

# Handbook of Space Shuttle Missions & Space Shuttle Orbiters

Zayne Brown

Edgar Minton



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# Chapter 1

## STS-1

### STS-1

#### Mission insignia



#### Mission statistics

<b>Mission name</b>	STS-1
<b>Space shuttle</b>	<i>Columbia</i>
<b>Crew size</b>	2
<b>Launch pad</b>	Kennedy Space Center, Florida LC 39A
<b>Launch date</b>	12 April 1981 12:00:03 UTC
<b>Landing site</b>	Edwards AFB, Runway 23
<b>Landing</b>	14 April 1981 18:20:57 UTC
<b>Mission duration</b>	2d/6:20:53

<b>Number of orbits</b>	37
<b>Apogee</b>	156 mi (251 km)
<b>Perigee</b>	149 mi (240 km)
<b>Orbital period</b>	89.4 min
<b>Orbital altitude</b>	307 km (191 mi)
<b>Orbital inclination</b>	40.3 degrees
<b>Distance traveled</b>	1,728,000 kilometres (1,074,000 mi)

**Crew photo**



Crew members John W. Young (left) and Robert L. Crippen pose in ejection escape suits (EES) with small model of the space shuttle orbiter.

**STS-1** was the first orbital flight of the United States Space Shuttle, launched on 12 April 1981, and returning to Earth 14 April. Space Shuttle *Columbia* orbited the earth 37 times in this 54.5-hour mission. It was the first US manned space flight since the Apollo-Soyuz Test Project on 15 July 1975. STS-1 was the only US manned maiden test flight of a new spacecraft system, although it was the culmination of atmospheric testing of the Space Shuttle orbiter.

## Crew

<b>Position</b>	<b>Astronaut</b>
<b>Commander</b>	John W. Young Fifth spaceflight
<b>Pilot</b>	Robert Crippen First spaceflight

### Backup crew

<b>Position</b>	<b>Astronaut</b>
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**Commander**  
**Pilot**

Joe Engle  
Richard Truly

## Mission parameters

- **Mass:**
  - *Orbiter Liftoff:* 219,256 lb (99,453 kg)
  - *Orbiter Landing:* 195,466 lb (88,662 kg)
  - *DFI payload:* 10,822 lb (4,909 kg)
- **Perigee:** 149 mi (240 km)
- **Apogee:** 156 mi (251 km)
- **Inclination:** 40.3°
- **Period:** 89.4 min

## Mission highlights

The first launch of the Space Shuttle occurred on 12 April 1981, exactly 20 years after the first manned space flight, when the orbiter *Columbia*, with two crew members, astronauts John W. Young, commander, and Robert L. Crippen, pilot, lifted off from Pad A, Launch Complex 39, at the Kennedy Space Center — the first of 24 launches from Pad A. It was exactly 7 a.m. EST. A launch attempt 2 days earlier was scrubbed because of a timing problem in one of *Columbia*'s general purpose computers.

Not only was this the first launch of the Space Shuttle, but it marked the first time that solid-fuel rockets were used for a U.S. manned launch. (Note that all Mercury and Apollo astronauts had relied on a solid-fuel motor in the escape tower.) It was also the first U.S. manned space vehicle launched without an unmanned powered test flight. The STS-1 orbiter, *Columbia*, also holds the record for the amount of time spent in the Orbiter Processing Facility (OPF) before launch — 610 days, time needed for replacement of many of its heat shield tiles.

Primary mission objectives of the maiden flight were to check out the overall Shuttle system, accomplish a safe ascent into orbit and to return to Earth for a safe landing. The only payload carried on the mission was a Development Flight Instrumentation (DFI) package which contained sensors and measuring devices to record orbiter performance and the stresses that occurred during launch, ascent, orbital flight, descent and landing. All of these objectives were met successfully, and the Shuttle's worthiness as a space vehicle was verified.

During Day 2, the astronauts received a phone call from Vice President George H. W. Bush. President Ronald Reagan originally intended to visit the Mission Control Center during the mission, but was still recovering from an assassination attempt two weeks before launch.

The STS-1 Shuttle reached an orbital altitude of 166 nautical miles (307 km). The 37-orbit, 1,074,567-mile (1,729,348 km)-long flight lasted 2 days, 6 hours, 20 minutes and 53 seconds. Landing occurred on Runway 23 at Edwards Air Force Base, California at 10:21 a.m. PST, 14 April 1981. *Columbia* was returned to Kennedy Space Center from California on April 28 atop the Shuttle Carrier Aircraft.

## Mission anomalies



STS-1 touches down at Edwards Air Force Base

STS-1 was the first test flight of what was, at the time, probably the most complex spacecraft ever built. There were numerous problems – 'anomalies' in NASA parlance – on the flight, as many systems could not be adequately tested on the ground or independently. Some of the more serious or interesting were:

- A tile next to the right-hand External Tank (ET) door on the underside of the shuttle was incorrectly installed, leading to excessive re-entry heating and melting of part of the ET door latch.
- Inspection by astronauts while in orbit showed significant damage to the thermal protection tiles on the OMS/RCS pods at the orbiter aft end, and John Young reported that two tiles on the nose looked like someone had taken 'big bites out of them'. Post-flight inspection of *Columbia's* heat shield revealed that an overpressure wave from the Solid Rocket Booster (SRB) ignition resulted in the loss of 16 tiles and damage to 148 others.
- The same overpressure wave pushed the body flap below the main engines at the rear of the shuttle well past the point where damage to the hydraulic system would be expected, which would have made a safe re-entry impossible. The crew were unaware of this until after the flight, and John Young reportedly said that if they had been aware of the potential damage at the time, they would have flown the shuttle up to a safe altitude and ejected, causing *Columbia* to have been lost on the first flight.

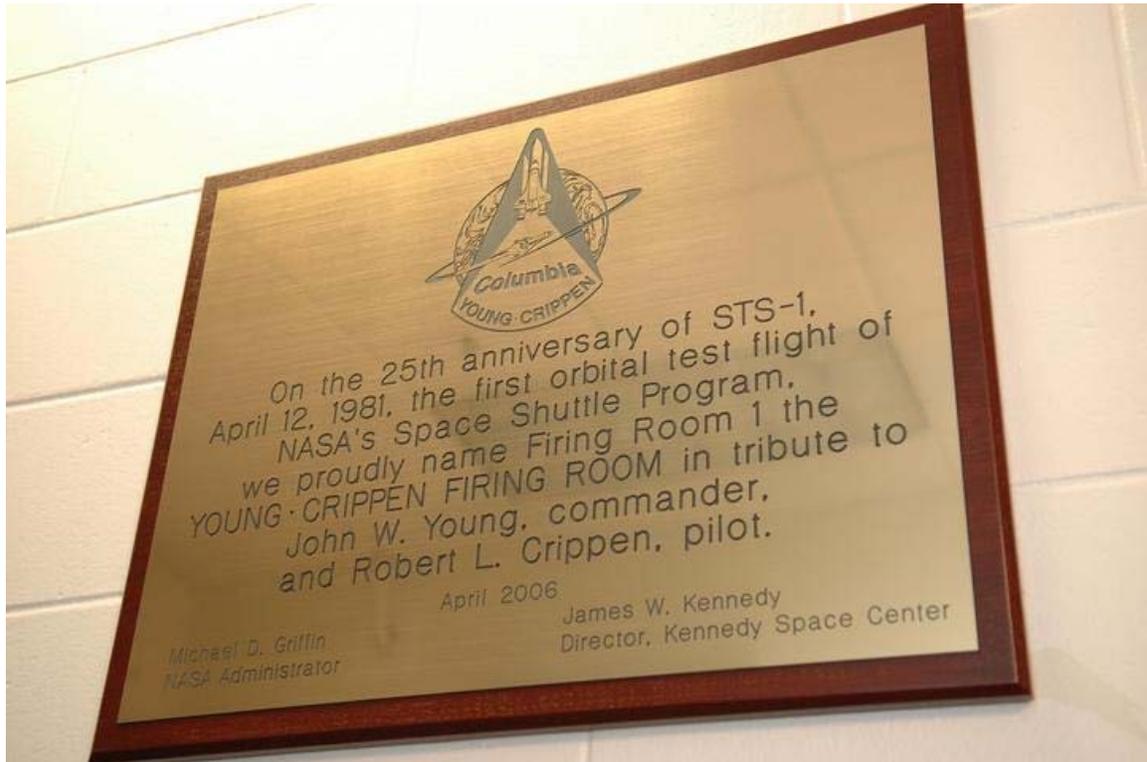
- Bob Crippen reported that all through the first stage of the launch up to SRB separation, he saw 'white stuff' coming off the External Tank and splattering the windows, which was probably the white paint covering the ET thermal foam.
- The toilet suffered from 'low urinal flow and a feces separation problem'.
- *Columbia's* aerodynamics at high Mach number were found to differ significantly in some respects from those estimated in pre-flight testing. A miscalculation of the location of the center of pressure (due to using an ideal gas model instead of a real gas model) caused the computer to extend the body flap by sixteen degrees rather than the expected eight or nine, and side-slip during the first bank reversal maneuver was twice as high as predicted.
- During remarks at a 2003 gathering, John Young stated that a protruding tile gap filler ducted hot gas into the right main landing gear well, which caused significant damage including buckling of the landing gear. Buckling of the door, but not the landing gear, is documented in the post-flight anomaly report.

Despite these problems, STS-1 was a successful test, and in most respects *Columbia* came through with flying colors. After some modifications to the shuttle and to the launch and re-entry procedures, *Columbia* would fly the next four Shuttle missions.

## **Mission insignia**

The artwork for the official mission insignia was designed by artist Robert McCall. It is a symbolic representation of the shuttle. The image does not depict the black wing roots present on the actual shuttle.

## Anniversary



The plaque of the Young-Crippen Firing Room in the Launch Control Center at Kennedy Space Center

The ultimate launch date of STS-1 fell on the 20th anniversary of Vostok 1, the first manned spaceflight. Another twenty years later, in 2001, Yuri's Night would be established to celebrate both events.

In tribute to the 25th anniversary of the first flight of Space Shuttle, Firing Room 1 in the Launch Control Center at Kennedy Space Center was renamed to the Young-Crippen Firing Room, dedicating the firing room that launched the historic flight and the crew of STS-1.

NASA described the mission as: *"The boldest test flight in history"*.

## External tank

STS-1 was one of only two shuttle flights to have its External Tank (ET) painted white. In an effort to reduce the Shuttle's overall weight, all flights from STS-3 onward used an unpainted tank. The use of an unpainted tank provides a weight savings of approximately 272 kilograms (600 lb), and gives the ET the distinctive orange color which is now associated with the Space Shuttle.

## Cultural references

The song "Countdown", by Rush, from the 1982 album *Signals*, was written about STS-1 and the inaugural flight of *Columbia*. The song was "dedicated with thanks to astronauts Young and Crippen and all the people of NASA for their inspiration and cooperation".

### *Hail Columbia!*

IMAX cameras filmed the launch, landing, and mission control during the flight, for a film entitled *Hail Columbia!*, which debuted in 1982 and is now available on DVD. The title of the film comes from the pre-1930s unofficial American national anthem, also titled *Hail, Columbia*.

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. This special musical track at the start of each day in space was chosen, sometimes by their families, to have a special meaning to an individual member of the crew or to the day's planned activities.

Flight Day	Song	Artist/Composer
Day 2	"Blast-Off Columbia"	Roy McCall
Day 3	"Reveille"	Houston DJs Hudson and Harrigan

## Chapter 2

# STS-126

### STS-126

#### Mission insignia



#### Mission statistics

<b>Mission name</b>	STS-126
<b>Space shuttle</b>	<i>Endeavour</i>
<b>Launch pad</b>	LC-39A
<b>Launch date</b>	14 November 2008 19:55 EST (Nov 15, 2008, 00:55 UTC)
<b>Landing</b>	30 November 2008 13:25:06 PST (21:25 UTC)
<b>Mission duration</b>	15 days, 20 hours, 30 minutes, 34 seconds
<b>Number of orbits</b>	251
<b>Orbital altitude</b>	Orbital insertion: 122 nautical miles (226 km), Rendezvous: 190 nautical miles (350 km)
<b>Orbital inclination</b>	51.6 degrees
<b>Distance traveled</b>	6,615,109 miles (10,645,986 km)

## Docking

**Docking date** 16 November 2008 22:01 UTC

**Undocking date** 28 November 2008 14:47 UTC

**Time docked** 11 days, 16 hours, 46 minutes

## Crew photo



From left to right: Magnus, Bowen, Pettit, Ferguson, Boe, Kimbrough and Stefanyshyn-Piper

## Related missions

### Previous mission

STS-124 

### Subsequent mission

STS-119 

**STS-126** was a Space Shuttle mission to the International Space Station (ISS) flown by Space Shuttle *Endeavour*. The purpose of the mission, referred to as **ULF2** by the ISS program, was to deliver equipment and supplies to the station, to service the Solar Alpha Rotary Joints (SARJ), and repair the problem in the starboard SARJ that had limited its use since STS-120. STS-126 launched on 14 November 2008 at 19:55:39 p.m. EST from Launch Pad 39A at NASA's Kennedy Space Center with no delays or issues. *Endeavour* successfully docked with the station on November 16. After spending 11 days, 16 hours, and 46 minutes docked to the station, during which the crew performed four spacewalks, and transferred cargo, the orbiter undocked on 28 November 2008. Due to poor weather at Kennedy Space Center, *Endeavour* landed at Edwards Air Force Base on 30 November 2008 at 21:25 UTC (13:25 PST).

# Crew

<b>Position</b>	<b>Launching Astronaut</b>	<b>Landing Astronaut</b>
<b>Commander</b>	Christopher Ferguson Second spaceflight	
<b>Pilot</b>	Eric A. Boe First spaceflight	
<b>Mission Specialist 1</b>	Heidemarie Stefanyshyn-Piper Second spaceflight	
<b>Mission Specialist 2</b>	Stephen G. Bowen First spaceflight	
<b>Mission Specialist 3</b>	Donald Pettit Second spaceflight	
<b>Mission Specialist 4</b>	Robert S. Kimbrough First spaceflight	
<b>Mission Specialist 5</b>	Sandra H. Magnus Expedition 18 Second spaceflight ISS Flight Engineer	Gregory Chamitoff Expedition 18 First spaceflight ISS Flight Engineer

## Crew notes

Originally scheduled to fly on STS-126 was Joan E. Higginbotham, who was a mission specialist on STS-116. On 21 November 2007, NASA announced a change in the crew manifest due to Higginbotham's decision to leave NASA to take a job in the private sector. Stephen G. Bowen was originally assigned to STS-124 but was moved to STS-126 to allow *Discovery* to rotate Greg Chamitoff with Garrett Reisman.

## Mission parameters

- **Mass:**
  - Orbiter liftoff: 266,894 pounds (121,061 kg)
  - Orbiter landing: 223,422 pounds (101,343 kg)
- **Perigee:** 185 nautical miles (343 km)
- **Apogee:** 190 nautical miles (350 km)
- **Inclination:** 51.6
- **Period:** 91.6 minutes

## Mission payloads

Location	Cargo	Mass
Bays 1-2	Orbiter Docking System EMU 3005 / EMU 3011	1,800 kilograms (4,000 lb) ~260 kilograms (570 lb)
Bay 3P	Shuttle Power Distribution Unit (SPDU)	~17 kilograms (37 lb)
Bay 3S	APC/SSPL Picosat launcher PSSC Picosats	50 kilograms (110 lb) 7 kilograms (15 lb)
Bay 7S	ROEU umbilical	~79 kilograms (170 lb)
Bay 7-12	Leonardo (MPLM FM-1)	12,748 kilograms (28,100 lb)
Bays 13	Lightweight MPES Carrier (LMC)	1,495 kilograms (3,300 lb)
Starboard Sill	Orbiter Boom Sensor System	~382 kilograms (840 lb)
Port Sill	Canadarm 201	410 kilograms (900 lb)
	<b>Total:</b>	<b>17,370 kilograms (38,300 lb)</b>

STS-126 was scheduled to be a sixteen day mission with four spacewalks, largely dedicated to servicing and repair of the Solar Alpha Rotary Joints (SARJ). An additional docked day was added to the flight plan to give the crew more time to complete their tasks. The starboard SARJ had shown anomalous behavior since August 2007, and its use has been minimized pending diagnosis and repair. Both the starboard and port SARJs were serviced. In addition to lubricating both bearings, the remaining 11 trundle bearings in the starboard SARJ were replaced. Trundle bearing assembly five was removed during an Expedition 16 EVA for further examination in December 2007.

STS-126 included the *Leonardo* Multi-Purpose Logistics Module (MPLM) on its fifth spaceflight. *Leonardo* held over 14,000 pounds of supplies and equipment. Among the items packed into the MPLM were two new crew quarters racks, a second galley (kitchen) for the *Destiny* laboratory, a second Waste and Hygiene Compartment (WHC) rack (lavatory), the advanced Resistive Exercise Device (aRED), two water reclamation racks, spare hardware, and new experiments. Also included in *Leonardo* was the General Laboratory Active Cryogenic ISS Experiment Refrigerator, or GLACIER, a double locker cryogenic freezer for transporting and preserving science experiments. The shuttle also carried irradiated turkey, candied yams, stuffing and dessert for a special Thanksgiving meal at the station, as well as an Official Flight Kit with mementos for those who supported the astronauts and helped them complete their mission successfully.

### Educational outreach

STS-126 carried the signatures of over 500,000 students that participated in the 2008 Student Signatures in Space program, jointly sponsored by NASA and Lockheed Martin. In celebration of Space Day last May, students from over 500 schools signed giant

posters, their signatures were scanned onto a disk, and the disk was flown on the STS-126 mission. The Student Signatures in Space project has been active since 1997, and has flown student signatures on seven other shuttle flights, starting with STS-86.

## **AgCam**

Also aboard STS-126 was the Agricultural Camera (AgCam) which was installed in the *Destiny* module and is used to assist farmers and provide educational opportunities for students around the country. Students and faculty at the University of North Dakota built the Agricultural Camera (AgCam), that was to be delivered and installed on the International Space Station. The students will operate the camera from their campus and work with NASA engineers and station astronauts to take visible and infrared light images of growing crops, grasslands, forests and wetlands in the Great Plains and Rocky Mountains regions.

The information from AgCam will provide data to agricultural producers in North Dakota and neighboring states, benefiting farmers and ranchers and providing ways for them to protect the environment. AgCam imagery also may assist in disaster management, such as flood monitoring and wild fire mapping.

## **Cow embryos in space**

STS-126 also flew the first bovine embryos on an American spacecraft for an experiment to evaluate effects of the environment of space on embryonic development. The project was a joint project of ZeroGravity Inc., University of Florida and USDA ARS.

## **Mission background**

The mission marks:

- 155th American manned space flight
- 124th shuttle mission since STS-1
- 99th post-*Challenger* mission
- 11th post-*Columbia* mission
- 22nd flight of *Endeavour*
- 27th shuttle mission to the ISS
- 31st night launch

## Shuttle processing



*Endeavour* at launch pad 39B prior to moving to pad 39A

Space Shuttle Endeavour was moved from the Orbiter Processing Facility (OPF-2) at Kennedy Space Center to the Vehicle Assembly Building on 11 September 2008. Rollout to launch pad 39B took place overnight on 18 September 2008 and was completed at 07:00EDT on 19 September 2008.

*Endeavour* was originally moved to launch pad 39B ahead of the normal schedule to be on standby as the Launch on Need (LON) flight for STS-125. In the event that something happened to *Atlantis* during its flight to service the Hubble Space Telescope, a rescue

flight could be performed with *Endeavour*. With both *Atlantis* and *Endeavour* on the pads, it was the 18th time that two flight-ready orbiters were in position at both launch pads at the same time.

On 29 September 2008, NASA announced that due to a problem with the Hubble telescope, they would be revising the manifest to postpone STS-125 until 2009, so a solution to the issue with the telescope could be integrated into the flight plan. This moved STS-126 to the next flight, so on 23 October 2008 *Endeavour* was moved from launch pad 39B to 39A.

The payload for STS-126, including the MPLM *Leonardo*, arrived at launch pad 39A early on 22 October 2008.

## Mission timeline

### Launch preparations



Space Shuttle *Endeavour* as it lifted off to begin the STS-126 mission to the International Space Station.

The countdown to launch began on 11 November 2008 and the crew flew in from Johnson Space Center to the Kennedy Space Center to prepare for the launch. On 12 November 2008, Mission Management Team (MMT) Chairman LeRoy Cain announced that the MMT gave the official "go" for *Endeavour's* launch on 13 November 2008 and Ferguson and Boe practiced landings in the Shuttle Training Aircraft. Weather reports on 13 November 2008 gave a seventy percent chance of acceptable weather conditions for launch.

### **November 14 (Flight day 1, Launch)**

Filling of the external tank with liquid hydrogen and liquid oxygen propellants started at 10:30 EST on 14 November 2008. After suiting up into the launch and entry suits, the crew left the Operations and Checkout building in the Astrovan and arrived at the launch pad at 16:22 EST. At 4:30 p.m., the crew began ingress into the orbiter, and by 17:25 EST, all crewmembers were in their seats and performed communications checks with the ground control personnel. At 18:00 EST, the closeout crew closed and locked *Endeavour's* hatch, and the orbiter's cabin was pressurized in preparation for launch. Despite a last minute issue with the white room closeout door not being fully secured, NASA Launch Director Mike Leinbach polled the team, determined the door did not pose a hazard to the orbiter or crew, and told the crew "Good luck, Godspeed and have a happy Thanksgiving in orbit." *Endeavour* lifted off on time at 19:55:39 EST (00:55 UTC). External tank separation occurred at 01:03 UTC.

After reaching orbit, the crew began working through the post-insertion timeline, which included opening the orbiter's payload bay doors, deploying the Ku band antenna, powering up and activating the shuttle robotic arm, and performing a burn of the Orbital Maneuvering System (OMS).

## November 15 (Flight day 2)



On November 15, Kimbrough stops for a photo while working on the aft flight deck of *Endeavour*.

The second day in space for the crew was devoted to completing the initial inspection of *Endeavour's* heat shield. Using the shuttle's robotic arm and the Orbiter Boom Sensor System (OBSS), the crew took detailed images of the exterior of the orbiter for the image analysis team to review. The crew also continued to prepare for docking with the station on Sunday, by extending the docking ring, installing the centerline camera, and organizing the tools needed for rendezvous with the station. The crew also performed a checkout of the spacesuits that will be used for the spacewalks during the mission.

During the Mission Management Team briefing, LeRoy Cain noted that upon initial review of the ascent imagery, a small piece of thermal blanket appeared to come loose under the left Orbital Maneuvering System (OMS) pod, but explained that the area is not in an area of concern, as it does not experience high heat during reentry. During the Mission Status briefing, lead Flight Director Mike Sarafin said that after having the crew focus the camera on the left OMS pod, it did not appear that there was any damage, but the image analysis team would take a closer look at the area.

Two issues with the orbiter's Ku antenna were noted by Cain, although he stated they would not impact the mission. The antenna was not handing over from Ku to S-band automatically as it should, which meant that teams on the ground had to manually switch the antenna from Ku to S Band and back again. Sarafin noted that this was likely a

software issue, and would not affect the crew on board, or the mission. The other issue had to do with the antenna's failure to "lock on" to satellite targets after being given the pointing data. Instead, the antenna was drifting, which meant that the teams on the ground would have to use an alternate method of pointing the antenna. There was a possibility that the shuttle crew would need to use a backup procedure during rendezvous with the station, but it was not a concern, and would not change the timeline, Cain noted.

### **November 16 (Flight day 3)**



Backdropped by a blue and white Earth, *Endeavour* prepares to perform the Rendezvous pitch maneuver prior to docking with the International Space Station.

After waking up, the crew set to work preparing for the rendezvous and docking with the station. The orbiter performed a final burn of the engines at 19:27 UTC to refine the approach, and by 21:00 UTC, the shuttle was in position below the station to allow the station crew to photograph the underside of the orbiter. Ferguson guided the shuttle manually through the Rendezvous pitch maneuver (RPM) while station crew used 400mm and 800mm cameras to take high-resolution images of the thermal tiles on *Endeavour*. The images were downlinked to NASA's image analysis team to assist in the evaluation of the thermal protection system of the orbiter. After the RPM was complete, Ferguson guided the orbiter into a safe docking at 22:01 UTC (17:01 EST), and the hatches were opened at 00:16 UTC (19:16 EST). Upon entering the station, Ferguson joked "Hey, we figured we'd go for a 10-year anniversary party for the space station, so that's what we showed up for." Ferguson was referring to the 20 November 1998 launch of Zarya, the first component of the International Space Station.

After the two crews exchanged greetings, they performed a safety briefing, and then set right to work, beginning transfers and preparing for robotic operations. At 02:50 UTC, Chamitoff and Magnus officially switched positions, with the swap of their Soyuz seatliners. Chamitoff joined the STS-126 crew as a Mission Specialist, and Magnus officially became the Flight Engineer 2 for Expedition 18.

During the mission status briefing, LeRoy Cain stated that the image analysis team was still evaluating the ascent imagery, but that the vehicle looked very clean, and the only event that was seen on launch, the area under the left OMS pod, appeared to have been ice. The images taken during the flight day two survey showed that all of the thermal blankets in that area were intact, as were the tiles. Cain stated that the item did not strike the orbiter, it was the only event that the Mission Management Team was still evaluating, and that the orbiter was in good shape. Mike Sarafin confirmed that the Ku band antenna performed properly in radar mode, and docking was carried out without any problems with the antenna.

#### **November 17 (Flight day 4)**



Following the docking of *Endeavour*, Expedition 18 crewmembers welcome the shuttle crew into the station.



Mission Specialist Stefanyshyn-Piper handles the Nitrogen Tank Assembly during EVA1.

Following the wake up call, the two crews began the procedures to move the *Leonardo* MPLM out of the orbiter's payload bay to install it on the Earth-facing port of the *Harmony* module. Using the station's robotic arm, Pettit and Kimbrough began maneuvering the 27,000 lb container around 16:45 UTC, and by at 18:04 UTC it was locked in place. After performing leak checks, the hatch was opened at 23:43 UTC. The crews took air samples and examined the container for any signs of condensation or shifting of the contents during launch. The container had no issues, and transfer of cargo between the container and the station began shortly after the hatch was opened. The team also worked on experiments that were flown with *Endeavour*, including one that involves observing spiders and butterflies in space. The experiment from Florida, Texas and

Colorado schoolchildren is being conducted to compare spider webs created in microgravity with those on Earth. The insects will be returned to Earth with the shuttle for additional study.

Later in the day, the crew members reviewed spacewalk procedures to prepare for the first of the four planned EVAs. Piper and Bowen began the protocol known as the "campout" prior to their sleep period. Camping out consists of spending the night in the *Quest* airlock at lower air pressure (10.2 psi) to lessen the time needed to acclimate to the environment in the spacesuits.

During the Mission Management Team briefing, LeRoy Cain confirmed that the orbiter's wing leading edge had been cleared, and that no focused inspection would be required. The time that was scheduled for that inspection on day six would instead be spent working on the station's new water reclamation unit. While the image analysis team was still reviewing the imagery from the day two inspection and RPM, Cain said the orbiter was "doing extremely well", and expected the image analysis team to clear it for re-entry within a day. Cain noted that the imagery from the external tank showed it to be extremely clean, with only three small areas of foam loss noted.

During the Mission Status briefing, ISS Deputy Program Manager Kirk Shireman noted the upcoming ten-year anniversary of the International Space Station. Shireman reviewed the progress and advancements that have come from the project, and reviewed some of the major milestones. Thirty Progress vehicles have visited the station, seventeen Soyuz vehicles, twenty-seven shuttles, and one Automated Transfer Vehicle (ATV). One hundred sixty-four people had visited the station from fourteen nations prior to STS-126, (167 once STS-126 docked) and on Thursday, the tenth anniversary, Shireman said the station will have orbited the Earth 57,509 times, for a total distance of over 1.3 billion miles.

## November 18 (Flight day 5)



The crew lock bag holding tools floats away from the space station during EVA 1

Following their post-sleep period, the crews set to work preparing for the first spacewalk of the mission. Stefanyshyn-Piper and Bowen were suited up and in the airlock ahead of schedule, and the EVA started at 18:09 UTC, with Piper becoming the first female Lead Spacewalker. While Piper was preparing to begin work on the SARJ, she noticed a significant amount of grease in her tool bag, "I think we had a grease gun explode in the large bag, because there's grease in the bag," Piper reported to Kimbrough, who was working inside the shuttle to help coordinate the EVA. Mission Control managers instructed Piper to clean up the grease using a dry wipe, and while she was doing the cleanup, one of the crew lock bags floated away. "I guess one of my crew lock bags was not transferred and it's loose," Piper told Kimbrough. The bag floated aft and starboard of the station, and did not pose a risk to the station or orbiter. After taking an inventory of the items inside the lost bag, managers on the ground determined that Bowen had all those items in his bag, and the two could share equipment. While it extended the EVA duration slightly, the major objectives were not changed, and all EVA tasks were accomplished. The estimated value of the lost tool bag was \$100,000 USD. It was not the first time that equipment had got away from spacewalkers, items lost in the past include tools, nuts and bolts, glue guns, cameras, cloths, and even a robotic arm. The United States Space Surveillance Network constantly monitors over 12,500 items in orbit around the Earth.

During the Mission Status Briefing, lead ISS Flight Director Ginger Kerrick noted that there was no way to know what caused the bag to come loose. "We don't know that this incident occurred because they forgot to tether something. We don't know if perhaps the hook just came loose inside the bag," Kerrick said. "You've got to remember, we are working with humans here and we are prone to human error. We do the best we can, and we learn from our mistakes." Kerrick noted that the team would be taking extra precautions to avoid any further problems with the grease guns, by attaching them to the outside of the bags instead of inside to prevent the plungers from being inadvertently activated.

### **November 19 (Flight day 6)**



Chamitoff and Magnus transfer one of the two new crew quarters racks. Visible on the back of the rack are the signatures of the members of the ground team that worked on the new equipment.

Flight day six was devoted to transfer operations, and the two crews worked through the morning to complete all the rack transfers. Magnus and Chamitoff successfully installed the two crew quarters racks into the *Harmony* node, and installed a rack with equipment to be returned to Earth into the MPLM. During the Mission Status briefing, Lead ISS Flight Director Ginger Kerrick noted that all the racks were now on station, and about 25% of the cargo transfers had been completed, which was slightly ahead of schedule. The two crews also began working on activating the Water Recovery System, so that samples of water from two areas could be taken and returned to Earth with *Endeavour*. The system's initial checkout was initiated, and water samples would be taken after

several days of operation. Later in the day, the two crews reviewed procedures for the mission's second EVA, and Stefanyshyn-Piper and Kimbrough would sleep in the station's airlock as part of the pre-EVA campout procedure.

### **November 20 (Flight day 7)**



Following the traditional joint crew news conference, shuttle and station crews posed for a group photo.

On the tenth anniversary of the International Space Station, Stefanyshyn-Piper and Kimbrough successfully conducted the mission's second spacewalk. The EVA was 6 hours and 45 minutes in duration, and all tasks were accomplished without complications. Two crew equipment carts were relocated in preparation for the arrival of the final set of solar arrays, the station's robotic arm was lubricated, and the work on the starboard SARJ continued. Inside the station, crewmembers continued to transfer cargo from *Leonardo* to the station, items to be returned to Earth into the MPLM, and continued the activation of the Water Recovery System.

### **November 21 (Flight day 8)**

Following the crew wake up call, the two crews set to work on the day's planned activities. Fincke and Magnus tested latches on the Exposed Facility Berthing Mechanism for the Japanese Kibo laboratory. Magnus continued with the installation of the Total Organic Carbon Analyzer (TOCA), while engineers on the ground worked through

troubleshooting of the Urine Processor Assembly. The component ran initially on Thursday evening, but shut itself down during that initial test, and shut down again the following morning after two hours of operations. Engineers were considering if the issue was a problem with the sensors, or with the centrifuge motor. At 17:10, Ferguson and Boe used the shuttle's engines to reboost the station's altitude, raising it by about one nautical mile to prepare for the next Progress arrival.

The two crews also participated in the traditional Joint Crew News Conference, answering questions from reporters around the world, and took the traditional crew photo. Cargo transfers continued between the vehicles, and the crew was about seventy-five percent complete with all transfers to and from the MPLM. After a bit of off-duty time, the two crews participated in an EVA review, in preparation for the mission's third spacewalk. Piper and Bowen spent the night in the *Quest* airlock for the campout prior to the next day's spacewalk.

### **November 22 (Flight day 9)**



Bowen works on the SARJ during the mission's third spacewalk

After awakening, the two crews set right to work preparing for the mission's third EVA, which began at 18:01 UTC. The entire spacewalk was devoted to completing the cleaning, lubrication, removal and replacement of the trundle bearings assemblies in the starboard SARJ. The final trundle bearing assembly installation was deferred to the fourth EVA, but all other tasks scheduled were accomplished without any issues. Stefanyshyn-Piper's fifth EVA moved her to the twenty-fifth spot in cumulative EVA time with thirty three hours, forty two minutes.

On the station, the crews continued to work on transfer operations, and continued work on the water reclamation system. During the Mission Status Briefing, lead ISS Flight Director Ginger Kerrick noted that a sample was taken from the Water Processor Assembly that contained 10% urine and 90% condensate, and would be returned to the ground with the shuttle. Kerrick noted that if activation of the system continued on schedule, a sample from the potable water dispenser would be taken on flight day eleven. The ground crew continued to troubleshoot the Urine Processor Assembly, looking at whether there is a sensor touching part of the system's centrifuge as it rotates, which might be causing it to slow down.

### **November 23 (Flight day 10)**



Mission Specialist Stephen Bowen during the mission's final spacewalk

The two crews continued transfer operations, and Finke and Pettit worked together to reconfigure the Urine Processing Assembly (UPA) to try to dampen any vibration that may be contributing to the unit's shutting down prematurely. The unit has continued to operate sporadically, shutting itself down after two to three hours of operations, and the engineers on the ground are still evaluating the possible causes and solutions. Managers

on the ground would make a decision Monday on whether to extend *Endeavour's* mission by one docked day, to help with the troubleshooting of the Water Recovery System (WRS). The *Endeavour* crew had several hours of off-duty time, and participated in media interviews.

### **November 24 (Flight day 11)**



Continuing a long standing tradition, Pilot Eric Boe places the STS-126 patch onto a wall in the *Unity* node of the International Space Station.

Following the wake up call, the two crews got to work preparing for the mission's final spacewalk. Bowen and Kimbrough officially began the EVA at 18:24 UTC. Shortly before the spacewalk began, managers on the ground radioed up to the crew that the Mission Management Team had approved an extra docked day of operations for the crews, extending the mission to sixteen days. The extra time was being given to allow the crews more time to resolve the issues with the Urine Processing Assembly. The spacewalk successfully concluded after 6 hours and 7 minutes, bringing the total time spent in EVA activities for the mission to 26 hours, 41 minutes.

### **November 25 (Flight day 12)**

The crews dedicated most of the day to completing the transfer of supplies from the space station to *Endeavour* and *Leonardo*. The starboard Solar Alpha Rotary Joint was automatically tracking the sun for the first time in more than a year during a three-hour, two-orbit test that was initiated at 10:55 UTC. The Urine Processor Assembly completed its second full five hour run.

During the Mission Status Briefing, International Space Station Program Manager Mike Suffredini noted that the water recycling system appeared to be functioning normally after the modifications performed by the crew on orbit. Additional water samples were taken, and the crew would be bringing home approximately six liters of sample water for extensive testing. The crew on the station would not be drinking any of the water until the engineers and scientists on the ground had a chance to thoroughly analyze the samples taken. Suffredini also noted that while the goal of the EVA activities to perform maintenance on the starboard SARJ was to allow it to operate "periodically", the initial test showed encouraging results, and the lubrication and other work done by the spacewalkers may allow for more routine operations than originally expected. It would be weeks before a more complete assessment could be given, the joint would need to be put through more testing, as well as analysis of the results from engineers on the ground, but Suffredini was encouraged by the initial results.

### **November 26 (Flight day 13)**



Commander Chris Ferguson continued the long standing tradition of placing the cloth patch for STS-126 crew in the *Zvezda* module.

Pettit and Kimbrough used the station's Canadarm2 to move *Leonardo* from the *Harmony* module and placed in the shuttle's cargo bay at 21:52 UTC. Stefanyshyn-Piper packed up equipment and supplies used for the four spacewalks and moved them to Endeavour for return, while Magnus continued work on the station's new regenerative life support system. She drained a condensate collection tank to create the optimum ratio of condensate and distillate from the Urine Processor Assembly (UPA), and gathered additional water samples for testing.

### **November 27 (Flight day 14)**

In their final day of joint operations, the two crews had some off-duty time, spoke to reporters, and shared a Thanksgiving Day meal together. Following the meal, the crews worked on last minute transfers, and gathered in the *Harmony* node to bid farewell. The hatches between the two vehicles were closed 23:31 UTC, with the crew of *Endeavour* reviewing the procedures and tools they would use the next day for undocking, scheduled for 14:47 UTC.

### **November 28 (Flight day 15)**

*Endeavour* undocked from the International Space Station at 14:47 UTC. The total docked time was 11 days, 16 hours, and 46 minutes, making it the second-longest docked shuttle mission to the station, after STS-123's 11 days, 20 hours and 36 minutes. Pilot Eric Boe maneuvered the shuttle through a flyaround inspection of the complex, but the final separation burn was delayed to avoid bringing the shuttle near the remains of a Russian Cosmos satellite that broke apart in March. While the burn would have only brought them about eleven kilometers from the debris, Flight Director Mike Sarafin noted during the Mission Status Briefing that "Per the flight rules, it was the safe course of action to not perform that burn." The burn was instead completed at 23:23 UTC. After separating from the station, the crew of *Endeavour* conducted an inspection of the shuttle's heat shield with the robotic arm.

### **November 29 (Flight day 16)**

Following the late inspection of *Endeavour's* heat shield, the Mission Management Team officially cleared the orbiter for re-entry. The crew spent the day preparing for landing, performing inspections and checkout of the shuttle's flight control surfaces and reaction control system thrusters. Near the end of the crew's day, a Department of Defense satellite, Picosat, was deployed. The satellite will test two new types of photovoltaic solar cells, to determine their effectiveness for generating power.

Due to a less than favorable forecast for Kennedy Space Center on Sunday that was not expected to improve by Monday, mission managers decided to call up Edwards Air Force Base for the first day of landing opportunities. There were two KSC opportunities, with two more opportunities for Edwards later in the day. If the first two opportunities at KSC were called off due to weather, Bryan Lunney, Entry Flight Director stated during the Mission Status Briefing that they would take the Edwards opportunities; the weather was

not likely to improve, so there would be no reason to delay landing for a day. The forecast at KSC called for thunderstorms within 30 miles of the landing site, as well as high crosswinds, both conditions that would violate the weather constraints for landing.

**November 30 (Flight day 17)**



Space shuttle *Endeavour* and the STS-126 crew land at Edwards Air Force Base, Calif. after completing a mission to the International Space Station.



*Endeavour* lands back at Kennedy Space Center atop the 747 Shuttle Carrier Aircraft

After awakening, the crew of *Endeavour* got to work preparing for reentry. While working through the deorbit timeline, Entry Flight Director Bryan Lunney, after reviewing the weather, waved off the first KSC landing opportunity due to excessive crosswinds on the runway. After evaluating the weather, the second KSC landing opportunity was also waived off, as the weather was "no go" and forecasted "no go" per the landing weather requirements. Lunney continued to watch the weather for possible changes in Monday's weather forecast prior to making the decision whether to land at Edwards, or wait one day to get a Kennedy landing, but following further analysis of the projected weather in Florida for Monday, Lunney decided to take the first Edwards Air Force Base landing opportunity. The deorbit burn was initiated at 20:19 UTC (12:19 PST), and the orbiter landed at Edwards Air Force Base at 21:25 UTC (13:25 PST).

*Endeavour* was the first and last orbiter to land on the temporary runway 04 at Edwards AFB, as the main runway was completing refurbishment. The use of the temporary runway required new braking and rollout techniques that have never been used before, as the runway is three thousand feet shorter than the normal runway.

Endeavour was returned to Florida on top of one of NASA's Shuttle Carrier Aircraft, arriving back at the Kennedy Space Center 12 December 2008 after a three day cross-country trip.

## Extra-vehicular activity

Four spacewalks were scheduled and completed during STS-126. The cumulative time in extra-vehicular activity during the mission was 26 hours and 41 minutes.

EVA #	Spacewalkers	Start (UTC)	End (UTC)	Duration
EVA 1	Heidemarie Stefanyshyn-Piper Stephen G. Bowen	18 November 18:09	19 November 01:01	6 hours, 52 minutes
	Transferred an empty nitrogen tank assembly from ESP-3 to the shuttle's cargo bay, transferred a new flex hose rotary coupler to ESP-3 for future use, removed an insulation cover on the <i>Kibo</i> External Facility berthing mechanism, began cleaning and lubrication of the starboard SARJ, and replacement of eleven trundle bearing assemblies.			
EVA 2	Stefanyshyn-Piper Robert S. Kimbrough	20 November 17:58	21 November 00:43	6 hours, 45 minutes
	Relocated two Crew and Equipment Translation Aid (CETA) carts from the starboard side of the Mobile Transporter to the port side, lubricated the station robotic arm's Latching End Effector (LEE) "A" snare bearings, continued cleaning and lubrication of the starboard SARJ.			
EVA 3	Stefanyshyn-Piper Bowen	22 November 18:01	23 November 00:58	6 hours, 57 minutes
	Completed cleaning, lubrication, and replacement of all but one of the trundle bearing assemblies on the starboard SARJ. The final TBA will be replaced during EVA 4.			
EVA 4	Bowen Kimbrough	24 November 18:24	25 November 00:31	6 hours, 7 minutes
	Completed replacement of trundle bearing assemblies on starboard SARJ, lubricated the port SARJ, installed a video camera, re - installed insulation covers on the <i>Kibo</i> External Facility berthing mechanism, performed <i>Kibo</i> robotic arm grounding tab maintenance, installed spacewalk handrails on <i>Kibo</i> , installed Global Positioning Satellite (GPS) antennae on <i>Kibo</i> , photographed radiators, and photographed trailing umbilical system cables.			

# Chapter 3

## STS-127

### STS-127

#### Mission insignia



#### Mission statistics

<b>Mission name</b>	STS-127
<b>Space shuttle</b>	<i>Endeavour</i>
<b>Launch pad</b>	LC-39A
<b>Launch date</b>	15 July 2009, 18:03:10 EDT (22:03 UTC)
<b>Landing</b>	31 July 2009, 10:48 EDT (14:48 UTC)
<b>Mission duration</b>	15 days, 16 hours, 44 minutes, 58 seconds
<b>Number of orbits</b>	248
<b>Orbital period</b>	94 minutes
<b>Orbital altitude</b>	356 kilometres (221 mi) (221 statute miles)
<b>Orbital inclination</b>	51.6 degrees
<b>Distance traveled</b>	10,537,748 kilometres (6,547,853 mi)

#### Docking

<b>Docking date</b>	17 July 2009 17:47 UTC
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**Undocking date** 28 July 2009 17:26 UTC

**Time docked** 10 days, 23 hours, 41 minutes

### Crew photo



From left to right: Wolf, Cassidy, Hurley, Payette, Polansky, Marshburn, and Kopra

### Related missions

#### Previous mission



STS-125

#### Subsequent mission



STS-128

**STS-127** (ISS assembly flight **2J/A**) was a space shuttle mission to the International Space Station (ISS). It was the twenty-third flight of Space Shuttle *Endeavour*. The primary purpose of the STS-127 mission was to deliver and install the final two components of the Japanese Experiment Module: the Exposed Facility (JEM EF), and the Exposed Section of the Experiment Logistics Module (ELM-ES). When *Endeavour* docked with ISS, it set a record for the most humans in space at the same time in the same vehicle, the first time thirteen people have been at the station at the same time. It also tied the record of thirteen people in space at any one time.

The first launch attempt, on 13 June 2009, was scrubbed due to a gaseous hydrogen leak observed during tanking. The Ground Umbilical Carrier Plate (GUCP) on the external fuel tank experienced a potentially hazardous hydrogen gas leak similar to the fault that delayed the Space Shuttle *Discovery*, mission STS-119 in March 2009. Since a launch date of 18 June 2009 would have conflicted with the launch of the Lunar Reconnaissance Orbiter (LRO)/Lunar Crater Observation and Sensing Satellite (LCROSS), NASA managers discussed the scheduling conflict with both the Lunar Reconnaissance Orbiter project and the Air Force Eastern Range, which provides tracking support for rockets launched from Florida. A decision was made to allow the shuttle to attempt a second launch on 17 June 2009, allowing LRO to launch on June 18, 2009.

The second launch attempt on 17 June 2009 was also scrubbed due to hydrogen leak issues seen from the Ground Umbilical Carrier Plate. Due to conflicts with the launch of the LRO, and due to a solar heating in space constraint, the next available launch opportunity was scheduled for 11 July 2009. A successful tanking test for leak checks

was performed on 1 July 2009, with modified GUCP seals allowing launch preparations to proceed as scheduled. Because of lightning strikes near the launch pad during the evening of 10 July 2009, NASA scrubbed the launch for the third time and rescheduled for 12 July 2009. Due to a Return To Launch Site (RTLS) weather violation on the evening of 12 July 2009, NASA scrubbed the launch for the fourth time.

STS-127's fifth launch attempt on 13 July 2009 was also scrubbed due to anvil clouds and lightning within 10 nautical miles (19 km) of the launch site, which violated launch safety rules. STS-127's sixth launch attempt was successful, on 15 July 2009 at 18:03 EDT. Pieces of foam were observed falling off of the External Tank during launch, as happened when the space shuttle Columbia was lost. In this instance Endeavour only received minor scuffs to the heat shield, which were found to be of no concern to a safe reentry. The shuttle landed at Kennedy Space Center at 10:48 EDT on 31 July 2009 after a 16 day mission.

## Crew

<b>Position</b>	<b>Launching Astronaut</b>	<b>Landing Astronaut</b>
<b>Commander</b>	Mark L. Polansky Third spaceflight	
<b>Pilot</b>	Douglas G. Hurley First spaceflight	
<b>Mission Specialist 1</b>	Christopher J. Cassidy First spaceflight EV3	
<b>Mission Specialist 2</b>	Julie Payette, CSA Second spaceflight Flight Engineer	
<b>Mission Specialist 3</b>	Thomas H. Marshburn First spaceflight EV4	
<b>Mission Specialist 4</b>	David Wolf Fourth spaceflight Lead Spacewalker EV1	
<b>Mission Specialist 5</b>	Timothy Kopra Expedition 20 First spaceflight EV2	Koichi Wakata, JAXA Expedition 20 Third spaceflight

STS-127 marked the first time that two Canadian astronauts, Robert Thirsk and Julie Payette, were in space at the same time.

Christopher Cassidy was the 500th person to fly in space.

## Mission payload



Payload bay of the shuttle being loaded

Location	Cargo	Mass
Bays 1-2	Orbiter Docking System EMU 3003 / EMU 3018 SpaceX DragonEye LIDAR	1,800 kilograms (4,000 lb) ~260 kilograms (570 lb)
Bay 3P	Shuttle Power Distribution Unit (SPDU)	~17 kilograms (37 lb)
Bay 3S	APC/SSPL Dragonsat	51 kilograms (110 lb) 6 k
Bays 4-7	Kibo JEM Exposed Facility	3,820 kilograms (8,400 lb)
Bay 5P	APC/ECSH	~33 kilograms (73 lb)

Bay 5S	APC/PPSU	20 kilograms (44 lb)
Bay 6S	APC/PPSU	20 kilograms (44 lb)
Bays 8-9	Kibo ELM Exposed Section	2,453 kilograms (5,410 lb)
Bay 11	ICC-VLD	3,946 kilograms (8,700 lb)
Bay 13P	APC/ECSH	~33 kilograms (73 lb)
Bay 13S	SPA/CAPE/ANDE-2	265 kilograms (580 lb)
	ICU container	54 kilograms (120 lb)
	ANDE Active satellite	50 kilograms (110 lb)
	ANDE Passive satellite	25 kilograms (55 lb)
Starboard Sill Orbiter Boom Sensor System		~382 kilograms (840 lb)
Port Sill	Canadarm	410 kilograms (900 lb)
	<b>Total:</b>	<b>13,645 kilograms (30,080 lb)</b>

*Endeavour* carried a wide variety of equipment and cargo in the payload bay, with the largest item being the *Kibo* Japanese Experiment Module Exposed Facility (JEM EF), and the *Kibo* Japanese Experiment Logistics Module - Exposed Section (ELM-ES). The exposed facility is a part of *Kibo* that will allow astronauts to perform science experiments that are exposed to the vacuum of space. The exposed section is similar to the logistics module on the *Kibo* laboratory, but is not pressurized. Once its payloads are transferred to the JEM EF, the ELM-ES will be returned to the payload bay.

Also inside the payload bay was a Integrated Cargo Carrier that contains a variety of equipment and spare components for the station. The carrier contained six new batteries for installation on the P6 truss, that was installed during two of the mission's spacewalks, as well as a spare space-to-ground antenna and a spare linear drive unit and pump module which was stored on an external stowage platform on the station's truss during one of the spacewalks.

Two satellites were also carried by the orbiter, for deployment when the mission ended. The Dual Autonomous Global Positioning System On-Orbit Navigator Satellite, called DRAGONSAT, gathered data on autonomous spacecraft rendezvous and docking capabilities, and consists of two picosatellites, the AggieSat2, and PARADIGM (BEVO-1), which acquire GPS data from a device at NASA and send it to ground stations at Texas A&M University and the University of Texas at Austin. After release, the two picosatellites remained attached for two orbits to collect GPS data, and separate during the third orbit.

A second satellite, the Atmospheric Neutral Density Experiment (ANDE-2), is part of a United States Department of Defense project flown by the Naval Research Laboratory to provide high-quality satellites, and will measure the density and composition of the low Earth orbit atmosphere while being tracked from the ground, to better predict the movement and decay of objects in orbit. ANDE-2 consists of two spherical microsatellites, ANDE Active spacecraft (Castor) and the ANDE Passive spacecraft (Pollux), and will be tracked by the International Laser Ranging Service (ILRS) network

as well as the Space Surveillance Network (SSN). One of the satellites, Pollux, is running Arduino libraries, with its payload programmed and built by students.

A set of experiments to be deployed on the ISS were carried by STS-127, namely Dosimetry for Biological Experiments in Space (ESA), Validation of Procedures for Monitoring Crew Member Immune Function, the student-made Image Reversal in Space (CSA/ISU), Nutritional Status Assessment (NASA), NASA Biological Specimen Repository and Tomatosphere-II (CSA).

The STS-127 Official Flight Kit (OFK) includes water samples from each of the five Great Lakes, a resin statue of a water droplet for the One Drop Foundation and a copy of Beethoven's Fifth Symphony for the Montreal Symphony Orchestra, among other mementos.

The docking module was also mounted with the DragonEye LIDAR ranging system by SpaceX. The module was launched to test the docking system which will be used by the commercial SpaceX Dragon re-usable cargo carrier to send supplies to the ISS during the post-shuttle era. The Dragon module is scheduled for its first launch in 2010.

## Mission background



Mission poster

The mission marks:

- 158<sup>th</sup> American manned space flight
- 128<sup>th</sup> Space Shuttle mission
- 127<sup>th</sup> shuttle mission since STS-1
- 23<sup>rd</sup> flight of space shuttle *Endeavour*
- 29<sup>th</sup> shuttle mission to the ISS
- 102<sup>nd</sup> post-*Challenger* mission
- 14<sup>th</sup> post-*Columbia* mission
- 1<sup>st</sup> time that two Canadians have been in space at the same moment

## Shuttle processing



*Endeavour* at Launch Pad 39A

*Endeavour* served as the STS-400 rescue vehicle for STS-125, and was prepared for a possible liftoff from Launch Pad 39B on 15 May 2009, four days after the launch of STS-125. After *Atlantis* performed the late inspection and was cleared for re-entry, *Endeavour* was officially released from stand-by status on 21 May 2009, and preparations for STS-127 were initiated.

*Endeavour* moved from Launch Pad 39B to 39A on 31 May 2009 in preparation for STS-127. The crew of STS-127 arrived at Kennedy Space Center on 2 June 2009, for the

Terminal Countdown Demonstration Test (TCDT) that concluded with a full launch dress rehearsal. The Flight Readiness Review (FRR), a meeting during which NASA managers assess mission preparations and officially set the launch date, concluded on 3 June 2009. For the first time, live status updates about the FRR were published periodically during the meeting via NASA's Twitter stream.

## Launch attempts



Close-up view of the Ground Umbilical Carrier Plate on STS-127's external tank during the first maintenance effort

The launch countdown began 10 June 2009, but on 13 June 2009, as tanking was underway, a gaseous hydrogen leak on a vent line near the Ground Umbilical Carrier Plate was observed, and the 13 June 2009 launch was scrubbed at 00:26 EDT. As liquid hydrogen fuel is pumped in, some of it boils off as the extremely cold liquid enters the warm external tank. The vent line valve controls the resulting buildup of gas pressure by allowing excess gas to escape into a ground-side vent line, which leads to a flare stack at a safe distance away from the pad. A similar leak situation was seen during the first launch attempt of STS-119. NASA managers met on 14 June 2009 and 15 June 2009 and evaluated the leak, discussed steps that had to be taken, and set a new launch date of 17 June 2009, at 05:40 EDT.

A second launch attempt was made on 17 June 2009 for which NASA moved the planned launch of the Lunar Reconnaissance Orbiter to a new date. On 17 June 2009 loading of

the shuttle's external tank with liquid hydrogen and liquid oxygen was delayed three hours due to poor weather around the launch site, but tanking began once the weather cleared. Approximately two hours after tanking began, engineers saw leak indications in the GUCP similar to those seen during the first launch attempt. The launch was officially scrubbed at 01:55 EDT.

Following the launch scrub, Chairman of NASA's Mission Management Team LeRoy Cain noted that engineers would work to understand the hydrogen leak issue and come up with a solution to the problem. Cain said managers were hopeful that the issue could be resolved in time for the next available launch opportunity on 11 July 2009. Due to the delay of STS-127, managers noted that it was likely that the launch of STS-128 on 7 August 2009, would be pushed back slightly.



Lightning strikes *Endeavour's* Launch Pad

On 1 July 2009, the shuttle managers conducted a new series of tanking tests to confirm a hypothesis that a misaligned vent port housing was the root cause of the leaks. The existing rigid seal was replaced with a flexible one in the hope that it would maintain a tight fix even under the cryogenic conditions that seem to cause the leak. The test was declared a success with no leaks detected on the GUCP. The mission was announced to be targeting a 11 July 2009 launch. On the evening of 10 July 2009 the launch pad region was hit by eleven strikes of lightning, which pushed back the 11 July 2009 launch

time by at least 24 hours. Two of the strikes were strong enough to trigger an evaluation by NASA engineers. The inspections revealed that no damage had been done to the space shuttle.

NASA scrubbed *Endeavour*' 12 July 2009 launch attempt at T-minus 9 minutes and holding due to Cumulus clouds and lightning near the launch pad. During the final Go/No-Go polls, Mission Control in Houston declared a "No-Go" due to unacceptable weather forecast for a possible Return-To-Launch-Site (RTLS) abort, and planned for emergency scenarios when one or more engines shut down early leaving insufficient energy to reach the Transatlantic Abort Landing (TAL) sites. Similarly, during the 13 July 2009 attempt, RTLS weather was also "no go." Meanwhile, shuttle weather officer Kathy Winters informed the launch director, Pete Nickolenko, that the launch pad weather had changed to RED as the Phase-1 Lightning warning was issued for the Kennedy Space Center. The launch was scrubbed at T-minus 9 minutes and holding and was quickly reset for 15 July 2009 (a 48 hours scrub turn around) due to weather concerns on the 14 July 2009 and the desire to replace the Tyvek covers over the forward Reaction Control System thrusters.

Attempt	Planned	Result	Turnaround	Reason	Decision point	Weather go %	Notes
1	13 Jun 2009, 7:17:19 am	scrubbed ---		technical	13 Jun 2009, 12:26 am	90%	gaseous hydrogen leak on a vent line near the Ground Umbilical Carrier Plate
2	17 Jun 2009, 5:40:52 am	scrubbed	3 days, 22 hours, 24 minutes	technical	17 Jun 2009, 1:55 am	80%	leak persisted
3	11 Jul 2009, 7:39:38 pm	scrubbed	24 days, 13 hours, 59 minutes	weather		40%	lightning strikes to launch pad
4	12 Jul 2009, 7:13:55 pm	scrubbed	0 days, 23 hours, 34 minutes	weather	(T-9:00 hold)	70%	RTLS concerns, cumulus clouds and lightning near launch pad

5	13 Jul 2009, 6:51:24 pm	scrubbed	0 days, 23 hours, 37 minutes	weather (T-9:00 hold)	40%	Phase-1 Lightning warning at the launch site
6	15 Jul 2009, 6:03:10pm	success	1 days, 23 hours, 12 minutes		60%	

## Mission timeline

### July 15 (Flight Day 1, Launch)



Liftoff of space shuttle Endeavour from Launch Pad 39A

On 15 July 2009 at 18:03:10 EDT, the launch was finally successful. Upon reviewing the launch video footage, imagery analysts noted eight or nine instances of foam shedding from the External Tank. The pictures of the external tank taken when jettisoning showed loss of foam in the intertank ribbing. The chairman of the Mission Management Team was not concerned and felt that the Space Shuttle would be cleared for re-entry on its return voyage—which it was a few days later. The payload doors were opened after reaching orbit followed by deployment of the K<sub>u</sub> band antenna and activation of the shuttle's mechanical arm.

## July 16 (Flight Day 2)



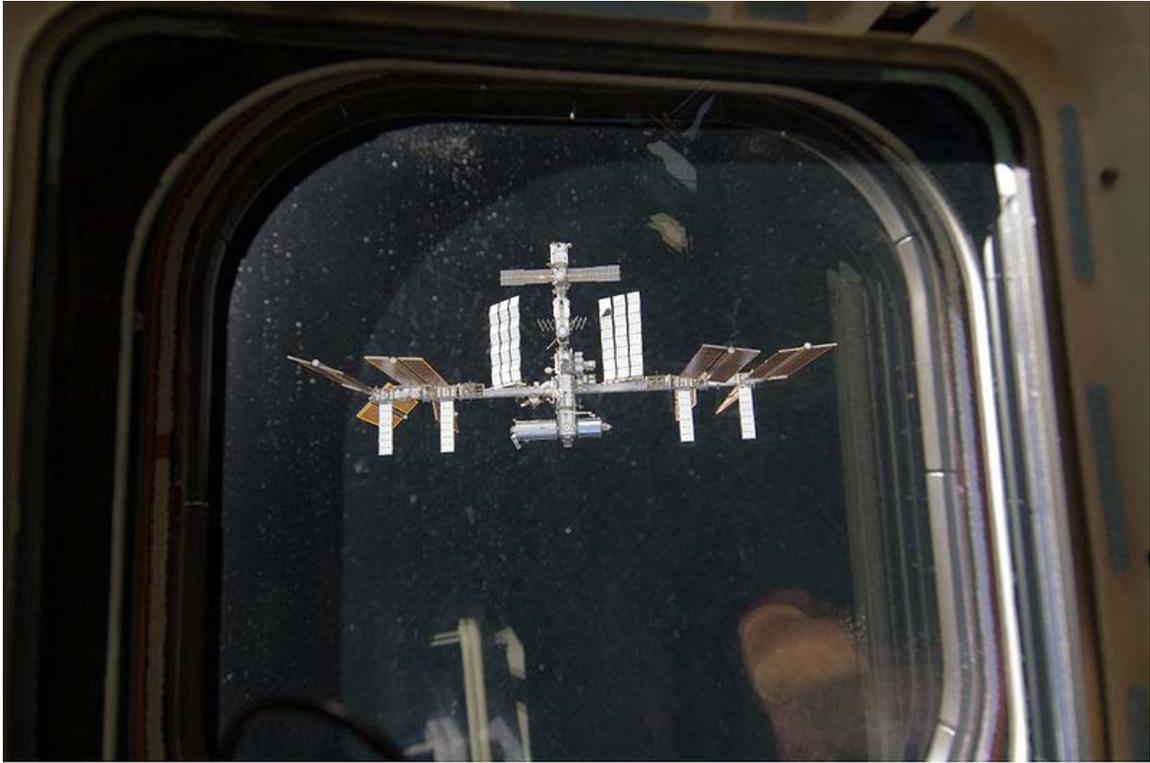
Julie Payette looks through an overhead window while operating controls on the aft flight deck of Endeavour during flight day two activities.

The thermal protection system was inspected with the Shuttle Robotic Arm/Orbiter Boom Sensor System (OBSS) and the voluminous data downlinked for analysis. The orbital maneuvering system pods were inspected for tile damage or protruding tiles. The extravehicular mobility units were checked in addition to the rendezvous system tests and centerline camera installation. In preparation for the docking, the docking ring was extended.

## July 17 (Flight Day 3, ISS Docking)

The shuttle successfully docked with the station 220 miles (350 km) above Earth following a rendezvous pitch maneuver (RPM) photography of Endeavour's thermal protection system by the Expedition 20 Crew. During this procedure, the shuttle flips over on its back to the station so that the station crew can capture high resolution imagery of the underside of the shuttle. The docking happened on the ISS's PMA-2 (Pressurized Mating Adapter) on the Harmony module and the hatch was opened after leak checks. As part of the crew swap, station crew member Koichi Wakata was replaced with Tim Kopra. The two astronauts specially fitted seatliners were interchanged. As part of preparation for EVA 1, astronauts Wolf and Kopra camped out in the Quest airlock. A quick review of the RPM imagery showed no serious concerns beyond two instances of

coating loss. Further analysis of the imagery will be done. A boost of the station was completed with the shuttles vernier thrusters to avoid a piece of space debris. The SRBs were retrieved and their camera imagery is expected to give more detail on the ET foam shedding.



One of Endeavour's aft flight deck windows frames the nearby International Space Station



Astronaut Christopher Cassidy uses a rangefinder to determine the distance to ISS before docking



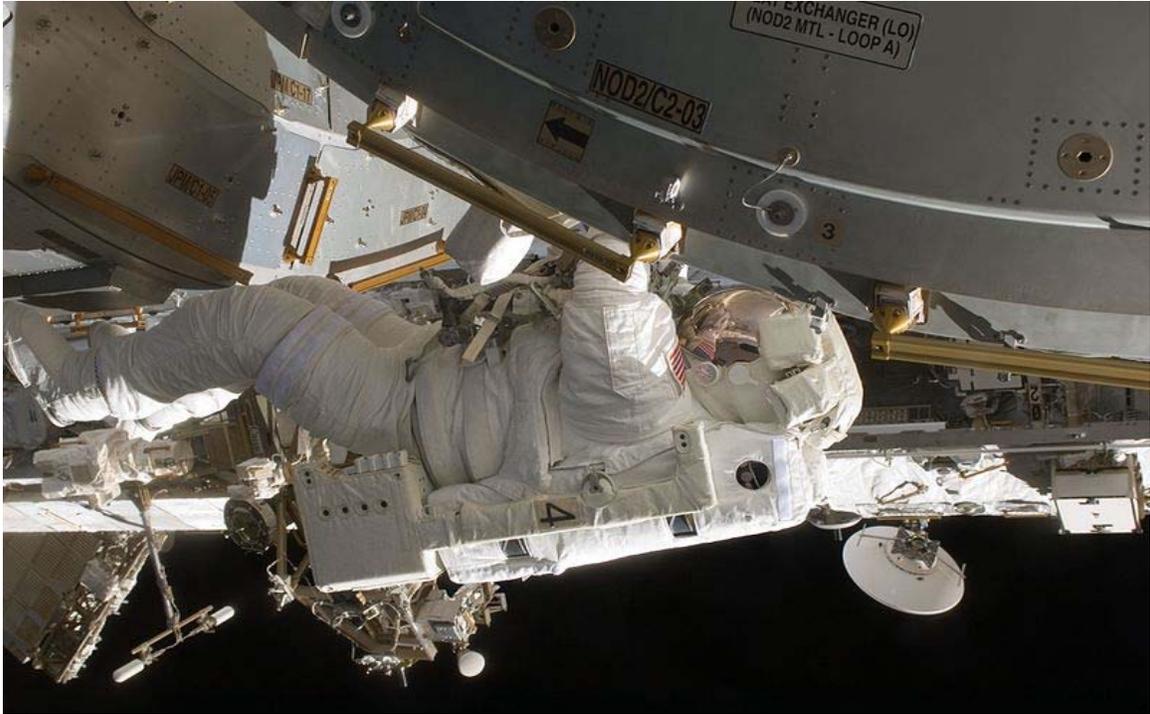
Endeavour as seen from ISS before docking. Payload including JEF and ICC-VLD visible in the shuttle bay



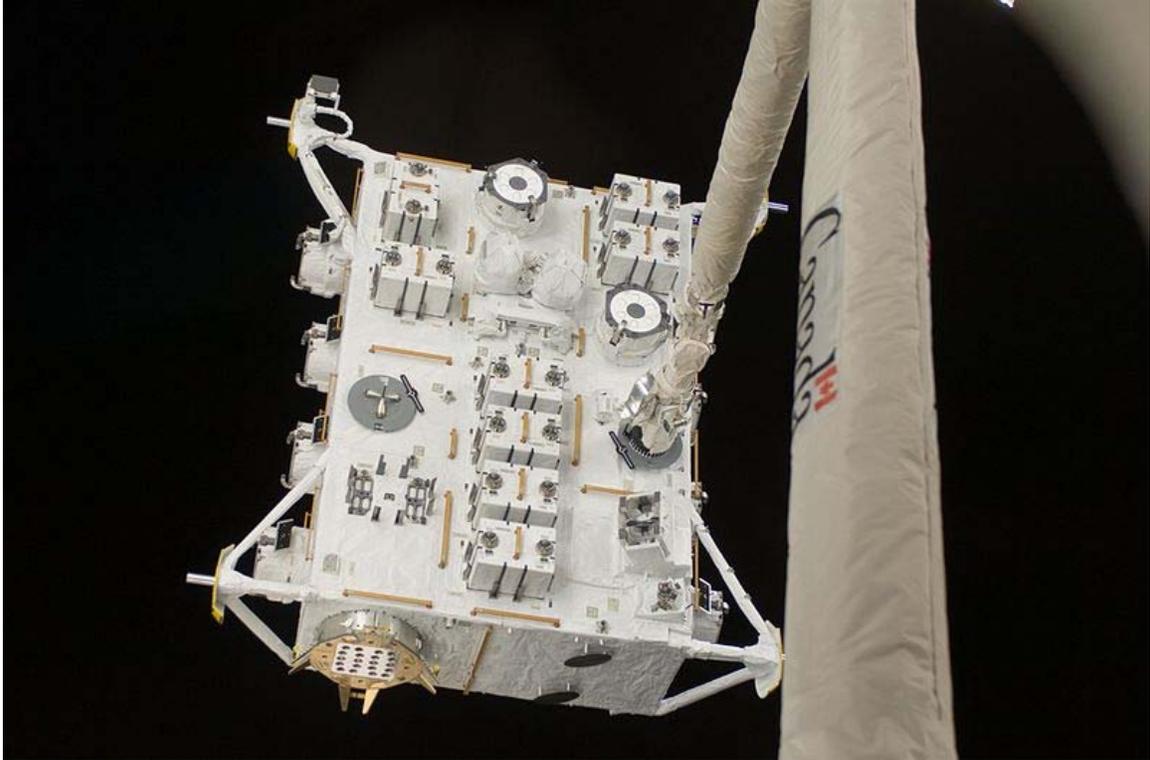
RPM image of Endeavour as taken from ISS

### **July 18 (Flight Day 4, Spacewalk 1)**

EVA 1 started with astronauts Dave Wolf and Tim Kopra switching their spacesuit power to internal battery at 16:19 UTC. Despite a communication problem with the spacewalkers, the Japanese Exposed Facility was successfully installed on the Japanese Experiment Module by means of a complex series of steps involving the robotic arms of both the station and the shuttle. The JEF was first unberthed from the shuttle payload bay by the station arm following which the shuttle arm took the load. The station arm was then moved to the worksite on Node-2 (Harmony) from which it took the 4.1 ton facility back. The facility was then successfully latched on to the Experiment Module. As part of the EVA, the spacewalkers successfully deployed the port Unpressurized Cargo Carrier Attach System (UCCAS), which could not be completed during STS-119. During the prior mission, the deployment failed due to a jamming caused by a stuck detent pin. Engineers designed a custom tool to force the pin to release which was used to deploy the mechanism. Meanwhile the shuttle managers announced that there will be no need for a focused inspection of the heat shield. The nose cap and wing leading edge panels of the shuttle are cleared for entry as is but a reentry clearance was not given. Beyond one impact site having a gouge, the rest of the impacts were found to be mostly a loss of coating. The other activity scheduled for EVA 1, the deployment of a starboard side cargo carrier, was postponed for want of time. A fuel cell issue found before launch is still being analyzed, though it continues to function as expected with no impact to the mission.



Tim Kopra working to prepare the berthing mechanisms on the Kibo laboratory and the Japanese Exposed Facility (JEF) for the JEF installation on Kibo, during space walk 1.



JEF in the grasp of the shuttle's robotic arm

## July 19 (Flight Day 5)



ICC handoff by shuttle's robotic arm

The installation of the Integrated Cargo Carrier-Vertical Light Deployable (ICC-VLD) on the port side of the station was successfully completed with the use of both the shuttle and station robotic arms. The cargo pallet, containing spares and fresh batteries for the station, was lifted out of the shuttle bay by the shuttle arm and handed off to the station's Canadarm2 which maneuvered it to its position. The pallet's contents will be setup in upcoming EVAs. A malfunction in a new toilet in the Destiny laboratory caused the crew to use the one in the Russian segment while attempts were made to identify the fault. Meanwhile the shuttle was cleared for reentry.

## July 20 (Flight Day 6, Spacewalk 2)

Astronauts Wolf and Marshburn began EVA 2 at 15:27 UTC out of the Quest airlock. The EVA was to transfer the spare components brought by the shuttle from the ICC-VLD to External Stowage Platform-3. The spares were handled by Wolf riding the station's robotic arm to the P3 truss stowage platform where he and Marshburn attached them for long term storage. The purpose of the spares was to provide redundancy to the station in the period following the shuttle's retirement. The spares unloaded include a Ku-Band Space-to-Ground antenna, a pump module for the coolant system and a drive unit for the station's robotic arm's mobile transporter. A planned installation of a camera on the Japanese Experiment Facility was postponed to a future EVA for want of time.

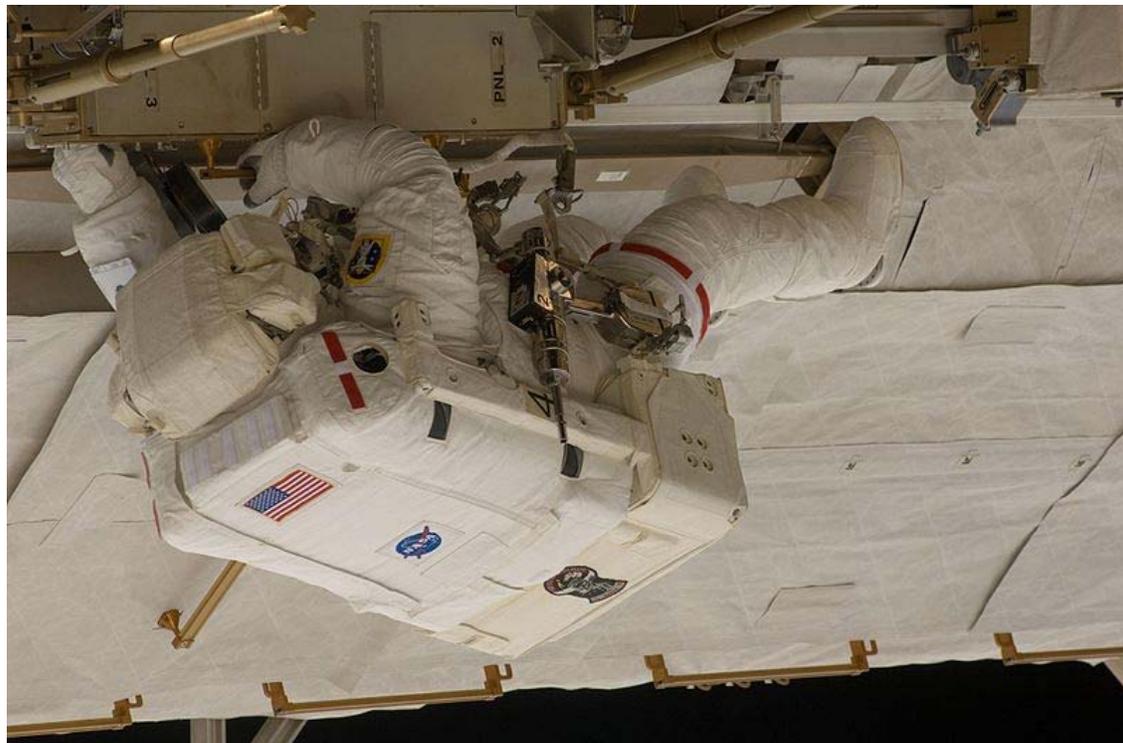
Meanwhile the malfunctioning toilet was set right with the replacement of internal parts and cleared for normal use after tests.



Dave Wolf performs his second space walk, which is also the second of five scheduled space walks for STS-127.

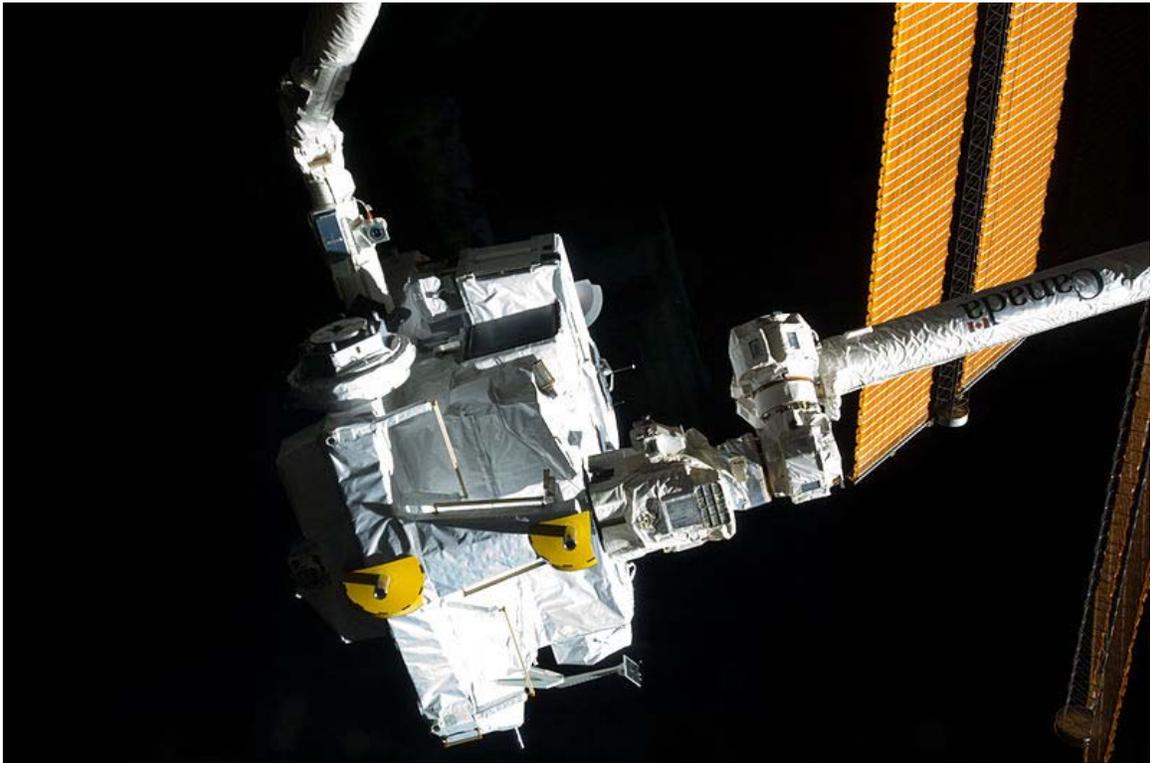


Tom Marshburn performs his first space walk, the STS-127 crew's second of the five scheduled.



Another view of Marshburn during his first space walk

## July 21 (Flight Day 7)



### Japanese logistics carrier(JLE) handoff from shuttle to station

In one of the more relaxed days, the Japanese logistics carrier was attached to the Japanese Exposed Facility. The cargo pallet was unberthed from the shuttle by the shuttle's robotic arm and handed to the station's robotic arm which then soft fixed it temporarily to the facility. After the experiments, containing an X-ray astronomy payload, a space environment monitor and a communications system, are installed the pallet will be returned back to Earth by the shuttle.

### July 22 (Flight Day 8, Spacewalk 3)



Cassidy works near the JEF during space walk 3

The spacewalk involving astronauts Wolf and Cassidy started at 14:32 UTC. As part of preparation for experiment installation on the Japanese external science deck, Cassidy removed the thermal covers off the experiment carrier. Meanwhile Wolf removed obstructions, consisting of a handrail and an equipment installation socket, from the Harmony node to clear the way for an upcoming Japanese automated resupply ship. The other task for EVA 3, involving replacement of four of the six batteries in the P6 truss, did not go as planned. Each 375 pound battery was to be removed and placed in a temporary stowage platform while a new one is taken from the ICC-VLD and fixed. The old ones will be returned to Earth. When two new batteries had been installed and three old ones removed, the CO<sub>2</sub> levels in Cassidy's suit showed an upward trend. Even though it never exceeded the safety limits, the EVA was called off with both astronauts returning into the station. This left one old battery in a temporary flexible stowage position. The rest of the batteries will be installed in a future EVA with the rest of the EVAs being under replanning.

### July 23 (Flight Day 9)

The Kibo robotic arm was inaugurated operationally with it being used to install experiments on to the Japanese exposed facility. The three experiments, transferred from the Japanese cargo pallet, consisted of Monitor of All-sky X-ray Image, Inter-orbit

Communication System and Space Environment Data Acquisition Equipment-Attached Payload. As per the revised plan for EVA 4 astronauts Cassidy and Marshburn will replace the remaining four batteries on P6 and complete the already deferred installation of a camera on the Japanese experiment facility.

#### **July 24 (Flight Day 10, Spacewalk 4)**

The fourth spacewalk, by Cassidy and Marshburn, involved replacement of the final four of the six batteries on P6 truss integrated electronics assembly. After berthing the old batteries in the ICC-VLD, the cargo pallet was returned to the Endeavour's payload bay by the shuttle's robotic arm. The elevated levels of CO<sub>2</sub> in Cassidy's suit during EVA 3 was attributed to the astronaut working at a fast pace.

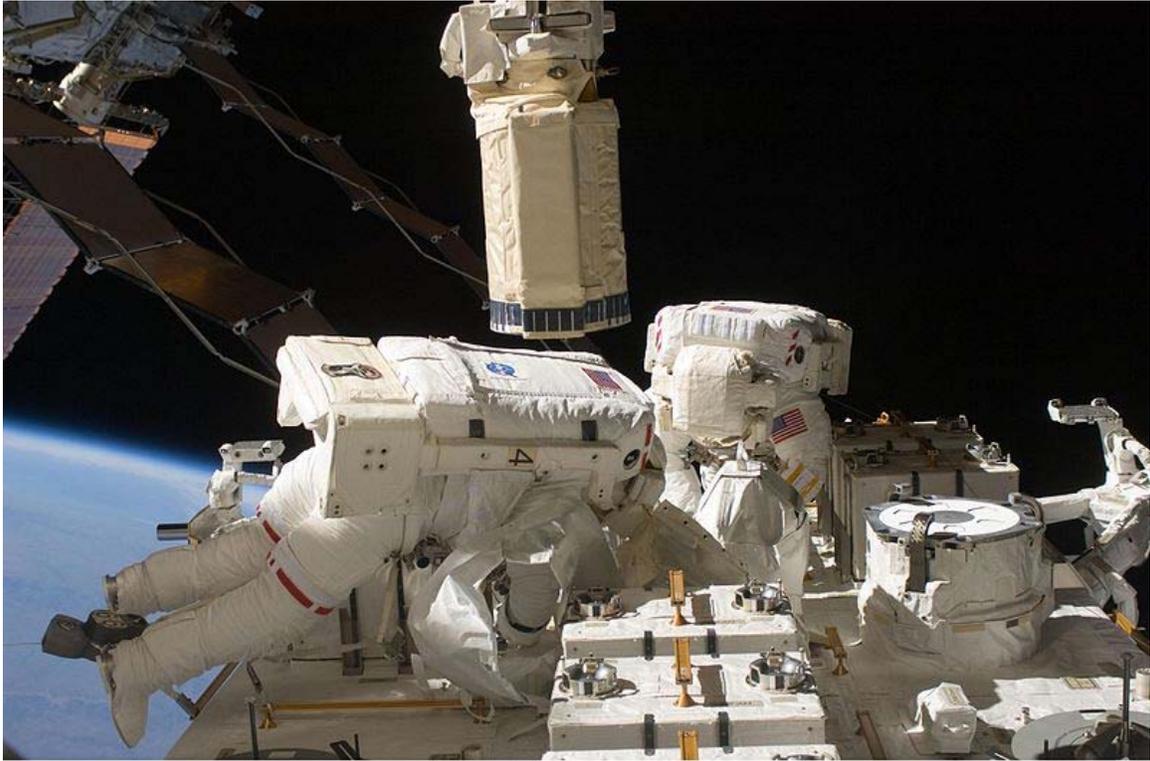
#### **July 25 (Flight Day 11)**

The crew of both the shuttle and station had a day off. The day was uneventful except for the station's American CO<sub>2</sub> removal system shutting down without any immediate impact.

#### **July 26 (Flight Day 12)**

The Japanese Exposed Section cargo carrier was berthed in Endeavour's payload bay by the shuttle's robotic arm after it was handed the pallet by the station's robotic arm. After this the crew of both the station and the shuttle held a joint news conference. Meanwhile the malfunctioning American CO<sub>2</sub> removal system has been transitioned to manual mode in order to keep it running.

## July 27 (Flight Day 13, Spacewalk 5)



Marshburn and Cassidy during space walk 5

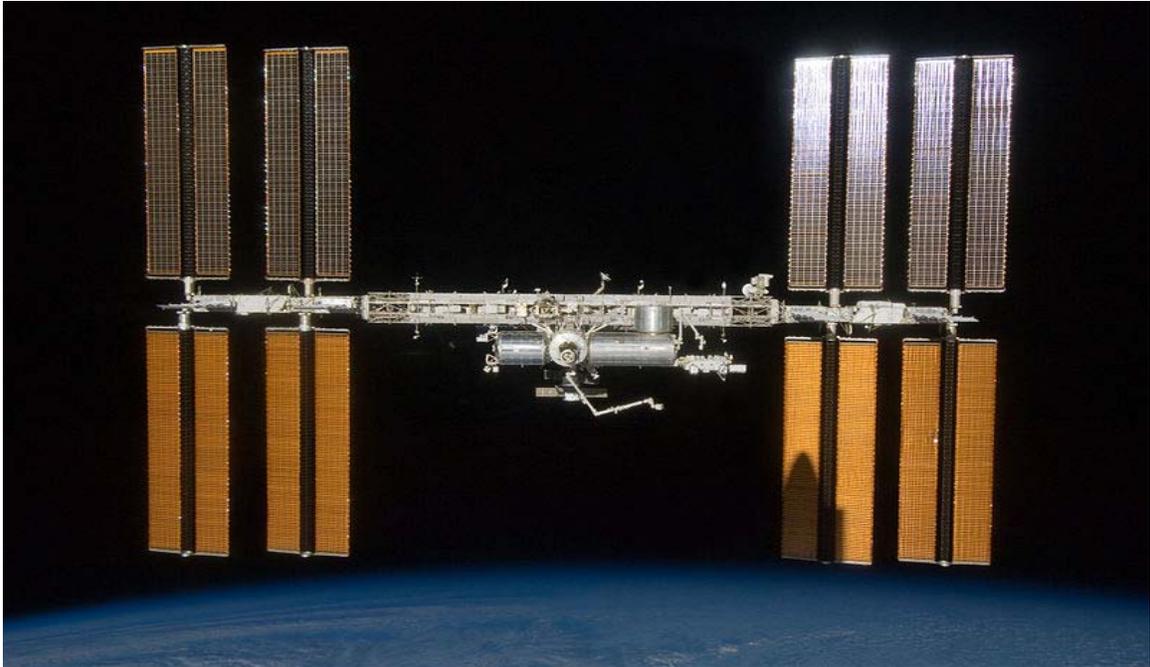
Cassidy and Marshburn started EVA 5 at 11:33 UTC when they switched their suit power to internal battery. For this spacewalk, the CO<sub>2</sub> absorbent system in the suits were changed from Lithium Hydroxide to METOX due to problems with Cassidy's usage. Cassidy completed the reconfiguring of power channels in the Zenith 1 patch panel which are used for the control moment gyroscopes. Before the rewiring, two of the gyroscopes were fed by the same power channel. Since a failure of the channel can knock down two gyros and put the station in a degraded position the reconfiguration was made necessary. This rewiring made the two gyros to operate from separate power channels. Meanwhile Marshburn secured some multi-layered insulation on the Dextre. Later both the spacewalkers installed video cameras on the front and back of the Japanese exposed facility which will be used in dockings of the Japanese cargo crafts and normal operation. The cameras flew up in launch configuration and now have been installed in an operational configuration, thus completing the JEF assembly. Meanwhile due to Cassidy's METOX limitation, the deployment of the PAS was deferred to a future spacewalk. Instead some get ahead tasks were completed which included installation of handrails and a portable foot restraint.

## July 28 (Flight Day 14)

After a crew farewell Endeavour undocked from the ISS at 17:26 UTC. Unlike most other launches, hatch closure, which happened at 15:08 UTC, and undocking happened on the same day due to the extended delay in launching and the arrival of the Progress 34 cargo craft. After undocking Hurley began a fly around of the station giving the shuttle crew an opportunity to photograph the station's current configuration in all directions. Then a final separation burn was completed at 3:09 pm EDT.



Endeavour shortly after the shuttle and station post-undocking separation



ISS shortly after the shuttle and station post-undocking separation with the JEF prominently seen

**July 29 (Flight Day 15)**



Image of orbital sunset taken from Endeavour one day before the shuttle landed

The OBSS was grappled by the shuttle's robotic arm and used to inspect Endeavour's thermal protection system for damage from orbital debris. The imagery will be analyzed to clear the shuttle for reentry. Meanwhile the foam loss on the external tank was initially attributed to substrate contamination ahead of the application of the foam. Later during the processing of STS-128, voids in the foam was highlighted as a trigger for the shedding. The air trapped in the voids could have expanded due to the high temperatures generated during ascent thus breaking the foam.

### **July 30 (Flight Day 16)**

The crew checked out the shuttle's systems for the landing and successfully deployed DRAGONSat and ANDE-2 satellites. The shuttle was also cleared for reentry with the TPS imagery showing no concerns. The shuttle will be tracking two chances of landing at KSC on Friday which has to be taken due to limitations of LiOH consumables.

### **July 31 (Flight Day 17, Landing)**

After a 16 day mission, Endeavour landed at Kennedy Space Center at 10:48 EDT. The landing had to be done before Saturday due to CO<sub>2</sub> scrubbing Lithium hydroxide limitations. There were two opportunities to land on 31 July 2009 of which the first was utilized.



Endeavour touches down at Kennedy Space Center



Endeavour deploys the drogue chute to slow down

## EVA's

Five spacewalks were completed in STS-127.

EVA #	Spacewalkers	Start (UTC)	End (UTC)	Duration
EVA 1	David A. Wolf	July 18	July 18	5 hours, 32 minutes
	Timothy Kopra	16:19	20:51	
JEF installed and P3 Nadir Unpressurized Cargo Carrier Attach System deployed. The S3 Zenith Outboard Payload Attachment System deployment was postponed due to time constraints.				
EVA 2	Wolf	20 July	20 July	6 hours, 53 minutes
	Thomas H. Marshburn	15:27	22:20	
Transferred Orbital Replacement Units (ORUs) from the Shuttle Integrated Cargo Carrier (ICC) to the External Stowage Platform-3 (ESP3). Transferred materials included a spare high-gain antenna, cooling-system pump module and spare parts for the Mobile Servicing System. The JEF Visual Equipment (JEF-VE) installation on the forward section was postponed due to time constraints.				
EVA 3	Wolf	22 July	22 July	5 hours, 59 minutes
	Christopher J. Cassidy	14:32	20:31	

JPM preparation work, ICS-EF MLI, and P6 battery replacement (2 of 6 units). EVA was cut short due to high levels of CO<sub>2</sub> in Cassidy's suit.

EVA 4	Cassidy	24 July	24 July	7 hours, 12 minutes
	Marshburn	13:54	21:06	
P6 battery replacement (final 4 of 6).				
EVA 5	Cassidy	27 July	27 July	4 hours, 54 minutes
	Marshburn	11:33	16:27	
SPDM thermal cover adjustment, Z1 patch panel reconfiguration, JEM visual equipment (JEM-VE) installation (forward and aft), and JEM-LTA reconfigurations. The S3 Nadir Payload Attachment System (outboard) deployment was postponed to a later mission.				

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. Each track is specially chosen, often by their families, and usually has a special meaning to an individual member of the crew, or is applicable to their daily activities.

Flight Day	Song	Artist	Played for
Day 2	“These Are Days”	10,000 Maniacs	Timothy Kopra
Day 3	“Here Comes the Sun”	The Beatles	Mark Polansky
Day 4	“Home”	Marc Broussard	David Wolf
Day 5	“Learning to Fly”	Tom Petty	Christopher Cassidy
Day 6	“Thunderbirds March”	Barry Gray	Julie Payette
Day 7	“Life Is a Highway”	Rascal Flatts	Tom Marshburn
Day 8	“Santa Monica”	Everclear	Douglas Hurley
Day 9	“Tiny Dancer”	Elton John	Mark Polansky
Day 10	“Wish You Were Here”	Pink Floyd	David Wolf
Day 11	“In Your Eyes”	Peter Gabriel	Tom Marshburn
Day 12	“Dixit Dominus”	George Frederic Handel	Julie Payette
Day 13	“On the Sunny Side of the Street”	Steve Tyrell	Mark Polansky
Day 14	“Proud to Be an American”	Lee Greenwood	Chris Cassidy

Day 15	“Yellow”	Coldplay	Doug Hurley
Day 16	“I Got You Babe”	Sonny & Cher	Koichi Wakata
Day 17	“Beautiful Day”	U2	Tom Marshburn

# Chapter 4

## STS-128

### STS-128

#### Mission insignia



#### Mission statistics

**Mission name** STS-128

**Space shuttle** *Discovery*

**Spacecraft** Orbiter/payload liftoff mass:  
**mass** 267,689 pounds (121,422 kg)

**Launch pad** 39A

August 28, 2009

23:59 EDT/

03:59 UTC August 29

**Launch date**

- Launch window: 9 minutes 45 seconds
- Shuttle liftoff mass:  
4,522,852 pounds (2,051,531 kg)

September 11, 2009

20:53 EDT (00:53 UTC)

**Landing**

Runway 22

Edwards Air Force Base, California

**Mission** 13 days 20:54:55

**duration**

**Number of orbits** 219

**Orbital period** 94 min

**Orbital altitude** Insertion: 122 nautical miles (226 km);  
Orbital: 188 nautical miles (348 km)

**Orbital inclination** 51.6 degrees

**Distance traveled** 5,755,275 miles (9,262,217 km)

**Docking**

**Docking date** August 31, 2009 00:54 UTC

**Undocking date** September 8, 2009 19:26 UTC

**Time docked** 8 days, 18 hours, 32 minutes

**Crew photo**



Seated (l-r) Ford and Sturckow. Standing (l-r) are Hernández, Olivas, Stott, Fuglesang and Forrester.

**Related missions**

**Previous mission**

STS-127 

**Subsequent mission**

STS-129 

**STS-128** (ISS assembly flight **17A**) was a space shuttle mission to the International Space Station (ISS) that launched on August 28, 2009. Space Shuttle *Discovery* carried the Multi-Purpose Logistics Module *Leonardo*, as the primary payload. Leonardo contained a collection of experiments for studying the physics and chemistry of microgravity. Three spacewalks were carried out during the mission, which removed and replaced a materials processing experiment outside ESA's *Columbus* module, and returned an empty ammonia tank assembly. The first launch attempt was delayed due to weather concerns, including multiple weather violations in NASA's launch rules, beginning over two hours before the scheduled launch. The second launch attempt scheduled for August 26, 2009 at 01:10:22 EDT was called off the previous evening due to an anomaly in a fuel valve of the orbiter. The launch took place on August 28, 2009 at 23:59 EDT.

## Crew

<b>Position</b>	<b>Launching astronaut</b>	<b>Landing astronaut</b>
<b>Commander</b>	Frederick W. Sturckow Fourth spaceflight	
<b>Pilot</b>	Kevin A. Ford First spaceflight	
<b>Mission Specialist 1</b>	Patrick G. Forrester Third spaceflight Intra-vehicular Officer (IV)	
<b>Mission Specialist 2</b>	José M. Hernández First spaceflight Flight engineer	
<b>Mission Specialist 3</b>	Christer Fuglesang, ESA Second spaceflight EV3	
<b>Mission Specialist 4</b>	John D. Olivas Second spaceflight Lead spacewalker EV1	
<b>Mission Specialist 5</b>	Nicole Stott Expedition 20 First spaceflight EV2	Timothy Kopra Expedition 20 First spaceflight

## Crew notes

Nicole Stott was originally scheduled to return aboard Soyuz TMA-15, but a change in the flight plan was made due to the possible flight delays in future shuttle missions, which may extend Canadian astronaut Robert Thirsk's mission beyond the six-month duration preferred for station crew members.

STS-128 is planned to be the final Space Shuttle flight used for ISS crew rotation, with Nicole Stott replacing Tim Kopra. Stott returned on STS-129, but that flight did not bring her replacement.

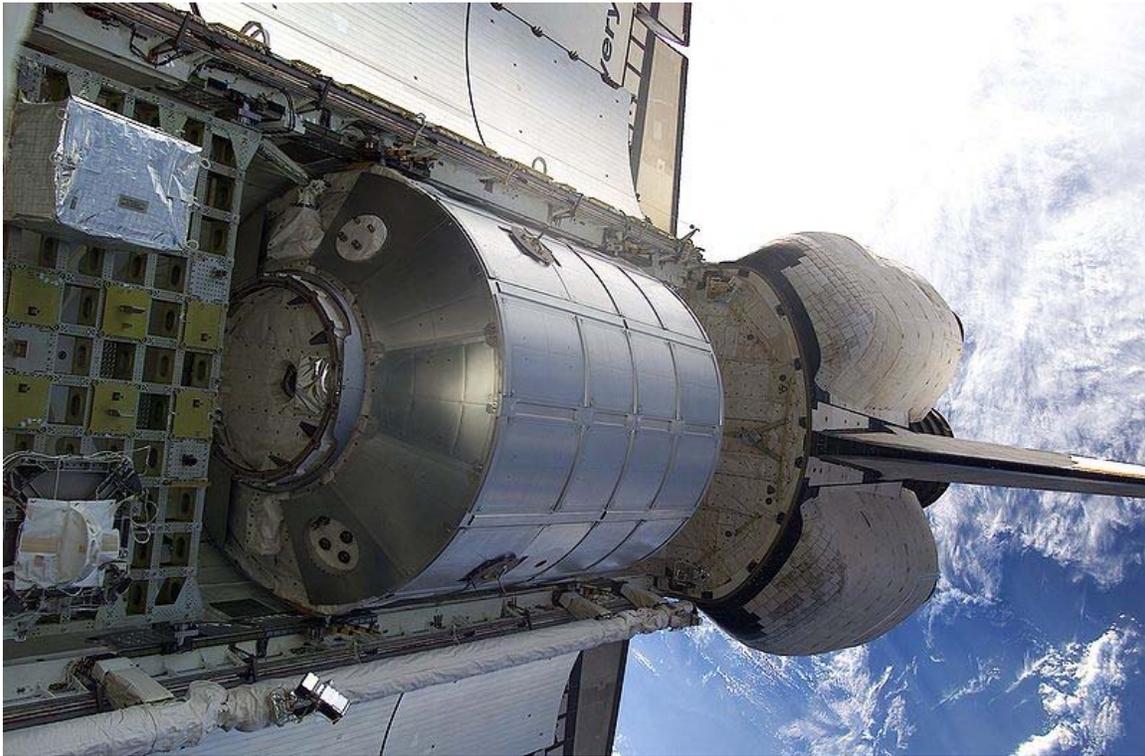
The mission of Christer Fuglesang is named *Alissé* by the European Space Agency. The name was proposed by Jürgen Modlich from Baierbrunn, Germany. The name refers to the 15th-century explorers who used the trade winds to follow Christopher Columbus across the oceans to the New World.

STS-128 also marked the first time two Hispanic Americans were on the same crew. John "Danny" Olivas of El Paso, Texas, made his second trip up into space, and José Hernández of Stockton, California, made his first. Both are of Mexican heritage.

## Mission payload

Location	Cargo	Mass
Bays 1-2	Orbiter Docking System EMU 3009 / EMU 3015	1,800 kilograms (4,000 lb) ~260 kilograms (570 lb)
Bay 3P	Shuttle Power Distribution Unit (SPDU)	~17 kilograms (37 lb)
Bay 4P	APC/MISSE Carrier	57 kilograms (130 lb)
Bay 5P	APC/MISSE Carrier	57 kilograms (130 lb)
Bay 7S	ROEU umbilical	~79 kilograms (170 lb)
Bays 7-12	Leonardo (MPLM FM-1)	12,131 kilograms (26,740 lb)
Bay 13	Lightweight MPESSE Carrier (LMC)	1,780 kilograms (3,900 lb)
Starboard Sill	Orbiter Boom Sensor System	~382 kilograms (840 lb)
Port Sill	Canadarm	410 kilograms (900 lb)
	<b>Total:</b>	<b>16,973 kilograms (37,420 lb)</b>

## **Multi-Purpose Logistics Module (MPLM) *Leonardo***



*Leonardo*, as flown on STS-102

The primary payload of STS-128 is the Multi-Purpose Logistics Module. *Leonardo's* purpose is to assist with establishing a six-man crew capacity by bringing extra supplies and equipment to the station. The Multi-Purpose Logistics Module will contain three racks for life support, a Crew quarter to be installed in Kibo, a new treadmill (COLBERT) that will temporarily be placed in Node 2 and later in Node 3, and an Air Revitalization System (ARS) that will temporarily be placed in Kibo and later in Node 3.

### *Leonardo* Specifications

- Length: 21 feet (6.4 m)
- Diameter: 15 feet (4.6 m)
- Payload Mass (launch): 27,510 pounds (12,480 kg)
- Payload Mass (return): 16,268 pounds (7,379 kg)
- Empty Weight: 9,810 pounds (4,450 kg)

### **Lightweight Multi-Purpose Carrier (LMC)**

The shuttle carried a Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC) with Ammonia Tank Assembly (ATA). The new ammonia tank will replace an empty tank during an EVA.

## **TriDAR**

The shuttle flew the first test flight of the TriDAR, a 3D dual-sensing laser camera, intended for potential use as an autonomous rendezvous and docking sensor. The TriDAR successfully tracked the ISS position and orientation from the shuttle during docking operations.

## **Other science packages**

It will also contain three racks dedicated to science, FIR (Fluids Integrated Rack) and the first Materials Science Research Rack (MSRR-1) to be placed in Destiny and MELFI-2 (Minus Eighty Laboratory Freezer for ISS) to be placed in Kibo. The FIR will enable detailed study of how liquids behave in microgravity, a crucial detail for many chemical reactions. One experiment, for instance, will examine how mixtures known as colloids behave without being stirred by sedimentation and convection. Another using the Light Microscopy Module (LMM) will examine how an ideal heat pipe works without the distortions of gravity.

## **Mission experiments**

The STS-128 mission (as did STS-125 and STS-127) took part in crew seat vibration tests that will help engineers on the ground understand how astronauts experience launch. They will then use the information to help design the crew seats that will be used in future NASA spacecraft.

STS-128 repeated the Boundary Layer Transition (BLT) Detailed Test Objective (DTO) experiment that was done by the same shuttle during STS-119. In this experiment, one of the thermal protection systems was raised to create a boundary layer transition in which the air flow becomes turbulent beyond a certain speed. During STS-119 the tile was raised 0.25 inches (6.4 mm) above the others, tripping the flow at Mach 15 during reentry. In the modification being done, the tile has been raised 0.35 inches (8.9 mm) to trip at Mach 18 producing more heat.



*Discovery on the pad August 6, 2009*



Discovery poised for lift-off



Launch from 180 miles away (long exposure)



STS-128 as seen from Bartram Springs in Jacksonville, FL

*Discovery* undertook the testing of a catalytic coating which is meant to be used by the Orion (spacecraft). Two TPS tiles located in the protuberance downstream from the BLT tile had been fully coated with the catalytic material in order to understand the entry heating performance. The tiles were instrumented to collect a wide variety of data.

## **Mission background**

The mission marks:

- 159th American manned space flight
- 128th shuttle mission since STS-1
- 37th flight of *Discovery*
- 30th shuttle mission to the ISS
- 103rd post-*Challenger* mission
- 15th post-*Columbia* mission
- 32nd shuttle night launch
- NASA's first space shuttle launch to take place during two calendar days
- 25th anniversary of *Discovery's* first flight, STS-41-D (30 August 1984)

## Shuttle processing

*Discovery* rolled from the Orbiter Processing Facility to the Vehicle Assembly Building after the external tank was cleared for use and was mated with it. The foam insulation on the tank underwent stringent pull tests after the foam liberated and hit the orbiter during STS-127. The STS-128's tank initially exhibited no concerns while the STS-127 case was determined to be a one off case due to surface contamination prior to foam application.

The main change from previous missions is the change of the Ground Umbilical Carrier Plate (GUCP) vent housing. The quick release vents exhibited leaks during STS-119 and STS-127, which were determined to be due to a misalignment in the vent. This led to the one part rigid seal in the external tank being replaced with a two part flexible seal.

*Discovery* later rolled out from the VAB to Launch Complex 39A on 4 August 2009, in a slow drive on the top of the Crawler-transporter. The 3.4-mile (5.5 km) rollout began at 02:07 EDT, and ended with the launch platform secured in place at about 13:50 EDT. The move took longer than expected due to adverse weather conditions, which included lightning warnings. The crawler also had to pause occasionally so mud could be removed from its treads and bearings. Technicians then quickly prepared the shuttle to host the crew's countdown dress rehearsal known as the Terminal Countdown Demonstration Test (TCDT). *Discovery's* seven astronauts flew to Kennedy on 5 August 2009 for the training activity which concludes later in the week with a complete practice countdown, minus liftoff, involving the crew and the launch team. Meanwhile, in an unprecedented operation, modifications were made to the left Solid rocket booster on the pad. The modifications involved replacement of a check valve filter assembly in the booster which was found to have broken. In a potentially delaying factor, in depth testing of the external tank with X-ray revealed voids in the foam which might have formed during the injection molding of the foam. This has also been decided as a suspect factor in the foam shedding during STS-127. The air in the voids could have expanded due to the high temperatures generated during ascent thus breaking the foam. The reviews considered a rollback as an option since the defect could not be set right in the pad. Later, the tank was cleared for launch as is without any additional inspections.



Long exposure picture of STS-128 launching





Olivas(left) and Stott (right) during EVA 1



Leonardo is placed back in Discovery's payload bay

### **Launch attempts**

The first launch attempt was delayed by 24 hours due to weather concerns including multiple weather violations in NASA's launch rules beginning over 2 hours before the scheduled launch. During the second attempt on Wednesday morning, a problem with a LH2 fill-and-drain fuel valve inside space shuttle Discovery's aft compartment led to another scrubbing. The problem arose when sensors did not detect the closure of the valve when commanded to do so. The issue was thought to be with the sensors rather than the valve itself. After inerting the orbiter's tank, which involved draining it, tests were conducted on the valves. Despite the valves working normally, another delay was called for to have more confidence in the system, and to give the console operators who performed the test some rest. The launch team evaluated the issue, passing on a possible launch window 27 August 2009 at 00:22 EDT. The launch was delayed till 23:59 EDT 28 August 2009 to allow the engineers to be fully satisfied with the vehicle. Later the mission was cleared for launch which involved a flight rule waiver for cycling the valve and a discussion to analyze the test failure of an Ares-1 booster that was similar to the SRBs used for the mission. NASA feared another delay when storms formed near the Kennedy Space Center on 28 August 2009 but the weather cleared in time for a successful launch of Discovery at 23:59 EDT.

Attempt	Planned	Result	Turnaround	Reason	Decision point	Weather go %	Notes
1	25 Aug 2009, 1:36:05 am	Scrubbed	---	Weather	25 Aug 2009, 1:25 am(T-9:00 hold)	80%	Precipitation and lightning in launch and landing area
2	26 Aug 2009, 12:22:07 am	Scrubbed	0 days, 22 hours, 46 minutes	Technical	25 Aug 2009, 5:52 pm	70%	Failure indicator on LH2 inboard fill and drain valve
3	28 Aug 2009, 11:59:37 pm	Successful	2 days, 23 hours, 38 minutes			60%; later 80%	

## Mission timeline

**Aug. 28 (Flight Day 1 – Launch)**



Space Shuttle *Discovery* launches from Kennedy Space Center, August 28, 2009

After launch at 23:59 EDT, *Discovery* opened her payload bay doors. Once the doors were opened the crew deployed the Ku-band antenna and activated the Shuttle Remote Manipulator System (SRMS). Once the Ku-band antenna was deployed and activated the crew then down-linked photos from the External Tank Umbilical Well Camera system, so controllers on the ground could see how the tank performed and how much if any foam was shed during ascent.

### **Aug. 29 (Flight Day 2 – TPS Survey)**

During *Discovery's* first full day on orbit, the crew used the SRMS to grapple the Orbiter Boom Sensor System (OBSS) and survey the wing leading edges, nose and other parts of the Thermal Protection System (TPS), as well as the Orbital Maneuvering System (OMS) Pods. During this time some of the crew were preparing the space suits that will be used during the 3 Extra-vehicular activities (EVA) and setting up the tools that will be used during the docking. This includes installing the Centerline Camera and extending the Orbiter Docking system Ring Extension.

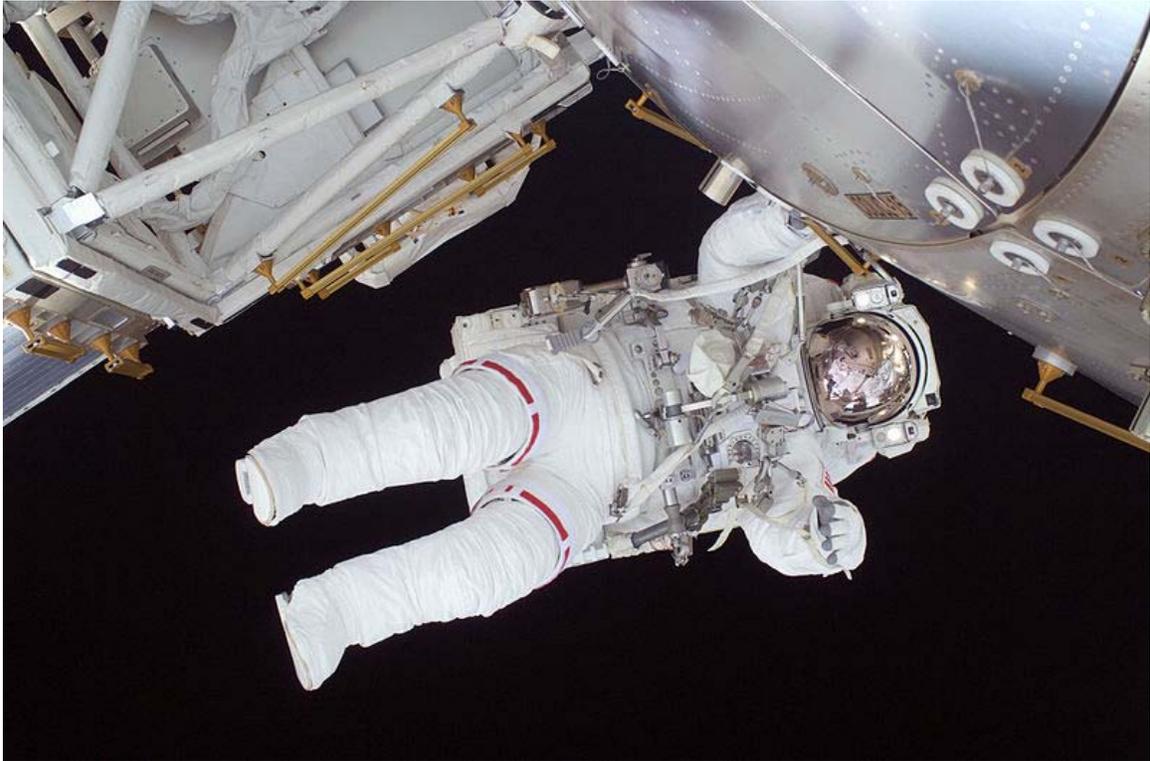
### **Aug. 30 (Flight Day 3 – Docking)**

*Discovery* docked with the Pressurized Mating Adapter (PMA) 2 on the front of the Harmony connecting module. Before the shuttle docked Commander Rick Sturckow performed what is known as the Rendezvous Pitch Maneuver (RPM), while Expedition 20 Commander Gennady Padalka and Flight Engineer Michael Barret took photos of the shuttles belly. The photos were down-linked to mission control for review. After docking, Nicole Stott and Tim Kopra switched Soyuz seat liners, making Stott an Expedition 20 Flight Engineer and Tim Kopra an STS-128 Mission Specialist. The joint crews also performed some transfers from the shuttle mid-deck and checked on the pressure in the MPLM Leonardo.

### **Aug. 31 (Flight Day 4 – MPLM Berthing)**

During flight day 4 the MPLM Leonardo was berthed to the Nadir or earth facing port on Harmony using the Space Station Remote Manipulator System (SSRMS). Once it was berthed, the crews activated it and opened the hatch for ingress. Some more items were transferred from the shuttle mid-deck including the MDS experiment and the space suits Danny Olivas and Nicole Stott will use during EVA 1. The pair also prepared all the tools that will be used during the EVA with some help from Tim Kopra. Later on during the night when the crews were asleep, the team of ground controllers vented the Port 1 (P1) Ammonia Tank Assembly (ATA) Nitrogen Vent lines, in preparation for the ATA to be removed during EVA 1.

## Sept. 1 (Flight Day 5 – EVA 1)



Nicole Stott during the STS-128 mission's first space-walk

EVA 1 was performed, and saw the removal of the empty Ammonia Tank Assembly, and the removal and stowage of the EuTef and MISSE 6 experiments. While the spacewalk was going on crew members inside were transferring the Crew Quarters, C.O.L.B.E.R.T treadmill and the Node 3 Air Revitalization System rack (ARS). The treadmill and ARS were temporarily stowed, while the crew Quarters was installed in the Kibo Module where setup and activation was begun.

## Sept. 2 (Flight Day 6)

During flight day 6 the joint crews continued the activation of the new crew quarters. The last of the major transfer items, the Fluids Integrated Rack (FIR), Materials Science Research Rack and the Minus Eighty Laboratory Freezer ISS 2 (MELFI-2) were transferred from the Multi-Purpose Logistics Module (MPLM) Leonardo. Astronauts Danny Olivas and José Hernández answered some questions submitted on Youtube and Twitter. Olivas along with Christer Fuglesang also prepared for the second EVA and "camped out" in the air lock at a lower pressure to help get ready for EVA 2 on flight day 7.

### **Sept. 3 (Flight Day 7 – EVA 2)**

On flight day 7, Danny Olivas and Christer Fuglesang performed the second spacewalk of the STS-128 mission. Olivas and Fuglesang installed and connected the new Ammonia Tank Assembly (ATA), and also performed two get aheads. The get ahead tasks included installing protective lens covers on the Space Station Remote Manipulator System (SSRMS) End B cameras . Once the ATA was installed, the tank was integrated into the cooling loop. While Olivas and Fuglesang were outside, the rest of the crew continued on transferring items to and from both the shuttle mid-deck and MPLM.

### **Sept. 4 (Flight Day 8)**

The first part of the crew day was spent off duty. The crews enjoyed a meal, took a crew photo and took part in a PAO event. More transfer was completed by both crews. The space station crew calibrated the Oxygen Generation System (OGS) H2 sensor. Timothy Kopra and Nicole Stott continued their hand over activities, helping Stott who is taking over from Kopra. Danny Olivas and Christer Fuglesang got their space suits ready for the third and final space walk. The pair spent the night in the Quest Joint Airlock, at a lower pressure of 10.2 psi instead of 14.7 psi.

### **Sept. 5 (Flight Day 9 - EVA 3)**



Danny Olivas during EVA 3



### **Highlights from the third spacewalk (2 min 21 secs)**

During flight day 9 Danny Olivas and Christer Fuglesang performed EVA 3. The pair completed all tasks that were to be done, including installing two GPS antennas and deploying the Starboard 3 (S3) Payload Attach System (PAS), a new Rate Gyro Assembly (RGA) 2 and routing of Node 3 Avionics cables. The joint crew also completed more transfer, mostly transfer for return to earth in the MPLM and space shuttle mid-deck. The ISS crew also replaced a bolt on the Common Berthing Mechanism (CBM) so that the MPLM won't get stuck, and also to ensure correct capture of the HTV.

### **Sept. 6 (Flight Day 10 - Off duty)**

Flight day 10 saw the joint crews transfer samples from the space station to the shuttle freezer known as Glacier. The samples will be returned to earth for examination by scientists who will develop ways to prevent bone and muscle loss in space as well as cures for other illnesses on earth. The crews also completed some close outs of the Multi-Purpose Logistics Module Leonardo. The last portion of the crew day was spent off duty.

### **Sept. 7 (Flight Day 11 - Hatch closure)**

On flight day 11 the joint ISS/shuttle crews completed transfers and closed the hatches with the MPLM. Once the hatches were closed, the MPLM was deactivated, demated and berthed back in the payload bay of the space shuttle. During this process José Hernández and Nicole Stott took part in a PAO event. The end of the crews work days saw the two crews say goodbye in a farewell ceremony and close the hatches between the shuttle and ISS. Once the hatches were closed, the Pressurized Mating Adapter 2 was depressurized, in advance of undocking. The shuttle crew setup and checked out the rendezvous tools before going to bed.

### **Sept. 8 (Flight Day 12 - Undocking)**

On flight day 12, space shuttle *Discovery* successfully undocked from the International Space Station at 19:26 UTC. After undocking, the shuttle backed out and performed a fly around of the ISS. The space shuttle then performed 2 separation burns using its thrusters. After the separation burns, astronauts Kevin Ford, José Hernández and Christer Fuglesang used the Orbiter Boom Sensor System (OBSS) to inspect the shuttle's Thermal Protection System (TPS). When they completed that task the OBSS was berthed on the starboard sill of the payload bay and the Shuttle Remote Manipulator System (SRMS) was powered down.

### **Sept. 9 (Flight Day 13 - End Of Mission Prep)**

On flight day 13 the space shuttle crew began stowing items for landing. During the course of the day commander Frederick W. Sturckow and pilot Kevin A. Ford performed standard checks of the Flight Control Systems (FCS), Reaction Control System (RCS) jets and communications with the ground. The crew also deactivated the Wing Leading Edge System (WLES), stowed the Ku-band antenna, and reviewed landing procedures.

### **Sept. 10 (Flight Day 14 - Landing Postponed)**

On flight day 14, *Discovery* was scheduled to land at Kennedy Space Center at 19:04 EDT (23:04 UTC) which was postponed due to weather conditions, the second opportunity at 20:40 EDT (00:40 UTC) was also postponed due to weather conditions.

## Sept. 11 (Flight Day 15 - Landing)



After weather delayed two landing opportunities at Kennedy Space Center, *Discovery* lands at Edwards Air Force Base, California.

On flight day 15 at 19:47 EDT (23:47 UTC), *Discovery* started the de-orbit burn for landing at Edwards Air Force Base after two landing attempts at Kennedy Space Center were waved off. *Discovery* touched down at 20:53 EDT (00:53 UTC).

## Spacewalks

Each spacewalk was planned to last approximately 6.5 hours.

EVA #	Spacewalkers	Start (UTC)	End (UTC)	Duration
	John D. Olivas Nicole Stott	1 September 21:49 UTC	2 September 04:24 UTC	6 hours, 35 minutes
EVA 1	Prepared for the replacement of an empty ammonia tank on the station's port truss by releasing its bolts. Retrieved the Materials International Space Station Experiment and European Technology Exposure Facility mounted outside the Columbus laboratory, and stowed them in <i>Discovery</i> 's cargo bay for their return to Earth. :Robotic Arm Operators: Ford and Thirsk			

John D. Olivas	3 September	4 September	6 hours, 39
Christer Fuglesang	22:13 UTC	04:51UTC	minutes

EVA 2

Removed the new ammonia tank from the shuttle's payload bay and replaced it with the used tank from the station. The new tank, weighing about 1,800 pounds (820 kg), was the most mass ever moved by spacewalking astronauts.

With this spacewalk, ESA astronaut Fuglesang became the first person, who is not from either an American or Russian space program, to have participated in four or more spacewalks.

:Robotic Arm Operators: Ford and Stott

John D. Olivas	5 September	6 September	7 hours, 01
Christer Fuglesang	20:39 UTC	03:40 UTC	minutes

EVA 3

Preparations for the arrival of the Tranquility node by attaching cables between the starboard truss and the Unity node, the area where Tranquility will be installed. Tranquility is targeted to arrive on STS-130 in February 2010. The spacewalkers also replaced a communications sensor device, installed two new GPS antennas, and replaced a circuit breaker.

## Wake-up calls

NASA began a tradition of playing music to astronauts during the Gemini program, which was first used to wake up a flight crew during Apollo 15. Each track is specially chosen, often by their families, and usually has a special meaning to an individual member of the crew, or is applicable to their daily activities.

Flight Day	Song	Artist	Played for
Day 2	“Back In The Saddle Again”	Gene Autry	Frederick W. Sturckow
Day 3	“Made to Love”	TobyMac	Nicole Stott
Day 4	“Mi Tierra”	Gloria Estefan	José Hernández
Day 5	“Indiana, Our Indiana”	Indiana University Band	Kevin A. Ford
Day 6	“What a Wonderful World”	Louis Armstrong	Christer Fuglesang
Day 7	“There is a God”	33Miles	Patrick G. Forrester
Day 8	“What a Wonderful World”	Louis Armstrong	Danny Olivas

Day 9	“El Hijo del Pueblo”	José Alfredo Jiménez	José Hernández
Day 10	“Rocket”	Andrew Peterson	Patrick G. Forrester
Day 11	“Only One”	Jeremy Kay	John D. Olivas
Day 12	"Beautiful Day"	U2	Timothy Kopra
Day 13	"Sailing"	Rod Stewart	Christer Fuglesang
Day 14	"Good Day Sunshine"	The Beatles	Kevin A. Ford
Day 15	"Big Boy Toys"	Aaron Tippin	Frederick W. Sturckow

## Chapter 5

# Space Shuttle

### Space Transportation System



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

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

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

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

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

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

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

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

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

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

## Early history

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

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

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

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

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

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

## Description



STS-1 on the launch pad (1981)

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

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



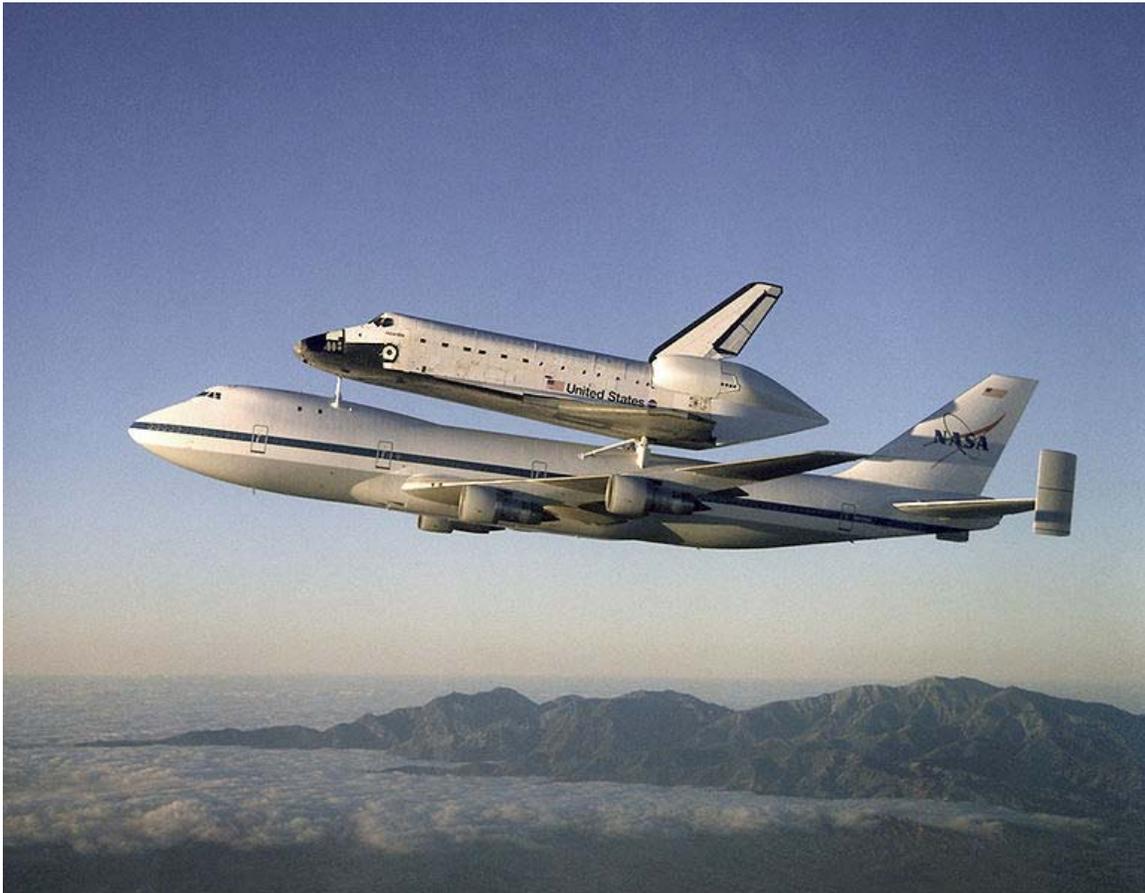
Each Space Shuttle is a reusable launch system that is composed of three main assemblies: the reusable Orbiter Vehicle (OV), the expendable external tank (ET), and the two reusable solid rocket boosters (SRBs). Only the orbiter enters orbit shortly after the tank and boosters are jettisoned. The vehicle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

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

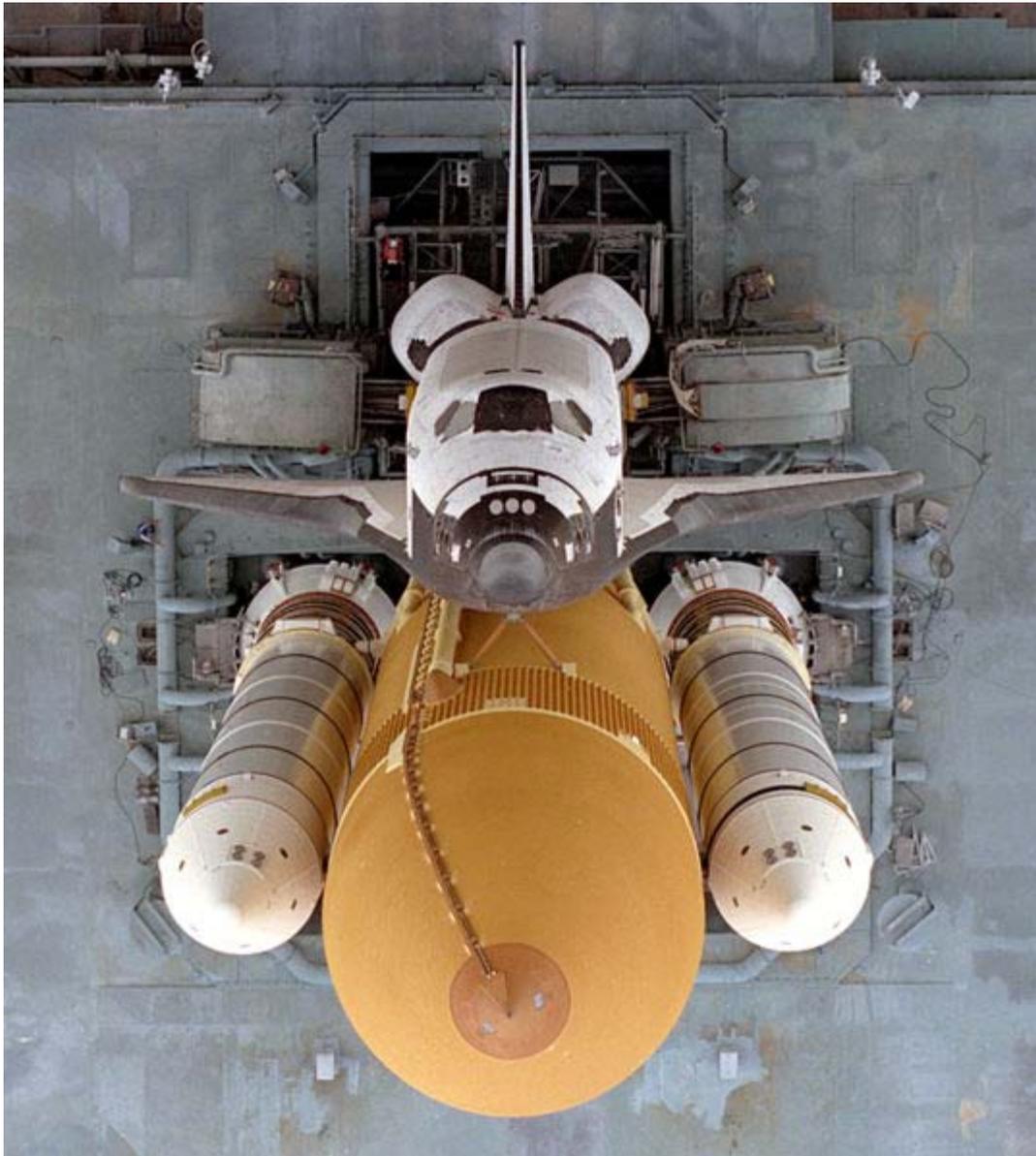
*Columbia* broke apart during re-entry in 2003. Building Space Shuttle Endeavour cost about US\$1.7 billion. One Space Shuttle launch costs around \$450 million.

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

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



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



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



Water is released onto the mobile launcher platform on Launch Pad 39A at the start of a sound suppression system test in 2004. During launch, 300,000 US gallons (1,100 m<sup>3</sup>) are poured onto the pad in only 41 seconds.



Space Shuttle *Endeavour* being transported by a Boeing 747

## **Orbiter vehicle**

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

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

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

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

## **External tank**

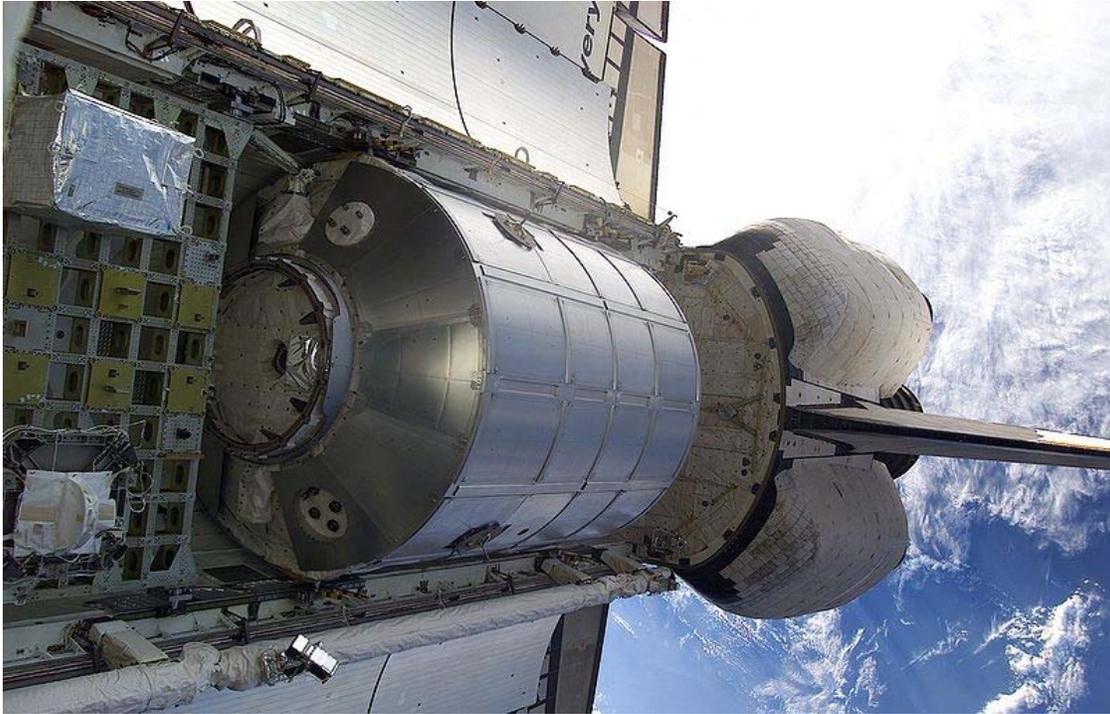
The main function of the Space Shuttle external tank is to supply the liquid oxygen and hydrogen fuel to the Space Shuttle main engines. It is also the backbone of the launch vehicle providing attachment points for the two Solid Rocket Boosters and the Orbiter. The external tank is the only part of the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

## **Solid Rocket Boosters**

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

## **Orbiter add-ons**

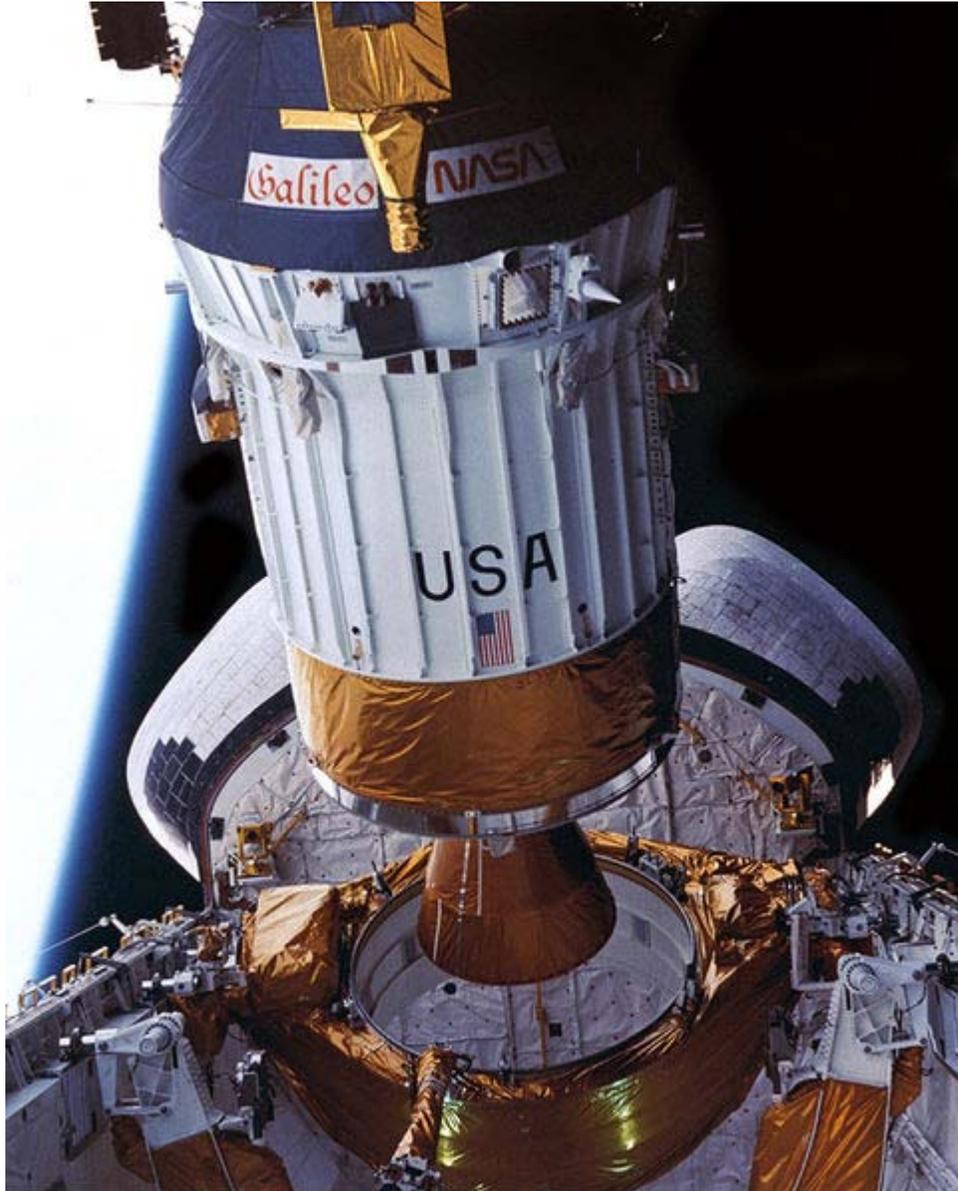
The orbiter can be used in conjunction with a variety of add-ons depending on the mission. This has included orbital laboratories (Spacelab, Spacehab), boosters for launching payloads farther into space (Inertial Upper Stage, Payload Assist Module), and other functions, such as provided by Extended Duration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



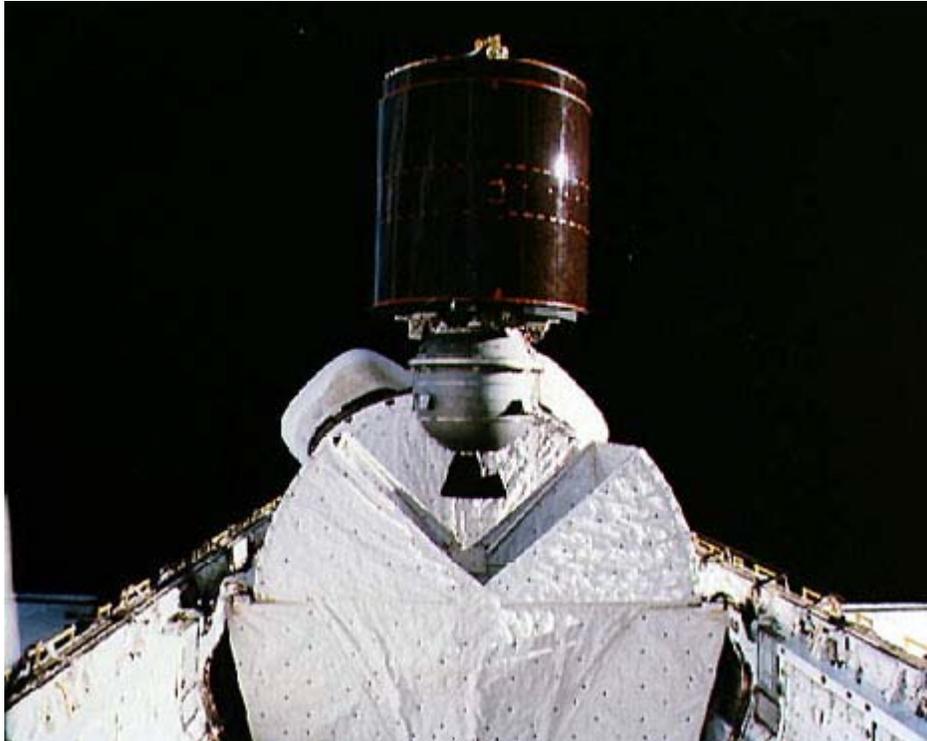
MPLM *Leonardo*



EDO being installed



IUS deploying with Galileo



PAM-D with satellite

## **Spacelab**

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

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

## Flight systems



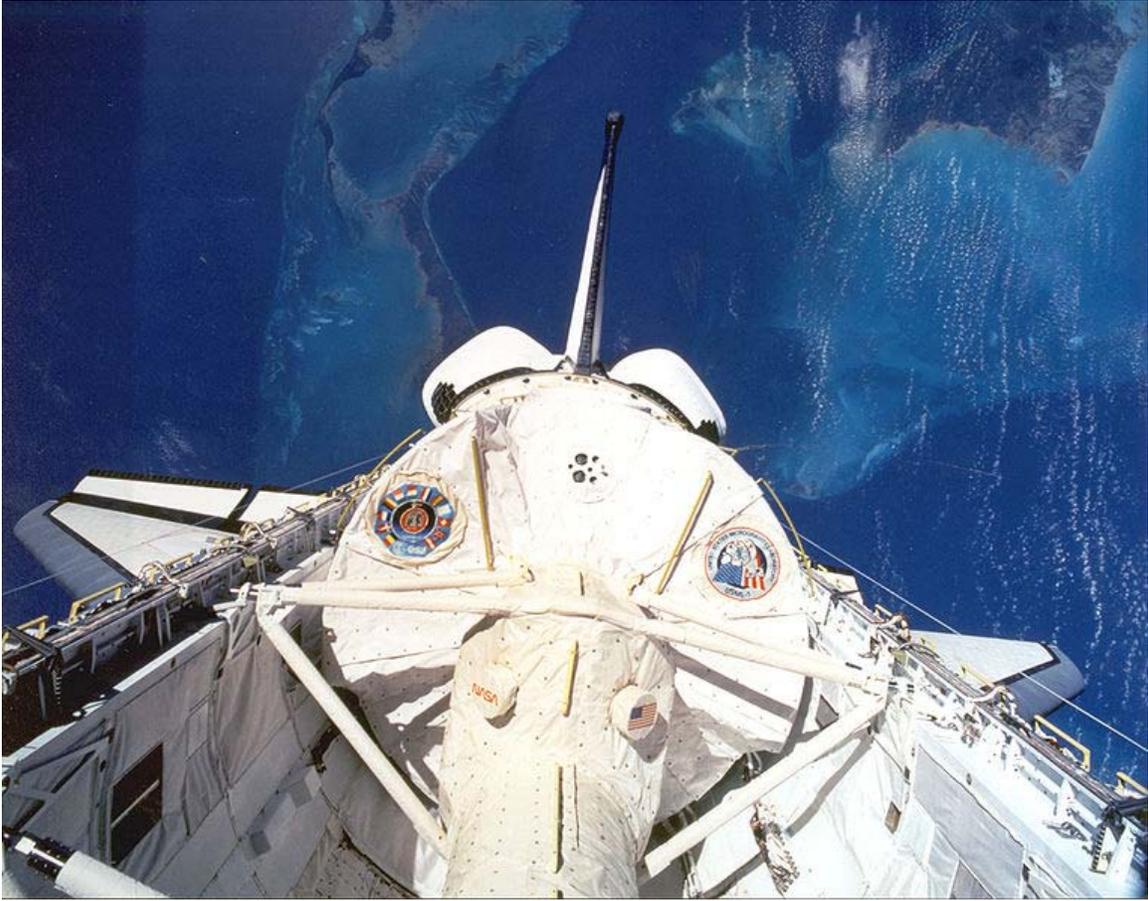
*Atlantis* deploys the landing gear before landing on a selected runway just like a common aircraft.

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

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

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

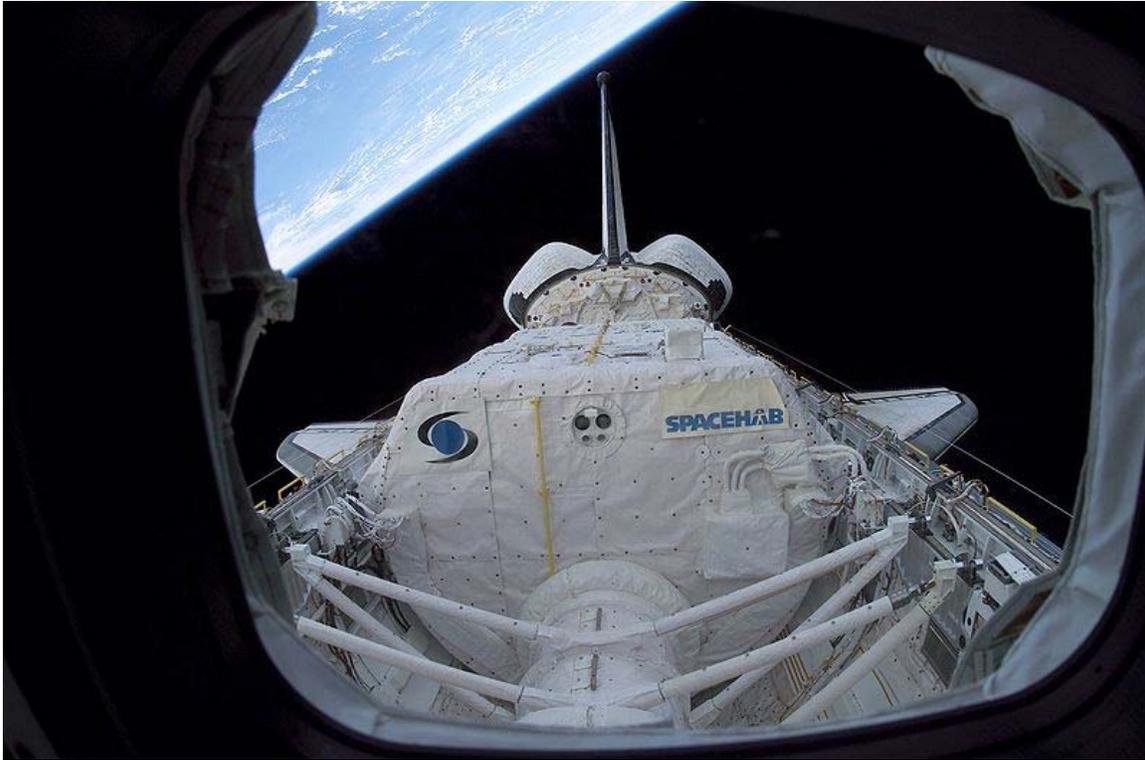
The four general-purpose computers operate essentially in lockstep, checking each other. If one computer fails, the three functioning computers "vote" it out of the system. This isolates it from vehicle control. If a second computer of the three remaining fails, the two functioning computers vote it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



Spacelab in orbit



RMS (Canadarm)



S107E05359

## Spacehab

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

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

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

In 1990, the original computers were replaced with an upgraded model AP-101S, which has about 2.5 times the memory capacity (about 1 megabyte) and three times the

processor speed (about 1.2 million instructions per second). The memory was changed from magnetic core to semiconductor with battery backup.

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

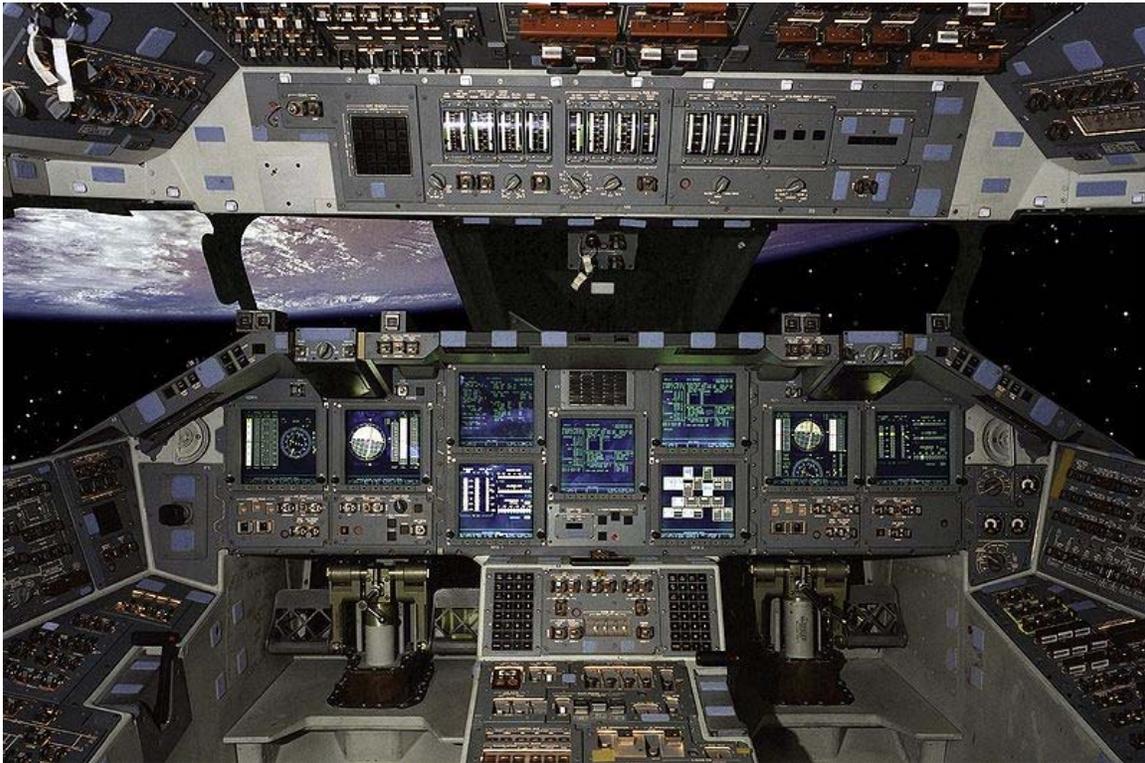


Space Shuttle program insignia

### **Markings and insignia**

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

## Upgrades



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

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

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

finally reached in flight hardware with the Block II engines in 2001. The normal maximum throttle is 104%, with 106% or 109% used for mission aborts.

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

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



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

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

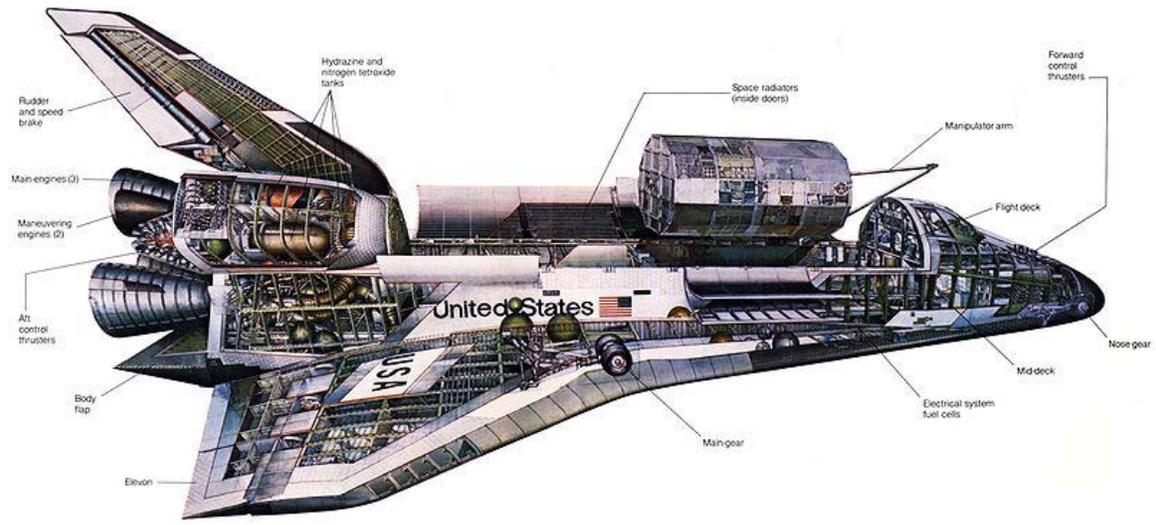
STS-70 was delayed in 1995, when woodpeckers bored holes in the foam insulation of *Discovery's* external tank. Since then, NASA has installed commercial plastic owl decoys and inflatable owl balloons which must be removed prior to launch. The delicate nature of the foam insulation has been the cause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

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

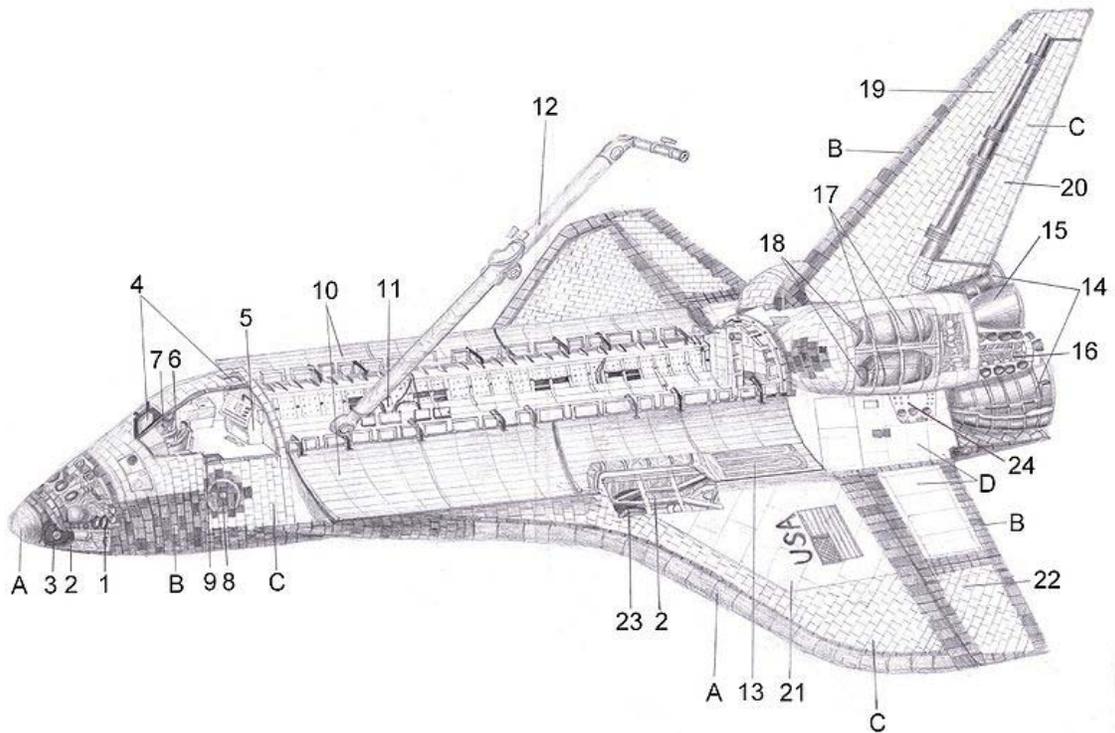
On the first four shuttle missions, astronauts wore modified U.S. Air Force high-altitude full-pressure suits, which included a full-pressure helmet during ascent and descent. From the fifth flight, STS-5, until the loss of *Challenger*, one-piece light blue nomex flight suits and partial-pressure helmets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

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

## Technical data



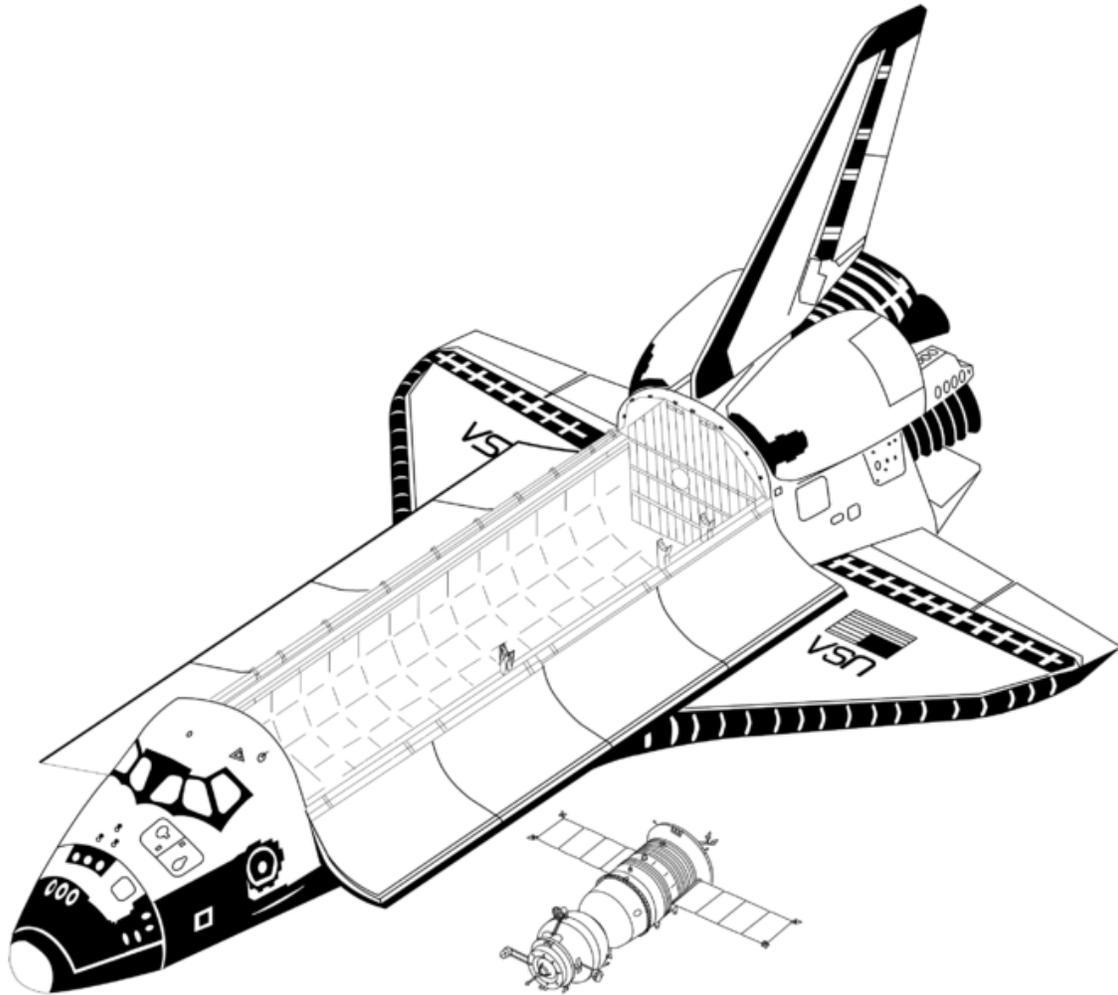
Space Shuttle orbiter illustration



Space Shuttle drawing



Space Shuttle wing cutaway



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

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

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

- Crossrange: 1,085 nmi (2,009 km; 1,249 mi)
- First Stage (SSME with external tank)
  - Main engines: Three Rocketdyne Block II SSMEs, each with a sea level thrust of 393,800 lbf (1.752 MN) at 104% power
  - Thrust (at liftoff, sea level, 104% power, all 3 engines): 1,181,400 lbf (5.255 MN)
  - Specific impulse: 455 s
  - Burn time: 480 s
  - Fuel: Liquid Oxygen/Liquid Hydrogen
- Second Stage
  - Engines: 2 Orbital Maneuvering Engines
  - Thrust: 53.4 kN (12,000 lbf) combined total vacuum thrust
  - Specific impulse: 316 s
  - Burn time: 1250 s
  - Fuel: MMH/N<sub>2</sub>O<sub>4</sub>
- Crew: Varies.

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

#### **External tank specifications (for SLWT)**

- Length: 46.9 m (154 ft)
- Diameter: 8.4 m (28 ft)
- Propellant volume: 2,025 m<sup>3</sup> (534,900 US gal)
- Empty weight: 26,535 kg (58,500 lb)
- Gross liftoff weight: 756,000 kg (1,670,000 lb)

#### **Solid Rocket Booster specifications**

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

## System Stack specifications

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

## Mission profile



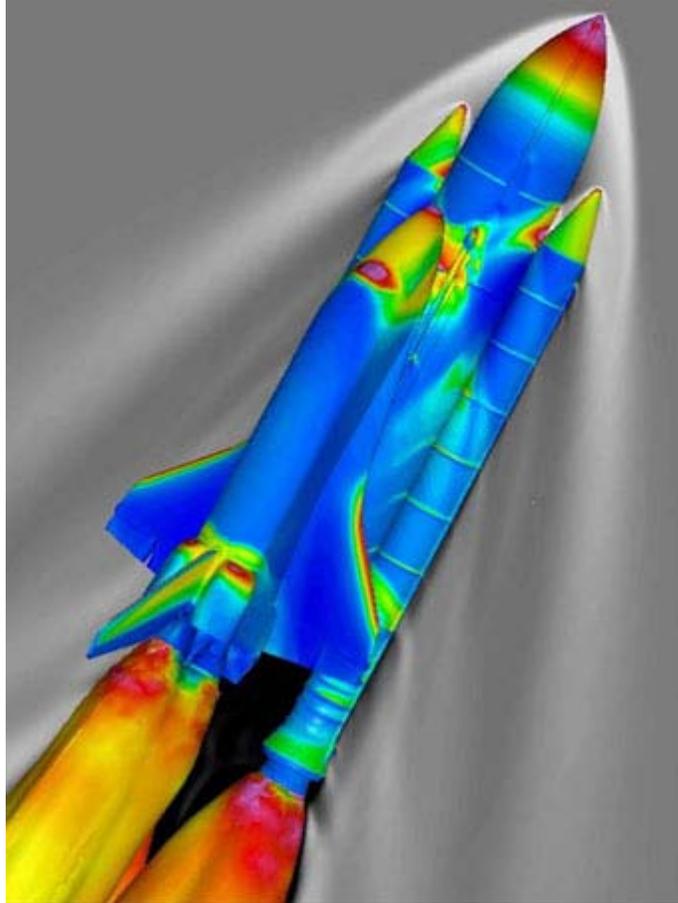
STS mission profile



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



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



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



Multicolored afterglow of the STS-131 launch

## Launch

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

Historically, the Shuttle was not launched if its flight would run from December to January (a year-end rollover or YERO). Its flight software, designed in the 1970s, was

not designed for this, and would require the orbiter's computers be reset through a change of year, which could cause a glitch while in orbit. In 2007, NASA engineers devised a solution so Shuttle flights could cross the year-end boundary.

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

At T minus 16 seconds, the massive sound suppression system (SPS) begins to drench the Mobile Launcher Platform (MLP) and SRB trenches with 300,000 US gallons (1,100 m<sup>3</sup>) of water to protect the Orbiter from damage by acoustical energy and rocket exhaust reflected from the flame trench and MLP during liftoff.

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

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

After the main engines start, but while the solid rocket boosters are still clamped to the pad, the offset thrust from the Shuttle's three main engines causes the entire launch stack (boosters, tank and shuttle) to pitch down about 2 m at cockpit level. This motion is called the "nod", or "twang" in NASA jargon. As the boosters flex back into their original

shape, the launch stack pitches slowly back upright. This takes approximately six seconds. At the point when it is perfectly vertical, the boosters ignite and the launch commences. The Johnson Space Center's Mission Control Center assumes control of the flight once the SRBs have cleared the launch tower.

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

Around a point called Max Q, where the aerodynamic forces are at their maximum, the main engines are temporarily throttled back to 72% to avoid overspeeding and hence overstressing the Shuttle, particularly in vulnerable areas such as the wings. At this point, a phenomenon known as the Prandtl-Glauert singularity occurs, where condensation clouds form during the vehicle's transition to supersonic speed. At  $T+70$  seconds, the main engines throttle up to their maximum cruise thrust of 104% rated thrust.

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

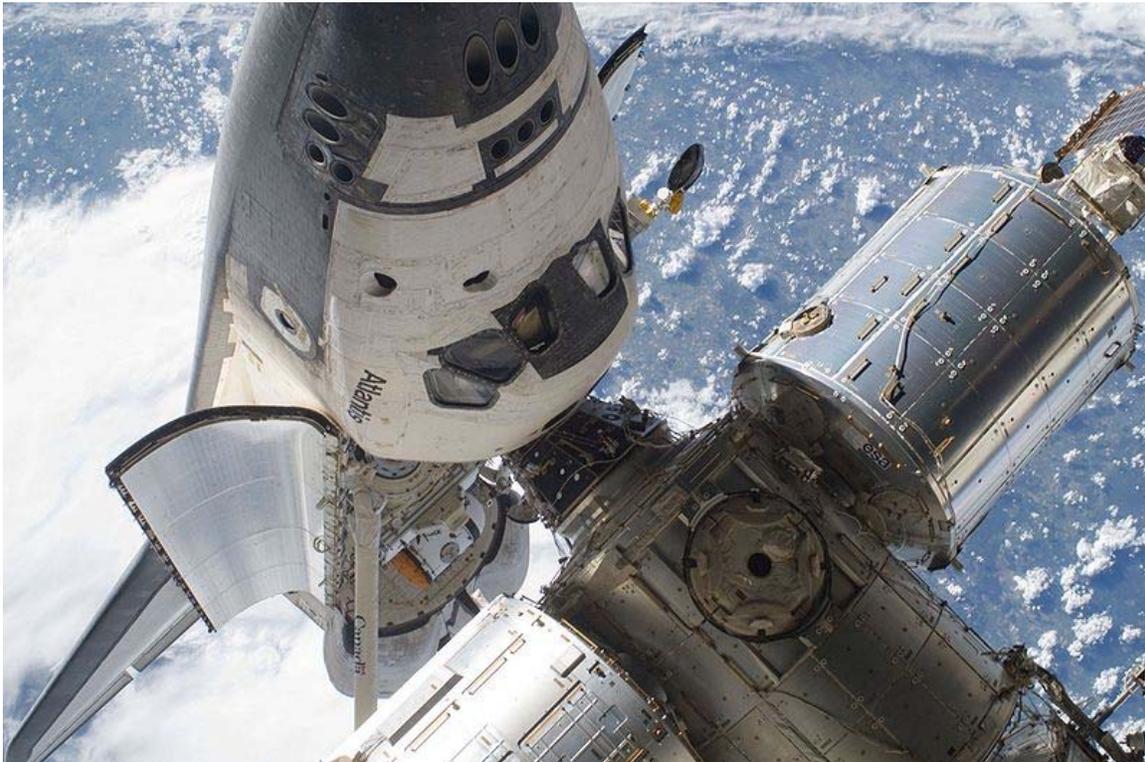
The vehicle continues to climb and takes on a somewhat nose-up angle to the horizon – it uses the main engines to gain and then maintain altitude while it accelerates horizontally towards orbit. At about five and three-quarter minutes into ascent, the orbiter's direct communication links with the ground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

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

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

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

### **In orbit**



*Atlantis and Harmony — spring 2010*

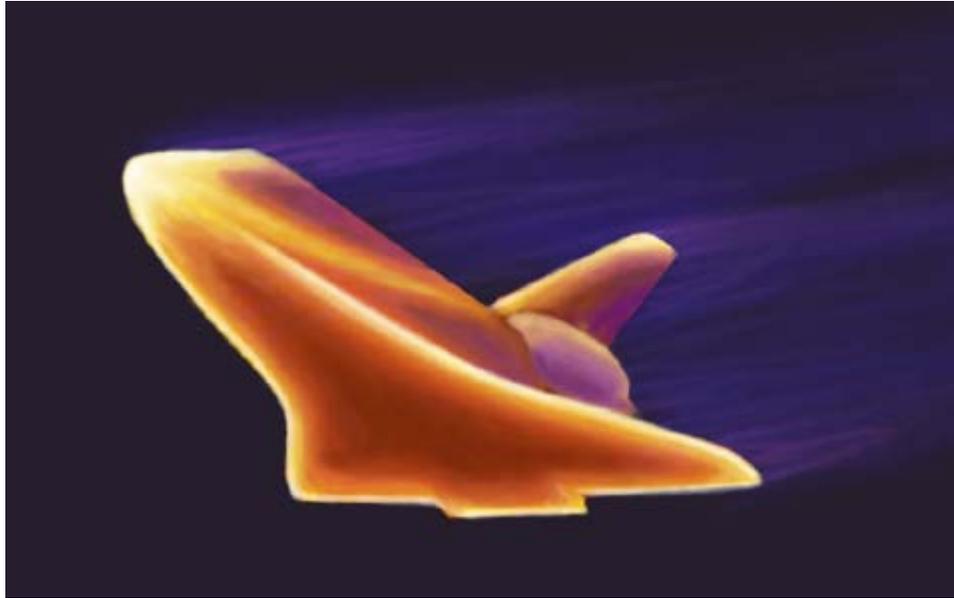
Once in orbit, the shuttle does any number of tasks, and usually some combination. In the 1980s and 1990s, many flights involved space science missions on the NASA/ESA Spacelab, or launching various types of satellites and science probes. By the 1990s and 2000s the focus shifted more to servicing space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

## **Re-entry and landing**

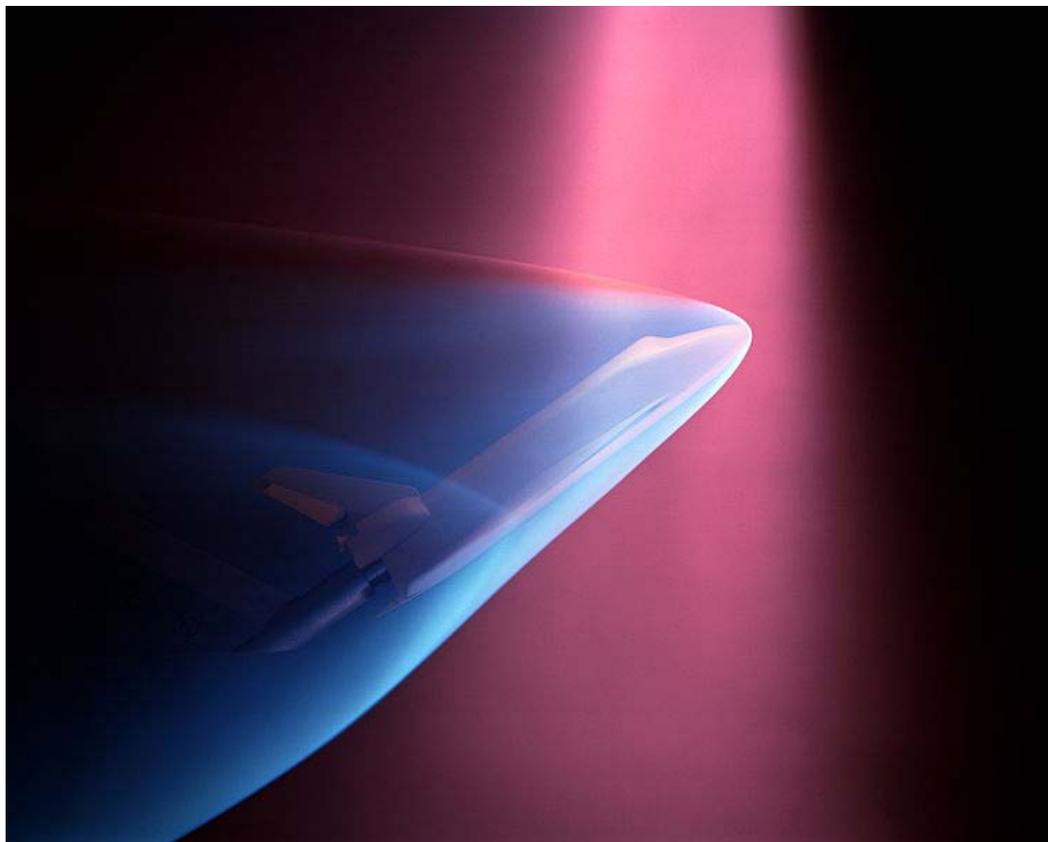
Almost the entire Space Shuttle re-entry procedure, except for lowering the landing gear and deploying the air data probes, is normally performed under computer control. However, the re-entry can be flown entirely manually if an emergency arises. The approach and landing phase can be controlled by the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

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

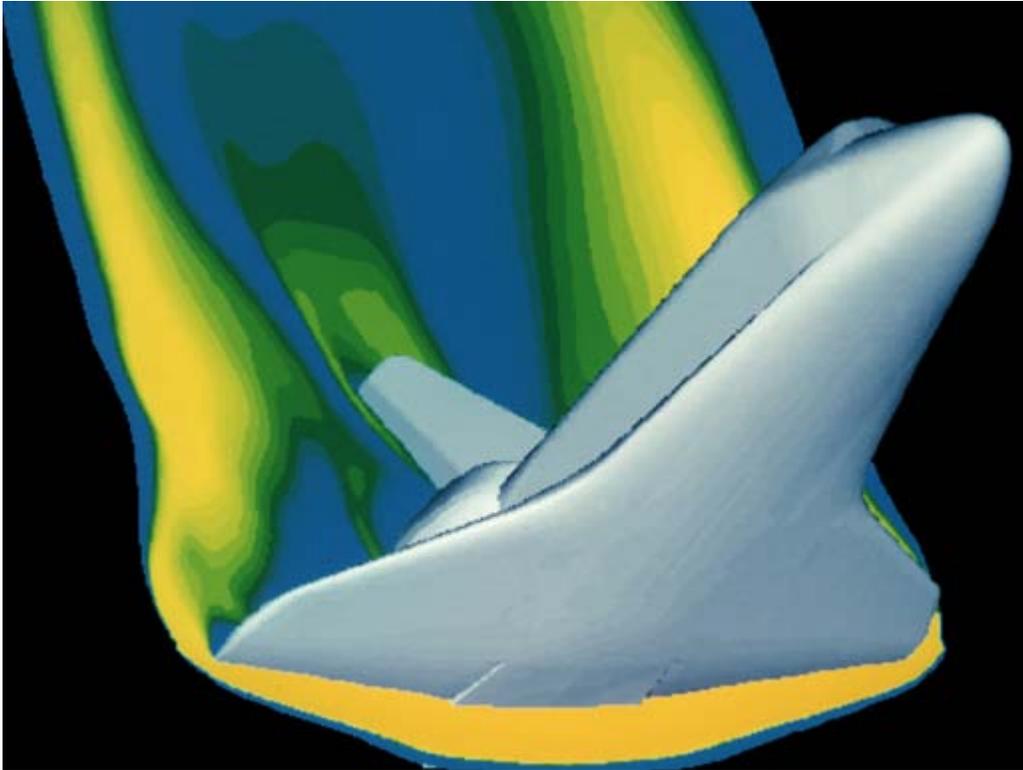
The vehicle starts encountering more significant air density in the lower thermosphere at about 400,000 ft (120 km), at around Mach 25, 8,200 m/s (30,000 km/h; 18,000 mph). The vehicle is controlled by a combination of RCS thrusters and control surfaces, to fly at a 40 degree nose-up attitude, producing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



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



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



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

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

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

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

After landing, the vehicle stands on the runway for several minutes to permit the fumes from poisonous hydrazine (which is used as a fuel for attitude control, and the orbiter's

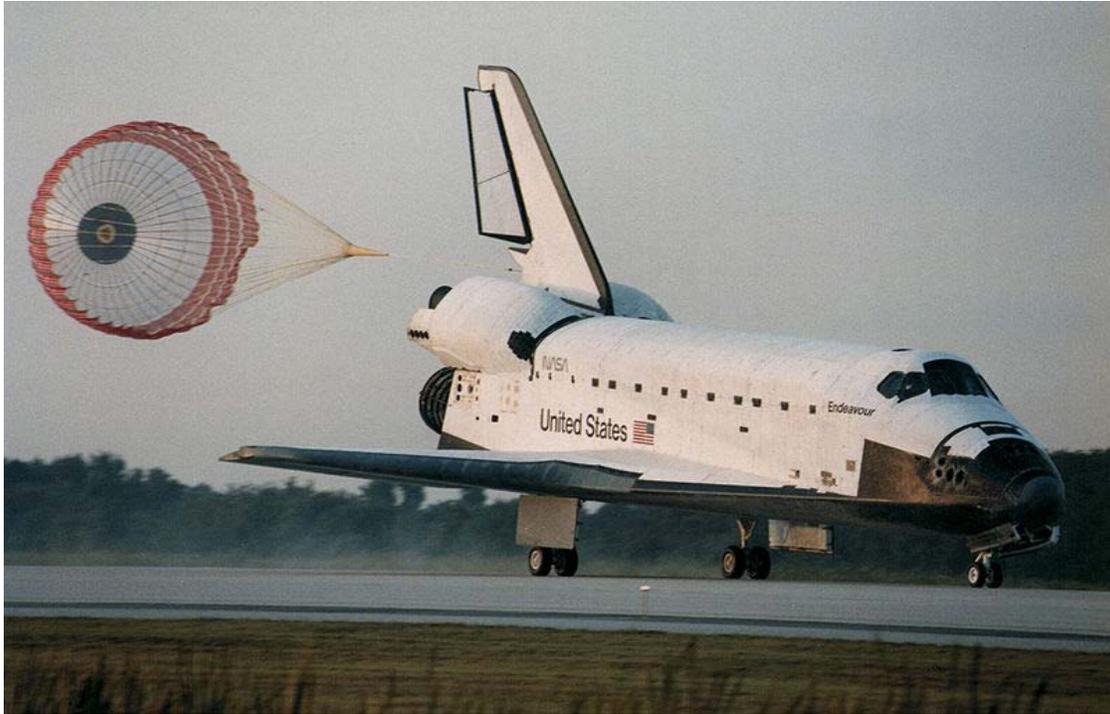
three APUs) to dissipate, and for the shuttle fuselage to cool before the astronauts disembark.



*Discovery touches down at the end of STS-95*



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



*Endeavour* brake chute deploys after touching down



*Discovery* after landing on Earth for crew disembarkment

## **Landing sites**

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

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

## **Risk contributors**

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

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

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

## Fleet history



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

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

<b>Space Shuttle major events</b>		
<b>Date</b>	<b>Orbiter</b>	<b>Major event / remarks</b>
February 18, 1977	<i>Enterprise</i>	First flight; Attached to Shuttle Carrier Aircraft throughout flight.
August 12, 1977	<i>Enterprise</i>	First free flight; Tailcone on; lakebed landing.
October 26, 1977	<i>Enterprise</i>	Final <i>Enterprise</i> free flight; First landing on Edwards AFB concrete runway.
April 12, 1981	<i>Columbia</i>	First <i>Columbia</i> flight, first orbital test flight; STS-1
November 11, 1982	<i>Columbia</i>	First operational flight of the Space Shuttle, first mission to carry four astronauts; STS-5
April 4, 1983	<i>Challenger</i>	First <i>Challenger</i> flight; STS-6
August 30, 1984	<i>Discovery</i>	First <i>Discovery</i> flight; STS-41-D

October 3, 1985	<i>Atlantis</i>	First <i>Atlantis</i> flight; STS-51-J
January 28, 1986	<i>Challenger</i>	Disaster starting 73 seconds after launch; STS-51-L; all seven crew members died.
September 29, 1988	<i>Discovery</i>	First post- <i>Challenger</i> mission; STS-26
May 4, 1989	<i>Atlantis</i>	The first Space Shuttle mission to launch a space probe, Magellan; STS-30
April 24, 1990	<i>Discovery</i>	Launch of the Hubble Space Telescope; STS-31
May 7, 1992	<i>Endeavour</i>	First <i>Endeavour</i> flight; STS-49
November 19, 1996	<i>Columbia</i>	Longest Shuttle mission to date at 17 days, 15 hours; STS-80
February 1, 2003	<i>Columbia</i>	Disintegrated during re-entry; STS-107; all seven crew members died.
July 25, 2005	<i>Discovery</i>	First post- <i>Columbia</i> mission; STS-114
May 14, 2010	<i>Atlantis</i>	Last planned <i>Atlantis</i> flight; STS-132

#### **Planned fleet events**

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

### **Shuttle disasters**

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

On February 1, 2003, Space Shuttle *Columbia* disintegrated during re-entry, killing its crew of seven, because of damage to the carbon-carbon leading edge of the wing caused during launch. Ground control engineers had made three separate requests for high-resolution images taken by the Department of Defense that would have provided an understanding of the extent of the damage, while NASA's chief thermal protection system (TPS) engineer requested that astronauts on board the *Columbia* be allowed to leave the vehicle to inspect the damage. NASA managers intervened to stop the Department of Defense's assistance and refused the request for the spacewalk, and thus the feasibility of

scenarios for astronaut repair or rescue by the Space Shuttle *Atlantis* were not considered by NASA management at the time.

## Planned retirement



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

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

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

## Final locations of retired orbiters



Space Shuttle Program commemorative patch

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

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

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

## **Space Shuttle successors and legacy**

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

### **Successor cancelled**

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

### **Commercial replacement vehicles and services**

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

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

## **Technology transfer**

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

### Launch vehicles

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

### Next-generation orbiters

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

## Chapter 6

# Space Shuttle Atlantis

*Atlantis*  
*OV-104*



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

<b>OV designation</b>	OV-104
<b>Country</b>	United States
<b>Contract award</b>	January 29, 1979
<b>Named after</b>	RV <i>Atlantis</i>
<b>Status</b>	Active
<b>First flight</b>	STS-51-J October 3–7, 1985

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

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

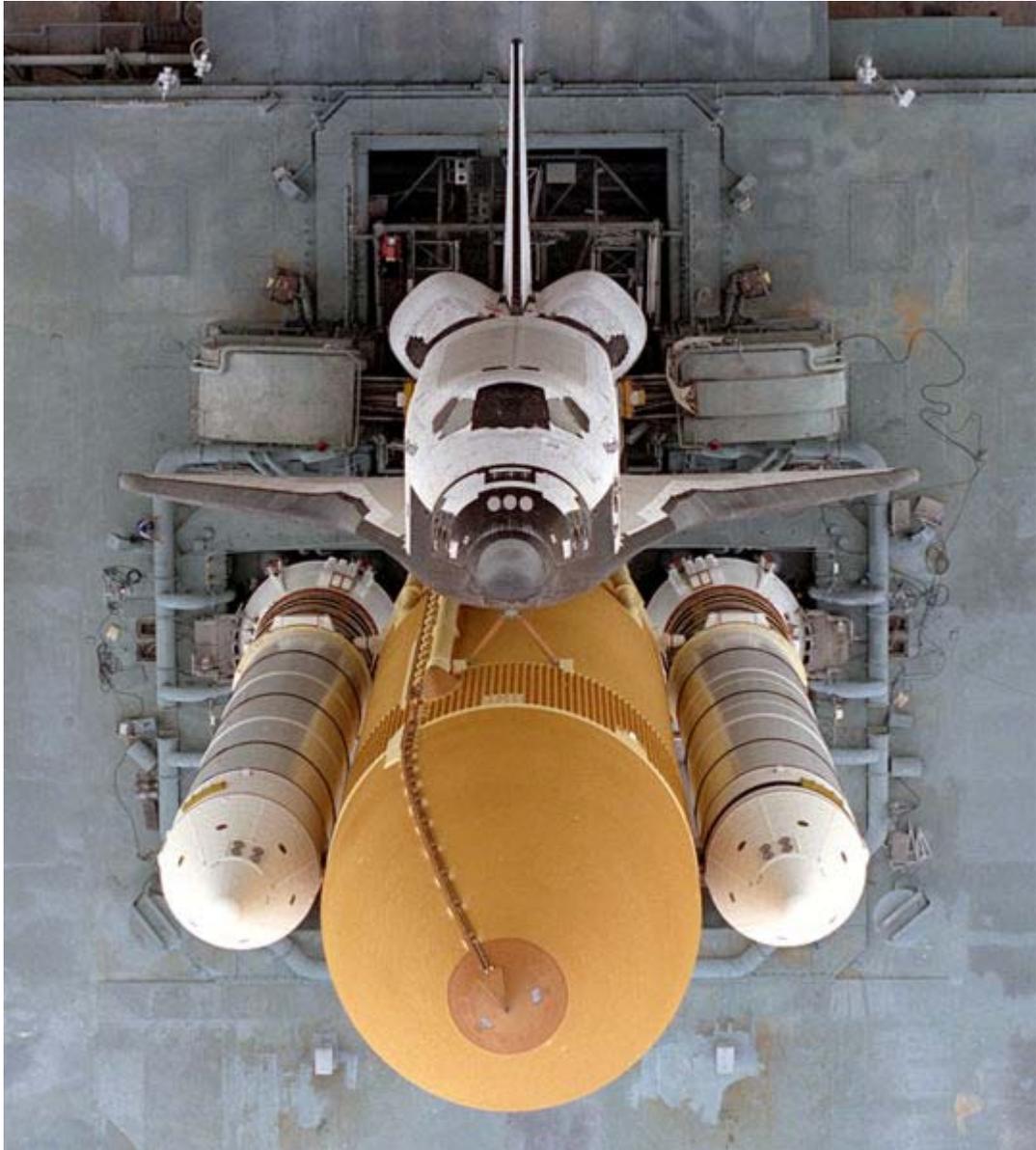
In early 2008, the NASA Administrator, with the approval of the President and the United States Congress, decided to continue with the *Atlantis* making space flights until sometime in 2010, the tentatively predetermined end of the Space Shuttle's spaceflight program. This reversed a previous decision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



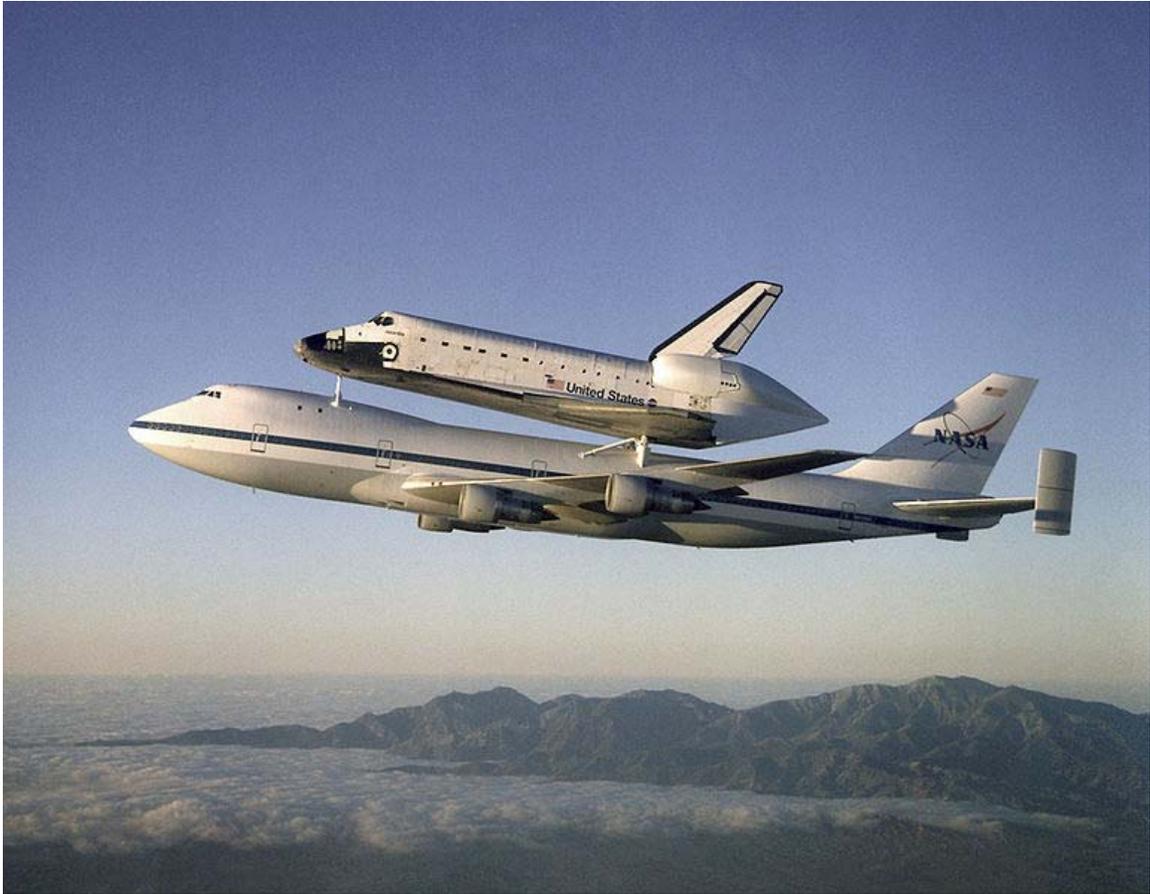
Space Shuttle *Atlantis* after it undocked from the Space Station on September 17, 2006



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



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



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

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

## History



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

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

## Construction milestones

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

## Notable missions



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

Space Shuttle *Atlantis* lifted off on its maiden voyage on October 3, 1985, on mission STS-51-J, the second dedicated Department of Defense flight. It flew one other mission, STS-61-B, the second night launch in the shuttle program, before the Space Shuttle Challenger disaster temporarily grounded the shuttle fleet in 1986. *Atlantis* was used for

ten flights between 1988 and 1992. Two of these, both flown in 1989, deployed the planetary probes Magellan to Venus (on STS-30) and Galileo to Jupiter (on STS-34). With STS-30 *Atlantis* became the first shuttle to launch an interplanetary probe. During another mission, STS-37 flown in 1991, *Atlantis* deployed the Compton Gamma Ray Observatory. Beginning in 1995 with STS-71, *Atlantis* made seven straight flights to the former Russian space station Mir as part of the Shuttle-Mir Program. STS-71 marked a number of historic firsts in human spaceflight: 100th U.S. manned space flight; first U.S. shuttle-Russian Space Station Mir docking and joint on-orbit operations; and first on-orbit changeout of shuttle crew. When linked, *Atlantis* and *Mir* together formed the largest spacecraft in orbit at the time.

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



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

In May 2009 *Atlantis* flew a seven member crew to the Hubble Space Telescope for its Servicing Mission 4, STS-125. The mission was a success, with the crew completing five

space walks totaling 37 hours to install new cameras, batteries, a gyroscope and other components to the telescope.

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

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

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

### **Orbiter Maintenance Down Periods**

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

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



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



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



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



Atlantis carrying the S1 Truss segment on mission STS-112

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

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

### **Planned decommissioning**

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

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

## Crews



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

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

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

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

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

## Remaining assigned missions

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

## Problems

### Composite overwrapped pressure vessels

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

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

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

### Knob

After the STS-125 mission, a work light knob was discovered jammed in the space between one of *Atlantis*'s front interior windows and the Orbiter dashboard structure. The knob was believed to have entered the space during flight, when the pressurized Orbiter was expanded to its maximum size. Then, once back on Earth, the Orbiter contracted, jamming the knob in place. Leaving "as-is" was considered unsafe for flight, and some options for removal (including window replacement) would have included a 6 month delay of *Atlantis*'s next mission (planned to be STS-129). Had the removal of the knob been unsuccessful, the worst-case scenario is that *Atlantis* could have been retired from flight, leaving *Discovery* and *Endeavour* to complete the manifest alone. On 29 June 2009, *Atlantis* was pressurised to 17 psi/120 kPa (3psi-delta), which forced the Orbiter to expand slightly. The knob was then frozen with dry ice, and was successfully removed. Small areas of damage to the window were discovered where the edges of the knob had been embedded into the pane. Subsequent investigation of the window damage

discovered a maximum defect depth of approximately 0.0003 in/0.0076 mm, less than the reportable depth threshold of 0.0015 in/0.038 mm and not serious enough to warrant the pane's replacement.

## Chapter 7

# Space Shuttle Challenger

### *Challenger* *OV-099*



*Challenger* launches, STS-7

<b>OV designation</b>	OV-099
<b>Country</b>	United States
<b>Contract award</b>	July 26, 1972
<b>Named after</b>	HMS <i>Challenger</i>
<b>Status</b>	destroyed January 28, 1986

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

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

## History

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

## Construction

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

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

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

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

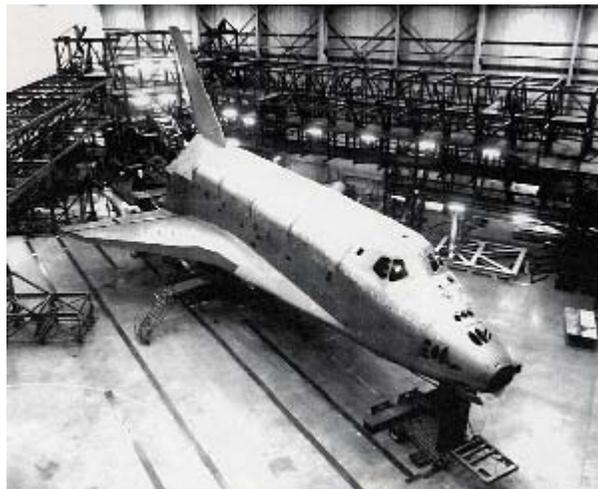
## **Flights and modifications**

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

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



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



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

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

spacewalk.  
 Deployed Earth  
 Radiation Budget  
 Satellite.

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

### Mission insignias

Mission insignia for Challenger flights				
				
<b>STS 6</b>	<b>STS 7</b>	<b>STS 8</b>	<b>STS 41-B</b>	<b>STS 41-C</b>
				
<b>STS-41-G</b>	<b>STS-51-B</b>	<b>STS-51-F</b>	<b>STS-61-A</b>	<b>STS-51-L</b>

## Loss of Challenger



The crew of the *Challenger's* final flight

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

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

## Chapter 8

# Space Shuttle Columbia

### *Columbia* *OV-102*



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

<b>OV designation</b>	OV-102
<b>Country</b>	United States
<b>Contract award</b>	July 26, 1972
<b>Named after</b>	Robert Gray's <i>Columbia Rediviva</i>
<b>Status</b>	Destroyed February 1, 2003
<b>First flight</b>	STS-1 April 12, 1981 - April 14, 1981
<b>Last flight</b>	STS-107 January 16, 2003 – February 1, 2003
<b>Number of missions</b>	28
<b>Crews</b>	160
<b>Time spent in space</b>	300 days 17:40:22
<b>Number of orbits</b>	4,808
<b>Distance travelled</b>	201,497,772 km (125,204,911 miles)

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

## History

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

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

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



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

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

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

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

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

## Prototype orbiter



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

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

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

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

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

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

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



*Columbia* on the launch pad before its first mission

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

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

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

## Flights

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

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

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

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

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

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

## Tribute

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

Fans of the original *Star Trek* television series were largely responsible for NASA naming the first Space Shuttle *Enterprise*. In the television series *Star Trek: Enterprise* both the first and second starships of the human-built NX-Class, registry numbers NX-01 & NX-02 respectively, were named in honor of pre-existing NASA space shuttles. The second vessel's name was first revealed in the season 3 episode "E2" to be *Columbia*, in honor of the space shuttle *Columbia* following its destruction on February 1, 2003. Uniforms on NX-02 *Columbia* bear a crew patch depicting 7 stars, in honor of the astronauts who died in the shuttle accident.

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

## Chapter 9

# Space Shuttle Discovery

### *Discovery* *OV-103*



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

<b>OV designation</b>	OV-103
<b>Country</b>	United States
<b>Contract award</b>	January 29, 1979
<b>Named after</b>	RRS <i>Discovery</i>
<b>Status</b>	Active
<b>First flight</b>	STS-41-D August 30, 1984 – September 5, 1984

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

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

## History

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



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



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



STS-119 on the morning of March 11, 2009



Discovery sits atop a Boeing 747 as it touches down

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

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

## **Construction milestones**

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

## **Upgrades and features**

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

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



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



The Space Shuttle *Discovery* soon after landing on earth



Modified Boeing 747 carrying Discovery

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

## Flights

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

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

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

### Flights listing

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

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

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

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

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

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

## Planned decommissioning

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

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