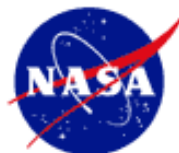


# Extending the Reach of the Space Station



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Updated April 9, 2001

# STS-100

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## Mission Overview

### Endeavour to Extend Human's Reach in Space

With a crew that hails from across the globe, the space shuttle Endeavour will extend the reach of humans in space as it launches a new generation of Canadian robotics to the International Space Station on mission STS-100 (ISS Assembly Flight 6A).

Endeavour will carry aloft the Canadarm2, a robotic arm for the station that is longer, stronger, more flexible and more capable than the shuttle's robotic arm. The installation and checkout of the new station arm will involve the most complex and intricate space robotics operations ever performed. Endeavour also will carry the second Italian Space Agency-supplied station logistics module, a cargo van named Raffaello that will carry more research equipment than any previous station mission as well as station supplies. Raffaello is valued at \$150 million.

Endeavour will carry nine scientific investigations to the station, more than any previous flight. The experiments carried aboard Endeavour range from the first plant growth research to be conducted aboard the complex to studies of space radiation.

Endeavour's crew - composed of space fliers from NASA, Canada, Russia and the European Space Agency - is the most diverse international crew ever flown aboard the space shuttle. Its members represent more nations than has any other single crew. Once aboard the station, four out of five of the project's major partners will be represented, the most that have ever been aboard the complex together.

Kent Rominger, 44, a Navy captain and a veteran of four shuttle flights - including one previous International Space Station assembly mission - will command Endeavour. Jeff Ashby, 46, also a Navy captain and a veteran of one shuttle flight, is pilot. Mission specialists include NASA astronauts Scott Parazynski, 39, and John Phillips, 50.

International crew members, also mission specialists, include Canadian Space Agency astronaut Chris Hadfield, 41, a colonel in the Canadian Air Force; European Space Agency astronaut Umberto Guidoni, 46; and Russian Aviation and Space Agency cosmonaut Yuri Lonchakov, 36, a colonel in the Russian Air Force. During Endeavour's mission, Guidoni will become the first European Space Agency astronaut to enter the orbiting International Space Station.

Hadfield and Parazynski will perform at least two space walks, with the capability to add a third space walk if it is needed. In addition to installing the Canadarm2 on the exterior of the station's Destiny laboratory during the space walks, they will attach an Ultra-High Frequency (UHF) antenna to enable future space walk communications outside the station as well as shuttle-station communications. They also will attach a spare piece of electronics equipment to an exterior stowage platform on Destiny and remove an unneeded Early Communications System antenna from the station's Unity module.

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The Canadarm2 is a space robotic arm of unprecedented capabilities. The station arm will be able to move more than three times as much mass as the shuttle's robotic arm--a mass greater than even a 100-ton space shuttle. The station arm also will have an amazing capability to move end-over-end about the station's exterior, in inchworm fashion, using either end to manipulate cargos. It can provide electrical power and make computer connections with the things it moves and has greater flexibility than the shuttle arm. It measures 57.7 feet, about 7 feet longer than the shuttle arm, and it is designed to be disassembled and repaired in space if necessary.

For the first time, two space robotic arms, controlled by different astronauts on different spacecraft, will work together. Operations of the station's Canadarm2 are critical for the success of many future International Space Station assembly flights. The installation of the station arm also includes the first exterior television cameras aboard the International Space Station. Four cameras are mounted to the arm, three of which can be used simultaneously.

Endeavour's flight will be the ninth shuttle mission to the International Space Station.

## Day 1 - Launch

Endeavour's crew will launch at the end of their day during a precisely timed, few-minutes-long launch window that begins the process of rendezvous with the International Space Station. The crew will go to sleep about four hours after they reach orbit.

## Day 2 - Equipment Checkouts, Rendezvous Preparations

Endeavour's crew will spend the first full day in space checking out the equipment that will be used for the mission's upcoming major activities. Checks will be made of the spacesuits and space-walking gear; the shuttle's robotic arm; and the controls and tools used for the final rendezvous and docking with the station. The crew also will power up and prepare the shuttle's docking system and perform several engine firings to fine-tune the rate at which Endeavour closes in on the station.

## Day 3 - Rendezvous and Docking

Endeavour is planned to dock with the International Space Station on Flight Day 3 of the mission, becoming the first shuttle to visit the station's second expedition crew of Commander Yury Usachev and Flight Engineers Jim Voss and Susan Helms since they began their stay aboard the outpost in March. Although Endeavour will dock to the station on Flight Day 3, the two crews will not greet one another in person until Flight Day 5 of the mission due to a lower cabin pressure that is maintained aboard the shuttle as part of the space walk preparations. The crews will, however, use an outer station compartment as a type of "airlock" to allow them to exchange a few items early on despite the differing cabin pressures on each spacecraft.

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## Day 4 - First Space Walk

The first space walk will take place on Flight Day 4. That day, as Hadfield and Parazynski are donning their spacesuits on Endeavour's lower deck, in the aft cockpit of Endeavour Ashby will power up the shuttle's robotic arm. Ashby, assisted by Guidoni, will use the shuttle arm to lift the pallet holding the station arm and the UHF antenna from the shuttle's cargo bay. He will then maneuver the pallet to latch to a cradle affixed to the station's Destiny lab. Then Hadfield and Parazynski will begin their 6 1/2 -hour space walk, during which they will first remove the UHF antenna from the pallet, attach it to another position on Destiny's exterior and deploy its boom. Next, they will make connections between the pallet and station, loosen retaining bolts on the Canadarm2 and unfold the new arm. Inside the station lab, Helms and Voss will verify several of the connections made by the space walkers from a Robotics Work Station, the arm's control center. Ashby will control the shuttle arm throughout the space walk, and Phillips will serve as the shuttle's in-cabin space walk coordinator.

## Day 5 - Hatches Open, Canadarm2 Walk-Off, Raffaello to Station

The hatches will be fully opened and the shuttle and station crews will greet one another for the first time on Flight Day 5. Inside the Destiny lab, Helms and Voss, assisted by Hadfield and Parazynski, will work at the control center for the newly attached station arm, powering it up and moving the Canadarm2 for the first time. They will maneuver the new arm, checking its operation and finally latching a free end to a fixture on the station's exterior. The other end will remain latched to a fixture on the pallet. Also on Day 5, Parazynski and Guidoni will use the shuttle's robotic arm to lift the Raffaello logistics module from the cargo bay and maneuver it to a berthing port on the station's Unity module, where it will be unloaded during the following days. At the end of Day 5, the hatches between Endeavour and the station will be closed again in preparation for another space walk.

## Day 6 - Second Space Walk, Raffaello Entry

Early on Flight Day 6, as Parazynski and Hadfield are donning spacesuits aboard Endeavour, the station crew will open the hatch to Raffaello and begin unloading the cargo module. Usachev and Voss, sometimes assisted by Helms, will continue the unloading throughout the day, including transfer of the two experiment racks, called Expedite the Processing of Experiments to Space Station (EXPRESS) racks. The EXPRESS racks will be installed in the station's Destiny lab and will eventually house experiments to be moved to Destiny from Endeavour's cabin later in the flight as well as investigations to be carried to the station on later missions.

Parazynski and Hadfield will begin their second 6 1/2 -hour space walk by opening a panel on the lab's exterior and connecting power, computer and video cables for the lab fixture to which the Canadarm2 is attached. This prepares the arm to "switch ends," using the lab fixture as its base and the end attached to the pallet as its free end. Also in preparation for that and the eventual return of the pallet to Endeavour's payload bay, the space walkers will disconnect the cables between the pallet and lab that they had hooked up on the previous space walk. Parazynski and Hadfield will then watch as, inside the lab, Helms lifts the 1.5-

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ton pallet with the new station arm, checking the arm's operation with cargo attached. Helms will maneuver the arm and pallet into a parked position where it will remain overnight.

In addition to the arm work, during the second space walk Parazynski and Hadfield will remove an Early Communications System antenna that is no longer needed from the exterior of the station's Unity module. They also will position a spare piece of electronics equipment, called a Direct Current Switching Unit, on a stowage bracket on the lab's exterior, where it will be ready if needed by future crews for station repairs. Throughout the space walk, Ashby, with help from Guidoni, will control the shuttle arm and Phillips will be the in-cabin coordinator for the space walkers. At the end of Flight Day 6, the crews will reopen hatches between Endeavour and the station.

## Day 7 - Shuttle Arm-Station Arm Handoff, Raffaello Unloading

On Flight Day 7, the Endeavour and station crews will engage in the first dual robotic arm operations ever conducted in space, a "handshake" between the Canadian robotic arms for the shuttle and station that will serve to relocate the pallet in the shuttle cargo bay.

Inside the station's Destiny lab, Helms will power up the station's arm, with the pallet still attached to its free end, and maneuver the pallet to a position high above the shuttle, within reach of the shuttle arm. The station arm's maneuvers will continue checks of the new arm with a payload attached.

Then, aboard Endeavour, Hadfield, assisted by Parazynski, will power up the shuttle arm. Hadfield will assist with the operation of both arms at times during the day. Once the station arm has the pallet properly positioned, Helms will lock it in place while Hadfield, at the controls of the shuttle arm, will latch onto it. Helms will then release the pallet from the station arm and Hadfield will maneuver the pallet, now affixed to the end of the shuttle arm, back to a position in Endeavour's payload bay to be latched for the return to Earth.

While the arm activities take place, members of the shuttle and station crews will continue unloading Raffaello throughout the day. If a third space walk is needed during the mission, the hatches between the shuttle and station will be closed again at the end of Flight Day 7.

## Day 8 - Third Space Walk or Canadarm2 Checks, Raffaello Unloading

Time has been set aside to allow a third 6 1/2 -hour space walk on Flight Day 8 if it is required by the mission's events. However, in the prelaunch plan, although time is set aside for the third space walk, no activities are planned during it. If it is needed, its activities will be planned during Endeavour's flight. If a third space walk is not needed, the crews will spend Day 8 together as another day of joint activities with hatches open aboard the shuttle and station. Helms, Hadfield and Voss will perform further checks of the station arm's operation. The checks include a "dry run" where the arm will be maneuvered in the same positions that will be required to lift a new station airlock from the shuttle's bay and install it on the station's Unity module on the next space shuttle flight, and the crews will continue unloading and reloading - with trash, unnecessary equipment, and Earth-bound items - the Raffaello logistics module.

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## Day 9 - Raffaello Closing, Reberth in Shuttle, Continue Canadarm2 Checkouts

Guidoni and Usachev will deactivate and close hatches between the Raffaello logistics module and the station early on Flight Day 9. Later, Parzynski, assisted by Guidoni, will use the shuttle's robotic arm to detach Raffaello from the station's Unity module and maneuver it back into Endeavour's payload bay, latching it in place for the return home. Meanwhile, in the station's Destiny lab, Helms, Hadfield and Voss will continue several hours of checkouts with the Canadarm2.

## Day 10 - Station Reboost, Shuttle-Station Hatch Closing, Undocking, Flyaround

Early on Flight Day 10, Rominger will fire Endeavour's small steering jets intermittently for about an hour to boost the shuttle and station altitude by several miles. Then, the shuttle and station crews will say a final farewell to one another and close hatches between the spacecraft. With Ashby at the helm, Endeavour will undock from the station, performing a three-quarter circle of the complex before departing the vicinity.

## Day 11 - Pre-Landing Checkouts, Cabin Stow

Flight Day 11 will include the standard day-before-landing flight control checks of Endeavour by Rominger and Ashby as well as the normal steering jet test firing. The crew will spend most of the day stowing away gear onboard the shuttle and preparing for the return home.

## Day 12 - Entry and Landing

The Kennedy Space Center, Fla., will be Endeavour's preferred landing site on Flight Day 12.



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## Mission Objectives



**Launch: Thursday, April 19, 2001  
1:41 PM (eastern time)**

Endeavour's mission on STS-100 is centered on the delivery and installation of the Canadian-contributed International Space Station robotic arm, called Canadarm2.

The highest priority objectives of the flight are the installation, activation and checkout of the robotic arm on the station. The operation of the arm is critical to the capability to continue assembly of the International Space Station and to attach a new airlock to the station on the subsequent shuttle flight, mission STS-104, planned for launch in June.

Other major objectives for Endeavour's mission are to berth the Raffaello logistics module to the station, activate it, transfer cargo between Raffaello and the station, and reberth Raffaello in the shuttle's payload bay. Raffaello is the second of three Italian Space Agency-developed multi-purpose logistics modules to be launched to the station. The Leonardo module was launched and returned on the last shuttle flight, STS-102, in March.

Remaining objectives include the transfer of other equipment to the station such as an Ultra-High Frequency communications antenna and a spare electronics component to be attached to the exterior during space walks. Finally, the transfer of supplies and water for use aboard the station, the transfer of experiments and experiment racks to the complex, and the transfer of items for return to Earth from the station to the shuttle are among the objectives.

Endeavour also is planned to boost the station's altitude and perform a flyaround survey of the complex, including recording views of the station with an IMAX cargo bay camera.

## Crew

<b>Commander:</b>	Kent V. Rominger
<b>Pilot:</b>	Jeffrey S. Ashby
<b>Mission Specialist 1:</b>	Chris A. Hadfield
<b>Mission Specialist 2:</b>	John L. Phillips
<b>Mission Specialist 3:</b>	Scott E. Parazynski
<b>Mission Specialist 4:</b>	Umberto Guidoni
<b>Mission Specialist 5:</b>	Yuri V. Lonchakov

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## Launch

<b>Orbiter:</b>	Endeavour
<b>Launch Site:</b>	Kennedy Space Center Launch Pad 39A
<b>Launch Window:</b>	2.5 to 5 Minutes
<b>Altitude:</b>	173 Nautical Miles
<b>Inclination:</b>	51.6 Degrees
<b>Duration:</b>	10 Days 19 Hrs. 58 Min.

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## Vehicle Data

<b>Shuttle Liftoff Weight:</b>	4521931 lbs.
<b>Orbiter/Payload Liftoff Weight:</b>	228188 lbs.
<b>Orbiter/Payload Landing Weight:</b>	219890 lbs.

## Payload Weights

Canadarm2	3,960 pounds
Multi-Purpose Logistics Module (MPLM)	9,000 pounds (almost 4.1 metric tons)

**Software Version:** OI-28

## Space Shuttle Main Engines

**SSME 1:** 2054                      **SSME 2:** 2043                      **SSME 3:** 2049

**External Tank:** ET-108A                      ( Super Light Weight Tank)

**SRB Set:** BI107PF

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## Shuttle Aborts

### Abort Landing Sites

**RTLS:** Kennedy Space Center Shuttle Landing Facility

**TAL:** Zaragoza

**AOA:** Kennedy Space Center Shuttle Landing Facility

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## Landing

**Landing Date:** 04/30/01

**Landing Time:** 9:00 AM (eastern time)

**Primary Landing Site:** Kennedy Space Center Shuttle Landing Facility

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## Payloads

### Cargo Bay

Canadarm2

Raffaello -- A Space-Age Moving Van

External UHF Antenna

## Crew Profile Menu

### **Commander:** Kent V. Rominger

Kent V. Rominger (Capt., USN), 44, Endeavour's commander, is making his fifth flight into space, his second flight as commander and his second flight to the International Space Station. He will dock Endeavour to the ISS on the third space shuttle mission of the year. He is responsible for the overall safety and success of STS-100. While Endeavour is docked to the space station, Rominger will play an active part in the transfer of cargo from Endeavour and the Multi-Purpose Logistics Module Raffaello to the ISS. Initially selected as an astronaut in 1992, Rominger first worked on technical issues for the Astronaut Office Operations Development Branch.



### **Previous Space Flights**

Rominger flew as pilot on STS-73 in 1995, STS-80 in 1996 and STS-85 in 1997. He commanded STS-96, a logistics and resupply mission to the ISS, in 1999.

**Ascent Seating:** Flight Deck - Port Forward

**Entry Seating:** Flight Deck - Port Forward

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### **Pilot:** Jeffrey S. Ashby

Jeff Ashby (Capt., USN), 46, is making his second flight into space. He is a former Navy fighter pilot and test pilot with more than 6,000 flight hours and 1,000 carrier landings. He will be responsible for key shuttle systems during launch and landing, will work on any in-flight maintenance that may be required and will fly Endeavour during undocking, ISS flyaround and separation from the space station. He also will operate the shuttle robotic arm during the space walks, helping to install the Canadarm2 on the U.S. laboratory Destiny and maneuvering space walkers attached to the shuttle arm's foot platform.



### **Previous Space Flights**

Ashby was pilot on STS-93, the mission to launch the Chandra X-Ray Observatory. STS-100 is his second space flight.

**Ascent Seating:** Flight Deck - Starboard Forward

**Entry Seating:** Flight Deck - Starboard Forward

**RMS**

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## **Mission Specialist 1: Chris A. Hadfield**

Chris Hadfield (Col., CAF), 41, is a Canadian Space Agency astronaut with one space flight to his credit. A former fighter pilot and test pilot, he was selected as one of four Canadian astronauts in 1992 from 5,330 applicants. Hadfield, designated EV1 and wearing the spacesuit with red stripes, will perform at least two space walks, becoming the first Canadian to conduct a space walk. He will help install the Canadian robotic arm on the space station and perform other tasks, including installation of a UHF antenna and attachment of a spare for a piece of electronics equipment to the outside of the ISS. He will also operate the shuttle robotic arm during the handoff of the Pallet from the Space Station Remote Manipulator System (SSRMS) to the shuttle robotic arm. In addition, he will work in the Destiny lab with the International Space Station crew during all SSRMS ops as the STS-100 crew SSRMS expert. He also will be in charge of the orbiter docking system.



### **Previous Space Flights**

Hadfield was a mission specialist on STS-74, the second space shuttle flight to dock with the Russian Space Station Mir.

**Ascent Seating:** Flight Deck - Starboard Aft

**Entry Seating:** Mid Deck – Center

**EV1**

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## **Mission Specialist 2: John L. Phillips**

John Phillips, Ph.D., 50, will serve as Endeavour's flight engineer during launch and landing. He is a graduate of the U.S. Naval Academy and is a Naval aviator with more than 4,000 flight hours and 250 carrier landings. After leaving the Navy in 1982, he completed his doctorate in geophysics and space physics at the University of California, Los Angeles in 1987. He worked at Los Alamos National Laboratory before being selected as an astronaut in 1996. He is the author of more than 150 scientific papers on the plasma environments of the sun, Earth, other planets, comets and spacecraft. Once on orbit, he will serve as the coordinator for the two space walks and will control the Common Berthing Mechanism, which mates the Multi-Purpose Logistics Module to Unity. He will also operate the IMAX cameras and assist with a range of other Endeavour operations.



### **Previous Space Flights**

Phillips is making his first space flight.

**Ascent Seating:** Flight Deck - Center Aft

**Entry Seating:** Flight Deck - Center Aft

**IV2**

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## **Mission Specialist 3: Scott E. Parazynski**

Scott Parazynski, M.D., 39, is a graduate of Stanford Medical School, a commercial-rated pilot with more than 1,500 flight hours and one of the nation's top 10 competitors in the luge in the 1988 Olympic trials. He served his medical internship at the Brigham and Women's Hospital of Harvard Medical School. He had completed 22 months of a residency program in emergency medicine in Denver, Colo., when he was selected as an astronaut in 1992.



He served as the Astronaut Office Operations Planning Branch crew representative for space shuttle, space station and Soyuz training, was assigned to the Astronaut Office EVA Branch, and most recently served as deputy (Operations and Training) of the Astronaut Office ISS Branch. During STS-100 he will perform two space walks to install the Canadian ISS robotic arm and a UHF antenna, attach a spare for a piece of electronics equipment to the outside of the ISS, and complete other tasks. He will be designated EV2 and wear the all-white spacesuit. He also will operate the shuttle's robotic arm during the unberthing and berthing of the Raffaello Multi-Purpose Logistics Module, and is responsible for navigation tools during rendezvous and docking.

### **Previous Space Flights**

Parazynski is making his fourth space flight. He flew on STS-66 in 1994, STS-86 in 1997 (during which he and Russian cosmonaut Vladimir Titov performed a 5-hour, 1-minute space walk) and STS-95 (with fellow crewmember John Glenn) in 1998.

**Ascent Seating:** Mid Deck - Port

**Entry Seating:** Mid Deck – Port

**EV2**

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## **Mission Specialist 4: Umberto Guidoni**

Umberto Guidoni, Ph.D., 46, is a European Space Agency astronaut. He earned a doctorate in astrophysics from the University of Rome in 1978. He was selected to be trained as a payload specialist by the Italian Space Agency (ASI) for the second Tethered Satellite System shuttle mission, STS-75, in 1996. He was selected by ASI to attend NASA astronaut candidate training and reported to Johnson Space Center in 1996 and subsequently qualified as a mission specialist. He joined the astronaut corps of the European Space Agency in 1998. He will be responsible for Multi-Purpose Logistics Module (MPLM) activation and deactivation, as well as cargo transfer between the MPLM and the station. He will operate the Space Vision System and supervise payload bay door closing. He will serve as backup for shuttle robotic arm operations, as well as conduct photo documentation and Earth observations.



### **Previous Space Flights**

Guidoni served as a payload specialist on STS-75 in 1996, the reflight of the Tethered Satellite System.

**Ascent Seating:** Mid Deck - Center

**Entry Seating:** Flight Deck - Starboard Aft

**RMS**

## **Mission Specialist 5: Yuri V. Lonchakov**

Yuri Valentinovich Lonchakov (Lt. Col., Russian Air Force), 36, will serve with Phillips as space walk choreographer during the second space walk. He graduated with honors from the Oresburg Air Force Pilot School in 1986 as a pilot engineer. He graduated with honors from the Zhukovski Air Force Academy as a pilot-engineer-researcher in 1998. He later served as an Air Force Brigade commander. He has logged more than 1,400 hours in aircraft including the L-29, Tu-134 and Tu-16. He was selected as a test-cosmonaut candidate of the Gagarin Cosmonaut Training Center in 1997. On STS-100 he will assist with cargo transfer and powered payloads and conduct photo and video documentation as well as Earth observations.



### **Previous Space Flights**

Lonchakov is making his first space flight.

**Ascent Seating:** Mid Deck - Starboard

**Entry Seating:** Mid Deck - Starboard

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## Flight Plan

### Flight Day Summary

DATE	TIME (EST)	DAY	MET	EVENT
04/19/01	1:41:00 PM	1	000/00:00	Launch
04/21/01	6:26:00 AM	3	001/16:45	TI Burn
04/21/01	8:47:00 AM	3	001/19:06	Docking
04/21/01	11:22:00 AM	3	001/21:41	PMA 2 Open
04/22/01	6:41:00 AM	4	002/17:00	EVA 1 Start (SSRMS Deploy)
04/23/01	4:01:00 AM	5	003/14:20	ISS Ingress
04/24/01	8:01:00 AM	6	004/18:20	EVA 2 Start
04/24/01	3:56:00 PM	6	005/02:15	ISS Ingress
04/26/01	7:51:00 AM	8	006/18:10	EVA 3 Start
04/26/01	4:11:00 PM	8	007/02:30	ISS Ingress
04/28/01	10:45:00 AM	10	008/21:04	Undocking
04/28/01	11:43:00 AM	9	008/22:02	Final Sep
04/30/01	8:33:00 AM	12	010/18:52	Deorbit Burn
04/30/01	9:39:00 AM	12	010/19:58	Landing

Updated: 04/05/2001

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## Rendezvous

### Rendezvous and Docking Overview

#### Rendezvous and Docking

Endeavour's rendezvous and docking with the International Space Station begins with the precisely timed launch of the shuttle on a course for the station. During the first two days of the mission, periodic engine firings will gradually bring Endeavour to a point about 9 ½ statute miles behind the station, the starting point for a final approach to the station.

About 2 ½ hours before the scheduled docking time on Flight Day Three, Endeavour will reach a point about 50,000 feet behind the ISS. At that time, Endeavour's jets will be fired in a Terminal Intercept (TI) burn to begin the final phase of the rendezvous. Endeavour will close the final miles to the station during the next orbit.

As Endeavour closes in, the shuttle's rendezvous radar system will begin tracking the station and providing range and closing rate information to the crew. During the approach toward the station, the shuttle will have an opportunity to conduct four small mid-course corrections at regular intervals. Just after the fourth correction is completed, Endeavour will reach a point about half a mile below the station. At that time, about an hour before the scheduled docking, Commander Kent Rominger will take over manual control of the approach.

Rominger will slow Endeavour's approach and fly to a point about 600 feet directly below the station, from which he will begin a quarter-circle of the station, slowly moving to a position in front of the complex, in line with its direction of travel. Rominger will be assisted by Pilot Jeff Ashby in controlling Endeavour's approach. Mission Specialists Chris Hadfield and Scott Parazynski also will play key roles in the rendezvous, with Parazynski helping with the rendezvous navigation and Hadfield operating a handheld laser-ranging device. Hadfield and Parazynski also will operate the shuttle's docking mechanism to latch the station and Endeavour together after the two spacecraft make contact.

Rominger will fly the quarter-circle of the station, starting 600 feet below it, while slowly closing in on the complex, stopping at a point a little more than 300 feet directly in front of the station. From that point, he will begin slowly closing in on the station - moving at a speed of about a tenth of a mile per hour. Using a view from a camera mounted in the center of Endeavour's docking mechanism as a key alignment aid, Rominger will precisely center the docking ports of the two spacecraft. Rominger will fly to a point where the docking mechanisms are 30 feet apart, and pause for about five minutes to check the alignment.

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For Endeavour's docking, Rominger will maintain the shuttle's speed relative to the station at about one-tenth of a foot per second, and keep the docking mechanisms aligned to within three inches of one another. When Endeavour makes contact with the station, preliminary latches will automatically attach the two spacecraft together. Immediately after Endeavour docks, the shuttle's steering jets will be deactivated to reduce the forces acting at the docking interface. Shock absorber-type springs in the docking mechanism will dampen any relative motion between the shuttle and the station.

Once relative motion between the spacecraft has been stopped, Hadfield and Parazynski will secure the docking mechanism, sending commands for Endeavour to retract and close a final set of latches between the shuttle and station.

## **Undocking, Separation and Flyaround**

Once Endeavour is ready to undock, Hadfield and Parazynski will send a command that will release the docking mechanism. The initial separation of the spacecraft will be performed by springs in the docking mechanism that will gently push the shuttle away from the station. Endeavour's steering jets will be shut off to avoid any inadvertent firings during this initial separation.

Once the docking mechanism's springs have pushed Endeavour away to a distance of about two feet, when the docking devices will be clear of one another, Ashby will turn the steering jets back on and fire them to begin very slowly moving away. From the aft flight deck, Ashby will manually control Endeavour within a tight corridor as he separates from the ISS, essentially the reverse of the task performed by Rominger when Endeavour docked.

Endeavour will continue away to a distance of about 450 feet, where Ashby will begin a close flyaround of the station, making almost three-fourths of a circle around it. During the flyaround if available propellant permits, Ashby will slightly angle Endeavour to allow an IMAX film camera in the payload bay to record scenes of the station with the Earth below. Ashby will pass directly above the station, then behind, then directly underneath it. At that point, Ashby will fire Endeavour's jets for final separation from the station. The flyaround is expected to be completed a little over an hour after undocking.

## EVA

### **STS-100 Space Walks -- Installing a New Generation of Robotics**

#### **Overview**

Astronauts Chris Hadfield and Scott Parazynski will perform at least two 6 1/2-hour space walks during STS-100 to install and activate the Canadarm2, a robotic arm for the International Space Station developed and contributed by Canada. Time also is set aside during the mission to allow a third space walk if required by mission events. The activities during a third space walk would be planned during the mission. During the space walks, Hadfield, designated EV1, will be distinguishable by red stripes around the legs of his spacesuit. Parazynski, designated EV2, will wear an all-white suit. Endeavour Pilot Jeff Ashby, with help from Mission Specialist Umberto Guidoni, will operate the robotic arm during the space walks and John Phillips will serve as the intravehicular crew member, coordinating the space walkers' activities from within the shuttle's cabin.

#### **Flight Day 4 - First Space Walk: UHF Antenna Install, Canadarm2 Install**

The first space walk will take place on Flight Day 4, the day after Endeavour docks with the International Space Station. Hadfield and Parazynski will connect cables that will feed the initial electrical power, computer commands and video between the station and the Canadarm2. They will next install and deploy an Ultra-High Frequency (UHF) communications antenna that will enable the station to conduct future space walk communications and that will improve future shuttle-station communications. Then they will release launch bolts that held the Canadarm2 secure during its trip to orbit, unfold the arm and prepare it for control from inside the station.

As Hadfield and Parazynski are donning their spacesuits on Endeavour's lower deck, in the aft cockpit, Ashby will power up the shuttle's robotic arm. Ashby will use the shuttle arm to lift a Spacelab Pallet holding the station arm and the UHF communications antenna from the shuttle's cargo bay. He will then maneuver the pallet, with the Canadarm2 and antenna attached, to latch to a cradle affixed to the station's Destiny lab. At that point, Hadfield and Parazynski will leave the shuttle's airlock and begin their space walk.

During much of the first space walk, Hadfield will work from a foot platform attached to the shuttle's robotic arm, controlled by Ashby. Parazynski will work free-floating or from fixtures attached to the station. For the first task, connecting the initial station power, command and video cables to the arm, Hadfield will release a set of cables from restraints on the Spacelab Pallet to which the arm is attached. The four cable connections to be made will provide space station power, commanding and video to and from the Flight Support Equipment Grapple Fixture (FSEGF) on the pallet, which serves as the arm's initial base. Parazynski will connect the cables to the station's Destiny lab, enabling the arm to later be controlled from a Robotics Work Station within the lab.

# STS-100

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Next, the two space walkers will remove the UHF antenna from its launch restraints on the pallet, and Hadfield will hold it while Ashby maneuvers him to the position where the antenna will be installed on the station. Parazynski will bolt the antenna to the station and connect cables between the new system and the complex. The antenna's booms will then be deployed by the space walkers.

Then, the space walkers will turn their attention back to the robotic arm. They will remove several insulating blankets from the arm and pallet and verify that station electrical power is being supplied to the arm before beginning to release bolts that held the arm in place during launch. They will sequentially release 32 smaller bolts called jackbolts that hold tight eight large, four-foot-long "superbolts" that secure the arm in place on the pallet. As they are removed, the long superbolts will be placed into a "quiver," a container that will hold them securely for a return to Earth on the pallet.

Once the launch restraint bolts are removed, Ashby will maneuver Hadfield at the end of the shuttle's arm to begin unfolding the station arm. As each of two booms are unfolded, the space walkers will tighten bolts, called Expandable Diameter Fasteners, that will make the booms rigid. The Canadarm2 is planned to be ready for its first operations once this space walk is completed, operations that will have it "walk off" the Spacelab Pallet on the next day of the mission. On that day, controlled from inside the station, the arm will be moved to a configuration that will have one end latched to the pallet and the other latched to a fixture on the Destiny lab's exterior.

## **Flight Day 6 - Second Space Walk: Canadarm2 Checkouts**

During much of the second space walk, Parazynski will be working from a foot platform attached to the end of Endeavour's robotic arm, again controlled by Ashby, while Hadfield works either free-floating or from fixtures attached to the station's exterior.

Their second space walk begins with Hadfield and Parazynski opening a panel on the lab's exterior and Parazynski then connecting power, computer and video cables for the Destiny lab fixture to which one end of the Canadarm2 will then be attached. Parazynski will make eight cable connections to prepare the arm to "switch ends" using the lab fixture, called a Power and Data Grapple Fixture (PDGF), as its base and the end attached to the pallet as its free end.

While Parazynski is working with the connections, Hadfield will climb to the station's Unity module and remove an Early Communications System antenna, a box-shaped, 100-pound antenna that was used as part of an early station system that is no longer needed. The antenna must be removed from Unity to clear the way for the arrival of the station airlock to be launched on the STS-104 space shuttle mission. Hadfield will carry the removed antenna back to Endeavour's payload bay, where it will be taken into the cabin at the end of the space walk.

Once the station crew has confirmed that power is being provided to the arm through the connections made by Parazynski, Hadfield will begin disconnecting the four power, command and video cables that were installed between the pallet and station during the first space walk. The four cables provided the initial power, command and video to the arm

## STS-100

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but will now no longer be required and must be removed to allow the Spacelab Pallet to be unlatched from the station and eventually returned to the shuttle bay. While Hadfield is disconnecting those cables, Parazynski will remove a Video Signal Converter (VSC) from the Spacelab Pallet that is now no longer needed for the arm's operation. The unit will be stowed aboard the station as a spare.

The two space walkers will then begin stowing some of their tools while they monitor the movement of the Canadarm2, controlled from inside the station by station crew member Susan Helms, as it "switches ends." Now using the fixture on the exterior of Destiny as its base, the arm will lift the Spacelab Pallet, now attached to the arm's free end, and maneuver to a parked position where it will be locked in place overnight. The arm's move also clears the way for the final space walk task, attaching a spare piece of station electronics equipment to an external stowage platform on the exterior of the Destiny lab.

Working from a foot platform attached to the end of the shuttle's robotic arm, Parazynski will remove the spare piece of electronics, a critical part for the station's electrical system called a Direct Current Switching Unit, from a platform in the shuttle bay. Ashby will then maneuver Parazynski to the exterior of Destiny, where, assisted by Hadfield, he will secure the spare unit to the stowage platform, in place for use by future crews if needed.

### **Day 8 - Possible Third Space Walk**

Time has been set aside to allow a third 6 1/2 -hour space walk on Flight Day 8 if it is required by the mission's events. However, in the prelaunch plan, although time is set aside for the third space walk, no activities are planned for it. If it is needed, its activities will be planned during Endeavour's flight. If a third space walk is not needed, the crews will spend Flight Day 8 as another day of joint activities with hatches open aboard the shuttle and station.

## EVA Timeline for STS-100 Space Walks -- Installing a New Generation of Robotics

Time	Event
002/16:40	EVA 1 Egress
002/16:55	EVA 1 Setup
002/17:40	EVA 1 FSEGF Cable Connect
002/18:25	EVA 1 UHF Antenna Installation
002/19:25	EVA 1 SSRMS Deploy
002/22:25	EVA 1 Cleanup
002/22:55	EVA 1 Ingress
004/18:25	EVA 2 Egress
004/18:35	EVA 2 Setup
004/19:20	EVA 2 J400 Panel Reconfig
004/19:35	EVA 2 Starboard ECOM Removal
004/20:50	EVA 2 FSEGF Umbilical Release
004/21:05	EVA 2 VSC Removal
004/21:35	EVA 2 Hardware Stow
004/22:35	EVA 2 DCSU Transfer
004/23:35	EVA 2 Cleanup
005/00:35	EVA 2 Ingress

Updated: 04/05/2001

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## Payloads

### Canadarm2

#### Overview

#### **The Mobile Servicing System, Canada's Next Generation of Space Robotics for the International Space Station**

The Mobile Servicing System (MSS) is essential to the construction of the station, to many station operations and to the maintenance of the station throughout its service life. The MSS includes facilities on Earth for mission support and astronaut training. Built at a cost of U.S. dollars \$896 million (over 20 years), the MSS is actually composed of three separate parts:

- 1) Canadarm2, also known by its technical name, the Space Station Remote Manipulator System (SSRMS);
- 2) The Special Purpose Dexterous Manipulator (SPDM), a smaller, highly advanced detachable two-armed robot that can be placed on the end of the space arm. It will perform sophisticated operations including installing and removing small payloads, such as batteries, power supplies and computers.

This robot can also handle tools, such as specialized wrenches and socket extensions, for delicate maintenance and servicing tasks, provide power and data connectivity to payloads, as well as manipulate, remove and inspect scientific payloads. The SPDM is also equipped with lights, video, equipment, a tool platform and four tool holders.

This robot will be able to touch and feel much like humans. It can sense various forces and moments on a payload and, in response, can automatically compensate to ensure payloads are moved smoothly. The SPDM will be controlled by the ISS crew via the Robotic Workstation, and can perform a great many of the tasks that would otherwise require an astronaut to perform during space walks.

- 3) The final component is the Mobile Remote Servicer Base System (MBS), a movable platform for Canadarm2 and the SPDM that slides along rails on the space station's main truss structure to transport Canadarm2 to various points on the Station. It is equipped with four Power Data Grapple Fixtures and a Latching End Effector to hold payloads (or alternatively, the SPDM).

## Payload

### Canadarm2 to Build the International Space Station

In April 2001, Canadarm2, Canada's next generation of space robots, will be unfolded from its protective metal cradle. Then, like a baby gingerly taking its first step, it will climb out to begin exploring its new home—the International Space Station.

The new robotic arm Canadarm2—also known by its technical name, the Space Station Remote Manipulator System—will have one of its two identical “hands” attached to a device that will provide the lifblood it needs to survive in this new environment: electrical power and a link to the robotic control center inside the station.

Eventually, after a few limbering-up exercises, it will swing its free hand around to latch onto one of the connection devices around the station, known as a Power Data Grapple Fixture (PDGF) — which provide the arm with power and a link to the station — thus allowing the first hand to be released.

For Canadians, this moment will be comparable to the day when the Canadarm was first lofted above the space shuttle's payload bay. Like the original Canadarm, Canadarm2 will be a distinctive Canadian contribution to the international space program, an essential tool without which the space station could not be assembled and maintained.

“The Canadarm's successful track record on the shuttle made robotics a natural choice as Canada's contribution to the station,” says Savi Sachdev, acting director general of space systems for the Canadian Space Agency. “Robotics was identified as a strategic technology for Canada. It was a critical component of infrastructure which gave Canada an important role and status in building the International Space Station.”



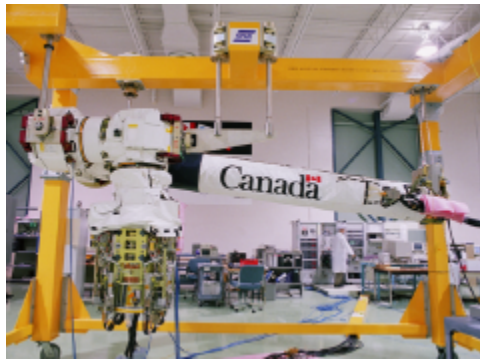
*This 17-meter, 1.8-ton arm is essential to the construction of the ISS, to many station operations and to the maintenance of the station throughout its service life.*



## STS-100

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Canada selected a robotic system as its main contribution to the space station in order to fortify its world leadership in space robotics and encourage innovation and ingenuity in Canada's high-tech industries. Canada's participation in the space station also ensures Canadian scientists a boarding pass to conduct leading-edge research in the station's microgravity environment to advance our knowledge in fields like biotechnology, biomedical research, fluid physics, materials science, Earth observation and space science. And perhaps most importantly, as one of the partners in the International Space Station (along with the United States, Russia, Japan, and the European Space Agency), Canada is a key player on the world stage as nations learn to work together in the largest peacetime collaborative effort in human history.



*Canadarm2 during testing*

When Canadarm2 takes its first step, it will provide a dramatic demonstration of robotic evolution. Unlike the original Canadarm, Canadarm2 is not permanently anchored at one end; instead, either hand is equipped with a Latching End Effector (LEE) that can be used as an anchor point while the opposite one performs various tasks, including grabbing another connecting point on the station (PDGF). This design gives Canadarm2 the unique ability to move around the station like an “inchworm,” flipping end-over-end among grapple fixtures located on the exterior of the station.

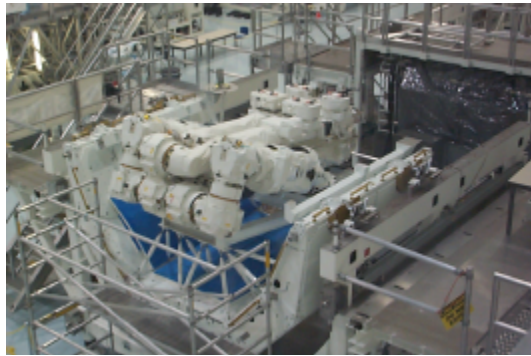
It's a simple and elegant concept, but according to James Middleton, vice-president of business development for MD Robotics, transforming it into working hardware was a challenge. Middleton, who led the engineering team that designed and built Canadarm2 for the Canadian Space Agency, says that “the space station was very large and it was clear that we had to be able to provide mobility—the ability to relocate the arm from spot to spot.”

Another difficult task was designing the Canadarm2 to withstand the forces of liftoff. Larger and heavier than the shuttle's Canadarm—it has a mass of about 1,800 kilograms compared with 410 kg for the original Canadarm—it will be subjected to greater loads during the 8 ½-minute ride into orbit.

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Unlike the original Canadarm, which is secured full length along the side of the shuttle's cargo bay, Canadarm2 will be folded into a U-shaped pallet that fits across the width of the bay. "We had to bend it in pieces," Middleton explains. "How to fasten it down was a very complex design process. To be able to hold it in a manner that the loads were adequately relieved during the shuttle launch was a tough challenge for the engineering team."



*Canadarm2 folded on its pallet, awaiting its launch in April 2001*

The complex process of preparing the Canadarm2 for launch has been going on since it was delivered to the Kennedy Space Center in May 1999. In August 2000, it was folded into its final launch configuration and nestled in its pallet, ready to be placed in the payload bay of the shuttle Endeavour a few weeks before launch.

Canadian Space Agency Astronaut Chris Hadfield will play a major role in installing Canadarm2 on the station and, in the process, will become the first Canadian to perform a space walk. In a spectacular moment, two generations of Canadian technology will come together as the Canadarm lifts the pallet with the Canadarm2 out of the payload bay and attaches it to the station's Lab Cradle Assembly, a claw-like latch on the U.S.-built laboratory. Hadfield and his partner, American Astronaut Scott Parazynski, will remove eight, one-meter-long bolts that hold the new arm to its pallet. They will then unfold its booms manually and secure the hinges in the middle using a special bolt that expands in diameter (known as an Expandable Diameter Fastener).

Next comes the first "inchworm" maneuver; while still on its pallet, Canadarm2 will eventually be commanded to take its first step. It will grasp a grapple fixture (PDGF) on the U.S. lab and step out of its pallet transferring its anchor point from one hand to the other, and take its first step.

After a few more tests, on day seven of the mission, it will pick up the pallet still attached to the station, and give it back to the shuttle's Canadarm, which will put it back in the shuttle's cargo bay. This procedure has already been dubbed the first "handshake" between the two Canadian arms. By the end of the flight, the arm will be put through all of its basic functions and will be ready to assume its role in helping to put together the rest of the station.

## STS-100

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According to Sachdev, the installation of Canadarm2 is “absolutely critical” to the station’s development. “We simply would not be able to build the International Space Station without Canadarm2,” he adds. “Every single space station mission will need it.”

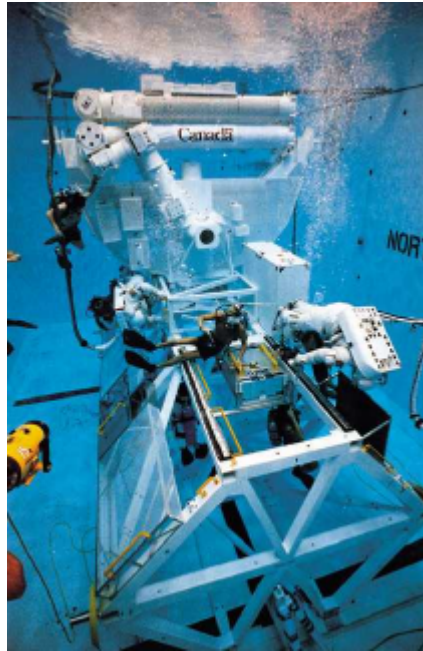
The original Canadarm — the most widely recognized piece of Canadian technology — and Canadarm2 will work together, handing payloads to one another. Canadarm2 is more flexible because the number and placement of its joints provides seven degrees of freedom rather than just six. This gives it a greater ability to bend, rotate and maneuver (“pitch,” “yaw” and “roll”) itself into difficult spots. Because Canadarm2 can almost fully rotate all of its joints, it is even more agile than a human arm. This is crucial capability since the space station is a larger and more complex operational environment than the shuttle’s payload bay.

This flexibility will be greatly enhanced by the Canadian Space Agency’s Special Purpose Dexterous Manipulator (SPDM), a highly advanced smaller robot with two arms that has 15 degrees of freedom. Currently slated for launch in 2003, the SPDM has complex “hands” capable of wielding specialized tools for delicate maintenance and servicing tasks. It also gives operators feedback about the forces and movements it experiences as it works, providing a “touch and feel” capability akin to that of the human hand; it will thus reduce the time that astronauts spend working in the hostile and dangerous environment of space.



*Artist's rendering of the Special Purpose Dexterous Manipulator*

What makes the Canadarm2 and SPDM so important is that most of the equipment on the outside of the station will be made up of “Orbital Replacement Units”—self-contained packages that can be swapped for old units when they wear out or fail. “The whole space station design is based on ORUs so we can repair and maintain it in space,” explains Sachdev. “We don’t have to bring anything down.”



*Testing Canadarm2 in the Neutral Buoyancy Lab at the Johnson Space Center*

That includes the Canadarm2 itself—all of its components are replaceable. Unlike the shuttle's Canadarm, it will probably never return to Earth.

Astronauts on board the space station will control the Canadarm2, but like shuttle astronauts, they will be in constant contact with Mission Control. Here, too, Canada will play a role. The Canadian Space Agency has built a control center for the Canadarm2 at its Saint-Hubert, Quebec, headquarters that will be linked directly to NASA's Mission Control at the Johnson Space Center in Houston.

Containing half a dozen computer consoles similar to those in Mission Control in Houston, the Canadian Space Agency's Space Operations Support Center will function as a technical "back room," offering real-time support and troubleshooting while Canadarm2 operations are going on in space. The performance of the Canadarm2 will be monitored through the operations center and analyzed by robotics specialists at the Canadian Space Agency, who will be on standby to help with any problems that the astronauts can't solve using standard malfunction procedures.

The Canadian Space Agency has also created another facility, the Mission Operations and Training Simulator, to train astronauts from all the partner countries in the basics of operating the Canadarm2. The Expedition Two crew members who will operate the Canadarm2 received their training at the Canadian Space Agency. All space station astronauts will receive their training at the operations facility in Saint-Hubert, in order to practice complex maneuvers before they are attempted in space.

## STS-100

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Helping to build and maintain the space station will be the most tangible role for the Canadarm2, but it has another less visible but equally significant role: it has provided Canadian scientists with access to space station laboratory facilities to conduct scientific experiments.



*The Space Operations Support Center at the Canadian Space Agency's headquarters in Saint-Hubert, Quebec*

The contribution of the robotic system buys Canadians the right to use 2.3% of the space designated for scientific equipment inside the non-Russian part of the station, as well as access to a platform outside for experiments exposed to the space environment. Canada is also entitled to send one astronaut to the station every three years on a tour of duty lasting three to four months.

**Comparison Chart of Canadarm and Canadarm2**

	<b>Canadarm</b>	<b>Canadarm2</b>
	Returns to Earth after every shuttle mission.	Permanently in space.
<b>Range of Motion</b>	Reach limited to length of arm.	Moves end-over-end to reach many parts of International Space Station in an inchworm-like movement; limited only by number of Power Data Grapple Fixtures (PDGFs) on the station. PDGFs located around the station provide power, data and video to the arm through its Latching End Effectors (LEEs). The arm can also travel the entire length of the space station on the Mobile Base System.
<b>Fixed joint</b>	Fixed to the shuttle by one end.	No fixed end. Equipped with LEEs at each end to provide power, data and video signals to arm.
<b>Degrees of freedom</b>	6 degrees of freedom. Similar to a human arm: shoulder (2 joints), elbow (1 joint) and wrists (3 joints).	7 degrees of freedom. Much like a human arm: shoulder (3 joints), elbow (1 joint) and wrists (3 joints). However, Canadarm2 can change configuration without moving its hands.
<b>Joint rotation</b>	Limited elbow rotation (limited to 160 degrees).	Full joint rotation. Joints (7) rotate 540 degrees. Larger range of motion than a human arm.
<b>Senses</b>	No sense of touch.	Force moment sensors provide a sense of touch. Automatic vision feature for capturing free-flying payloads. Automatic collision avoidance.
<b>Length</b>	50 feet, 3 inches (15 meters)	57 feet, 9 inches (17.6 meters)
<b>Weight</b>	905 lbs. (410 kg)	3,960 lbs. (1800 kg)

# STS-100

	<b>Canadarm</b>	<b>Canadarm2</b>
<b>Diameter (Ext. Diameter of Composite Boom)</b>	13 inches (33 cm)	14 inches (35 cm)
<b>Mass handling capacity</b>	66,000 lbs. (29,937 kg) design case handling payload	255,700 lbs. (116,000 kg) design case handling payload
<b>Speed of Operations</b>	Unloaded: 2 feet per second (60 cm/sec) Loaded: 2 inches per second (6 cm/sec)	Unloaded: 15 inches per second (37 cm/sec) Loaded: For station assembly, less than 1 inch per second (2 cm/sec.). For EVA support, 6 inches per second (15 cm/sec). Less than half an inch per second with 100-ton load (1.2 cm/sec). Stopping distance under maximum load: 2 feet (0.6 m).
<b>Composition</b>	16 plies of high modulus carbon fiber—epoxy	19 plies of high strength carbon fiber—thermoplastic
<b>Repairs</b>	Repaired on Earth.	Designed to be repaired in space by replacing ORUs (Orbital Replacement Units). Built-in redundancy.
<b>Control</b>	Autonomous operation or astronaut control	Autonomous operation or astronaut control
<b>Cameras</b>	2 (one on the elbow and one on the wrist)	4 color cameras (one at each side of the elbow, the other two on the LEEs)

## Payloads

### External UHF Antenna Payload Bay

#### Overview

An external Ultra-High Frequency (UHF) antenna will be launched aboard Endeavour on the Spacelab Pallet that also holds the Canadarm 2. The antenna will be attached to the station's U.S. laboratory Destiny by space-walking astronauts Chris Hadfield and Scott Parazynski during the mission's first space walk.

The antenna, on a four-foot boom, is part of the UHF Communications Subsystem of the station. It will interact with systems already aboard the ISS, including the Space-to-Space Station Radio (SSSR) transceivers. A second antenna will be delivered on STS-115/11A next year.

Once in operation the UHF subsystem will be used for space-to-space communication (voice, commands and telemetry for the space station). It can support up to five users on the same frequency and provides:

--Two-way voice communications between the station and space walkers, the station and orbiter and between the Mission Control Center in Houston and space walkers (using the UHF with the S-band subsystem).

--Orbiter commanding of critical station functions such as going to free drift during undocking operations. Commands are encrypted for security. That capability is to be used during Endeavour's undocking on STS-100.

--ISS transmission of critical telemetry to the orbiter during undocking operations, again beginning with STS-100 undocking.

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## Payloads

### **Raffaello -- A Space-Age Moving Van**

Payload Bay

9,000 pounds (almost 4.1 metric tons)

#### **Overview**

The Raffaello Multi-Purpose Logistics Module (MPLM), built by the Italian Space Agency (ASI), is the second of three such pressurized modules that will serve as the International Space Station's "moving vans," carrying laboratory racks filled with equipment, experiments and supplies to and from the International Space Station aboard the space shuttle.

Construction of ASI's Raffaello module was the responsibility of Alenia Aerospazio in Turin, Italy. Raffaello was delivered to Kennedy Space Center from Italy in July 1999 by a special Beluga cargo aircraft. The cylindrical module is about 6.4 meters (21 feet) long and 4.6 meters (15 feet) in diameter. It weighs about 9,000 pounds (almost 4.1 metric tons). It can carry up to 20,000 pounds (9.1 metric tons) of cargo packed into 16 standard space station equipment racks.

Although built in Italy, Raffaello and two additional MPLMs are owned by the U.S. They were provided in exchange for Italian access to U.S. research time on the station.

The unpiloted, reusable logistics module functions as both a cargo carrier and a space station module when it is flown. To function as an attached station module as well as a cargo transport, Raffaello contains components that provide some life support, fire detection and suppression, electrical distribution and computer functions. Eventually, the modules also will carry refrigerator freezers for transporting experiment samples and food to and from the station.

On this mission, Raffaello will be mounted in the space shuttle's payload bay for launch and remain there until after docking. Once the shuttle is docked to the station, the shuttle's robotic arm will remove Raffaello from the payload bay and berth it to the Unity Module on the ISS. During its berthed period to the station, two payload racks and individual components will be transferred to the ISS.

After Raffaello is unloaded, used equipment and trash will be transferred to it from the station for return to Earth. The Raffaello logistics module will then be detached from the station and positioned back into the shuttle's cargo bay for the trip home. When in the cargo bay, Raffaello is independent of the shuttle cabin, and there is no passageway for shuttle crew members to travel from the shuttle cabin to the module.

# STS-100

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Raffaello will be filled with equipment and supplies to outfit the U.S. laboratory Destiny, which was carried to the International Space Station on STS-98 in February 2001. Of the 16 racks the module can carry, this mission brings four resupply stowage racks, four resupply stowage platforms, and two scientific experiment racks (Express Racks #1 and #2).

Express Rack #1 and Express Rack #2 will add additional science capability to the ISS. The EXPRESS (Expedite the Processing of Experiments to the Space Station) Rack concept was developed to support small payloads on orbit with a shortened ground integration period. The rack provides standard interfaces and resources for sub-rack payloads. It accommodates multiple payload disciplines and supports the simultaneous and independent operation of multiple payloads within the rack. The EXPRESS Rack is launched with the initial payload complement and remains on orbit, allowing payloads to be changed out as required. EXPRESS Rack #2 is the first ISS rack equipped with the Active Rack Isolation System (ARIS). ARIS is designed to isolate the experiment within the rack from vibrations occurring in the rest of the ISS.

There are also four Resupply Stowage Racks (RSR) and four Resupply Stowage Platforms (RSP) within the MPLM. These eight racks contain equipment required for activation of the two EXPRESS racks and the ARIS system, components to augment existing ISS systems, spare parts for systems already on the station, in addition to food and supplies to support the crew. Resupply Stowage Racks and Resupply Stowage Platforms use Cargo Transfer Bags (CTB) to carry components to the ISS but the racks, platforms, and bags themselves remain in the Raffaello module and are returned to Earth aboard the shuttle.

## **History/Background**

Raffaello is the second of three MPLMs supplied by the Italian Space Agency. The first, Leonardo, flew on STS-102 in March.

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## **DTO/DSO/RME**

### **Monitoring Latent Virus Reactivation and Shedding in Astronauts DSO 493**

#### **Overview**

The premise of this DSO is that the incidence and duration of latent virus reactivation in saliva and urine will increase during spaceflight. The objective is to determine the frequency of induced reactivation of latent viruses, latent virus shedding, and clinical disease after exposure to the physical, physiological, and psychological stressors associated with spaceflight.

#### **History/Background**

Spaceflight-induced alterations in the immune response become increasingly important on long missions, particularly the potential for reactivation and dissemination (shedding) of latent viruses. An example of a latent virus is Herpes Simplex Type 1 (HSV-1), which infects 70 to 80 percent of all adults. Its classic manifestations are cold sores, pharyngitis, and tonsillitis; and it usually is acquired through contact with the saliva, skin, or mucous membranes of an infected individual. However, many recurrences are asymptomatic, resulting in shedding of the virus. Twenty subjects have been studied for Epstein-Barr virus. Three additional viruses will be examined in an expanded subject group.

## **DTO/DSO/RME**

### **Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance DSO 496**

#### **Overview**

Susceptibility to postflight orthostatic intolerance -- lightheadedness or fainting upon return to Earth -- is highly individual. Some astronauts are little affected, while others have severe symptoms. Women are more often affected than men. The goal of this DSO is to discover the mechanisms responsible for these differences in order to customize countermeasure protocols.

#### **History/Background**

It has been well documented that spaceflight significantly alters cardiovascular function. One of the most important changes from a crew safety standpoint is postflight loss of orthostatic tolerance, which causes astronauts to have difficulty walking independently and induces lightheadedness or fainting. These effects may impair their ability to leave the orbiter after it lands.

This DSO will perform a flight-related study, designed to clarify preflight and postflight differences in susceptible and nonsusceptible astronauts. There are no on-orbit activities associated with this DSO.

## DTO/DSO/RME

### **Spaceflight and Immune Functions DSO 498**

#### **Overview**

Astronauts face an increasing risk of contracting infectious diseases as they work and live for longer periods in the crowded conditions and closed environments of spacecraft such as the International Space Station. The effects of spaceflight on the human immune system, which plays a pivotal role in warding off infections, is not fully understood. Understanding the changes in immune functions caused by exposure to microgravity will allow researchers to develop countermeasures to minimize the risk of infection.

#### **History/Background**

The objective of this DSO is to characterize the effects of spaceflight on neutrophils, monocytes, and cytotoxic cells, which play an important role in maintaining an effective defense against infectious agents. The premise of this study is that the space environment alters the essential functions of these elements of human immune response.

Researchers will conduct a functional analysis of neutrophils and monocytes from blood samples taken from astronauts before and after the flight. They will also assess the subjects' pre- and postflight production of cytotoxic cells and cytokine.

This study will complement previous and continuing immunology studies of astronauts' adaptation to space.

## DTO/DSO/RME

### **Eye Movements and Motion Perception Induced by Off-Vertical-Axis Rotation (OVAR) at Small Angles of Tilt After Spaceflight DSO 499**

#### **Overview**

Astronauts returning to Earth have experienced perceptual and motor coordination problems caused by sensorimotor adaptation to microgravity. The hypothesis is that the central nervous system changes the way it processes gravitational tilt information that it receives from the vestibular (otolith) system. Eye movements and perceptual responses during constant-velocity off-vertical-axis rotation will reflect changes in otolith function as astronauts readapt to gravity. The length of recovery is a function of flight duration (i.e., the longer astronauts are exposed to microgravity, the longer they will take to recover).

#### **History/Background**

This DSO will examine changes in astronauts' spatial neural processing of gravitational tilt information following readaptation to gravity. Postflight oculomotor and perceptual responses during off-vertical-axis rotation will be compared to preflight responses to track the time of recovery.

## **DTO/DSO/RME**

### **International Space Station On-Orbit Loads Validation DTO 261**

#### **Overview**

This DTO will use the shuttle's aft primary reaction control system jets to measure the structural dynamics (natural frequencies, modal amplitudes, and structural dampening) of the ISS and use the results to validate critical areas of the on-orbit loads prediction models.

Three tests will be conducted to obtain various measurements. Test 1 will obtain photogrammetric measurements of the photovoltaic arrays. Test 2 will obtain photogrammetric measurements of the radiator. Test 3 will obtain acceleration and dynamic strain measurements in Unity, Zarya, Zvezda, and Destiny. The Internal Wireless Instrumentation System (IWIS) kit, which contains remote sensors, accelerometers, cables, and antennas for use on the shuttle or the ISS, will be used as part of Test 3.

#### **History/Background**

This is the fourth flight of DTO 261.

## **DTO/DSO/RME**

### **On-Orbit Bicycle Ergometer Loads Measurement DTO 262**

#### **Overview**

The purpose of this DTO is to study the possibility of reducing the engineering conservatism by measuring the joined shuttle/International Space Station natural frequencies, using the bicycle ergometer as the natural frequency excitation source. Reduction of conservatism would allow more operational flexibility by reducing preflight load predictions and, thus, operational constraints.

#### **History/Background**

This is the first of seven planned flights of DTO 262.



## **DTO/DSO/RME**

### **International Space Station On-Orbit Loads Validation DTO 264**

#### **Overview**

The purpose of this DTO is to ensure stable shuttle control system performance and acceptable loads on the Space Station Remote Manipulator System (SSRMS) induced by shuttle jet firings.

During planned SSRMS handling of payloads, there will be a brief pause at a specific planned SSRMS geometric configuration in the trajectory. At this configuration, crew inputs to SSRMS motion will be commanded, followed by an SSRMS brakes-on command. This will be performed three times to excite two lateral bending modes and one torsion mode of the SSRMS, while the SSRMS data system in the end effector will be active to measure the SSRMS transient load response.

#### **History/Background**

This is the first flight of DTO 264.

## **DTO/DSO/RME**

### **Single-String Global Positioning System DTO 700-14**

#### **Overview**

The purpose of the Single-String Global Positioning System (GPS) is to demonstrate the performance and operation of the GPS during orbiter ascent, on orbit, entry, and landing phases using a modified military GPS receiver processor and the existing orbiter GPS antennas. GPS data may be downlinked during all mission phases.

#### **History/Background**

This is the 16th flight of DTO 700-14.

## **DTO/DSO/RME**

### **Crew Return Vehicle (CRV) Space Integrated Global Positioning System/Inertial Navigation System (SIGI) DTO 700-22**

#### **Overview**

The Crew Return Vehicle SIGI is intended to be the primary navigation source for the ISS CRV. DTO 700-22 will measure both Global Positioning System (GPS) only and GPS/Inertial Navigation System (INS) blended position, velocity, time, and attitude performance during on-orbit and entry operations and will also measure the time to first GPS fix (position, velocity, time) during on-orbit operations after warm or cold starts of the SIGI.

#### **History/Background**

This is the first flight of DTO 700-22.

## DTO/DSO/RME

### **Crosswind Landing Performance DTO 805**

#### **Overview**

The purpose of this DTO is to demonstrate the capability to perform a manually controlled landing in the presence of a crosswind. The testing is done in two steps.

1. Prelaunch: Ensure planning will allow selection of a runway with Microwave Scanning Beam Landing System support, which is a set of dual transmitters located beside the runway providing precision navigation vertically, horizontally, and longitudinally with respect to the runway. This precision navigation subsystem helps provide a higher probability of a more precise landing with a crosswind of 10 to 15 knots as late in the flight as possible.

2. Entry: This test requires that the crew perform a manually controlled landing in the presence of a 90-degree crosswind component of 10 to 15 knots steady state.

During a crosswind landing, the drag chute will be deployed after nose gear touchdown when the vehicle is stable and tracking the runway centerline.

#### **History/Background**

This DTO has been manifested on 64 previous flights.

## **DTO/DSO/RME**

### **Micro-Wireless Instrumentation System (Micro-WIS) HTD 1403**

#### **Overview**

This HTD will demonstrate the operational utility and functionality of Micro-WIS on orbit, initially in the crew cabin of the orbiter and then in the International Space Station. The Micro-WIS sensor/transmitter will provide important real-time temperature measurements. The Micro-WIS sensor/recorder will provide recorded temperature readings for postflight evaluation.

#### **History/Background**

This is the fourth flight of HTD 1403.

## Shuttle Reference and Data

### Shuttle Abort History

#### RSLS Abort History:

##### **(STS-41 D) June 26, 1984**

The countdown for the second launch attempt for Discovery's maiden flight ended at T-4 seconds when the orbiter's computers detected a sluggish valve in main engine #3. The main engine was replaced and Discovery was finally launched on August 30, 1984.

##### **(STS-51 F) July 12, 1985**

The countdown for Challenger's launch was halted at T-3 seconds when on-board computers detected a problem with a coolant valve on main engine #2. The valve was replaced and Challenger was launched on July 29, 1985.

##### **(STS-55) March 22, 1993**

The countdown for Columbia's launch was halted by on-board computers at T-3 seconds following a problem with purge pressure readings in the oxidizer preburner on main engine #2. Columbia's three main engines were replaced on the launch pad, and the flight was rescheduled behind Discovery's launch on STS-56. Columbia finally launched on April 26, 1993.

##### **(STS-51) August 12, 1993**

The countdown for Discovery's third launch attempt ended at the T-3 second mark when on-board computers detected the failure of one of four sensors in main engine #2 which monitor the flow of hydrogen fuel to the engine. All of Discovery's main engines were ordered replaced on the launch pad, delaying the Shuttle's fourth launch attempt until September 12, 1993.

##### **(STS-68) August 18, 1994**

The countdown for Endeavour's first launch attempt ended 1.9 seconds before liftoff when on-board computers detected higher than acceptable readings in one channel of a sensor monitoring the discharge temperature of the high pressure oxidizer turbopump in main engine #3. A test firing of the engine at the Stennis Space Center in Mississippi on September 2nd confirmed that a slight drift in a fuel flow meter in the engine caused a slight increase in the turbopump's temperature. The test firing also confirmed a slightly slower start for main engine #3 during the pad abort, which could have contributed to the higher temperatures. After Endeavour was brought back to the Vehicle Assembly Building to be outfitted with three replacement engines, NASA managers set October 2nd as the date for Endeavour's second launch attempt.

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## **Abort to Orbit History:**

### **(STS-51 F) July 29, 1985**

After an RSLS abort on July 12, 1985, Challenger was launched on July 29, 1985. Five minutes and 45 seconds after launch, a sensor problem resulted in the shutdown of center engine #1, resulting in a safe "abort to orbit" and successful completion of the mission.

## Shuttle Reference and Data

### Shuttle Abort Modes

#### RSLS ABORTS

These occur when the onboard Shuttle computers detect a problem and command a halt in the launch sequence after taking over from the Ground Launch Sequencer and before Solid Rocket Booster ignition.

#### ASCENT ABORTS

Selection of an ascent abort mode may become necessary if there is a failure that affects vehicle performance, such as the failure of a space shuttle main engine or an orbital maneuvering system. Other failures requiring early termination of a flight, such as a cabin leak, might also require the selection of an abort mode.

There are two basic types of ascent abort modes for space shuttle missions: **intact aborts** and **contingency aborts**. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit flight crew survival following more severe failures when an intact abort is not possible. A contingency abort would generally result in a ditch operation.

#### INTACT ABORTS

There are four types of intact aborts: abort to orbit (ATO), abort once around (AOA), transoceanic abort landing (TAL) and return to launch site (RTL).

##### Return to Launch Site

The RTL abort mode is designed to allow the return of the orbiter, crew, and payload to the launch site, Kennedy Space Center, approximately 25 minutes after lift-off.

The RTL profile is designed to accommodate the loss of thrust from one space shuttle main engine between lift-off and approximately four minutes 20 seconds, at which time not enough main propulsion system propellant remains to return to the launch site.

An RTL can be considered to consist of three stages—a powered stage, during which the space shuttle main engines are still thrusting; an ET separation phase; and the glide phase, during which the orbiter glides to a landing at the Kennedy Space Center. The powered RTL phase begins with the crew selection of the RTL abort, which is done after solid rocket booster separation. The crew selects the abort mode by positioning the abort rotary switch to RTL and depressing the abort push button. The time at which the RTL is selected depends on the reason for the abort. For example, a three-engine RTL is selected at the last moment, approximately three minutes 34 seconds into the mission; whereas an RTL chosen due to an engine out at lift-off is selected at the earliest time, approximately two minutes 20 seconds into the mission (after solid rocket booster separation).



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After RTLS is selected, the vehicle continues downrange to dissipate excess main propulsion system propellant. The goal is to leave only enough main propulsion system propellant to be able to turn the vehicle around, fly back towards the Kennedy Space Center and achieve the proper main engine cutoff conditions so the vehicle can glide to the Kennedy Space Center after external tank separation. During the downrange phase, a pitch-around maneuver is initiated (the time depends in part on the time of a space shuttle main engine failure) to orient the orbiter/external tank configuration to a heads up attitude, pointing toward the launch site. At this time, the vehicle is still moving away from the launch site, but the space shuttle main engines are now thrusting to null the downrange velocity. In addition, excess orbital maneuvering system and reaction control system propellants are dumped by continuous orbital maneuvering system and reaction control system engine thrustings to improve the orbiter weight and center of gravity for the glide phase and landing.

The vehicle will reach the desired main engine cutoff point with less than 2 percent excess propellant remaining in the external tank. At main engine cutoff minus 20 seconds, a pitch-down maneuver (called powered pitch-down) takes the mated vehicle to the required external tank separation attitude and pitch rate. After main engine cutoff has been commanded, the external tank separation sequence begins, including a reaction control system translation that ensures that the orbiter does not recontact the external tank and that the orbiter has achieved the necessary pitch attitude to begin the glide phase of the RTLS.

After the reaction control system translation maneuver has been completed, the glide phase of the RTLS begins. From then on, the RTLS is handled similarly to a normal entry.

## **Transoceanic Abort Landing**

The TAL abort mode was developed to improve the options available when a space shuttle main engine fails after the last RTLS opportunity but before the first time that an AOA can be accomplished with only two space shuttle main engines or when a major orbiter system failure, for example, a large cabin pressure leak or cooling system failure, occurs after the last RTLS opportunity, making it imperative to land as quickly as possible.

In a TAL abort, the vehicle continues on a ballistic trajectory across the Atlantic Ocean to land at a predetermined runway. Landing occurs approximately 45 minutes after launch. The landing site is selected near the nominal ascent ground track of the orbiter in order to make the most efficient use of space shuttle main engine propellant. The landing site also must have the necessary runway length, weather conditions and U.S. State Department approval. Currently, the three landing sites that have been identified for a due east launch are Moron,, Spain; Dakar, Senegal; and Ben Guerur, Morocco (on the west coast of Africa)

To select the TAL abort mode, the crew must place the abort rotary switch in the TAL/AOA position and depress the abort push button before main engine cutoff. (Depressing it after main engine cutoff selects the AOA abort mode.) The TAL abort mode begins sending commands to steer the vehicle toward the plane of the landing site. It also rolls the vehicle heads up before main engine cutoff and sends commands to begin an orbital maneuvering system propellant dump (by burning the propellants through the orbital maneuvering

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system engines and the reaction control system engines). This dump is necessary to increase vehicle performance (by decreasing weight), to place the center of gravity in the proper place for vehicle control, and to decrease the vehicle's landing weight.

TAL is handled like a nominal entry.

## **Abort to Orbit**

An ATO is an abort mode used to boost the orbiter to a safe orbital altitude when performance has been lost and it is impossible to reach the planned orbital altitude. If a space shuttle main engine fails in a region that results in a main engine cutoff under speed, the Mission Control Center will determine that an abort mode is necessary and will inform the crew. The orbital maneuvering system engines would be used to place the orbiter in a circular orbit.

## **Abort Once Around**

The AOA abort mode is used in cases in which vehicle performance has been lost to such an extent that either it is impossible to achieve a viable orbit or not enough orbital maneuvering system propellant is available to accomplish the orbital maneuvering system thrusting maneuver to place the orbiter on orbit and the deorbit thrusting maneuver. In addition, an AOA is used in cases in which a major systems problem (cabin leak, loss of cooling) makes it necessary to land quickly. In the AOA abort mode, one orbital maneuvering system thrusting sequence is made to adjust the post-main engine cutoff orbit so a second orbital maneuvering system thrusting sequence will result in the vehicle deorbiting and landing at the AOA landing site (White Sands, N.M.; Edwards Air Force Base; or the Kennedy Space Center.. Thus, an AOA results in the orbiter circling the Earth once and landing approximately 90 minutes after lift-off.

After the deorbit thrusting sequence has been executed, the flight crew flies to a landing at the planned site much as it would for a nominal entry.

## **CONTINGENCY ABORTS**

Contingency aborts are caused by loss of more than one main engine or failures in other systems. Loss of one main engine while another is stuck at a low thrust setting may also necessitate a contingency abort. Such an abort would maintain orbiter integrity for in-flight crew escape if a landing cannot be achieved at a suitable landing field.

Contingency aborts due to system failures other than those involving the main engines would normally result in an intact recovery of vehicle and crew. Loss of more than one main engine may, depending on engine failure times, result in a safe runway landing. However, in most three-engine-out cases during ascent, the orbiter would have to be ditched. The in-flight crew escape system would be used before ditching the orbiter.

## **ABORT DECISIONS**

There is a definite order of preference for the various abort modes. The type of failure and the time of the failure determine which type of abort is selected. In cases where performance loss is the only factor, the preferred modes would be ATO, AOA, TAL and RTLS, in that order. The mode chosen is the highest one that can be completed with the remaining vehicle performance.

In the case of some support system failures, such as cabin leaks or vehicle cooling problems, the preferred mode might be the one that will end the mission most quickly. In these cases, TAL or RTLS might be preferable to AOA or ATO. A contingency abort is never chosen if another abort option exists.

The Mission Control Center-Houston is prime for calling these aborts because it has a more precise knowledge of the orbiter's position than the crew can obtain from onboard systems. Before main engine cutoff, Mission Control makes periodic calls to the crew to tell them which abort mode is (or is not) available. If ground communications are lost, the flight crew has onboard methods, such as cue cards, dedicated displays and display information, to determine the current abort region.

Which abort mode is selected depends on the cause and timing of the failure causing the abort and which mode is safest or improves mission success. If the problem is a space shuttle main engine failure, the flight crew and Mission Control Center select the best option available at the time a space shuttle main engine fails.

If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires approximately 90 minutes. Which of these is selected depends on the time of the failure with three good space shuttle main engines.

The flight crew selects the abort mode by positioning an abort mode switch and depressing an abort push button.

## Shuttle Reference and Data

### Space Shuttle Rendezvous Maneuvers

#### COMMON SHUTTLE RENDEZVOUS MANEUVERS

**OMS-1 (Orbit insertion)** - Rarely used ascent abort burn

**OMS-2 (Orbit insertion)** - Typically used to circularize the initial orbit following ascent, completing orbital insertion. For ground-up rendezvous flights, also considered a rendezvous phasing burn

**NC (Rendezvous phasing)** - Performed to hit a range relative to the target at a future time

**NH (Rendezvous height adjust)** - Performed to hit a delta-height relative to the target at a future time

**NPC (Rendezvous plane change)** - Performed to remove planar errors relative to the target at a future time

**NCC (Rendezvous corrective combination)** - First on-board targeted burn in the rendezvous sequence. Using star tracker data, it is performed to remove phasing and height errors relative to the target at  $T_i$

**Ti (Rendezvous terminal intercept)** - Second on-board targeted burn in the rendezvous sequence. Using primarily rendezvous radar data, it places the Orbiter on a trajectory to intercept the target in one orbit

**MC-1, MC-2, MC-3, MC-4 (Rendezvous midcourse burns)** - These on-board targeted burns use star tracker and rendezvous radar data to correct the post-Ti trajectory in preparation for the final, manual proximity operations phase

## Shuttle Reference and Data

### Space Shuttle Solid Rocket Boosters

The two SRBs provide the main thrust to lift the space shuttle off the pad and up to an altitude of about 150,000 feet, or 24 nautical miles (28 statute miles). In addition, the two SRBs carry the entire weight of the external tank and orbiter and transmit the weight load through their structure to the mobile launcher platform.

Each booster has a thrust (sea level) of approximately 3,300,000 pounds at launch. They are ignited after the three space shuttle main engines' thrust level is verified. The two SRBs provide 71.4 percent of the thrust at lift-off and during first-stage ascent. Seventy-five seconds after SRB separation, SRB apogee occurs at an altitude of approximately 220,000 feet, or 35 nautical miles (40 statute miles). SRB impact occurs in the ocean approximately 122 nautical miles (140 statute miles) downrange.

The SRBs are the largest solid-propellant motors ever flown and the first designed for reuse. Each is 149.16 feet long and 12.17 feet in diameter.

Each SRB weighs approximately 1,300,000 pounds at launch. The propellant for each solid rocket motor weighs approximately 1,100,000 pounds. The inert weight of each SRB is approximately 192,000 pounds.

Primary elements of each booster are the motor (including case, propellant, igniter and nozzle), structure, separation systems, operational flight instrumentation, recovery avionics, pyrotechnics, deceleration system, thrust vector control system and range safety destruct system.

Each booster is attached to the external tank at the SRB's aft frame by two lateral sway braces and a diagonal attachment. The forward end of each SRB is attached to the external tank at the forward end of the SRB's forward skirt. On the launch pad, each booster also is attached to the mobile launcher platform at the aft skirt by four bolts and nuts that are severed by small explosives at lift-off.

During the downtime following the Challenger accident, detailed structural analyses were performed on critical structural elements of the SRB. Analyses were primarily focused in areas where anomalies had been noted during postflight inspection of recovered hardware.

One of the areas was the attach ring where the SRBs are connected to the external tank. Areas of distress were noted in some of the fasteners where the ring attaches to the SRB motor case. This situation was attributed to the high loads encountered during water impact. To correct the situation and ensure higher strength margins during ascent, the attach ring was redesigned to encircle the motor case completely (360 degrees). Previously, the attach ring formed a C and encircled the motor case 270 degrees.

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Additionally, special structural tests were performed on the aft skirt. During this test program, an anomaly occurred in a critical weld between the hold-down post and skin of the skirt. A redesign was implemented to add reinforcement brackets and fittings in the aft ring of the skirt.

These two modifications added approximately 450 pounds to the weight of each SRB.

The propellant mixture in each SRB motor consists of an ammonium perchlorate (oxidizer, 69.6 percent by weight), aluminum (fuel, 16 percent), iron oxide (a catalyst, 0.4 percent), a polymer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent (1.96 percent). The propellant is an 11-point star-shaped perforation in the forward motor segment and a double-truncated-cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by approximately a third 50 seconds after lift-off to prevent overstressing the vehicle during maximum dynamic pressure.

The SRBs are used as matched pairs and each is made up of four solid rocket motor segments. The pairs are matched by loading each of the four motor segments in pairs from the same batches of propellant ingredients to minimize any thrust imbalance. The segmented-casing design assures maximum flexibility in fabrication and ease of transportation and handling. Each segment is shipped to the launch site on a heavy-duty rail car with a specially built cover.

The nozzle expansion ratio of each booster beginning with the STS-8 mission is 7-to-79. The nozzle is gimballed for thrust vector (direction) control. Each SRB has its own redundant auxiliary power units and hydraulic pumps. The all-axis gimbaling capability is 8 degrees. Each nozzle has a carbon cloth liner that erodes and chars during firing. The nozzle is a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.

The cone-shaped aft skirt reacts the aft loads between the SRB and the mobile launcher platform. The four aft separation motors are mounted on the skirt. The aft section contains avionics, a thrust vector control system that consists of two auxiliary power units and hydraulic pumps, hydraulic systems and a nozzle extension jettison system.

The forward section of each booster contains avionics, a sequencer, forward separation motors, a nose cone separation system, drogue and main parachutes, a recovery beacon, a recovery light, a parachute camera on selected flights and a range safety system.

Each SRB has two integrated electronic assemblies, one forward and one aft. After burnout, the forward assembly initiates the release of the nose cap and frustum and turns on the recovery aids. The aft assembly, mounted in the external tank/SRB attach ring, connects with the forward assembly and the orbiter avionics systems for SRB ignition commands and nozzle thrust vector control. Each integrated electronic assembly has a multiplexer/demultiplexer, which sends or receives more than one message, signal or unit of information on a single communication channel.

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Eight booster separation motors (four in the nose frustum and four in the aft skirt) of each SRB thrust for 1.02 seconds at SRB separation from the external tank. Each solid rocket separation motor is 31.1 inches long and 12.8 inches in diameter.

Location aids are provided for each SRB, frustum/ drogue chutes and main parachutes. These include a transmitter, antenna, strobe/ converter, battery and salt water switch electronics. The location aids are designed for a minimum operating life of 72 hours and when refurbished are considered usable up to 20 times. The flashing light is an exception. It has an operating life of 280 hours. The battery is used only once.

The SRB nose caps and nozzle extensions are not recovered.

The recovery crew retrieves the SRBs, frustum/ drogue chutes, and main parachutes. The nozzles are plugged, the solid rocket motors are dewatered, and the SRBs are towed back to the launch site. Each booster is removed from the water, and its components are disassembled and washed with fresh and deionized water to limit salt water corrosion. The motor segments, igniter and nozzle are shipped back to Thiokol for refurbishment.

Each SRB incorporates a range safety system that includes a battery power source, receiver/ decoder, antennas and ordnance.

## **HOLD-DOWN POSTS**

Each solid rocket booster has four hold- down posts that fit into corresponding support posts on the mobile launcher platform. Hold- down bolts hold the SRB and launcher platform posts together. Each bolt has a nut at each end, but only the top nut is frangible. The top nut contains two NASA standard detonators, which are ignited at solid rocket motor ignition commands.

When the two NSDs are ignited at each hold- down, the hold- down bolt travels downward because of the release of tension in the bolt (pretensioned before launch), NSD gas pressure and gravity. The bolt is stopped by the stud deceleration stand, which contains sand. The SRB bolt is 28 inches long and is 3.5 inches in diameter. The frangible nut is captured in a blast container.

The solid rocket motor ignition commands are issued by the orbiter's computers through the master events controllers to the hold- down pyrotechnic initiator controllers on the mobile launcher platform. They provide the ignition to the hold- down NSDs. The launch processing system monitors the SRB hold- down PICs for low voltage during the last 16 seconds before launch. PIC low voltage will initiate a launch hold.

## **SRB IGNITION**

SRB ignition can occur only when a manual lock pin from each SRB safe and arm device has been removed. The ground crew removes the pin during prelaunch activities. At T minus five minutes, the SRB safe and arm device is rotated to the arm position. The solid rocket motor ignition commands are issued when the three SSMEs are at or above 90-percent rated thrust, no SSME fail and/or SRB ignition PIC low voltage is indicated and there are no holds from the LPS.

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The solid rocket motor ignition commands are sent by the orbiter computers through the MECs to the safe and arm device NSDs in each SRB. A PIC single-channel capacitor discharge device controls the firing of each pyrotechnic device. Three signals must be present simultaneously for the PIC to generate the pyro firing output. These signals- arm, fire 1 and fire 2-originate in the orbiter general- purpose computers and are transmitted to the MECs. The MECs reformat them to 28-volt dc signals for the PICs. The arm signal charges the PIC capacitor to 40 volts dc (minimum of 20 volts dc).

The fire 2 commands cause the redundant NSDs to fire through a thin barrier seal down a flame tunnel. This ignites a pyro booster charge, which is retained in the safe and arm device behind a perforated plate. The booster charge ignites the propellant in the igniter initiator; and combustion products of this propellant ignite the solid rocket motor initiator, which fires down the length of the solid rocket motor igniting the solid rocket motor propellant.

The GPC launch sequence also controls certain critical main propulsion system valves and monitors the engine- ready indications from the SSMEs. The MPS start commands are issued by the onboard computers at T minus 6.6 seconds (staggered start- engine three, engine two, engine one- all approximately within 0.25 of a second), and the sequence monitors the thrust buildup of each engine. All three SSMEs must reach the required 90-percent thrust within three seconds; otherwise, an orderly shutdown is commanded and safing functions are initiated.

Normal thrust buildup to the required 90-percent thrust level will result in the SSMEs being commanded to the lift- off position at T minus three seconds as well as the fire 1 command being issued to arm the SRBs. At T minus three seconds, the vehicle base bending load modes are allowed to initialize (movement of approximately 25.5 inches measured at the tip of the external tank, with movement towards the external tank).

At T minus zero, the two SRBs are ignited, under command of the four onboard computers; separation of the four explosive bolts on each SRB is initiated (each bolt is 28 inches long and 3.5 inches in diameter); the two T-0 umbilicals (one on each side of the spacecraft) are retracted; the onboard master timing unit, event timer and mission event timers are started; the three SSMEs are at 100 percent; and the ground launch sequence is terminated.

The solid rocket motor thrust profile is tailored to reduce thrust during the maximum dynamic pressure region.

## **ELECTRICAL POWER DISTRIBUTION**

Electrical power distribution in each SRB consists of orbiter- supplied main dc bus power to each SRB via SRB buses A, B and C. Orbiter main dc buses A, B and C supply main dc bus power to corresponding SRB buses A, B and C. In addition, orbiter main dc bus C supplies backup power to SRB buses A and B, and orbiter bus B supplies backup power to SRB bus C. This electrical power distribution arrangement allows all SRB buses to remain powered in the event one orbiter main bus fails.

The nominal dc voltage is 28 volts dc, with an upper limit of 32 volts dc and a lower limit of 24 volts dc.



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## HYDRAULIC POWER UNITS

There are two self-contained, independent HPUs on each SRB. Each HPU consists of an auxiliary power unit, fuel supply module, hydraulic pump, hydraulic reservoir and hydraulic fluid manifold assembly. The APUs are fueled by hydrazine and generate mechanical shaft power to a hydraulic pump that produces hydraulic pressure for the SRB hydraulic system. The two separate HPUs and two hydraulic systems are located on the aft end of each SRB between the SRB nozzle and aft skirt. The HPU components are mounted on the aft skirt between the rock and tilt actuators. The two systems operate from T minus 28 seconds until SRB separation from the orbiter and external tank. The two independent hydraulic systems are connected to the rock and tilt servoactuators.

The APU controller electronics are located in the SRB aft integrated electronic assemblies on the aft external tank attach rings.

The APUs and their fuel systems are isolated from each other. Each fuel supply module (tank) contains 22 pounds of hydrazine. The fuel tank is pressurized with gaseous nitrogen at 400 psi, which provides the force to expel (positive expulsion) the fuel from the tank to the fuel distribution line, maintaining a positive fuel supply to the APU throughout its operation.

The fuel isolation valve is opened at APU startup to allow fuel to flow to the APU fuel pump and control valves and then to the gas generator. The gas generator's catalytic action decomposes the fuel and creates a hot gas. It feeds the hot gas exhaust product to the APU two-stage gas turbine. Fuel flows primarily through the startup bypass line until the APU speed is such that the fuel pump outlet pressure is greater than the bypass line's. Then all the fuel is supplied to the fuel pump.

The APU turbine assembly provides mechanical power to the APU gearbox. The gearbox drives the APU fuel pump, hydraulic pump and lube oil pump. The APU lube oil pump lubricates the gearbox. The turbine exhaust of each APU flows over the exterior of the gas generator, cooling it, and is then directed overboard through an exhaust duct.

When the APU speed reaches 100 percent, the APU primary control valve closes, and the APU speed is controlled by the APU controller electronics. If the primary control valve logic fails to the open state, the secondary control valve assumes control of the APU at 112-percent speed.

Each HPU on an SRB is connected to both servoactuators on that SRB. One HPU serves as the primary hydraulic source for the servoactuator, and the other HPU serves as the secondary hydraulics for the servoactuator. Each servoactuator has a switching valve that allows the secondary hydraulics to power the actuator if the primary hydraulic pressure drops below 2,050 psi. A switch contact on the switching valve will close when the valve is in the secondary position. When the valve is closed, a signal is sent to the APU controller that inhibits the 100-percent APU speed control logic and enables the 112-percent APU speed control logic. The 100-percent APU speed enables one APU/HPU to supply sufficient operating hydraulic pressure to both servoactuators of that SRB.

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The APU 100-percent speed corresponds to 72,000 rpm, 110-percent to 79,200 rpm, and 112-percent to 80,640 rpm.

The hydraulic pump speed is 3,600 rpm and supplies hydraulic pressure of 3,050, plus or minus 50, psi. A high- pressure relief valve provides overpressure protection to the hydraulic system and relieves at 3,750 psi.

The APUs/HPUs and hydraulic systems are reusable for 20 missions.

## **THRUST VECTOR CONTROL**

Each SRB has two hydraulic gimbal servoactuators: one for rock and one for tilt. The servoactuators provide the force and control to gimbal the nozzle for thrust vector control.

The space shuttle ascent thrust vector control portion of the flight control system directs the thrust of the three shuttle main engines and the two SRB nozzles to control shuttle attitude and trajectory during lift- off and ascent. Commands from the guidance system are transmitted to the ATVC drivers, which transmit signals proportional to the commands to each servoactuator of the main engines and SRBs. Four independent flight control system channels and four ATVC channels control six main engine and four SRB ATVC drivers, with each driver controlling one hydraulic port on each main and SRB servoactuator.

Each SRB servoactuator consists of four independent, two- stage servovalves that receive signals from the drivers. Each servovalve controls one power spool in each actuator, which positions an actuator ram and the nozzle to control the direction of thrust.

The four servovalves in each actuator provide a force- summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator force-sum action prevents a single erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure sensing activates a selector valve to isolate and remove the defective servovalve hydraulic pressure, permitting the remaining channels and servovalves to control the actuator ram spool.

Failure monitors are provided for each channel to indicate which channel has been bypassed. An isolation valve on each channel provides the capability of resetting a failed or bypassed channel.

Each actuator ram is equipped with transducers for position feedback to the thrust vector control system. Within each servoactuator ram is a splashdown load relief assembly to cushion the nozzle at water splashdown and prevent damage to the nozzle flexible bearing.

## **SRB RATE GYRO ASSEMBLIES**

Each SRB contains two RGAs, with each RGA containing one pitch and one yaw gyro. These provide an output proportional to angular rates about the pitch and yaw axes to the orbiter computers and guidance, navigation and control system during first- stage ascent flight in conjunction with the orbiter roll rate gyros until SRB separation. At SRB separation, a switchover is made from the SRB RGAs to the orbiter RGAs.

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The SRB RGA rates pass through the orbiter flight aft multiplexers/ demultiplexers to the orbiter GPCs. The RGA rates are then mid-value- selected in redundancy management to provide SRB pitch and yaw rates to the user software. The RGAs are designed for 20 missions.

## **SRB SEPARATION**

SRB separation is initiated when the three solid rocket motor chamber pressure transducers are processed in the redundancy management middle value select and the head- end chamber pressure of both SRBs is less than or equal to 50 psi. A backup cue is the time elapsed from booster ignition.

The separation sequence is initiated, commanding the thrust vector control actuators to the null position and putting the main propulsion system into a second-stage configuration (0.8 second from sequence initialization), which ensures the thrust of each SRB is less than 100,000 pounds. Orbiter yaw attitude is held for four seconds, and SRB thrust drops to less than 60,000 pounds.

The SRBs separate from the external tank within 30 milliseconds of the ordnance firing command.

The forward attachment point consists of a ball (SRB) and socket (ET) held together by one bolt. The bolt contains one NSD pressure cartridge at each end. The forward attachment point also carries the range safety system cross-strap wiring connecting each SRB RSS and the ET RSS with each other.

The aft attachment points consist of three separate struts: upper, diagonal and lower. Each strut contains one bolt with an NSD pressure cartridge at each end. The upper strut also carries the umbilical interface between its SRB and the external tank and on to the orbiter.

There are four booster separation motors on each end of each SRB. The BSMs separate the SRBs from the external tank. The solid rocket motors in each cluster of four are ignited by firing redundant NSD pressure cartridges into redundant confined detonating fuse manifolds.

The separation commands issued from the orbiter by the SRB separation sequence initiate the redundant NSD pressure cartridge in each bolt and ignite the BSMs to effect a clean separation.

## Shuttle Reference and Data

### Space Shuttle Super Light Weight Tank (SLWT)

The super lightweight external tank (SLWT) made its first Shuttle flight June 2, 1998 on mission STS-91. The SLWT is 7,500 pounds lighter than the standard external tank. The lighter weight tank will allow the shuttle to deliver International Space Station elements (such as the service module) into the proper orbit.

The SLWT is the same size as the previous design. But the liquid hydrogen tank and the liquid oxygen tank are made of aluminum lithium, a lighter, stronger material than the metal alloy used for the Shuttle's current tank. The tank's structural design has also been improved, making it 30% stronger and 5% less dense.

The SLWT, like the standard tank, is manufactured at Michoud Assembly, near New Orleans, Louisiana, by Lockheed Martin.

The 154-foot-long external tank is the largest single component of the space shuttle. It stands taller than a 15-story building and has a diameter of about 27 feet. The external tank holds over 530,000 gallons of liquid hydrogen and liquid oxygen in two separate tanks. The hydrogen (fuel) and liquid oxygen (oxidizer) are used as propellants for the Shuttle's three main engines.

## Media Assistance

### **NASA Television Transmission**

NASA Television is available through the GE2 satellite system which is located on Transponder 9C, at 85 degrees west longitude, frequency 3880.0 MHz, audio 6.8 MHz.

The schedule for television transmissions from the orbiter and for mission briefings will be available during the mission at Kennedy Space Center, FL; Marshall Space Flight Center, Huntsville, AL; Dryden Flight Research Center, Edwards, CA; Johnson Space Center, Houston, TX; and NASA Headquarters, Washington, DC. The television schedule will be updated to reflect changes dictated by mission operations.

### **Status Reports**

Status reports on countdown and mission progress, on-orbit activities and landing operations will be produced by the appropriate NASA newscenter

### **Briefings**

A mission press briefing schedule will be issued before launch. During the mission, status briefings by a flight director or mission operations representative and when appropriate, representatives from the payload team, will occur at least once each day. The updated NASA television schedule will indicate when mission briefings are planned.

### **Internet Information**

Information is available through several sources on the Internet. The primary source for mission information is the NASA Human Space Flight Web, part of the World Wide Web. This site contains information on the crew and its mission and will be updated regularly with status reports, photos and video clips throughout the flight. The NASA Shuttle Web's address is:

<http://spaceflight.nasa.gov>

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General information on NASA and its programs is available through the NASA Home Page and the NASA Public Affairs Home Page:

<http://www.nasa.gov>

or

<http://www.nasa.gov/newsinfo/index.html>

Shuttle Pre-Launch Status Reports

<http://www-pao.ksc.nasa.gov/kscpao/status/stsstat/current.htm>

Information on other current NASA activities is available through the Today@NASA page:

<http://www.nasa.gov/today/index.html>

The NASA TV schedule is available from the NTV Home Page:

<http://spaceflight.nasa.gov/realdata/nasatv/schedule.html>

Resources for educators can be found at the following address:

<http://education.nasa.gov>

## **Access by Compuserve**

Users with Compuserve accounts can access NASA press releases by typing "GO NASA" (no quotes) and making a selection from the categories offered.

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## Media Contacts

### NASA PAO Contacts

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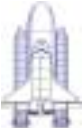
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# SHUTTLE FLIGHTS AS OF APRIL 2001

103 TOTAL FLIGHTS OF THE SHUTTLE SYSTEM -- 78 SINCE RETURN TO FLIGHT

STS-93 07/23/99 - 07/27/99		STS-102 03/08/01 - 03/21/01		
STS-90 04/17/98 - 05/03/98		STS-92 10/11/00 - 10/24/00		
STS-87 11/19/97 - 12/05/97		STS-103 12/19/99 - 12/27/99		
STS-94 07/01/97 - 07/17/97		STS-96 05/27/99 - 06/06/99		
STS-83 04/04/97 - 04/08/97		STS-95 10/29/98 - 11/07/98		
STS-80 11/19/96 - 12/07/96		STS-91 06/02/09 - 06/12/98		
STS-78 06/20/96 - 07/07/96		STS-85 08/07/97 - 08/19/97	STS-98 02/07/01 - 02/20/01	
STS-75 02/22/96 - 03/09/96		STS-82 02/11/97 - 02/21/97	STS-106 09/08/00 - 09/20/00	
STS-73 10/20/95 - 11/05/95		STS-70 07/13/95 - 07/22/95	STS-101 05/19/00 - 05/29/00	
STS-65 07/08/94 - 07/23/94		STS-63 02/03/95 - 02/11/95	STS-86 09/25/97 - 10/06/97	
STS-62 03/04/94 - 03/18/94		STS-64 09/09/94 - 09/20/94	STS-84 05/15/97 - 05/24/97	
STS-58 10/18/93 - 11/01/93		STS-60 02/03/94 - 02/11/94	STS-81 01/12/97 - 01/22/97	
STS-55 04/26/93 - 05/06/93		STS-51 09/12/93 - 09/22/93	STS-79 09/16/96 - 09/26/96	
STS-52 10/22/92 - 11/01/92		STS-56 04/08/83 - 04/17/93	STS-76 03/22/96 - 03/31/96	
STS-50 06/25/92 - 07/09/92		STS-53 12/02/92 - 12/09/92	STS-74 11/12/95 - 11/20/95	STS-97 11/30/00 - 12/11/00
STS-40 06/05/91 - 06/14/91		STS-42 01/22/92 - 01/30/92	STS-71 06/27/95 - 07/07/95	STS-99 02/11/00 - 02/22/00
STS-35 12/02/90 - 12/10/90	STS-51L 01/28/86	STS-48 09/12/91 - 09/18/91	STS-66 11/03/94 - 11/14/94	STS-88 12/04/98 - 12/15/98
STS-32 01/09/90 - 01/20/90	STS-61A 10/30/85 - 11/06/85	STS-39 04/28/91 - 05/06/91	STS-46 07/31/92 - 08/08/92	STS-89 01/22/98 - 01/31/98
STS-28 08/08/89 - 08/13/89	STS-51F 07/29/85 - 08/06/85	STS-41 10/06/90 - 10/10/90	STS-45 03/24/92 - 04/02/92	STS-77 05/19/96 - 05/29/96
STS-61C 01/12/86 - 01/18/86	STS-51B 04/29/85 - 05/06/85	STS-31 04/24/90 - 04/29/90	STS-44 11/24/91 - 12/01/91	STS-72 01/11/96 - 11/20/96
STS-9 11/28/83 - 12/08/83	STS-41G 10/05/84 - 10/13/84	STS-33 11/22/89 - 11/27/89	STS-43 08/02/91 - 08/11/91	STS-69 09/07/95 - 09/18/95
STS-5 11/11/82 - 11/16/82	STS-41C 04/06/84 - 04/13/84	STS-29 03/13/89 - 03/18/89	STS-37 04/05/91 - 04/11/91	STS-67 03/02/95 - 03/18/95
STS-4 06/27/82 - 07/04/82	STS-41B 02/03/84 - 02/11/84	STS-26 09/29/88 - 10/03/88	STS-38 11/15/90 - 11/20/90	STS-68 09/30/94 - 10/11/94
STS-3 03/22/82 - 03/30/82	STS-8 08/30/83 - 09/05/83	STS-51-I 08/27/85 - 09/03/85	STS-36 02/28/90 - 03/04/90	STS-59 04/09/94 - 04/20/94
STS-2 11/12/81 - 11/14/81	STS-7 06/18/83 - 06/24/83	STS-51G 06/17/85 - 06/24/85	STS-34 10/18/89 - 10/23/89	STS-61 12/02/93 - 12/13/93
STS-1 04/12/81 - 04/14/81	STS-6 04/04/83 - 04/09/83	STS-51D 04/12/85 - 04/19/85	STS-30 05/04/89 - 05/08/89	STS-57 06/21/93 - 07/01/93
		STS-51C 01/24/85 - 01/27/85	STS-27 12/02/88 - 12/06/88	STS-54 01/13/93 - 01/19/93
		STS-51A 11/08/84 - 11/16/84	STS-61B 11/26/85 - 12/03/85	STS-47 09/12/92 - 09/20/92
		STS-41D 08/30/84 - 09/05/84	STS-51J 10/03/85 - 10/07/85	STS-49 05/07/92 - 05/16/92

**OV-102  
Columbia  
(26 flights)**

**OV-099  
Challenger  
(10 flights)**

**OV-103  
Discovery  
(29 flights)**

**OV-104  
Atlantis  
(23 flights)**

**OV-105  
Endeavour  
(15 flights)**