autogenerated1-2) The first of four orbital test flights occurred in 1981, leading to operational flights beginning in 1982. It was used on a total of 135 missions from 1981 to 2011, launched from the [Kennedy Space Center](http://en.wikipedia.org/wiki/Kennedy_Space_Center) (KSC) in Florida. Operational missions launched numerous satellites, interplanetary probes, and the [Hubble Space Telescope](http://en.wikipedia.org/wiki/Hubble_Space_Telescope) (HST); conducted science experiments in orbit; and participated in construction and servicing of the [International Space Station](http://en.wikipedia.org/wiki/International_Space_Station).

Shuttle components included the [Orbiter Vehicle](http://en.wikipedia.org/wiki/Space_Shuttle_orbiter) (OV), a pair of recoverable [solid rocket boosters](http://en.wikipedia.org/wiki/Space_Shuttle_Solid_Rocket_Booster) (SRBs), and the expendable [external tank](http://en.wikipedia.org/wiki/Space_Shuttle_external_tank) (ET) containing [liquid hydrogen](http://en.wikipedia.org/wiki/Liquid_hydrogen) and [liquid oxygen](http://en.wikipedia.org/wiki/Liquid_oxygen). The Shuttle was [launched vertically](http://en.wikipedia.org/wiki/VTHL) like a conventional rocket, with the two SRBs operating in parallel with the OV's three [main engines](http://en.wikipedia.org/wiki/Space_Shuttle_main_engine), which were fueled from the ET. The SRBs were jettisoned before the vehicle reached orbit, and the ET was jettisoned just before [orbit insertion](http://en.wikipedia.org/wiki/Orbit_insertion)using the orbiter's two [Orbital Maneuvering System](http://en.wikipedia.org/wiki/Space_Shuttle_Orbital_Maneuvering_System) (OMS) engines. At the conclusion of the mission, the orbiter fired its OMS to drop out of orbit and [re-enter the atmosphere](http://en.wikipedia.org/wiki/Atmospheric_reentry). The orbiter [glided](http://en.wikipedia.org/wiki/Rocket_glider) to a runway landing on [Rogers Dry Lake](http://en.wikipedia.org/wiki/Rogers_Dry_Lake) at[Edwards Air Force Base](http://en.wikipedia.org/wiki/Edwards_Air_Force_Base) in California or at the [Shuttle Landing Facility](http://en.wikipedia.org/wiki/Shuttle_Landing_Facility) at the KSC. After the landings at Edwards, the orbiter was flown back to KSC on the [Shuttle Carrier Aircraft](http://en.wikipedia.org/wiki/Shuttle_Carrier_Aircraft), a specially modified Boeing 747.

The first orbiter, [*Enterprise*](http://en.wikipedia.org/wiki/Space_Shuttle_Enterprise), was built purely for [Approach and Landing Tests](http://en.wikipedia.org/wiki/Approach_and_Landing_Tests) and had no capability to fly into orbit. Four fully operational orbiters were initially built: [*Columbia*](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia), [*Challenger*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger), [*Discovery*](http://en.wikipedia.org/wiki/Space_Shuttle_Discovery), and [*Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis). Of these, *Challenger* and*Columbia* were destroyed in mission accidents in 1986 and 2003, respectively, in which a total of fourteen astronauts were killed. A fifth operational orbiter, [*Endeavour*](http://en.wikipedia.org/wiki/Space_Shuttle_Endeavour), was built in 1991 to replace *Challenger*. The Space Shuttle was retired from service upon the conclusion of *Atlantis*' final flight on July 21, 2011.

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Overview[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=1" \o "Edit section: Overview)]

The Space Shuttle was a partially reusable[[3]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-ft20110930-3) [human spaceflight](http://en.wikipedia.org/wiki/Human_spaceflight) vehicle capable of reaching [low Earth orbit](http://en.wikipedia.org/wiki/Low_Earth_orbit), commissioned and operated by the US [National Aeronautics and Space Administration](http://en.wikipedia.org/wiki/National_Aeronautics_and_Space_Administration) (NASA) from 1981 to 2011. It resulted from shuttle design studies conducted by NASA and the US Air Force in the 1960s and was first proposed for development as part of an ambitious second-generation [Space Transportation System](http://en.wikipedia.org/wiki/Space_Transportation_System) (STS) of space vehicles to follow the [Apollo program](http://en.wikipedia.org/wiki/Apollo_program) in a September 1969 report of a Space Task Group headed by Vice President [Spiro Agnew](http://en.wikipedia.org/wiki/Spiro_Agnew) to President [Richard Nixon](http://en.wikipedia.org/wiki/Richard_Nixon). Post-Apollo NASA budgeting realities impelled Nixon to withhold support of all system components except the Shuttle, to which NASA applied the STS name.[[2]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-autogenerated1-2)

The vehicle consisted of a [spaceplane](http://en.wikipedia.org/wiki/Spaceplane" \o "Spaceplane) for orbit and re-entry, fueled by expendable liquid hydrogen and liquid oxygen tanks, with reusable strap-on solid booster rockets. The [first](http://en.wikipedia.org/wiki/STS-1) of four orbital test flights occurred in 1981, leading to operational flights beginning in 1982, all launched from the [Kennedy Space Center](http://en.wikipedia.org/wiki/John_F._Kennedy_Space_Center), Florida. The system was retired from service in 2011 after 135 missions[[4]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-4) on July 8, 2011, with Space Shuttle Atlantis performing that 135th launch - the final launch of the three-decade Shuttle program.[[5]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-latimes-5) The program ended after Atlantis landed at the Kennedy Space Center on July 21, 2011. Major missions included launching numerous satellites and interplanetary probes,[[6]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-coolt-6) conducting space science experiments, and servicing and construction of space stations. The first [orbiter](http://en.wikipedia.org/wiki/Space_Shuttle_orbiter) vehicle, named [*Enterprise*](http://en.wikipedia.org/wiki/Space_Shuttle_Enterprise), was built for the initial [Approach and Landing Tests](http://en.wikipedia.org/wiki/Approach_and_Landing_Tests) phase and lacked engines, heat shield,[[*citation needed*](http://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] and other equipment necessary for orbital flight. A total of five operational orbiters were built, and of these, two were destroyed in accidents.

It was used for orbital space missions by NASA, the [US Department of Defense](http://en.wikipedia.org/wiki/U.S._Department_of_Defense), the [European Space Agency](http://en.wikipedia.org/wiki/European_Space_Agency), Japan, and Germany.[[7]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Interavia85-7)[[8]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-life-8) The United States funded Shuttle development and operations except for the Spacelab modules used on [D1](http://en.wikipedia.org/wiki/STS-61-A) and [D2](http://en.wikipedia.org/wiki/STS-55)—sponsored by Germany.[[7]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Interavia85-7)[[9]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-9)[[10]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-10)[[11]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-11)[[12]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-12) [SL-J](http://en.wikipedia.org/wiki/STS-47) was partially funded by Japan.[[8]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-life-8)

At launch, it consisted of the "stack", including the dark orange [external tank](http://en.wikipedia.org/wiki/Space_Shuttle_external_tank) (ET);[[13]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-et_paint1-13)[[14]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-et_paint2-14) two white, slender [solid rocket boosters](http://en.wikipedia.org/wiki/Space_Shuttle_Solid_Rocket_Booster) (SRBs); and the [Orbiter Vehicle](http://en.wikipedia.org/wiki/Space_Shuttle_orbiter), which contained the [crew](http://en.wikipedia.org/wiki/List_of_Space_Shuttle_crews) and payload. Some payloads were launched into higher orbits with either of two different upper stages developed for the STS (single-stage [Payload Assist Module](http://en.wikipedia.org/wiki/Payload_Assist_Module) or two-stage [Inertial Upper Stage](http://en.wikipedia.org/wiki/Inertial_Upper_Stage)). The Space Shuttle was stacked in the [Vehicle Assembly Building](http://en.wikipedia.org/wiki/Vehicle_Assembly_Building), and the stack mounted on a mobile launch platform held down by four [frangible nuts](http://en.wikipedia.org/wiki/Pyrotechnic_fastener)[[15]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-nuts0-15) on each SRB, which were detonated at launch.[[16]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-16)

The Shuttle stack launched vertically like a conventional rocket. It lifted off under the power of its two SRBs and three [main engines](http://en.wikipedia.org/wiki/Space_Shuttle_Main_Engine), which were fueled by liquid hydrogen and liquid oxygen from the ET. The Space Shuttle had a two-stage ascent. The SRBs provided additional thrust during liftoff and first-stage flight. About two minutes after liftoff, frangible nuts were fired, releasing the SRBs, which then parachuted into the ocean, to be retrieved by [ships](http://en.wikipedia.org/wiki/NASA_recovery_ship) for refurbishment and reuse. The orbiter and ET continued to ascend on an increasingly horizontal flight path under power from its main engines. Upon reaching 17,500 mph (7.8 km/s), necessary for low Earth orbit, the main engines were shut down. The ET, attached by two frangible nuts[[17]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-nuts-17) was then jettisoned to burn up in the atmosphere.[[18]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-etuse-18) After jettisoning the external tank, the [orbital maneuvering system](http://en.wikipedia.org/wiki/Orbital_maneuvering_system) (OMS) engines were used to adjust the orbit.



[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space-shuttle-endeavour-montage-2013-0216.webm)

Montage of the Space Shuttle Endeavour parked on the ground at Los Angeles's California Science Center.

The orbiter carried [astronauts](http://en.wikipedia.org/wiki/Astronaut) and payloads such as satellites or space station parts into low Earth orbit, the Earth's upper atmosphere or [thermosphere](http://en.wikipedia.org/wiki/Thermosphere).[[19]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-atmos-19) Usually, five to seven crew members rode in the orbiter. Two crew members, the commander and pilot, were sufficient for a minimal flight, as in the first four "test" flights, STS-1 through STS-4. The typical payload capacity was about 50,045 pounds (22,700 kg) but could be increased depending on the choice of launch configuration. The orbiter carried its payload in a large cargo bay with doors that opened along the length of its top, a feature which made the Space Shuttle unique among spacecraft. This feature made possible the deployment of large satellites such as the [Hubble Space Telescope](http://en.wikipedia.org/wiki/Hubble_Space_Telescope) and also the capture and return of large payloads back to Earth.

When the orbiter's space mission was complete, it fired its OMS thrusters to drop out of orbit and re-enter the lower atmosphere.[[19]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-atmos-19) During descent, the orbiter passed through different layers of the atmosphere and decelerated from [hypersonic](http://en.wikipedia.org/wiki/Hypersonic) speed primarily by [aerobraking](http://en.wikipedia.org/wiki/Aerobraking" \o "Aerobraking). In the lower atmosphere and landing phase, it was more like a[glider](http://en.wikipedia.org/wiki/Glider_aircraft) but with [reaction control system](http://en.wikipedia.org/wiki/Reaction_control_system) (RCS) thrusters and [fly-by-wire](http://en.wikipedia.org/wiki/Fly-by-wire)-controlled hydraulically actuated flight surfaces controlling its descent. It landed on a long runway as a spaceplane. The aerodynamic shape was 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 had a relatively high [sink rate](http://en.wikipedia.org/wiki/Sink_rate) at low altitudes, and it transitioned during re-entry from using RCS thrusters at very high altitudes to flight surfaces in the lower atmosphere.

Early history[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=2" \o "Edit section: Early history)]

*Further information:*[*Space Shuttle program*](http://en.wikipedia.org/wiki/Space_Shuttle_program)*and*[*Space Shuttle design process*](http://en.wikipedia.org/wiki/Space_Shuttle_design_process)

[](http://en.wikipedia.org/wiki/File:President_Nixon_and_James_Fletcher_Discuss_the_Space_Shuttle_-_GPN-2002-000109.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:President_Nixon_and_James_Fletcher_Discuss_the_Space_Shuttle_-_GPN-2002-000109.jpg)

President Nixon (right) with [NASA Administrator](http://en.wikipedia.org/wiki/NASA_Administrator) [Fletcher](http://en.wikipedia.org/wiki/James_C._Fletcher) in January 1972, three months before Congress approved funding for the Shuttle program

The formal design of what became the Space Shuttle began with the "Phase A" contract design studies issued in the late 1960s. Conceptualization [had begun two decades earlier](http://en.wikipedia.org/wiki/Space_Shuttle_design_process), before the [Apollo program](http://en.wikipedia.org/wiki/Apollo_program) of the 1960s. One of the places the concept of a spacecraft returning from space to a horizontal landing originated was within [NACA](http://en.wikipedia.org/wiki/NACA), in 1954, in the form of an [aeronautics](http://en.wikipedia.org/wiki/Aeronautics) research experiment later named the [X-15](http://en.wikipedia.org/wiki/North_American_X-15). The NACA proposal was submitted by [Walter Dornberger](http://en.wikipedia.org/wiki/Walter_Dornberger).

In 1958, the X-15 concept further developed into proposal to launch an X-15 into space, and another [X-series](http://en.wikipedia.org/wiki/X-plane) [spaceplane](http://en.wikipedia.org/wiki/Spaceplane" \o "Spaceplane) proposal, named [X-20 Dyna-Soar](http://en.wikipedia.org/wiki/Boeing_X-20_Dyna-Soar), as well as variety of aerospace plane concepts and studies. [Neil Armstrong](http://en.wikipedia.org/wiki/Neil_Armstrong) was selected to pilot both the X-15 and the X-20. Though the X-20 was not built, another spaceplane similar to the X-20 was built several years later and delivered to NASA in January 1966 called the [HL-10](http://en.wikipedia.org/wiki/Northrop_HL-10) ("HL" indicated "horizontal landing").

In the mid-1960s, the [US Air Force](http://en.wikipedia.org/wiki/US_Air_Force) conducted classified [studies](http://en.wikipedia.org/wiki/North_American_DC-3#History) on next-generation space transportation systems and concluded that semi-reusable designs were the cheapest choice. It 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 possible "Class III" fully reusable design later. In 1967, [George Mueller](http://en.wikipedia.org/wiki/George_Mueller_(NASA)) held a one-day symposium at NASA headquarters to study the options. Eighty people attended and presented a wide variety of designs, including earlier US Air Force designs such as the X-20 Dyna-Soar.

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](http://en.wikipedia.org/wiki/Houston) and [Huntsville](http://en.wikipedia.org/wiki/Huntsville,_Alabama" \o "Huntsville, Alabama)jointly issued a [Request for Proposal](http://en.wikipedia.org/wiki/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. For example, one of the responses was for a two-stage design, featuring a large booster and a small orbiter, called the [DC-3](http://en.wikipedia.org/wiki/North_American_DC-3), one of several Phase A Shuttle designs. After the aforementioned "Phase A" studies, B, C, and D phases progressively evaluated in-depth designs up to 1972. In the final design, the bottom stage was recoverable solid rocket boosters, and the top stage used an expendable external tank.[[20]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-lindroos-20)

In 1969, President [Richard Nixon](http://en.wikipedia.org/wiki/Richard_Nixon) decided to [support proceeding](http://en.wikipedia.org/wiki/Space_Shuttle_design_process#Decision-making_process) with Space Shuttle development. A series of development programs and analysis refined the basic design, prior to full development and testing. In August 1973, the [X-24B](http://en.wikipedia.org/wiki/Martin-Marietta_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](http://en.wikipedia.org/wiki/Spacelab) program.[[21]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-sl98-21) Spacelab would provide a multidisciplinary orbital space laboratory and additional space equipment for the Shuttle.[[21]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-sl98-21)

Description[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=3" \o "Edit section: Description)]

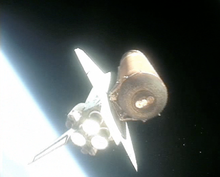
[](http://en.wikipedia.org/wiki/File:Columba.sts-1.launch_pad_arival.triddle.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Columba.sts-1.launch_pad_arival.triddle.jpg)

STS-1 on the launch pad, 1981

The Space Shuttle was the first operational orbital spacecraft designed for [reuse](http://en.wikipedia.org/wiki/Reusable_launch_system). It carried different payloads to low Earth orbit, provided crew rotation and supplies for the [International Space Station](http://en.wikipedia.org/wiki/International_Space_Station) (ISS), and performed servicing missions. The orbiter could 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](http://en.wikipedia.org/wiki/Maxime_Faget" \o "Maxime Faget), who had also overseen the [Mercury](http://en.wikipedia.org/wiki/Project_Mercury), [Gemini](http://en.wikipedia.org/wiki/Project_Gemini), and [Apollo](http://en.wikipedia.org/wiki/Apollo_(spacecraft)) 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 military satellites, and have over 1,000 mile cross-range recovery range to meet the requirement for classified USAF missions for a once-around abort from a launch to a [polar orbit](http://en.wikipedia.org/wiki/Polar_orbit). The militarily specified 1,085 nm cross range requirement was one of the primary reasons for the Shuttle's large wings, compared to modern commercial designs with very minimal control surfaces and glide capability. 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](http://en.wikipedia.org/wiki/Space_exploration) by developing a spacecraft with reusable components.

Each Space Shuttle was a [reusable launch system](http://en.wikipedia.org/wiki/Reusable_launch_system) composed of three main assemblies: the reusable OV, the expendable ET, and the two reusable SRBs.[[22]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-22) Only the OV entered orbit shortly after the tank and boosters are jettisoned. The vehicle was launched vertically like a conventional rocket, and the orbiter glided to a horizontal landing like an airplane, after which it was refurbished for reuse. The SRBs parachuted to splashdown in the ocean where they were towed back to shore and refurbished for later Shuttle missions.

[](http://en.wikipedia.org/wiki/File:SRBsepfromDiscovery07042006.png)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:SRBsepfromDiscovery07042006.png)

*Discovery* rockets into orbit, seen here just after solid rocket booster (SRB) separation

Five operational OVs were built: *Columbia* (OV-102), [*Challenger*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger) (OV-099), *Discovery* (OV-103), *Atlantis* (OV-104), and *Endeavour* (OV-105). A mock-up, [*Inspiration*](http://en.wikipedia.org/wiki/Space_Shuttle_Inspiration), currently stands at the entrance to the Astronaut Hall of Fame. An additional craft,*[Enterprise](http://en.wikipedia.org/wiki/Space_Shuttle_Enterprise" \o "Space Shuttle Enterprise)* (OV-101), was built for atmospheric testing gliding and landing; it was originally intended to be outfitted for orbital operations after the test program, but it was found more economical to upgrade the structural test article STA-099 into orbiter *Challenger* (OV-099). *Challenger* [disintegrated](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster) 73 seconds after launch in 1986, and *Endeavour* was built as a replacement from structural spare components. *Columbia* [broke apart](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia_disaster) over Texas during re-entry in 2003. Building *Endeavour* cost about US$1.7 billion. A Space Shuttle launch cost around $450 million.[[23]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-23)

[Roger A. Pielke, Jr.](http://en.wikipedia.org/wiki/Roger_A._Pielke,_Jr.) has estimated that the [Space Shuttle program](http://en.wikipedia.org/wiki/Space_Shuttle_program) cost about US$170 billion (2008 dollars) through early 2008; the average cost per flight was about US$1.5 billion.[[24]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-duggins-24) Two missions were paid for by Germany, Spacelab [D1](http://en.wikipedia.org/wiki/STS-61-A) and [D2](http://en.wikipedia.org/wiki/STS-55)(D for *Deutschland*) with a payload control center in [Oberpfaffenhofen](http://en.wikipedia.org/wiki/Oberpfaffenhofen" \o "Oberpfaffenhofen).[[25]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-25)[[26]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-26) D1 was the first time that control of a manned STS mission payload was not in U.S. hands.[[7]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Interavia85-7)

At times, the orbiter itself was referred to as the Space Shuttle. This was not technically correct as the *Space Shuttle* was the combination of the orbiter, the external tank, and the two solid rocket boosters. These components, once assembled in the [Vehicle Assembly Building](http://en.wikipedia.org/wiki/Vehicle_Assembly_Building) originally built to assemble the Apollo Saturn V rocket, were commonly referred to as the "stack".[[27]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-27)

Responsibility for the Shuttle components was spread among multiple NASA field centers. The Kennedy Space Center was responsible for launch, landing and turnaround operations for equatorial orbits (the only orbit profile actually used in the program), the US Air Force at the [Vandenberg Air Force Base](http://en.wikipedia.org/wiki/Vandenberg_Air_Force_Base) was responsible for launch, landing and turnaround operations for polar orbits (though this was never used), the [Johnson Space Center](http://en.wikipedia.org/wiki/Johnson_Space_Center) served as the central point for all Shuttle operations, the [Marshall Space Flight Center](http://en.wikipedia.org/wiki/Marshall_Space_Flight_Center) was responsible for the main engines, external tank, and solid rocket boosters, the [John C. Stennis Space Center](http://en.wikipedia.org/wiki/John_C._Stennis_Space_Center) handled main engine testing, and the [Goddard Space Flight Center](http://en.wikipedia.org/wiki/Goddard_Space_Flight_Center) managed the global tracking network.[[28]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-28)

**Orbiter vehicle**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=4" \o "Edit section: Orbiter vehicle)]

*Main article:*[*Space Shuttle orbiter*](http://en.wikipedia.org/wiki/Space_Shuttle_orbiter)

[](http://en.wikipedia.org/wiki/File:Atlantis_is_landing_after_STS-30_mission.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Atlantis_is_landing_after_STS-30_mission.jpg)

[*Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis) deploys the [landing gear](http://en.wikipedia.org/wiki/Landing_gear) before landing on a selected runway.

The orbiter resembles a conventional aircraft, with double-[delta wings](http://en.wikipedia.org/wiki/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](http://en.wikipedia.org/wiki/Elevon" \o "Elevon), mounted at the trailing edge of the wings, and the [rudder](http://en.wikipedia.org/wiki/Rudder)/speed brake, attached at the trailing edge of the stabilizer, with the body flap, controlled the orbiter during descent and landing.

The orbiter's payload bay measures 15 by 60 feet (4.6 by 18 m), comprising most of the [fuselage](http://en.wikipedia.org/wiki/Fuselage). Information declassified in 2011 showed that the payload bay was designed specifically to accommodate the [KH-9 HEXAGON](http://en.wikipedia.org/wiki/KH-9_HEXAGON) spy satellite operated by the [National Reconnaissance Office](http://en.wikipedia.org/wiki/National_Reconnaissance_Office).[[29]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-29) Two mostly symmetrical lengthwise payload bay doors hinged on either side of the bay comprise its entire top. Payloads were 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](http://en.wikipedia.org/wiki/Canada_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 engine nozzles can [gimbal](http://en.wikipedia.org/wiki/Gimbal) 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](http://en.wikipedia.org/wiki/Aluminium) [alloy](http://en.wikipedia.org/wiki/Alloy), although the engine structure is made primarily from [titanium](http://en.wikipedia.org/wiki/Titanium) alloy.

The operational orbiters built were OV-102 *Columbia*, OV-099 *Challenger*, OV-103 *Discovery*, OV-104 *Atlantis*, and OV-105 *Endeavour*.[[30]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-30)

* [](http://en.wikipedia.org/wiki/File:Atlantis_on_Shuttle_Carrier_Aircraft.jpg)

[Space Shuttle *Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis)transported by a [Boeing 747](http://en.wikipedia.org/wiki/Boeing_747) [Shuttle Carrier Aircraft](http://en.wikipedia.org/wiki/Shuttle_Carrier_Aircraft)(SCA), 1998 (NASA)

* [](http://en.wikipedia.org/wiki/File:Space_Shuttle_Transit.jpg)

Space Shuttle *Endeavour*being transported by a Shuttle Carrier Aircraft

* [](http://en.wikipedia.org/wiki/File:STS-79_rollout.jpg)

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

* [](http://en.wikipedia.org/wiki/File:Sound_suppression_water_system_test_at_KSC_Launch_Pad_39A.jpg)

Water is released onto the mobile launcher platform on [Launch Pad 39A](http://en.wikipedia.org/wiki/Launch_Pad_39A) at the start of a sound suppression system test in 2004. During launch, 350,000 US gallons (1,300,000 L) of water are poured onto the pad in 41 seconds.[[31]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-31)

**External tank**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=5" \o "Edit section: External tank)]

*Main article:*[*Space Shuttle external tank*](http://en.wikipedia.org/wiki/Space_Shuttle_external_tank)

The main function of the Space Shuttle external tank was to supply the liquid oxygen and hydrogen fuel to the main engines. It was also the backbone of the launch vehicle, providing attachment points for the two solid rocket boosters and the orbiter. The external tank was the only part of the Shuttle system that was not reused. Although the external tanks were always discarded, it would have been possible to take them into orbit and re-use them (such as for incorporation into a space station).[[18]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-etuse-18)[[32]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-etuse2-32)

**Solid rocket boosters**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=6" \o "Edit section: Solid rocket boosters)]

*Main article:*[*Space Shuttle Solid Rocket Booster*](http://en.wikipedia.org/wiki/Space_Shuttle_Solid_Rocket_Booster)

Two solid rocket boosters (SRBs) each provided 12.5 million newtons (2.8 million lbf) of thrust at liftoff,[[33]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-Columbia_Accid_Report_D.7-33) which was 83% of the total thrust at liftoff. The SRBs were jettisoned two minutes after launch at a height of about 150,000 feet (46 km), and then deployed parachutes and landed in the ocean to be recovered.[[34]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-34) The SRB cases were made of steel about ½ inch (13 mm) thick.[[35]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-35) The solid rocket boosters were re-used many times; the casing used in [Ares I](http://en.wikipedia.org/wiki/Ares_I) engine testing in 2009 consisted of motor cases that had been flown, collectively, on 48 Shuttle missions, including STS-1.[[36]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-36)

**Orbiter add-ons**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=7" \o "Edit section: Orbiter add-ons)]

The orbiter could be used in conjunction with a variety of add-ons depending on the mission. This included orbital laboratories ([Spacelab](http://en.wikipedia.org/wiki/Spacelab), [Spacehab](http://en.wikipedia.org/wiki/Spacehab" \o "Spacehab)), boosters for launching payloads farther into space ([Inertial Upper Stage](http://en.wikipedia.org/wiki/Inertial_Upper_Stage), [Payload Assist Module](http://en.wikipedia.org/wiki/Payload_Assist_Module)), and other functions, such as provided by[Extended Duration Orbiter](http://en.wikipedia.org/wiki/Extended_Duration_Orbiter), [Multi-Purpose Logistics Modules](http://en.wikipedia.org/wiki/Multi-Purpose_Logistics_Module), or [Canadarm](http://en.wikipedia.org/wiki/Canadarm" \o "Canadarm) (RMS). An upper stage called [Transfer Orbit Stage](http://en.wikipedia.org/wiki/Transfer_Orbit_Stage) (Orbital Science Corp. TOS-21) was also used once.[[37]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-37) 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](http://en.wikipedia.org/wiki/Shuttle_Radar_Topography_Mission).[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38)

* [](http://en.wikipedia.org/wiki/File:Mplm_in_shuttle.jpg)

[MPLM *Leonardo*](http://en.wikipedia.org/wiki/Multi-Purpose_Logistics_Module)

* [](http://en.wikipedia.org/wiki/File:1989_s34_Galileo_Deploy2.jpg)

IUS deploying with [Galileo](http://en.wikipedia.org/wiki/Galileo_(spacecraft))

* [](http://en.wikipedia.org/wiki/File:SBS-3_with_PAM-D_stage.jpg)

[PAM-D](http://en.wikipedia.org/wiki/Payload_Assist_Module) with satellite

* [](http://en.wikipedia.org/wiki/File:EDO_pallet.jpg)

[EDO](http://en.wikipedia.org/wiki/Extended_Duration_Orbiter) being installed

* [](http://en.wikipedia.org/wiki/File:STS-9_Spacelab_1.jpg)

[Spacelab](http://en.wikipedia.org/wiki/Spacelab) in orbit

* [](http://en.wikipedia.org/wiki/File:1996_s72_Scott_EVA.jpg)

[RMS (Canadarm)](http://en.wikipedia.org/wiki/Canadarm)

* [](http://en.wikipedia.org/wiki/File:Spacehab_S107e05359.jpg)

[Spacehab](http://en.wikipedia.org/wiki/Spacehab)

**Spacelab**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=8" \o "Edit section: Spacelab)]

*Main article:*[*Spacelab*](http://en.wikipedia.org/wiki/Spacelab)

[](http://en.wikipedia.org/wiki/File:German_Spacelab_03.JPG)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:German_Spacelab_03.JPG)

Spacelab LM2

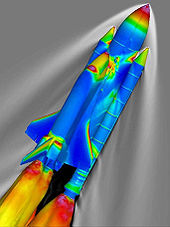
A major component of the Space Shuttle Program was Spacelab, primarily contributed by a consortium of European countries, and operated in conjunction with the United States and international partners.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38) Supported by a modular system of pressurized modules, pallets, and systems, Spacelab missions executed on multidisciplinary science, orbital logistics, and international cooperation.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38) Over 29 missions flew on subjects ranging from astronomy, microgravity, radar, and life sciences, to name a few.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38) Spacelab hardware also supported missions such as Hubble (HST) servicing and space station resupply.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38) STS-2 and STS-3 provided testing, and the first full mission was Spacelab-1 ([STS-9](http://en.wikipedia.org/wiki/STS-9)) launched on November 28, 1983.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38)

Spacelab formally began in 1973, after a meeting in Brussels, Belgium, by European heads of state.[[21]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-sl98-21) Within the decade, Spacelab went into orbit and provided Europe and the United States with an orbital workshop and hardware system.[[21]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-sl98-21)International cooperation, science, and exploration were realized on Spacelab.[[38]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA28-38)

**Flight systems**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=9" \o "Edit section: Flight systems)]

The Shuttle was one of the earliest craft to use a computerized [fly-by-wire](http://en.wikipedia.org/wiki/Fly-by-wire) digital [flight control system](http://en.wikipedia.org/wiki/Flight_control_system). This means no mechanical or hydraulic linkages connected the pilot's control stick to the control surfaces or reaction control system thrusters.

A concern with digital fly-by-wire systems is reliability. Considerable research went into the Shuttle computer system. The Shuttle used five identical redundant IBM 32-bit general purpose computers (GPCs), model [AP-101](http://en.wikipedia.org/wiki/IBM_AP-101), constituting a type of[embedded system](http://en.wikipedia.org/wiki/Embedded_system). Four computers ran specialized software called the Primary Avionics Software System (PASS). A fifth backup computer ran separate software called the Backup Flight System (BFS). Collectively they were called the Data Processing System (DPS).[[39]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-LogicD-39)[[40]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-ibm-40)

[](http://en.wikipedia.org/wiki/File:SSLV_ascent.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:SSLV_ascent.jpg)

Simulation of 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](http://en.wikipedia.org/wiki/Overflow_(software)) software package.

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

The four general-purpose computers operated essentially in lockstep, checking each other. If one computer failed, the three functioning computers "voted" it out of the system. This isolated it from vehicle control. If a second computer of the three remaining failed, the two functioning computers voted it out. In the unlikely case that two out of four computers simultaneously failed (a two-two split), one group was to be picked at random.

The Backup Flight System (BFS) was separately developed software running on the fifth computer, used only if the entire four-computer primary system failed. The BFS was created because although the four primary computers were hardware redundant, they all ran the same software, so a generic software problem could crash all of them. Embedded system [avionic](http://en.wikipedia.org/wiki/Avionics) software was developed under totally different conditions from public commercial software: the number of code lines was tiny compared to a public commercial software, changes were only made infrequently and with extensive testing, and many programming and test personnel worked on the small amount of computer code. However, in theory it could have still failed, and the BFS existed for that contingency. While the BFS could run in parallel with PASS, the BFS never engaged to take over control from PASS during any Shuttle mission.

The software for the Shuttle computers was written in a high-level language called [HAL/S](http://en.wikipedia.org/wiki/HAL/S), somewhat similar to [PL/I](http://en.wikipedia.org/wiki/PL/I). It is specifically designed for a [real time](http://en.wikipedia.org/wiki/Real-time_computing) embedded system environment.

The IBM AP-101 computers originally had about 424 kilobytes of [magnetic core memory](http://en.wikipedia.org/wiki/Magnetic_core_memory) each. The CPU could process about 400,000 instructions per second. They had no hard disk drive, and loaded software from magnetic tape cartridges.

In 1990, the original computers were replaced with an upgraded model AP-101S, which had 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](http://en.wikipedia.org/wiki/GRiD_Compass" \o "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.[[41]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-GRiD-41) NASA was one of its main customers.[[42]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-GRiDNASA-42)

**Orbiter markings and insignia**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=10" \o "Edit section: Orbiter markings and insignia)]

The [typeface](http://en.wikipedia.org/wiki/Typeface) used on the Space Shuttle Orbiter is [Helvetica](http://en.wikipedia.org/wiki/Helvetica).[[43]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-43)

The prototype orbiter *Enterprise* originally had a [flag of the United States](http://en.wikipedia.org/wiki/Flag_of_the_United_States) on the upper surface of the left wing and the letters "USA" in black on the right wing. The name "Enterprise" was painted in black on the payload bay doors just above the hinge and behind the crew module; on the aft end of the payload bay doors was the [NASA "worm" logotype](http://en.wikipedia.org/wiki/NASA_insignia) in gray. Underneath the rear of the payload bay doors on the side of the fuselage just above the wing is the text "United States" in black with a flag of the United States ahead of it.

The first operational orbiter, *Columbia*, originally had the same markings as *Enterprise*, although the letters "USA" on the right wing were slightly larger and spaced farther apart. *Columbia* also had black markings which *Enterprise* lacked on its forward RCS module, around the cockpit windows, and on its vertical stabilizer, and had distinctive black "chines" on the forward part of its upper wing surfaces, which none of the other orbiters had.

*Challenger* established a modified marking scheme for the shuttle fleet that was matched by *Discovery*, *Atlantis* and *Endeavour*. The letters "USA" in black above an American flag were displayed on the left wing, with the NASA "worm" logotype in gray centered above the name of the orbiter in black on the right wing. The name of the orbiter was inscribed not on the payload bay doors, but on the forward fuselage just below and behind the cockpit windows. This would make the name visible when the shuttle was photographed in orbit with the doors open.

In 1983, *Enterprise* had its wing markings changed to match *Challenger*, and the NASA "worm" logotype on the aft end of the payload bay doors was changed from gray to black. Some black markings were added to the nose, cockpit windows and vertical tail to more closely resemble the flight vehicles, but the name "Enterprise" remained on the payload bay doors as there was never any need to open them. *Columbia* had its name moved to the forward fuselage to match the other flight vehicles after [STS-61-C](http://en.wikipedia.org/wiki/STS-61-C), during the 1986–88 hiatus when the shuttle fleet was grounded following the [loss of *Challenger*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger_Disaster), but retained its original wing markings until its last overhaul (after [STS-93](http://en.wikipedia.org/wiki/STS-93)), and its unique black wing "chines" for the remainder of its operational life.

Beginning in 1998, the flight vehicles' markings were modified to incorporate the NASA ["meatball" insignia](http://en.wikipedia.org/wiki/NASA_insignia). The "worm" logotype, which the agency had phased out, was removed from the payload bay doors and the "meatball" insignia was added aft of the "United States" text on the lower aft fuselage. The "meatball" insignia was also displayed on the left wing, with the American flag above the orbiter's name, left-justified rather than centered, on the right wing. The three surviving flight vehicles, *Discovery*, *Atlantis* and *Endeavour*, still bear these markings as museum displays.*Enterprise* became the property of the [Smithsonian Institution](http://en.wikipedia.org/wiki/Smithsonian_Institution) in 1985 and was no longer under NASA's control when these changes were made, hence the prototype orbiter still has its 1983 markings and still has its name on the payload bay doors.

**Upgrades**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=11" \o "Edit section: Upgrades)]

[](http://en.wikipedia.org/wiki/File:STSCPanel.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:STSCPanel.jpg)

[*Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis) was the first Shuttle to fly with a[glass cockpit](http://en.wikipedia.org/wiki/Glass_cockpit), on [STS-101](http://en.wikipedia.org/wiki/STS-101). (composite image)

The Space Shuttle was initially developed in the 1970s,[[44]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-shuttle_sale-44) but received many upgrades and modifications afterward to improve performance, reliability and safety. Internally, the Shuttle remained 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, called a [glass cockpit](http://en.wikipedia.org/wiki/Glass_cockpit), which is similar to those of contemporary airliners. With the coming of the ISS, the orbiter's internal airlocks were 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) had several improvements to enhance reliability and power. This explains phrases such as "Main engines throttling up to 104 percent." This did not mean the engines were being run over a safe limit. The 100 percent figure was the original specified power level. During the lengthy development program, [Rocketdyne](http://en.wikipedia.org/wiki/Rocketdyne" \o "Rocketdyne) determined the engine was capable of safe reliable operation at 104 percent of the originally specified thrust. NASA could have rescaled the output number, saying in essence 104 percent is now 100 percent. To clarify this would have required revising much previous documentation and software, so the 104 percent number was retained. SSME upgrades were denoted as "block numbers", such as block I, block II, and block IIA. The upgrades 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 was 104 percent, with 106 percent or 109 percent used for mission aborts.

For the first two missions, STS-1 and [STS-2](http://en.wikipedia.org/wiki/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 resulted in an increase in payload capability to orbit.[[45]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-aerospaceweb-45) 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](http://en.wikipedia.org/wiki/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 was not flown unmanned, each of these improvements was "tested" on operational flights.

The solid rocket boosters underwent improvements as well. Design engineers added a third [O-ring](http://en.wikipedia.org/wiki/O-ring) seal to the joints between the segments after the 1986 Space Shuttle *Challenger* disaster.

[](http://en.wikipedia.org/wiki/File:SSME1.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:SSME1.jpg)

The three nozzles of the[Space Shuttle Main Engine](http://en.wikipedia.org/wiki/Space_Shuttle_Main_Engine) with the two [Orbital Maneuvering System](http://en.wikipedia.org/wiki/Orbital_Maneuvering_System) (OMS) pods, and the[vertical stabilizer](http://en.wikipedia.org/wiki/Vertical_stabilizer) above.

Several other SRB improvements were planned 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](http://en.wikipedia.org/wiki/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.[[46]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-46) The loss of the ASRB program resulted in the development of the Super LightWeight external Tank (SLWT), which provided some of the increased payload capability, while not providing any of the safety improvements. In addition, the US Air Force developed their own much lighter single-piece SRB design using a filament-wound system, but this too was canceled.

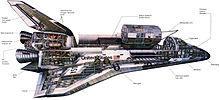
[STS-70](http://en.wikipedia.org/wiki/STS-70) was delayed in 1995, when [woodpeckers](http://en.wikipedia.org/wiki/Woodpecker) bored holes in the foam insulation of *Discovery'*s external tank. Since then, NASA has installed commercial plastic owl decoys and inflatable owl balloons which had to be removed prior to launch.[[47]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-47) The delicate nature of the foam insulation had been the cause of damage to the [Thermal Protection System](http://en.wikipedia.org/wiki/Space_Shuttle_thermal_protection_system), the tile heat shield and heat wrap of the orbiter. NASA remained confident that this damage, while it was the primary cause of the Space Shuttle*Columbia* disaster on February 1, 2003, would not jeopardize the completion of the International Space Station (ISS) in the projected time allotted.

A cargo-only, unmanned variant of the Shuttle was variously proposed and rejected since the 1980s. It was called the [Shuttle-C](http://en.wikipedia.org/wiki/Shuttle-C), and would have traded re-usability for cargo capability, with large potential savings from reusing technology developed for the Space Shuttle. Another proposal was to convert the payload bay into a passenger area, with versions ranging from 30 to 74 seats, three days in orbit, and cost US$1.5 million per seat.[[48]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-david-48)

On the first four Shuttle missions, astronauts wore modified US Air Force high-altitude full-pressure suits, which included a full-pressure helmet during ascent and descent. From the fifth flight, [STS-5](http://en.wikipedia.org/wiki/STS-5), until the loss of *Challenger*, one-piece light blue [nomex](http://en.wikipedia.org/wiki/Nomex" \o "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](http://en.wikipedia.org/wiki/Advanced_Crew_Escape_Suit) (ACES), which resembled the [Gemini space suit](http://en.wikipedia.org/wiki/Gemini_space_suit) in design, but retained the orange color of the Launch-Entry Suit.

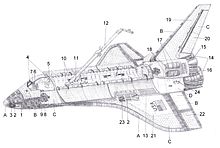
To extend the duration that orbiters could stay docked at the ISS, the [Station-to-Shuttle Power Transfer System](http://en.wikipedia.org/wiki/Station-to-Shuttle_Power_Transfer_System) (SSPTS) was installed. The SSPTS allowed these orbiters to use power provided by the ISS to preserve their consumables. The SSPTS was first used successfully on [STS-118](http://en.wikipedia.org/wiki/STS-118).

**Technical data**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=12" \o "Edit section: Technical data)]

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Orbiter-Illustration.jpg)

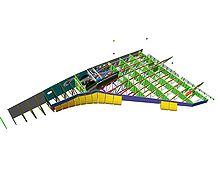
[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Orbiter-Illustration.jpg)

Space Shuttle orbiter illustration

[](http://en.wikipedia.org/wiki/File:Pl%C3%A1nik_orbitera_2.JPG)

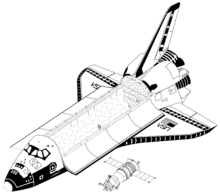
[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Pl%C3%A1nik_orbitera_2.JPG)

Space Shuttle drawing

[](http://en.wikipedia.org/wiki/File:Shuttle_Left_Wing_Cutaway_Diagram.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Shuttle_Left_Wing_Cutaway_Diagram.jpg)

Space Shuttle wing cutaway

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_vs_Soyuz_TM_-_to_scale_drawing.png)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_vs_Soyuz_TM_-_to_scale_drawing.png)

Space Shuttle Orbiter and [Soyuz-TM](http://en.wikipedia.org/wiki/Soyuz-TM)(drawn to scale).

[](http://en.wikipedia.org/wiki/File:Space_shuttles_Atlantis_(STS-125)_and_Endeavour_(STS-400)_on_launch_pads.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_shuttles_Atlantis_(STS-125)_and_Endeavour_(STS-400)_on_launch_pads.jpg)

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.

**Orbiter specifications**[[49]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-tech-49) (for *Endeavour*, OV-105)

* Length: 122.17 ft (37.237 m)
* Wingspan: 78.06 ft (23.79 m)
* Height: 56.58 ft (17.25 m)
* Empty weight: 172,000 lb (78,000 kg)[[50]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-50)
* Gross liftoff weight (Orbiter only): 240,000 lb (110,000 kg)
* Maximum landing weight: 230,000 lb (100,000 kg)
* Payload to Landing (Return Payload): 32,000 lb (14,400 kg)[[1]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-woodcock-1)
* Maximum payload: 55,250 lb (25,060 kg)
* Payload to LEO: 53,600 lb (24,310 kg)
* Payload to LEO @ 51.6° [inclination](http://en.wikipedia.org/wiki/Orbital_Inclination) (ISS):
* Payload to GTO: 8,390 lb (3,806 kg)
* Payload to Polar Orbit: 28,000 lb (12,700 kg)
* Note launch payloads modified by External Tank (ET) choice (ET, LWT, or SLWT)
* Payload bay dimensions: 15 by 59 ft (4.6 by 18 m)
* Operational altitude: 100 to 520 [nmi](http://en.wikipedia.org/wiki/Nautical_mile" \o "Nautical mile) (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)
* Main Stage (SSME with external tank)
  + Engines: Three Rocketdyne Block II SSMEs, each with a sea level [thrust](http://en.wikipedia.org/wiki/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 Hydrogen/Liquid Oxygen
* [Orbital Maneuvering System](http://en.wikipedia.org/wiki/Orbital_Maneuvering_System)
  + Engines: 2 OMS Engines
  + Thrust: 53.4 kN (12,000 lbf) combined total vacuum thrust
  + Specific impulse: 316 s
  + Burn time: 150–250 s typical burn; 1250 s deorbit burn
  + Fuel: MMH/N2O4
* Crew: Varies.

The earliest Shuttle flights had the minimum crew of two; many later missions a crew of five. By program end, typically seven people would fly: ([commander](http://en.wikipedia.org/wiki/Commander), [pilot](http://en.wikipedia.org/wiki/Aviator), several [mission specialists](http://en.wikipedia.org/wiki/Mission_specialist), one of whom (MS-2) acted as the [flight engineer](http://en.wikipedia.org/wiki/Flight_engineer)starting with STS-9 in 1983). On two occasions, eight astronauts have flown ([STS-61-A](http://en.wikipedia.org/wiki/STS-61-A), [STS-71](http://en.wikipedia.org/wiki/STS-71)). Eleven people could be accommodated in an emergency mission (see [STS-3xx](http://en.wikipedia.org/wiki/STS-3xx)).

**External tank specifications** (for SLWT)

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

**Solid Rocket Booster specifications**

* Length: 45.46 m (149 ft)[[51]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Jenkins_3rd-51)
* Diameter: 3.71 m (12.2 ft)[[51]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Jenkins_3rd-51)
* Empty weight (per booster): 68,000 kg (150,000 lb)[[51]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Jenkins_3rd-51)
* Gross liftoff weight (per booster): 571,000 kg (1,260,000 lb)[[52]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-STS_prop_systems-52)
* Thrust (at liftoff, sea level, per booster): 12.5 [MN](http://en.wikipedia.org/wiki/Newton_(unit)) (2,800,000 [lbf](http://en.wikipedia.org/wiki/Pound-force" \o "Pound-force))[[33]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Columbia_Accid_Report_D.7-33)
* 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[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=13" \o "Edit section: Mission profile)]

[](http://en.wikipedia.org/wiki/File:Space_shuttle_mission_profile.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_shuttle_mission_profile.jpg)

STS [mission](http://en.wikipedia.org/wiki/Space_mission) profile

[](http://en.wikipedia.org/wiki/File:Atlantis_launch_plume_edit.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Atlantis_launch_plume_edit.jpg)

Shuttle launch of *Atlantis* at sunset in 2001. The Sun is behind the camera, and the plume's shadow intersects the [Moon](http://en.wikipedia.org/wiki/Moon" \o "Moon)across the sky.

**Launch**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=14" \o "Edit section: Launch)]

*See also:*[*Space shuttle launch countdown*](http://en.wikipedia.org/wiki/Space_shuttle_launch_countdown)*and*[*Space shuttle launch commit criteria*](http://en.wikipedia.org/wiki/Space_shuttle_launch_commit_criteria)

All Space Shuttle missions were launched from Kennedy Space Center (KSC). The [weather criteria used for launch](http://en.wikipedia.org/wiki/Space_shuttle_launch_commit_criteria) included, but were not limited to: precipitation, temperatures, cloud cover, lightning forecast, wind, and humidity.[[53]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-weather_launch_criteria-53) The Shuttle was not launched under conditions where it could have been struck by [lightning](http://en.wikipedia.org/wiki/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](http://en.wikipedia.org/wiki/Ground_(electricity)). Like most jet airliners, the Shuttle was mainly constructed of conductive aluminum, which would normally shield and protect the internal systems. However, upon liftoff the Shuttle sent out a long exhaust plume as it ascended, and this plume could have triggered lightning by providing a current path to ground. The NASA Anvil Rule for a Shuttle launch stated that an [anvil cloud](http://en.wikipedia.org/wiki/Anvil_cloud) could not appear within a distance of 10 [nautical miles](http://en.wikipedia.org/wiki/Nautical_miles).[[54]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-54) The Shuttle Launch Weather Officer monitored conditions until the final decision to scrub a launch was announced. In addition, the weather conditions had to be acceptable at one of the Transatlantic Abort Landing sites (one of several [Space Shuttle abort modes](http://en.wikipedia.org/wiki/Space_Shuttle_abort_modes)) to launch as well as the solid rocket booster recovery area.[[53]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-weather_launch_criteria-53)[[55]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-55) While the Shuttle might have safely endured a lightning strike, a [similar strike caused problems on Apollo 12](http://en.wikipedia.org/wiki/Apollo_12#Mission_highlights), so for safety [NASA](http://en.wikipedia.org/wiki/NASA) chose not to launch the Shuttle if lightning was 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.[[56]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-YERO-56)

On the day of a launch, after the final hold in the countdown at T-minus 9 minutes, the Shuttle went through its final preparations for launch, and the countdown was automatically controlled by the Ground Launch Sequencer (GLS), software at the Launch Control Center, which stopped the count if it sensed a critical problem with any of the Shuttle's onboard systems. The GLS handed 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) began to drench the [Mobile Launcher Platform](http://en.wikipedia.org/wiki/Mobile_Launcher_Platform) (MLP) and SRB trenches with 300,000 US gallons (1,100 m3) of water to protect the Orbiter from damage by [acoustical](http://en.wikipedia.org/wiki/Acoustical) energy and rocket exhaust reflected from the flame trench and MLP during lift off ([NASA article](http://www.nasa.gov/mission_pages/shuttle/launch/sound-suppression-system.html)).[[57]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-sps-57)

At T-minus 10 seconds, hydrogen igniters were activated under each engine bell to quell the stagnant gas inside the cones before ignition. Failure to burn these gases could 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 began charging the combustion chambers with liquid hydrogen and liquid oxygen at this time. The computers reciprocated this action by allowing the redundant computer systems to begin the firing phase.

[](http://en.wikipedia.org/wiki/File:020408_STS110_Atlantis_launch.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:020408_STS110_Atlantis_launch.jpg)

Space Shuttle Main Engine ignition

The three main engines (SSMEs) started at T-minus 6.6 seconds. The main engines ignited sequentially via the Shuttle's general purpose computers (GPCs) at 120 millisecond intervals. The GPCs required that the engines reach 90 percent of their rated performance to complete the final gimbal of the main engine nozzles to liftoff configuration.[[58]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-countdown101-58) When the SSMEs started, water from the sound suppression system flashed into a large volume of steam that shot southward. All three SSMEs had to reach the required 100 percent thrust within three seconds, otherwise the onboard computers would initiate an [RSLS abort](http://en.wikipedia.org/wiki/RSLS_Abort). If the onboard computers verified normal thrust buildup, at T minus 0 seconds, the 8 [pyrotechnic nuts](http://en.wikipedia.org/wiki/Pyrotechnic_fastener) holding the vehicle to the pad were detonated and the SRBs were ignited. At this point the vehicle was committed to liftoff, as the SRBs could not be turned off once ignited.[[59]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-59) The plume from the solid rockets exited 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 mandated the firing sequences via the Master Events Controller, a computer program integrated with the Shuttle's four redundant computer systems. There were extensive emergency procedures ([abort modes](http://en.wikipedia.org/wiki/Space_Shuttle_abort_modes)) to handle various failure scenarios during ascent. Many of these concerned SSME failures, since that was the most complex and highly stressed component. After the Challenger disaster, there were extensive upgrades to the abort modes.

After the main engines started, but while the solid rocket boosters were still bolted to the pad, the offset thrust from the Shuttle's three main engines caused the entire launch stack (boosters, tank and Shuttle) to pitch down about 2 m at cockpit level. This motion was called the "nod", or "twang" in NASA jargon. As the boosters flexed back into their original shape, the launch stack pitched slowly back upright. This took approximately six seconds. At the point when it was perfectly vertical, the boosters ignited and the launch commenced. The [Johnson Space Center](http://en.wikipedia.org/wiki/Johnson_Space_Center)'s [Mission Control Center](http://en.wikipedia.org/wiki/Mission_Control_Center) assumed control of the flight once the SRBs had cleared the launch tower.

Shortly after clearing the tower, the Shuttle began a combined roll, pitch and yaw maneuver that positioned the orbiter head down, with wings level and aligned with the launch pad. The Shuttle flew upside down during the ascent phase. This orientation allowed a trim angle of attack that was 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 climbed in a progressively flattening arc, accelerating as the weight of the SRBs and main tank decreased. To achieve low orbit requires much more horizontal than vertical acceleration. This was not visually obvious, since the vehicle rose vertically and was 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 or 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, missions going there must set orbital inclination to the same value in order to rendezvous with the station.

Around a point called [Max Q](http://en.wikipedia.org/wiki/Max_Q), where the aerodynamic forces are at their maximum, the main engines were temporarily throttled back to 72 percent to avoid [over-speeding](http://en.wikipedia.org/wiki/Overspeed_(aircraft)) and hence overstressing the Shuttle, particularly in vulnerable areas such as the wings. At this point, a phenomenon known as the [Prandtl-Glauert singularity](http://en.wikipedia.org/wiki/Prandtl-Glauert_singularity" \o "Prandtl-Glauert singularity) occurred, where condensation clouds formed during the vehicle's transition to supersonic speed.

A few seconds later, after the shuttle had gained more altitude and reached a region of lower atmospheric pressure, this dangerous point is passed. At *T*+70 seconds the main engines throttled up to their maximum cruise thrust of 104% rated thrust.

[](http://en.wikipedia.org/wiki/File:STS-1_The_Shuttle%27s_Solid_Rocket_Boosters_break_away_from_Columbia%27s_External_Tank.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:STS-1_The_Shuttle%27s_Solid_Rocket_Boosters_break_away_from_Columbia%27s_External_Tank.jpg)

Solid Rocket Booster (SRB) separation during STS-1. The white external tank pictured was used on STS-1 and STS-2.

At *T*+126 seconds after launch, [pyrotechnic fasteners](http://en.wikipedia.org/wiki/Pyrotechnic_fastener) released the SRBs and small separation rockets pushed them laterally away from the vehicle. The SRBs parachuted back to the ocean to be reused. The Shuttle then began accelerating to orbit on the main engines. The vehicle at that point in the flight had a thrust-to-weight ratio of less than one – the main engines actually had insufficient thrust to exceed the force of gravity, and the vertical speed given to it by the SRBs temporarily decreased. However, as the burn continued, the weight of the propellant decreased and the thrust-to-weight ratio exceeded 1 again and the ever-lighter vehicle then continued to accelerate towards orbit.

The vehicle continued to climb and take on a somewhat nose-up angle to the horizon – it used the main engines to gain and then maintain altitude while it accelerated horizontally towards orbit. At about five and three-quarter minutes into ascent, the orbiter's direct communication links with the ground began to fade, at which point it rolled heads up to reroute its communication links to the [Tracking and Data Relay Satellite](http://en.wikipedia.org/wiki/Tracking_and_Data_Relay_Satellite) system.

Finally, in the last tens of seconds of the main engine burn, the mass of the vehicle was low enough that the engines had to be throttled back to limit vehicle acceleration to 3 *g* (29.34 m/s²), largely for astronaut comfort. At approximately eight minutes post launch, the main engines were shut down.

The main engines were shut down before complete depletion of propellant, as running dry would have destroyed the engines. The oxygen supply was terminated before the hydrogen supply, as the SSMEs reacted 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 was released by firing pyrotechnic fasteners, largely burning up in the atmosphere, though some fragments fell into the ocean, in either the Indian Ocean or the Pacific Ocean depending on launch profile.[[49]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-tech-49) The sealing action of the tank plumbing and lack of pressure relief systems on the external tank helped it break up in the lower atmosphere. After the foam burned away during re-entry, the heat caused a pressure buildup in the remaining liquid oxygen and hydrogen until the tank exploded. This ensured that any pieces that fell back to Earth were small.

To prevent the Shuttle from following the external tank back into the lower atmosphere, the [Orbital maneuvering system](http://en.wikipedia.org/wiki/Orbital_maneuvering_system) (OMS) engines were fired to raise the perigee higher into the upper atmosphere. On some missions (e.g., missions to the ISS), the OMS engines were also used while the main engines were still firing. The reason for putting the orbiter on a path that brought it back to Earth was not just for external tank disposal but also one of safety: if the OMS malfunctioned, or the cargo bay doors could not open for some reason, the Shuttle was already on a path to return to earth for an emergency abort landing.

**Ascent tracking**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=15" \o "Edit section: Ascent tracking)]

[](http://en.wikipedia.org/wiki/File:Contraves-Goerz_Kineto_Tracking_Mount.jpeg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Contraves-Goerz_Kineto_Tracking_Mount.jpeg)

Contraves-Goerz Kineto Tracking Mount used to image the space Shuttle during launch ascent

[](http://en.wikipedia.org/wiki/File:STS-131_afterglow.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:STS-131_afterglow.jpg)

Multicolored [afterglow](http://en.wikipedia.org/wiki/Afterglow) of the [STS-131](http://en.wikipedia.org/wiki/STS-131)launch

The Shuttle was monitored throughout its ascent for short range tracking (10 seconds before liftoff through 57 seconds after), medium range (7 seconds before liftoff through 110 seconds after) and long range (7 seconds before liftoff through 165 seconds after). Short range cameras included 22 16mm cameras on the Mobile Launch Platform and 8 16mm on the Fixed Service Structure, 4 high speed fixed cameras located on the perimeter of the launch complex plus an additional 42 fixed cameras with 16mm motion picture film. Medium range cameras included remotely operated tracking cameras at the launch complex plus 6 sites along the immediate coast north and south of the launch pad, each with 800mm lens and high speed cameras running 100 frames per second. These cameras ran for only 4–10 seconds due to limitations in the amount of film available. Long range cameras included those mounted on the external tank, SRBs and orbiter itself which streamed live video back to the ground providing valuable information about any debris falling during ascent. Long range tracking cameras with 400-inch film and 200-inch video lenses were operated by a photographer at [Playalinda Beach](http://en.wikipedia.org/wiki/Playalinda_Beach" \o "Playalinda Beach) as well as 9 other sites from 38 miles north at the [Ponce Inlet](http://en.wikipedia.org/wiki/Ponce_Inlet) to 23 miles south to [Patrick Air Force Base](http://en.wikipedia.org/wiki/Patrick_Air_Force_Base) (PAFB) and additional mobile optical tracking camera was stationed on Merritt Island during launches. A total of 10 HD cameras were used both for ascent information for engineers and broadcast feeds to networks such as [NASA TV](http://en.wikipedia.org/wiki/NASA_TV) and [HDNet](http://en.wikipedia.org/wiki/HDNet" \o "HDNet) The number of cameras significantly increased and numerous existing cameras were upgraded at the recommendation of the [Columbia Accident Investigation Board](http://en.wikipedia.org/wiki/Columbia_Accident_Investigation_Board) to provide better information about the debris during launch. Debris was also tracked using a pair of [Weibel](http://en.wikipedia.org/wiki/Weibel_Scientific" \o "Weibel Scientific) Continuous Pulse Doppler X-band radars, one on board the SRB recovery ship [MV Liberty Star](http://en.wikipedia.org/wiki/MV_Liberty_Star) positioned north east of the launch pad and on a ship positioned south of the launch pad. Additionally, during the first 2 flights following the loss of Columbia and her crew, a pair of NASA [WB-57](http://en.wikipedia.org/wiki/WB-57) reconnaissance aircraft equipped with HD Video and Infrared flew at 60,000 feet (18,000 m) to provide additional views of the launch ascent.[[60]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-60) Kennedy Space Center also invested nearly $3 million in improvements to the digital video analysis systems in support of debris tracking.[[61]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-61)

**In orbit**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=16" \o "Edit section: In orbit)]

Once in orbit, the Shuttle usually flew at an altitude of 200 miles (321.9 km), and occasionally as high as 400 miles.[[62]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-62) 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 the space station, with fewer satellite launches. Most missions involved staying in orbit several days to two weeks, although longer missions were possible with the [Extended Duration Orbiter](http://en.wikipedia.org/wiki/Extended_Duration_Orbiter) add-on or when attached to a space station.

|  |  |
| --- | --- |
| [http://upload.wikimedia.org/wikipedia/commons/thumb/e/e8/STS-132_Atlantis_at_ISS_1.jpg/220px-STS-132_Atlantis_at_ISS_1.jpg](http://en.wikipedia.org/wiki/File:STS-132_Atlantis_at_ISS_1.jpg)  [http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:STS-132_Atlantis_at_ISS_1.jpg)  *Atlantis* docked at *Harmony* module of the International Space Station | [http://upload.wikimedia.org/wikipedia/commons/thumb/5/58/Capturing_the_Solar_Maximum_Mission_satellite.jpg/220px-Capturing_the_Solar_Maximum_Mission_satellite.jpg](http://en.wikipedia.org/wiki/File:Capturing_the_Solar_Maximum_Mission_satellite.jpg)  [http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Capturing_the_Solar_Maximum_Mission_satellite.jpg)  Astronaut with satellite to repair it |

**Re-entry and landing**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=17" \o "Edit section: Re-entry and landing)]

|  |  |
| --- | --- |
| http://upload.wikimedia.org/wikipedia/en/thumb/9/99/Question_book-new.svg/50px-Question_book-new.svg.png | This section **needs additional citations for verification**. Please help [improve this article](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit) by [adding citations to reliable sources](http://en.wikipedia.org/wiki/Help:Introduction_to_referencing/1). Unsourced material may be [challenged](http://en.wikipedia.org/wiki/Template:Citation_needed) and [removed](http://en.wikipedia.org/wiki/Wikipedia:Verifiability#Burden_of_evidence). *(June 2007)* |

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

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Atlantis_in_the_sky_on_July_21,_2011,_to_its_final_landing.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Atlantis_in_the_sky_on_July_21,_2011,_to_its_final_landing.jpg)

Glowing plasma trail from Shuttle re-entry as seen from the Space Station

The vehicle began 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 reduced the Shuttle's velocity by about 200 mph (322 km/h). The resultant slowing of the Shuttle lowered its orbital [perigee](http://en.wikipedia.org/wiki/Perigee) down into the upper atmosphere. The Shuttle then flipped over, by pushing its nose down (which was actually "up" relative to the Earth, because it was flying upside down). This OMS firing was done roughly halfway around the globe from the landing site.

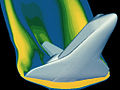
The vehicle started encountering more significant air density in the lower thermosphere at about 400,000 ft (120 km), at around [Mach](http://en.wikipedia.org/wiki/Mach_number) 25, 8,200 m/s (30,000 km/h; 18,000 mph). The vehicle was controlled by a combination of [RCS thrusters](http://en.wikipedia.org/wiki/Reaction_Control_System) 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 encountered progressively denser air, it began 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 performed 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 dissipated speed sideways rather than upwards. This occurred during the 'hottest' phase of re-entry, when the heat-shield glowed red and the G-forces were at their highest. By the end of the last turn, the transition to aircraft was almost complete. The vehicle leveled its wings, lowered its nose into a shallow dive and began its approach to the landing site.

* [](http://en.wikipedia.org/wiki/File:Stsheat.jpg)

[Simulation](http://en.wikipedia.org/wiki/Simulation) of the outside of the Shuttle as it heats up to over 1,500  °C during re-entry.

* [](http://en.wikipedia.org/wiki/File:Nasa_Shuttle_Test_Using_Electron_Beam_full.jpg)

A Space Shuttle model undergoes a [wind tunnel](http://en.wikipedia.org/wiki/Wind_tunnel)test in 1975. This test is simulating the ionized gasses that surround a Shuttle as it reenters the atmosphere.

* [](http://en.wikipedia.org/wiki/File:CFD_Shuttle.jpg)

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

The orbiter's maximum [glide ratio](http://en.wikipedia.org/wiki/Glide_ratio)/[lift-to-drag ratio](http://en.wikipedia.org/wiki/Lift-to-drag_ratio) varies considerably with speed, ranging from 1:1 at [hypersonic](http://en.wikipedia.org/wiki/Hypersonic) speeds, 2:1 at supersonic speeds and reaching 4.5:1 at subsonic speeds during approach and landing.[[63]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-63)

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)(9800fpm). 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.

**Final approach and landing phase**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=18" \o "Edit section: Final approach and landing phase)]



[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Sts-127_landing.ogg)

[STS-127](http://en.wikipedia.org/wiki/STS-127), Space Shuttle *Endeavour*landing video (2009)

When the approach and landing phase began, the orbiter was at a 3,000 m (9,800 ft) altitude, 12 km (7.5 mi) from the runway. The pilots applied aerodynamic braking to help slow down the vehicle. The orbiter's speed was 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 was deployed while the Orbiter was flying at 430 km/h (270 mph). To assist the speed brakes, a 12 m (39 ft) drag chute was deployed either after main gear or nose gear touchdown (depending on selected chute deploy mode) at about 343 km/h (213 mph). The chute was jettisoned once the orbiter slowed to 110 km/h (68.4 mph).

* [*Discovery*](http://en.wikipedia.org/wiki/Space_Shuttle_Discovery) touches down for the final time at the end of [STS-133](http://en.wikipedia.org/wiki/STS-133).

* [](http://en.wikipedia.org/wiki/File:Space_Shuttle_Endeavour_landing.jpg)

[*Endeavour*](http://en.wikipedia.org/wiki/Space_Shuttle_Endeavour) brake chute deploys after touching down

http://upload.wikimedia.org/wikipedia/en/thumb/4/4a/Commons-logo.svg/12px-Commons-logo.svg.png Media related to [Landings of space Shuttles](http://commons.wikimedia.org/wiki/Category:Landings_of_space_shuttles) at Wikimedia Commons

**Post-landing processing**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=19" \o "Edit section: Post-landing processing)]

*Main article:*[*Orbiter Processing Facility*](http://en.wikipedia.org/wiki/Orbiter_Processing_Facility)

[](http://en.wikipedia.org/wiki/File:Discovery_mission_completed_q.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Discovery_mission_completed_q.jpg)

*Discovery* after landing on Earth for crew disembarkment

After landing, the vehicle stayed on the runway for several hours for the orbiter to cool. Teams at the front and rear of the orbiter tested for presence of [hydrogen](http://en.wikipedia.org/wiki/Hydrogen), [hydrazine](http://en.wikipedia.org/wiki/Hydrazine), [monomethylhydrazine](http://en.wikipedia.org/wiki/Monomethylhydrazine" \o "Monomethylhydrazine), [nitrogen tetroxide](http://en.wikipedia.org/wiki/Nitrogen_tetroxide) and [ammonia](http://en.wikipedia.org/wiki/Ammonia) (fuels and by products of the control and the orbiter's three [APUs](http://en.wikipedia.org/wiki/Auxiliary_Power_Unit)). If hydrogen was detected, an emergency would be declared, the orbiter powered down and teams would evacuate the area. A convoy of 25 specially designed vehicles and 150 trained engineers and technicians approached the orbiter. Purge and vent lines were attached to remove toxic gases from fuel lines and the cargo bay about 45–60 minutes after landing. A [flight surgeon](http://en.wikipedia.org/wiki/Flight_surgeon) boarded the orbiter for initial medical checks of the crew before disembarking. Once the crew left the orbiter, responsibility for the vehicle was handed from the Johnson Space Center back to the Kennedy Space Center[[64]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-afterlandingpao-64)

If the mission ended at [Edwards Air Force Base](http://en.wikipedia.org/wiki/Edwards_Air_Force_Base) in California, [White Sands Space Harbor](http://en.wikipedia.org/wiki/White_Sands_Space_Harbor) in New Mexico, or any of the [runways the orbiter might use in an emergency](http://en.wikipedia.org/wiki/List_of_space_shuttle_landing_runways), the orbiter was loaded atop the [Shuttle Carrier Aircraft](http://en.wikipedia.org/wiki/Shuttle_Carrier_Aircraft), a modified 747, for transport back to the Kennedy Space Center, landing at the [Shuttle Landing Facility](http://en.wikipedia.org/wiki/Shuttle_Landing_Facility). Once at the Shuttle Landing Facility, the orbiter was then towed 2 miles (3.2 km) along a tow-way and access roads normally used by tour buses and KSC employees to the [Orbiter Processing Facility](http://en.wikipedia.org/wiki/Orbiter_Processing_Facility) where it began a months-long preparation process for the next mission.[[64]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-afterlandingpao-64)

**Landing sites**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=20" \o "Edit section: Landing sites)]

*See also:*[*List of space shuttle landing runways*](http://en.wikipedia.org/wiki/List_of_space_shuttle_landing_runways)

NASA preferred Space Shuttle landings to be at [Kennedy Space Center](http://en.wikipedia.org/wiki/Kennedy_Space_Center).[[65]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-65) If weather conditions made landing there unfavorable, the Shuttle could 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 meant that after touchdown the Shuttle must be mated to the Shuttle Carrier Aircraft and returned to [Cape Canaveral](http://en.wikipedia.org/wiki/Cape_Canaveral). Space Shuttle *Columbia* ([STS-3](http://en.wikipedia.org/wiki/STS-3)) once landed at the [White Sands Space Harbor](http://en.wikipedia.org/wiki/White_Sands_Space_Harbor), [New Mexico](http://en.wikipedia.org/wiki/New_Mexico); this was viewed as a last resort as NASA scientists believe that the sand could potentially damage the Shuttle's exterior.

There were many [alternative landing sites](http://en.wikipedia.org/wiki/Emergency_landing_sites) that were never used.[[66]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-66)[[67]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-67)

**Risk contributors**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=21" \o "Edit section: Risk contributors)]

[](http://en.wikipedia.org/wiki/File:STS-133_docked_to_ISS.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:STS-133_docked_to_ISS.jpg)

Discovery at ISS in 2011 (STS-133)

An example of technical risk analysis for a STS mission is SPRA iteration 3.1 top risk contributors for STS-133:[[68]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-copv-68)[[69]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-69)

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 rocket motors of the SRBs)
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](http://en.wikipedia.org/wiki/Lyndon_B._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.[[70]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-70)

Fleet history[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=22" \o "Edit section: Fleet history)]

[](http://en.wikipedia.org/wiki/File:OV-101_first_flight.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:OV-101_first_flight.jpg)

OV-101 *Enterprise* takes flight for the first time over [Dryden Flight Research Facility](http://en.wikipedia.org/wiki/Dryden_Flight_Research_Facility), Edwards, California in 1977 as part of the Shuttle program's [Approach and Landing Tests](http://en.wikipedia.org/wiki/Approach_and_Landing_Tests) (ALT).

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Atlantis_launches_from_KSC_on_STS-132_side_view.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Atlantis_launches_from_KSC_on_STS-132_side_view.jpg)

[*Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis) lifts off from Launch Pad 39A at NASA's [Kennedy Space Center](http://en.wikipedia.org/wiki/Kennedy_Space_Center) in Florida on the [STS-132](http://en.wikipedia.org/wiki/STS-132) mission to the [International Space Station](http://en.wikipedia.org/wiki/International_Space_Station) at 2:20 pm EDT on May 14, 2010. This was one of the last scheduled flights for *Atlantis* before it was retired.

*Main article:*[*List of space shuttle missions*](http://en.wikipedia.org/wiki/List_of_space_shuttle_missions)

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

|  |  |  |
| --- | --- | --- |
| **Space Shuttle major events** | | |
| **Date** | **Orbiter** | **Major event / remarks** |
| September 17, 1976 | [*Enterprise*](http://en.wikipedia.org/wiki/Space_Shuttle_Enterprise) | Prototype Space Shuttle *Enterprise* was rolled out of its assembly facility in Southern California and displayed before a crowd several thousand strong.[[71]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-71) |
| February 18, 1977 | *Enterprise* | First flight; Attached to [Shuttle Carrier Aircraft](http://en.wikipedia.org/wiki/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*](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia) | First *Columbia* flight, first orbital test flight; [STS-1](http://en.wikipedia.org/wiki/STS-1) |
| November 11, 1982 | *Columbia* | First operational flight of the Space Shuttle, first mission to carry four astronauts; [STS-5](http://en.wikipedia.org/wiki/STS-5) |
| April 4, 1983 | [*Challenger*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger) | First *Challenger* flight; [STS-6](http://en.wikipedia.org/wiki/STS-6) |
| August 30, 1984 | [*Discovery*](http://en.wikipedia.org/wiki/Space_Shuttle_Discovery) | First *Discovery* flight; [STS-41-D](http://en.wikipedia.org/wiki/STS-41-D) |
| October 3, 1985 | [*Atlantis*](http://en.wikipedia.org/wiki/Space_Shuttle_Atlantis) | First *Atlantis* flight; [STS-51-J](http://en.wikipedia.org/wiki/STS-51-J) |
| October 30, 1985 | *Challenger* | First crew of eight astronauts; [STS-61-A](http://en.wikipedia.org/wiki/STS-61-A) |
| January 28, 1986 | *Challenger* | [Disaster starting 73 seconds after launch](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster); [STS-51-L](http://en.wikipedia.org/wiki/STS-51-L); all seven crew members died. |
| September 29, 1988 | *Discovery* | First post-*Challenger* mission; [STS-26](http://en.wikipedia.org/wiki/STS-26) |
| May 4, 1989 | *Atlantis* | The first Space Shuttle mission to launch an interplanetary probe, [Magellan](http://en.wikipedia.org/wiki/Magellan_probe); [STS-30](http://en.wikipedia.org/wiki/STS-30) |
| April 24, 1990 | *Discovery* | Launch of the [Hubble Space Telescope](http://en.wikipedia.org/wiki/Hubble_Space_Telescope); [STS-31](http://en.wikipedia.org/wiki/STS-31) |
| May 7, 1992 | [*Endeavour*](http://en.wikipedia.org/wiki/Space_Shuttle_Endeavour) | First *Endeavour* flight; [STS-49](http://en.wikipedia.org/wiki/STS-49) |
| November 19, 1996 | *Columbia* | Longest Shuttle mission at 17 days, 15 hours; [STS-80](http://en.wikipedia.org/wiki/STS-80) |
| December 4, 1998 | *Endeavour* | First [ISS](http://en.wikipedia.org/wiki/ISS) mission; [STS-88](http://en.wikipedia.org/wiki/STS-88) |
| February 1, 2003 | *Columbia* | [Disintegrated during re-entry](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia_disaster); [STS-107](http://en.wikipedia.org/wiki/STS-107); all seven crew members died. |
| July 25, 2005 | *Discovery* | First post-*Columbia* mission; [STS-114](http://en.wikipedia.org/wiki/STS-114) |
| February 24, 2011 | *Discovery* | Last *Discovery* flight; [STS-133](http://en.wikipedia.org/wiki/STS-133) |
| May 16, 2011 | *Endeavour* | Last *Endeavour* mission; [STS-134](http://en.wikipedia.org/wiki/STS-134)[[72]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-72)[[73]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-73) |
| July 8, 2011 | *Atlantis* | Last *Atlantis* flight and last Space Shuttle flight; [STS-135](http://en.wikipedia.org/wiki/STS-135) |

Sources: NASA launch manifest,[[74]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-manifest-74) NASA Space Shuttle archive[[75]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-archive-75)

**Shuttle disasters**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=23" \o "Edit section: Shuttle disasters)]

*Main articles:*[*Space Shuttle Challenger disaster*](http://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster)*and*[*Space Shuttle Columbia disaster*](http://en.wikipedia.org/wiki/Space_Shuttle_Columbia_disaster)

On January 28, 1986, *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 O-ring, a mission critical seal used between segments of the SRB casing. The failure of a lower O-ring seal allowed hot combustion gases to escape from between the booster sections and burn through the adjacent [external tank](http://en.wikipedia.org/wiki/Space_Shuttle_external_tank), causing it to explode.[[76]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-76) 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) had been ignored by NASA managers.[[77]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-77)

On February 1, 2003, *Columbia* disintegrated during re-entry, killing its crew of seven, because of damage to the [carbon-carbon](http://en.wikipedia.org/wiki/Reinforced_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](http://en.wikipedia.org/wiki/Space_Shuttle_thermal_protection_system) (TPS) engineer requested that astronauts on board *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,[[78]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-78) and thus the feasibility of scenarios for astronaut repair or rescue by *Atlantis* were not considered by NASA management at the time.[[79]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-79)

Retirement[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=24" \o "Edit section: Retirement)]

*Main article:*[*Space Shuttle retirement*](http://en.wikipedia.org/wiki/Space_Shuttle_retirement)

[](http://en.wikipedia.org/wiki/File:Atlantis_welcome_home_ceremony_outside_the_OPF_July_22.png)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Atlantis_welcome_home_ceremony_outside_the_OPF_July_22.png)

Atlantis orbiter's final welcome home, 2011.

NASA retired the Space Shuttle in 2011, after 30 years of service. The Shuttle was originally conceived of and presented to the public as a "Space Truck", which would, among other things, be used to build a United States space station in [low earth orbit](http://en.wikipedia.org/wiki/Low_earth_orbit) in the early 1990s. When the US space station evolved into the International Space Station project, which suffered from long delays and design changes before it could be completed, the service life of the Space Shuttle was extended several times until 2011, serving at least 15 years longer than it was originally designed to do. *Discovery* was the first of NASA's three remaining operational Space Shuttles to be retired.[[80]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-80)

The final Space Shuttle mission was originally scheduled for late 2010, but the program was later extended to July 2011 when Michael Suffredini of the ISS program said that one additional trip was needed in 2011 to deliver parts to the International Space Station.[[81]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-81) The Shuttle's final mission consisted of just four astronauts—Christopher Ferguson (Commander), Douglas Hurley (Pilot), Sandra Magnus (Mission Specialist 1), and Rex Walheim (Mission Specialist 2);[[82]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-82) they conducted the 135th and last space Shuttle mission on board *Atlantis*, which launched on July 8, 2011, and landed safely at the Kennedy Space Center on July 21, 2011, at 5:57 AM EDT (09:57 UTC).[[83]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-83)

**Distribution of orbiters and other hardware**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=25" \o "Edit section: Distribution of orbiters and other hardware)]

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Program_Commemorative_Patch.png)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Program_Commemorative_Patch.png)

[Space Shuttle Program](http://en.wikipedia.org/wiki/Space_Shuttle_Program) commemorative patch

NASA announced it would transfer orbiters to education institutions or museums at the conclusion of the Space Shuttle program. Each museum or institution is responsible for covering the US$28.8 million cost of preparing and transporting each vehicle for display. Twenty museums from across the country submitted proposals for receiving one of the retired orbiters.[[84]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-retired_shuttle_display-84) NASA also made [Space Shuttle thermal protection system](http://en.wikipedia.org/wiki/Space_Shuttle_thermal_protection_system) tiles available to schools and universities for less than US$25 each.[[85]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-tiles-85) About 7,000 tiles were available on a [first-come, first-served](http://en.wikipedia.org/wiki/First-come,_first-served) basis, limited to one per institution.[[85]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-tiles-85)

On April 12, 2011, NASA announced selection of locations for the remaining Shuttle orbiters:[[86]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-NASA_New_Homes_for_Orbiters-86)[[87]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-intrepid-87)

* *Atlantis* is on display at the [Kennedy Space Center Visitor Complex](http://en.wikipedia.org/wiki/Kennedy_Space_Center_Visitor_Complex), near [Cape Canaveral](http://en.wikipedia.org/wiki/Cape_Canaveral), Florida. It was delivered to the Visitor Complex on November 2, 2012.
* *Discovery* was delivered to the [Udvar-Hazy Center](http://en.wikipedia.org/wiki/Steven_F._Udvar-Hazy_Center" \o "Steven F. Udvar-Hazy Center) of the [Smithsonian Institution](http://en.wikipedia.org/wiki/Smithsonian_Institution)'s [National Air and Space Museum](http://en.wikipedia.org/wiki/National_Air_and_Space_Museum) in [Chantilly, Virginia](http://en.wikipedia.org/wiki/Chantilly,_Virginia), near Washington, D.C. on April 19, 2012. On April 17, 2012, Discovery was flown atop a 747 Shuttle Carrier Aircraft escorted by a NASA T-38 Talon chase aircraft in a final farewell flight. The 747 and Discovery flew over Washington, D.C. and the metropolitan area around 10 am and arrived at Dulles around 11 am. The flyover and landing were widely covered on national news media.

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Endeavor_Touchdown_at_LAX.JPG)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Endeavor_Touchdown_at_LAX.JPG)

*Endeavour* at Los Angeles International Airport

* *Endeavour* was delivered to the [California Science Center](http://en.wikipedia.org/wiki/California_Science_Center) in Los Angeles, California on October 14, 2012. It arrived at Los Angeles International Airport on September 21, 2012, concluding a two-day, cross country journey atop the Shuttle Carrier Aircraft after stops at Ellington Field in Houston, Biggs Army Airfield in El Paso and the Dryden Flight Research Facility at Edwards Air Force Base, California.
* *Enterprise* (atmospheric test orbiter) was on display at the National Air and Space Museum's Udvar-Hazy Center but was moved to New York City's [Intrepid Sea-Air-Space Museum](http://en.wikipedia.org/wiki/Intrepid_Sea-Air-Space_Museum) in mid-2012.[[44]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-shuttle_sale-44)
* [*Explorer*](http://en.wikipedia.org/wiki/Space_Shuttle_Explorer), a full-scale orbiter mockup with interior access, formerly on display at the Kennedy Space Center Visitor Complex, was delivered by barge to the [Johnson Space Center](http://en.wikipedia.org/wiki/Johnson_Space_Center) in Houston, Texas for display at [Space Center Houston](http://en.wikipedia.org/wiki/Space_Center_Houston).

Flight and mid-deck training hardware will be taken from the [Johnson Space Center](http://en.wikipedia.org/wiki/Johnson_Space_Center) and will go to the National Air and Space Museum and the [National Museum of the U.S. Air Force](http://en.wikipedia.org/wiki/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](http://en.wikipedia.org/wiki/Museum_of_Flight) in Seattle. Mission Simulation and Training Facility's fixed simulator will go to the [Adler Planetarium](http://en.wikipedia.org/wiki/Adler_Planetarium) in Chicago, and the motion simulator will go to the [Texas A&M](http://en.wikipedia.org/wiki/Texas_A%26M) Aerospace Engineering Department in College Station, Texas. Other simulators used in Shuttle astronaut training will go to the [Wings of Dreams Aviation Museum](http://en.wikipedia.org/wiki/Wings_of_Dreams_Aviation_Museum) in Starke, Florida and the [Virginia Air and Space Center](http://en.wikipedia.org/wiki/Virginia_Air_and_Space_Center) in Hampton, Virginia.[[84]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-retired_shuttle_display-84)

In August 2011, the [NASA Office of Inspector General](http://en.wikipedia.org/wiki/NASA_Office_of_Inspector_General) (OIG) published a "Review of NASA's Selection of Display Locations for the Space Shuttle Orbiters"; the review had four main findings:[[88]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-oigreview-88)

* "NASA's decisions regarding Orbiter placement were the result of an Agency-created process that emphasized above all other considerations locating the Orbiters in places where the most people would have the opportunity to view them";
* "the Team made several errors during its evaluation process, including one that would have resulted in a numerical 'tie' among the Intrepid, the Kennedy Visitor Complex, and the National Museum of the U.S. Air Force (Air Force Museum) in Dayton, Ohio";
* there is "no evidence that the Team’s recommendation or the Administrator's decision were tainted by political influence or any other improper consideration";
* "some of the choices NASA made during the selection process – specifically, its decision to manage aspects of the selection as if it were a competitive procurement and to delay announcement of its placement decisions until April 2011 (more than 2 years after it first solicited information from interested entities)—may intensify challenges to the Agency and the selectees as they work to complete the process of placing the Orbiters in their new homes."

The NASA OIG had three recommendations, saying NASA should:[[88]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-oigreview-88)

* "expeditiously review recipients' financial, logistical, and curatorial display plans to ensure they are feasible and consistent with the Agency's educational goals and processing and delivery schedules";
* "ensure that recipient payments are closely coordinated with processing schedules, do not impede NASA's ability to efficiently prepare the Orbiters for museum display, and provide sufficient funds in advance of the work to be performed; and"
* "work closely with the recipient organizations to minimize the possibility of delays in the delivery schedule that could increase the Agency's costs or impact other NASA missions and priorities."

In September 2011, the CEO and two board members of Seattle's Museum of Flight met with NASA Administrator [Charles Bolden](http://en.wikipedia.org/wiki/Charles_Bolden), pointing out "significant errors in deciding where to put its four retiring Space Shuttles"; the errors alleged include inaccurate information on Museum of Flight's attendance and international visitor statistics, as well as the readiness of the [Intrepid Sea-Air-Space Museum](http://en.wikipedia.org/wiki/Intrepid_Sea-Air-Space_Museum)'s exhibit site.[[89]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-89)

Space Shuttle successors and legacy[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=26" \o "Edit section: Space Shuttle successors and legacy)]

*Main article:*[*Space Shuttle retirement*](http://en.wikipedia.org/wiki/Space_Shuttle_retirement)

[](http://en.wikipedia.org/wiki/File:Critical-ionization-velocity.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Critical-ionization-velocity.jpg)

STS conducted numerous experiments in space, such as this ionization experiment

Until another US manned spacecraft is ready, crews will travel to and from the International Space Station (ISS) exclusively aboard the Russian [Soyuz](http://en.wikipedia.org/wiki/Soyuz_(rocket_family)) spacecraft.

A planned successor to STS was the "Shuttle II", during the 1980s and 1990s, and later the Constellation program during the 2004–2010 period. CSTS was a proposal to continue to operate STS commercially, after NASA.[[90]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-coppinger-90) In September 2011,[NASA](http://en.wikipedia.org/wiki/NASA) announced the selection of the design for the new [Space Launch System](http://en.wikipedia.org/wiki/Space_Launch_System) that is planned to launch the [Orion spacecraft](http://en.wikipedia.org/wiki/Orion_spacecraft) and other hardware to missions beyond low earth-orbit.[[91]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-New_Heavy-lift_Rocket_Will_Take_Humans_Far_Beyond_Earth-91)[[92]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-NASA_Briefing_on_Deep_Space_Launch_System-92)[[93]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-Space_.26_Cosmos-93)

The [Commercial Orbital Transportation Services](http://en.wikipedia.org/wiki/Commercial_Orbital_Transportation_Services) program began in 2006 with the purpose of creating commercially operated unmanned cargo vehicles to service the ISS.[[94]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-94) The [SpaceX](http://en.wikipedia.org/wiki/SpaceX" \o "SpaceX) [Dragon](http://en.wikipedia.org/wiki/Dragon_(spacecraft)) became operational in 2012, and the [Orbital Sciences](http://en.wikipedia.org/wiki/Orbital_Sciences)'[Cygnus](http://en.wikipedia.org/wiki/Cygnus_(spacecraft)), is expected to be launched in September 2013. The [Commercial Crew Development](http://en.wikipedia.org/wiki/Commercial_Crew_Development) (CCDev) program was initiated in 2010 with the purpose of creating commercially operated manned spacecraft capable of delivering at least four crew members to the ISS, to stay docked for 180 days, and then return them back to Earth.[[95]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-95) These spacecraft are expected to become operational in the mid-2010s.[[96]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-96)

In culture[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=27" \o "Edit section: In culture)]

[](http://en.wikipedia.org/wiki/File:S123_Linnehan_through_the_window.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:S123_Linnehan_through_the_window.jpg)

Looking out a rear cabin window of the Shuttle in orbit

Space Shuttles have been features of fiction and nonfiction, from movies for kids to documentaries. Early examples include the 1979 [James Bond](http://en.wikipedia.org/wiki/James_Bond) film, *[Moonraker](http://en.wikipedia.org/wiki/Moonraker_(film)" \o "Moonraker (film))*, the 1982 [Activision](http://en.wikipedia.org/wiki/Activision) videogame *Space Shuttle: A Journey into Space* (1982) and [G. Harry Stine](http://en.wikipedia.org/wiki/G._Harry_Stine)'s 1981 novel [*Shuttle Down*](http://en.wikipedia.org/wiki/Shuttle_Down). In the 1986 film *[SpaceCamp](http://en.wikipedia.org/wiki/SpaceCamp" \o "SpaceCamp)*, *Atlantis* accidentally launched into space with a group of [U.S. Space Camp](http://en.wikipedia.org/wiki/U.S._Space_Camp) participants as its crew. The 1998 film [*Armageddon*](http://en.wikipedia.org/wiki/Armageddon_(1998_film)) portrayed a combined crew of offshore oil rig workers and US military staff who pilot two modified Shuttles to avert the destruction of Earth by an asteroid. Retired American test pilots visited a Russian satellite in the 2000 [Clint Eastwood](http://en.wikipedia.org/wiki/Clint_Eastwood) adventure film [*Space Cowboys*](http://en.wikipedia.org/wiki/Space_Cowboys). In the 2003 film *The Core,* the *Endeavour'*s landing is disrupted by the earth's magnetic core, and its crew is selected to pilot the vehicle designed to restart the core. The 2004 Bollywood movie *[Swades](http://en.wikipedia.org/wiki/Swades" \o "Swades)*, where a Space Shuttle was used to launch a special rainfall monitoring satellite, was filmed at Kennedy Space Center in the year following the [Columbia disaster](http://en.wikipedia.org/wiki/Columbia_disaster) that had taken the life of Indian-American astronaut [KC Chawla](http://en.wikipedia.org/wiki/Kalpana_Chawla). On television, the 1996 drama [*The Cape*](http://en.wikipedia.org/wiki/The_Cape_(1996_TV_series)) portrayed the lives of a group of NASA astronauts as they prepared for and flew Shuttle missions. [*Odyssey 5*](http://en.wikipedia.org/wiki/Odyssey_5) was a short lived sci-fi series that featured the crew of a Space Shuttle as the last survivors of a disaster that destroyed Earth.

The Space Shuttle has also been the subject of toys and models; for example, a large [Lego](http://en.wikipedia.org/wiki/Lego) Space Shuttle model was constructed by visitors at Kennedy Space Center,[[97]](http://en.wikipedia.org/wiki/Space_Shuttle" \l "cite_note-97) and smaller models have been sold commercially as a standard "LegoLand" set. A 1984 pinball machine "[Space Shuttle](http://en.wikipedia.org/wiki/Space_Shuttle_(pinball))" was produced by Williams and features a plastic Space Shuttle model among other artwork of astronauts on the play field.

**US postage commemorations**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=28" \o "Edit section: US postage commemorations)]

*Main article:*[*U.S. space exploration history on U.S. stamps#Space Shuttle Issues*](http://en.wikipedia.org/wiki/U.S._space_exploration_history_on_U.S._stamps#Space_Shuttle_Issues)

The U.S. Postal Service has released several postage issues that depict the Space Shuttle. The first such stamps were issued in 1981, and are on display at the [National Postal Museum](http://en.wikipedia.org/wiki/National_Postal_Museum).[[98]](http://en.wikipedia.org/wiki/Space_Shuttle#cite_note-98)

[](http://en.wikipedia.org/wiki/File:Space_Shuttle_Endeavor_1995_Issue.jpg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Space_Shuttle_Endeavor_1995_Issue.jpg)

Space Shuttle Endeavour Issue of 1995

See also[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=29" \o "Edit section: See also)]

|  |  |
| --- | --- |
| [Portal icon](http://en.wikipedia.org/wiki/File:RocketSunIcon.svg) | [***Spaceflight portal***](http://en.wikipedia.org/wiki/Portal:Spaceflight) |

**Space Shuttle related**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=30" \o "Edit section: Space Shuttle related)]

* [Chrysler SERV](http://en.wikipedia.org/wiki/Chrysler_SERV)
* [Criticism of the Space Shuttle program](http://en.wikipedia.org/wiki/Criticism_of_the_Space_Shuttle_program)
* [Getaway Special](http://en.wikipedia.org/wiki/Getaway_Special)
* [List of human spaceflights](http://en.wikipedia.org/wiki/List_of_human_spaceflights)
* [List of Space Shuttle crews](http://en.wikipedia.org/wiki/List_of_Space_Shuttle_crews)
* [NASA TV](http://en.wikipedia.org/wiki/NASA_TV), coverage of launches and missions
* [Orbiter Processing Facility](http://en.wikipedia.org/wiki/Orbiter_Processing_Facility)
* [Shuttle-Derived Launch Vehicle](http://en.wikipedia.org/wiki/Shuttle-Derived_Launch_Vehicle)
* [Shuttle Training Aircraft](http://en.wikipedia.org/wiki/Shuttle_Training_Aircraft)
* [Space accidents and incidents](http://en.wikipedia.org/wiki/Space_accidents_and_incidents)
* [HL-20 Personnel Launch System](http://en.wikipedia.org/wiki/HL-20_Personnel_Launch_System)

**Physics**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=31" \o "Edit section: Physics)]

* [Lifting body](http://en.wikipedia.org/wiki/Lifting_body)
* [Single-stage-to-orbit](http://en.wikipedia.org/wiki/Single-stage-to-orbit)

**Similar spacecraft**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=32" \o "Edit section: Similar spacecraft)]

* [Buran](http://en.wikipedia.org/wiki/Buran_program), Soviet Space shuttle program (1974–1992)
* [Comparison of orbital launchers families](http://en.wikipedia.org/wiki/Comparison_of_orbital_launchers_families)
* [Comparison of orbital launch systems](http://en.wikipedia.org/wiki/Comparison_of_orbital_launch_systems)
* DIRECT, a vehicle proposed as an alternative for [Constellation program](http://en.wikipedia.org/wiki/Constellation_program)
* [EADS Phoenix](http://en.wikipedia.org/wiki/EADS_Phoenix)
* [Hermes](http://en.wikipedia.org/wiki/Hermes_(shuttle)) (1975–1992)
* [HOPE-X](http://en.wikipedia.org/wiki/HOPE-X)
* [HOTOL](http://en.wikipedia.org/wiki/HOTOL) (cancelled)
* [Kliper](http://en.wikipedia.org/wiki/Kliper)
* [Orion](http://en.wikipedia.org/wiki/Orion_(spacecraft)) spacecraft
* [Skylon](http://en.wikipedia.org/wiki/Skylon_(spacecraft))
* [X-20 Dynasoar](http://en.wikipedia.org/wiki/X-20_Dynasoar) (1957–1963)
* [X-33](http://en.wikipedia.org/wiki/Lockheed_Martin_X-33) of Lockheed Martin (1995–2001)

External links[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=33" \o "Edit section: External links)]

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| http://upload.wikimedia.org/wikipedia/en/thumb/4/4a/Commons-logo.svg/30px-Commons-logo.svg.png | Wikimedia Commons has media related to [***Space Shuttle***](http://commons.wikimedia.org/wiki/Special:Search/Space_Shuttle). |

[](http://en.wikipedia.org/wiki/File:Shuttle_Patch.svg)

[http://bits.wikimedia.org/static-1.23wmf2/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Shuttle_Patch.svg)

Space Shuttle program insignia

**Further reading**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=34" \o "Edit section: Further reading)]

* [NSTS 1988 Reference manual](http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/stsref-toc.html)
* [How The Space Shuttle Works](http://science.howstuffworks.com/space-shuttle.htm)
* [NASA Space Shuttle News Reference – 1981 (PDF document)](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19810022734_1981022734.pdf)
* [Orbiter Vehicles](http://science.ksc.nasa.gov/shuttle/resources/orbiters/orbiters.html)
* [Lecture Series on the space shuttle](http://ocw.mit.edu/courses/aeronautics-and-astronautics/16-885j-aircraft-systems-engineering-fall-2005/lecture-notes/) from [MIT OpenCourseWare](http://en.wikipedia.org/wiki/MIT_OpenCourseWare)

**NASA**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=35" \o "Edit section: NASA)]

* [The Space Shuttle Era: 1981–2011; interactive multimedia on the space shuttle orbiters](http://www.nasa.gov/externalflash/the_shuttle/)
* [NASA Human Spaceflight – Shuttle](http://spaceflight.nasa.gov/shuttle/): Current status of shuttle missions
* Official NASA [Human Space Flight Orbital Tracking](http://spaceflight.nasa.gov/realdata/tracking/) system
* [NASA Shuttle Gallery: Newer images, audio, and video of the space shuttle program](http://spaceflight.nasa.gov/gallery/images/shuttle/index.html)
* [Older images of the space shuttle program](http://nix.larc.nasa.gov/search;?b=SC000249)
* [NASA History Series Publications](http://history.nasa.gov/series95.html) (many of which are on-line)

**Non-NASA**[[edit](http://en.wikipedia.org/w/index.php?title=Space_Shuttle&action=edit&section=36)]

* [Atlantis photo essay](http://www.boston.com/bigpicture/2010/05/first_of_the_last_space_shuttl.html) From Boston.com. (May 14, 2010)
* [Video of current and historical missions (STS-1 thru Current)](http://shuttlesource.com/)
* [Space Shuttle Newsgroup – sci.space.shuttle](news:sci.space.shuttle)
* [List of all Shuttle Landing Sites](http://www.globalsecurity.org/space/facility/sts-els.htm) and a [Map of Landing Sites](http://www.srh.noaa.gov/smg/lsitegif.htm)
* [Weather criteria for shuttle launch](http://chandra.harvard.edu/launch/status/weather_criteria2.html)
* [Different details and perspectives from the orbiter (Gallery drafts.de)](http://www.drafts.de/space_shuttle.htm) (ger.)
* [GRiD Compass History at Hrothgar's Cool Old Junk Page](http://pages.total.net/~hrothgar/museum/Compass/)
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