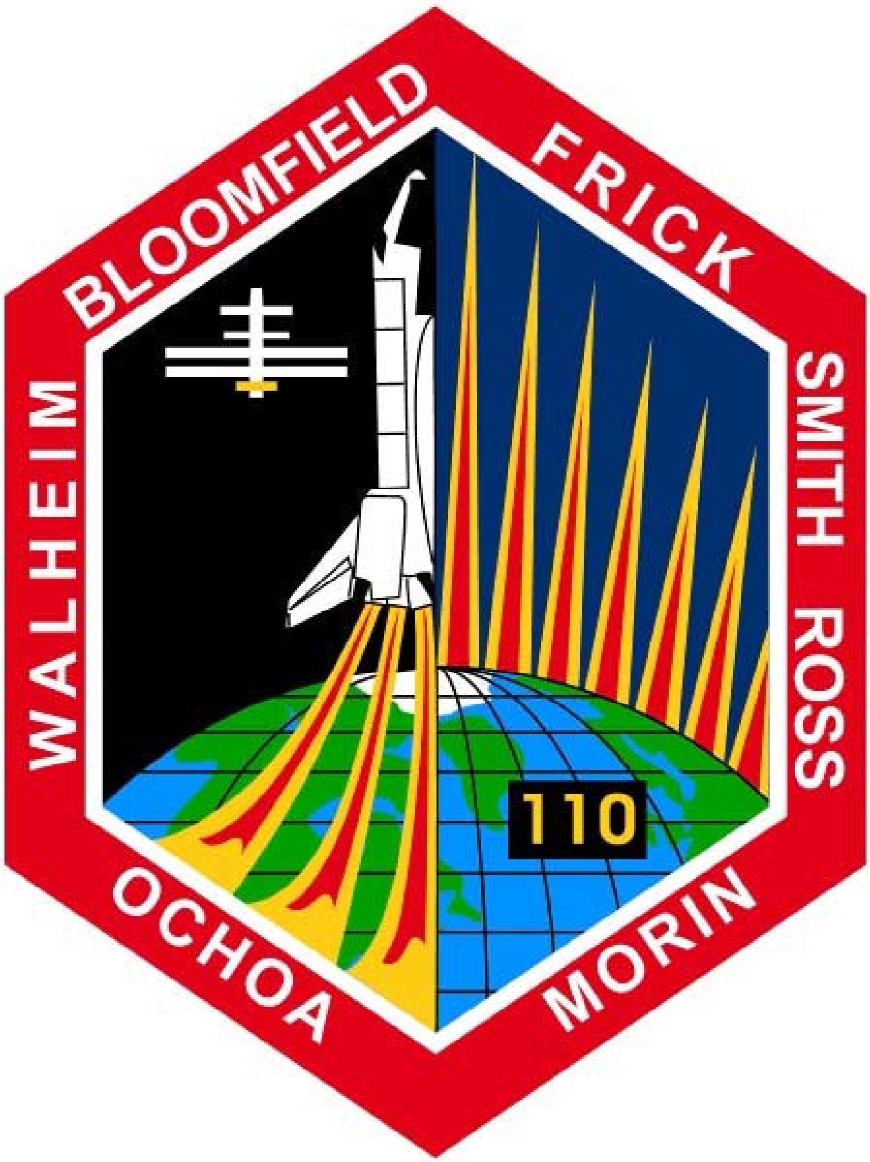
STS-110

FRAMEWORK FOR EXPANDING STATION RESEARCH



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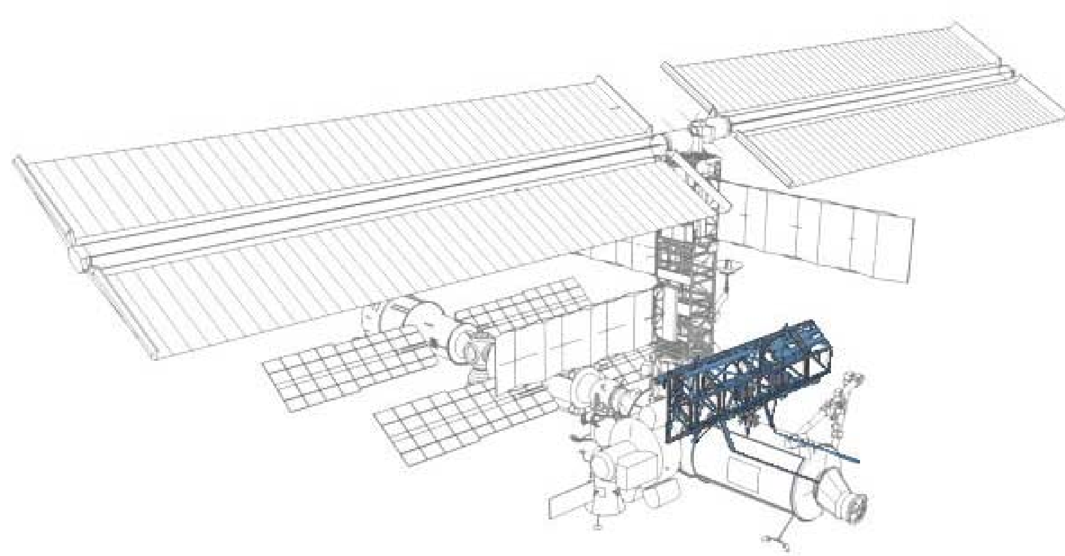
Overview

A Framework for Station Expansion and Increased Research

The Space Shuttle Atlantis will begin expanding the International Space Station on mission STS-110 (ISS Assembly Flight 8A), installing the initial section of a framework that eventually will hold systems needed to provide power and cooling for future research laboratories.



This line art highlights the S0 truss and Mobile Transporter additions that will be made to the International Space Station on STS-110/8A.

Atlantis' mission will be one of the most complex station assembly flights to date, including four spacewalks and operations with both the shuttle's robotic arm and the station's robotic arm. During the spacewalks, astronauts will truly take on the appearance of high-rise construction workers as they assemble beams, attach work lights, bolt girders and plug in electrical connections. The station's Canadarm2 robotic arm will be used exclusively to hoist the 13-ton truss section, called the S-Zero (S0) Integrated Truss Structure, from Atlantis and attach it to the station. The flight will be the first time the station's arm is used as a space "cherry picker" to maneuver spacewalkers. It also will be the first shuttle flight to have all spacewalks originate from the station's airlock.

Michael J. Bloomfield, 43, Lt. Col., USAF, a veteran of two previous spaceflights, will command Atlantis. Stephen N. Frick, 37, Cmdr., USN, will serve as pilot and will be making his first spaceflight. Rex J. Walheim, 39, Lt. Col., USAF, will be mission specialist 1, also making his first spaceflight. Ellen Ochoa, 43, will be flight engineer and mission specialist 2, making her fourth spaceflight. Lee M. E. Morin, 49, will be mission specialist 3, making his first spaceflight.

Jerry L. Ross, 54, will be mission specialist 4 and will be making a record seventh flight aboard the shuttle, the most of anyone in history. Ross also is the most experienced spacewalker in the U.S. astronaut corps, having completed seven previous spacewalks. Steven L. Smith, 43, will be mission specialist 5, making his fourth spaceflight. Smith and Walheim will form one team of spacewalkers while Ross and Morin will form a second spacewalking team.

Assisting with Atlantis' assembly work from aboard the International Space Station will be the current station residents, the Expedition Four crew, Commander Yury Onufrienko and Flight Engineers Dan Bursch and Carl Walz. The station crew has been aboard the complex since early December 2001.

The S0 truss is lifted into its transport canister at the Kennedy Space Center.

Atlantis will carry the first major external truss section for the station, a 43-foot-long girder-like segment that will lay the foundation for an eventual cross-beam that will stretch more than 350 feet. Nine additional truss segments will be linked on future missions to the centerpiece segment carried by Atlantis to form the finished structure. The finished truss will support almost an acre of solar panels and giant cooling radiators. Although the International Space Station already is a fully functional research complex with a single United States laboratory, the additional solar panels and radiators will provide the electricity and cooling necessary for Japanese and European laboratories to be attached to the station as well as a future U.S. centrifuge laboratory.

The truss segment carried to the station by Atlantis also will include the first space railroad. Attached to the truss before launch will be a space railcar called the Mobile Transporter and a section of track that will span the length of the truss segment. The Mobile Transporter, when it is coupled with a base system for the station's Canadian robotic arm later this year, will allow the station's robotic arm to ride up and down the length of the football-field-long finished truss. The rail system will allow the arm to be positioned wherever it may be needed along the truss for maintenance or assembly work.

The mission is planned to last 11 days, with Atlantis returning to the Kennedy Space Center, Fla., for landing. An overview of the flight activities includes:

Flight Day One: Launch

Atlantis' crew will launch near the end of their day, and they will begin a sleep period only a few hours after reaching orbit. Atlantis' orbital maneuvering engines will be fired to adjust the rate at which the shuttle closes in on the station and backup systems on the shuttle will be powered down to conserve electricity before the crew goes to sleep.

Flight Day Two: Spacewalk, Rendezvous, Docking Preparations

The second day of the mission day will be devoted to checks of the spacesuits and space-walking gear that will be used later in the mission. Atlantis' robotic arm also will be powered up and checked out, and television cameras on the arm will be used to survey the cargo bay. The crew also will check the operation of navigation aids and other equipment that will be used during the final phase of rendezvous with the station. Atlantis' thrusters will be fired periodically during the day to fine-tune the rate at which the shuttle is approaching the station, and the docking mechanism in Atlantis' cargo bay will be powered up and extended in readiness for the docking.

Flight Day Three: Rendezvous and Docking; Truss Installation Practice

Atlantis will rendezvous and dock to the International Space Station on the third day of the mission. Less than two hours after docking, the hatches between the shuttle and station will be opened and the crews will greet one another. The remainder of the day will be spent transferring supplies and equipment, including two crystal growth experiments, between the two spacecraft as well as a joint review by the two crews of plans for installation of the S0 truss and the first spacewalk. Ochoa and Bursch will power up the station's robotic arm and maneuver it through a practice run, going through the same motions that will be required to install the truss to the station. The station arm is planned to be left overnight in a position near the fixture it will latch onto to lift the truss out of Atlantis' payload bay.

Flight Day Four: S0 Truss Installation and First Spacewalk

Ochoa and Bursch will work together aboard the station to use the complex's Canadarm2 to lift the truss segment from Atlantis' cargo bay and attach it atop the station's Destiny laboratory. Frick will operate the shuttle's robotic arm aboard Atlantis to use views from television cameras on that arm to assist Ochoa and Bursch. As the truss is being installed, Smith and Walheim will be in the station's Quest airlock preparing to begin the first spacewalk. Once the truss has been latched to the Destiny lab via a mechanical "claw" closed remotely from within the station, they will begin their work outside. The 6 ½-hour spacewalk will be highlighted by completing initial connections to provide power and data to the truss and by the bolting of forward struts into place that will permanently attach the truss to the station. Mission Control will send commands to begin the activation of the initial S0 truss equipment and heaters.

Flight Day Five: Cargo Transfers, Spacewalk Preparations, Off-duty Time

The crews will turn their attention to continuing the transfer of supplies, equipment and experiments between the station and shuttle. Nitrogen and oxygen will be transferred from tanks aboard Atlantis to replenish tanks on the station's Quest airlock. All crewmembers also will have time set aside for a group review of plans for the upcoming second and third spacewalks. The crewmembers will have a couple of hours of off-duty time at the end of the day.

Flight Day Six: Second Spacewalk

The sixth day of the mission will see Ross and Morin conduct the second spacewalk, planned to last about 6 ½ hours. They will focus on completing more power and data connections on the S0 truss as well as bolting two aft struts into place to complete its permanent mechanical connection to the station. After the spacewalk has been completed, Bloomfield will set Atlantis' small thrusters to fire periodically over the course of an hour to gently boost the station's altitude by a few miles.

Flight Day Seven: Third Spacewalk

Smith and Walheim will work outside again on the seventh day of the mission, performing the third spacewalk, also planned to last about 6 ½ hours. The third spacewalk will include a release of the mechanical claw that provided the initial attachment of the S0 truss to the station, hookups of data and power to a robotic arm fixture located on the Mobile Transporter railcar, and the release of restraints that held the Mobile Transporter railcar secure during launch of the S0 truss. Smith and Walheim also will install a mechanical beam called the "airlock spur" between the Quest airlock and the new truss for use as a path for future spacewalkers. Because some of the connections to be made during this spacewalk will require powering off the station's robotic arm temporarily, the shuttle's robotic arm will be used to maneuver the astronauts for much of the day. A second boost of the station's altitude by Atlantis will be performed.

Flight Day Eight: Mobile Transporter Checks, EVA Preparations

The Mobile Transporter railcar will be commanded to move for the first time on the eighth day of the mission. A checkout of the space railway will command the transporter to roll up and down its 43-foot-long rails. Television cameras on Atlantis' robotic arm will be used to record the transporter checkout. Interior cargo will continue to be transferred during the day and preparations will be made for the fourth and final spacewalk. The crew also will have about a half-day off duty to rest.

Flight Day Nine: Fourth Spacewalk

Ross and Morin will conduct the fourth and final spacewalk on the ninth day of the flight, an excursion planned to also last about 6 ½ hours. The final spacewalk will include a variety of jobs, including the installation of two floodlights on the station’s exterior, partially assembling a work platform to be used during a later mission, attaching handrails on the S0 truss, and several other “get-ahead” tasks designed to ease the workload on future crews.

Flight Day Ten: Undocking and Flyaround

After spending a week working together, the crews of Atlantis and the International Space Station will bid one another farewell and the shuttle will undock from the station. Before undocking, some final refrigerated experiment samples will be transferred from the station to Atlantis for the trip home, and a new experiment refrigerator will be installed on the station. After undocking, Atlantis will circle the station one and a quarter times before separating the vicinity.

Flight Day Eleven: Landing Preparations

Atlantis’ crew will spend the 11th day of the flight checking out the navigation, flight controls, steering jets, aero surfaces and other equipment needed for the shuttle’s descent to Earth. The last part of the day will be spent stowing away gear in the cabin in preparation for landing.

Flight Day Twelve: Descent and Landing

Atlantis will fire its engines to re-enter the atmosphere and descend to a landing. The prime landing site for Atlantis will be the Kennedy Space Center, Fla.

STS-110

Crew

Commander:	Michael J. Bloomfield
Pilot:	Stephen N. Frick
Mission Specialist 1:	Rex J. Walheim
Mission Specialist 2:	Ellen Ochoa
Mission Specialist 3:	Lee M.E. Morin
Mission Specialist 4:	Jerry L. Ross
Mission Specialist 5:	Steven L. Smith

Launch

Orbiter:	Atlantis OV104
Launch Site:	Kennedy Space Center Launch Pad 39B
Launch Window:	No greater than 5 Minutes
Altitude:	122 Nautical Miles
Inclination:	51.6 Degrees
Duration:	10 Days 18 Hrs. 57 Min.

Vehicle Data

Shuttle Liftoff Weight:	4,520,940 lbs.
Orbiter/Payload Liftoff Weight:	257,079 lbs.
Orbiter/Payload Landing Weight:	200,657 lbs.
Software Version:	OI-29

Space Shuttle Main Engines:

SSME 1: 2048 **SSME 2:** 2051 **SSME 3:** 2045

External Tank: ET-114 (Super Light Weight Tank)

SRB Set: BI112PF

Shuttle Aborts

Abort Landing Sites

RTLS: Kennedy Space Center Shuttle Landing Facility
TAL: Zaragoza
AOA: Kennedy Space Center Shuttle Landing Facility

Landing

Landing Date:	04/15/02
Primary Landing Site:	Kennedy Space Center Shuttle Landing Facility

Mission Objectives

The primary objective of space shuttle mission STS-110 is to deliver the first segment of the International Space Station's external truss, the S0 (S-Zero) truss, together with various equipment that will be installed on the truss segment before launch.

Equipment installed on the truss before launch includes: the Mobile Transporter (MT) and its associated power and data umbilical reels; four direct-current-to-direct-current switching units; two rate gyroscope assemblies; main bus switching units; four secondary power distribution assemblies; four Global Positioning System antennas; a 21-foot-long radiator panel located on the truss' aft face to provide cooling for the electronics; and rails on the truss' forward face to provide a track for the MT.

The primary mechanical attachment of the S0 truss to the International Space Station is through four Module-to-Truss Structure struts, two forward and two aft. Various umbilicals provide power and data to and from units on the truss structure as well as to future additions that will be attached to other truss segments, such as radiators and solar arrays.

Priorities for STS-110 mission, International Space Station mission 8A, are:

- Unberth the S0 truss from the shuttle payload bay; install on Lab Cradle Assembly (LCA); install forward MTS struts on Destiny Lab; and provide minimum survival power for S0, including connection of primary trailing umbilical system (TUS 2) for the MT.
- Install the remaining MTS struts on Destiny Lab.
- Install S0-to-Destiny Lab avionics trays and connect umbilicals.
- Perform critical transfers to the International Space Station, including an as yet-to-be-determined volume of water, Crew and Equipment Translation Aid lights and stanchions and Circuit Interrupt Devices.
- Complete activation and checkout of S0 systems.
- Perform space station robotic arm power and data reconfiguration, installing connections for MT power and data grapple fixture.
- Perform transfer of powered experiments from shuttle to station.
- Activate MT and configure for translation test by installing redundant trailing umbilical cable to MT and releasing MT launch restraints.
- Remove and stow keel pins and drag links on S0.
- Translate MT from launch site to first worksite.

- Install Circuit Interrupt Devices.
- Perform remaining payload transfers from shuttle to station and station to shuttle and perform transfers of ISS crew provisions and resupply items.
- Open Lab Cradle Assembly (LCA) capture latch and back out LCA load release bolts.
- Install Quest Airlock Spur.
- Install MT to Mobile Base System bolt debris covers.
- Perform MT translation test in both directions.
- Prepare and deploy Extravehicular Charged Particle Detection System (EVCPDS).
- Deploy extravehicular activity lights.
- Install CETA-to-MT energy absorbers.
- Activate and check out external video switch system.
- Perform UF-2 get-ahead tasks such as assemble portable work platform and perform EVA tool configuration.
- Remove Z-1 thermal shrouds, install airlock handrail, install S0 face 2 handrails, deploy Unity node swing arm and reconfigure launch-to-activation cables.

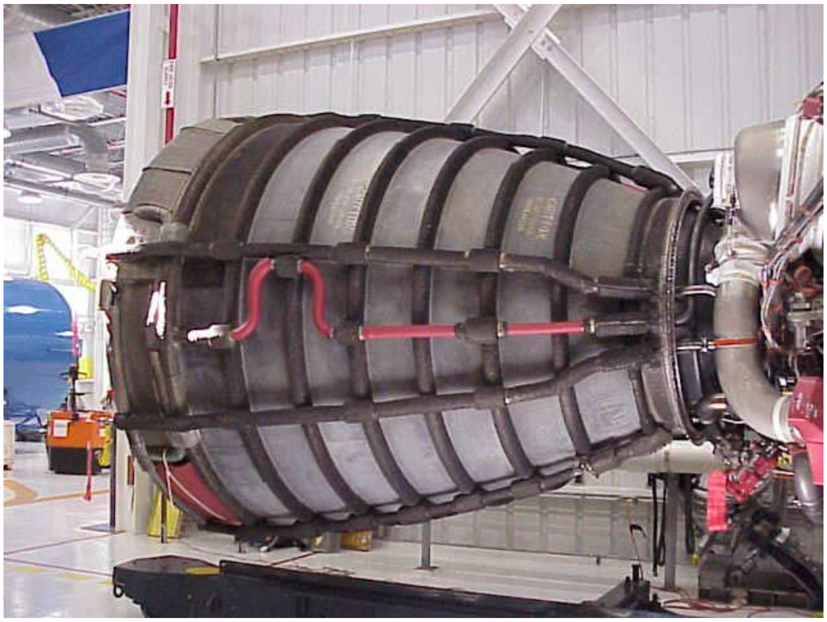
New, Safer Engines to Propel Atlantis

STS-110 will be the first space shuttle flight to rely exclusively on the latest redesign of the shuttle main engines, a design that has modified the engines to more than double estimates of their reliability and safety. All three Space Shuttle Main Engines on Atlantis will be Block II engines, the first time a shuttle has flown with a cluster of Block II engines. The first and only flight so far of a Block II main engine was a single engine that flew on shuttle mission STS-104 in July 2001 with the remaining two engines on that mission being of an older design.

Improvements to the main engines, managed by NASA's Marshall Space Flight Center in Huntsville, Ala., include a new Pratt & Whitney high-pressure fuel turbopump. The primary modification to the engine is the elimination of welds by using a casting process for the housing, and an integral shaft and disk with thin-wall blades and ceramic bearings. This makes the pump stronger and should increase the number of flights between major overhauls. Although the new pump adds 300 pounds (135 kilograms) of weight to the shuttle, the results are a more reliable and safer engine because of increased pump robustness.

Previous improvements to the Space Shuttle Main Engine include the Block I configuration, which featured an improved high-pressure liquid oxygen turbopump, two-duct engine power head and single-coil heat exchanger. The turbopump incorporated ball bearings of silicon nitride -- a ceramic material 30 percent harder and 40 percent lighter than steel. The Block I engine first flew in 1995.

The Block IIA engine added a larger-throat main-combustion chamber to Block I improvements. The new chamber lowered the engine's operating pressures and temperatures while increasing the engine's operational safety margin. This engine first flew in 1998.



Developed in the 1970s by Marshall, the Space Shuttle Main Engine is the world's most sophisticated reusable rocket engine. Each main engine is 14 feet long (4.3 meters), weighs about 7,000 pounds (3,175 kilograms) and is 7.5 feet (2.3 meters) in diameter at the end of the nozzle. The engines perform at greater temperature extremes than any mechanical system in common use today. At minus 423 degrees Fahrenheit (minus 217 degrees Celsius), the liquid hydrogen fuel is the second coldest liquid on Earth. When it and the liquid oxygen are combusted, the temperature in the main combustion chamber of the engine is 6,000 degrees Fahrenheit (3,316 degrees Celsius), hotter than the boiling point of iron. Boeing Rocketdyne in Canoga Park, Calif., manufactures the Space Shuttle Main Engine. Testing on the Block II Engine was completed at Stennis Space Center, Miss.

Crew Bios

STS-110 Crewmembers

Commander: Michael J. Bloomfield

Michael J. Bloomfield, 43, a lieutenant colonel in the U.S. Air Force, a former instructor pilot and a veteran of two space flights, is commander for STS-110. He received a bachelor of science in engineering mechanics from the U.S. Air Force Academy in 1981 and a master of science in engineering management from Old Dominion University in 1993. He will be responsible for overall mission success and safety during STS-110, as well as the rendezvous and docking of Atlantis to the International Space Station. Bloomfield and pilot Stephen Frick will use the shuttle's robotic arm cameras to take video on the first, second and fourth spacewalks. They also will use the shuttle arm to support the EVA crewmembers during most of the third spacewalk. Bloomfield will have primary responsibility for Earth observations, and will share responsibilities for the shuttle's guidance and navigation systems, computer systems and life support systems. He will land Atlantis at the end of the mission.

Selected by NASA in December 1994, Bloomfield has logged more than 494 hours in space, serving as pilot of STS-86 in 1997 and STS-97 in 2000. This flight will be his first as commander of a space shuttle mission.

Pilot: Stephen N. Frick

Stephen N. Frick, 37, a commander in the U.S. Navy, will serve as pilot. Frick received a bachelor of science in aerospace engineering from the U.S. Naval Academy in 1986 and a master of science in aeronautical engineering from the U.S. Naval Postgraduate School in 1994. NASA selected Frick in April 1996. He will be responsible for a number of orbiter systems during ascent and landing. He will operate the shuttle's robotic arm with the commander, supporting the installation of the S0 (S-Zero) truss and the four spacewalks. Frick also will be at the shuttle controls for the undocking from the ISS and subsequent flyaround.

Frick will be making his first spaceflight.

Mission Specialist 1: Rex J. Walheim

Rex J. Walheim, 39, a lieutenant colonel in the U.S. Air Force and a former flight test engineer, will be Mission Specialist 1. He received a bachelor of science in mechanical engineering from the University of California, Berkeley, in 1984, and a master of science in industrial engineering from the University of Houston in 1989. He was selected as an astronaut in March 1996. He will play a key role in the rendezvous, operating a handheld laser range-finding device. Walheim and Mission Specialist Steve Smith will conduct the first spacewalk of the mission, on flight day four, and the third, on flight day seven.

Walheim will be making his first spaceflight.

Mission Specialist 2: Ellen Ochoa

Ellen Ochoa, 43, will be flight engineer and Mission Specialist 2, making her fourth spaceflight. Ochoa received a bachelor of science in physics from San Diego State University in 1980 and a master of science and a doctorate in electrical engineering from Stanford University in 1981 and 1985, respectively. Selected by NASA in January 1990, Ochoa became an astronaut in July 1991. For the first, second and fourth spacewalks, she will move to the station's Destiny laboratory to operate Canadarm2, the station's robotic arm, to work with the spacewalking astronauts. For the installation of the S0 truss, Ochoa and Expedition Four Flight Engineer Dan Bursch will work together to use Canadarm2 to lift the truss segment from Atlantis' cargo bay and attach it atop the station's Destiny laboratory.

A veteran of three space flights, Ochoa has logged more than 719 hours in space. She was a mission specialist on STS-56 in 1993, the payload commander on STS-66 in 1994, and a mission specialist and flight engineer on STS-96 in 1999.

Mission Specialist 3: Lee M.E. Morin

Lee M. E. Morin, 49, a captain in the U.S. Navy, will be Mission Specialist 3. Morin received a bachelor of science in mathematical/electrical science from the University of New Hampshire in 1974, a master of science in biochemistry from New York University in 1978, a doctorate of medicine and microbiology degrees from New York University in 1981 and 1982, respectively, and a master of public health degree from the University of Alabama at Birmingham in 1988. Selected as an astronaut candidate by NASA in April 1996, he reported to the Johnson Space Center in August 1996. Morin, teamed with Mission Specialist Jerry Ross, will participate in the second and fourth spacewalks on flight days six and nine, respectively.

Morin will be making his first spaceflight.

Mission Specialist 4: Jerry L. Ross

A retired Air Force colonel, Jerry L. Ross, 54, will be Mission Specialist 4 and will be making a record seventh flight aboard the shuttle, the most of anyone in history. Ross received bachelor of science and master of science degrees in mechanical engineering from Purdue University in 1970 and 1972, respectively. He was selected as an astronaut in May 1980. Ross will be making his eighth and ninth spacewalks.

Ross was a mission specialist on STS 61-B (1985), STS-27 (1988) and STS-37 (1991), the payload commander on STS-55/Spacelab-D2 (1993), and a mission specialist on STS-74, the second space shuttle to rendezvous and dock with the Russian space station Mir (1995) and the first International Space Station assembly mission, STS-88, in 1998. Ross has logged more than 1,133 hours in space, including seven spacewalks totaling 44 hours and 9 minutes.

Mission Specialist 5: Steven L. Smith

Steven L. Smith, 43, a veteran of three spaceflights, is a mission specialist for STS-110. He received a bachelor of science in electrical engineering in 1981, a master of science in electrical engineering in 1982 and a master's degree in business administration in 1987. All three degrees are from Stanford University. Following his selection as an astronaut candidate by NASA in 1992, he completed one year of astronaut candidate training. Smith and Mission Specialist Rex Walheim will do the first spacewalk, on flight day four, and the third, on flight day seven. Smith will be making his sixth and seventh spacewalks.

Smith is making his fourth spaceflight. He served as a mission specialist aboard the Space Shuttle *Endeavour* on STS-68 in September 1994. He was one of two crewmembers trained to perform a spacewalk had one been required. He performed three spacewalks as a member of the February 1997 STS-82 *Discovery* crew which serviced the Hubble Space Telescope. He was the payload commander for STS-103 in December 1999, the Hubble Space Telescope 3A Servicing Mission. The crew performed three spacewalks to return Hubble to science operations with several upgraded subsystems. Smith has logged 700 hours in space, including five spacewalks totaling 35 hours.

Flight Day Summary Timeline

FLIGHT DAY	MET	EVENT
1	000/00:00	Launch
1	000/00:50	OMS 2 Burn
1	000/03:37	NC1 Burn
2	000/16:32	NC2 Burn
2	000/20:05	NPC Burn
2	001/00:58	NC3 Burn
3	001/14:00	NH Burn
3	001/15:24	NC4 Burn
3	001/16:15	Ti Burn
3	001/18:36	ISS Dock
3	001/20:25	ISS Hatch Open
3	001/21:08	Hand Shake
4	002/13:45	Grapple S0 Truss
4	002/15:00	Install S0 Truss
4	002/17:50	EVA-1 Start
6	004/17:50	EVA-2 Start
7	005/17:50	EVA-3 Start
9	007/17:50	EVA-4 Start
10	008/18:30	Farewell Ceremony
10	008/18:50	ISS Hatch Close
10	008/22:21	ISS Undock
10	008/22:41	ISS Flyaround
10	009/00:05	Final Sep Maneuver
12	010/17:52	Deorbit Burn
12	010/18:57	Landing

Rendezvous and Docking

A precisely timed launch with a window of only about five minutes begins the process that ultimately will take Atlantis to its rendezvous and docking with the International Space Station.

Atlantis will pursue the station during the first two days of the mission. Engine firings will adjust the orbit of the shuttle, bring Atlantis to a point about 9½ statute miles behind the station about 2½ hours before docking on flight day three.

There Commander Michael Bloomfield and pilot Stephen Frick will fire Atlantis' jets in a Terminal Phase Initiation (TI) burn to begin a final approach to the station.

S108E5593 2001:12:15 17:59:57

As Atlantis closes in, the shuttle's rendezvous radar system will provide range and closing rate information to the crew. During the approach, the shuttle will have an opportunity to make four, small mid-course corrections at regular intervals.

Just after the fourth correction, Atlantis will be about half a mile below and behind the station. There, about an hour before the scheduled docking, Bloomfield will take over manual control.

He will slow Atlantis' approach. Then, beginning at a point about 600 feet directly below the station, he will begin a quarter-circle of the orbiting laboratory, slowly moving to a position in front of the station.

Mission Specialists Rex Walheim and Ellen Ochoa also will play key roles in the rendezvous, with Walheim operating a handheld laser-ranging device. Ochoa will operate a laptop computer program that gives position and guidance information regarding the rendezvous.

Bloomfield will stop Atlantis a little more than 300 feet directly ahead of the station with the cargo bay facing it. There he will begin slowly moving directly toward the station's shuttle docking port – moving at about a tenth of a mile per hour.

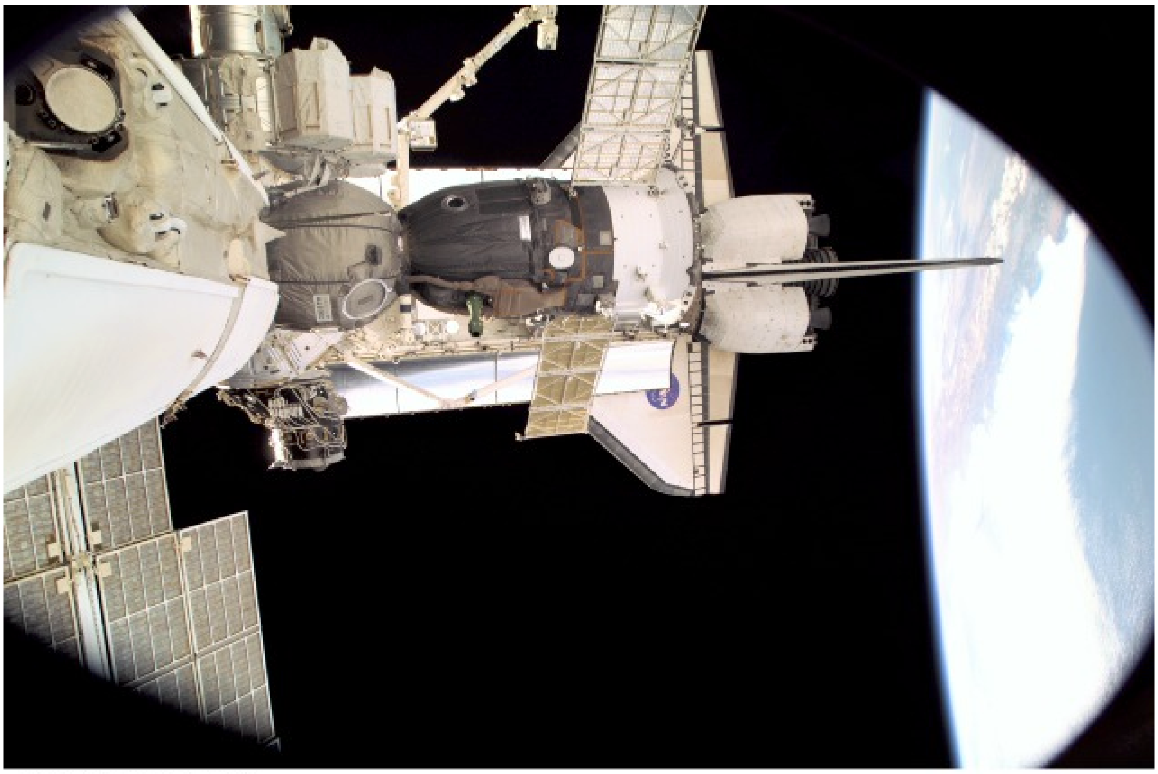
A view from the shuttle's aft flight deck showing the Orbiter Docking System.

Using a view from a camera mounted in the center of Atlantis' docking mechanism as a key alignment aid, Bloomfield will center the docking ports of the two spacecraft. When the docking mechanisms are 30 feet apart, he will stop Atlantis for a few minutes to check their alignment.

For Atlantis' docking, Bloomfield will move the shuttle at about a tenth of a foot per second toward the station, keeping the docking mechanisms aligned to within a three-inch tolerance. When the two spacecraft make contact, preliminary latches will automatically engage, attaching them to one another.

Just after docking, Bloomfield will deactivate the shuttle's steering jets 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, Mission Specialists Jerry Ross and Ellen Ochoa will secure the docking mechanism, sending commands for Atlantis' mechanism to retract and close a final set of latches between the shuttle and station.



S108E5217 2001:12:08 16:53:01

A picture from the Russian segment of the International Space Station (ISS) captured this rare scene during STS-108 that shows portions of three separate space vehicles linked together. The Soyuz spacecraft partially obstructs the view of the recently docked Space Shuttle Endeavour.

Undocking, Separation and Flyaround

Once Atlantis is ready to undock, Ross will send a command to release the docking mechanism. The initial separation will be provided by springs that will gently push the shuttle away from the station. Atlantis' steering jets will be deactivated during this initial separation.

Once the docking mechanism's springs have pushed Atlantis to a distance of about two feet and the docking devices are clear of one another, Frick will turn the steering jets back on and fire them to begin very slowly moving away. From the aft flight deck, Frick will manually fly Atlantis in a tight corridor as he separates from the ISS.

S108E5594 2001:12:15 18:01:44

Atlantis will continue away to a distance of about 450 feet, where Frick will begin a close, 90-minute flyaround of the station, circling it 1¼ times. Atlantis will move directly over the station, then behind it, underneath it, and back in front of the ISS, where the flyaround began. The last quarter-circle brings the shuttle directly above the station.

There Frick will fire Atlantis's jets to move away from the station.

EVA

Spacewalks

Four spacewalks are scheduled for the STS-110 flight of Atlantis. Each will last about 6½ hours, and each focuses on installation of the S0 (S-Zero) Truss on the U.S. laboratory Destiny of the International Space Station.

Astronauts Steve Smith, left, and Rex Walheim, suit up to practice their spacewalks.

Astronauts Steve Smith and Rex Walheim will do the first spacewalk, on flight day four, and the third, on flight day seven. They will be Smith's sixth and seventh, and Walheim's first and second spacewalks. Smith is designated EV1 (for Extravehicular crewmember) and will wear a spacesuit marked with solid red stripes. Walheim, EV2, will wear a solid white spacesuit.

Jerry Ross, left, and Lee Morin check out their EMUs.

The second spacewalk, on flight day six, and the fourth, on flight day nine, are to be done by astronauts Jerry Ross and Lee Morin. Ross will be making his eighth and ninth spacewalks, Morin his first and second. Ross, EV3, will wear the suit with broken red stripes and Morin, EV4, will have a suit marked by diagonally broken red stripes.

Ellen Ochoa practices for her duties in the Johnson Space Center Virtual Reality Lab.

For the first, second and fourth spacewalks, Atlantis crewmember Ellen Ochoa will move to the station's Destiny laboratory to operate Canadarm2, the station's robotic arm, to work with the spacewalking astronauts. For installation of the S0 Truss, Expedition 4 astronaut Dan Bursch will assist her in station arm operation. On spacewalks one and two, Commander Michael Bloomfield and pilot Stephen Frick will use the shuttle's robotic arm cameras to take video of the spacewalkers. They also will use the shuttle arm to support the third and fourth spacewalks.

Each EV crewmember also will serve as Intravehicular (IV) crewmember during one spacewalk while two other astronauts are outside. The IV crewmember helps spacewalkers by serving as a source of information and suggestions, and helping them stay on their timeline.

While Smith and Walheim are making the first spacewalk, Ross will be the IV crewmember, and while they are doing the third, Morin will provide IV support. During the second spacewalk, by Ross and Morin, Smith and Walheim will be the IV astronauts, and during the fourth spacewalk, Walheim will perform IV tasks.

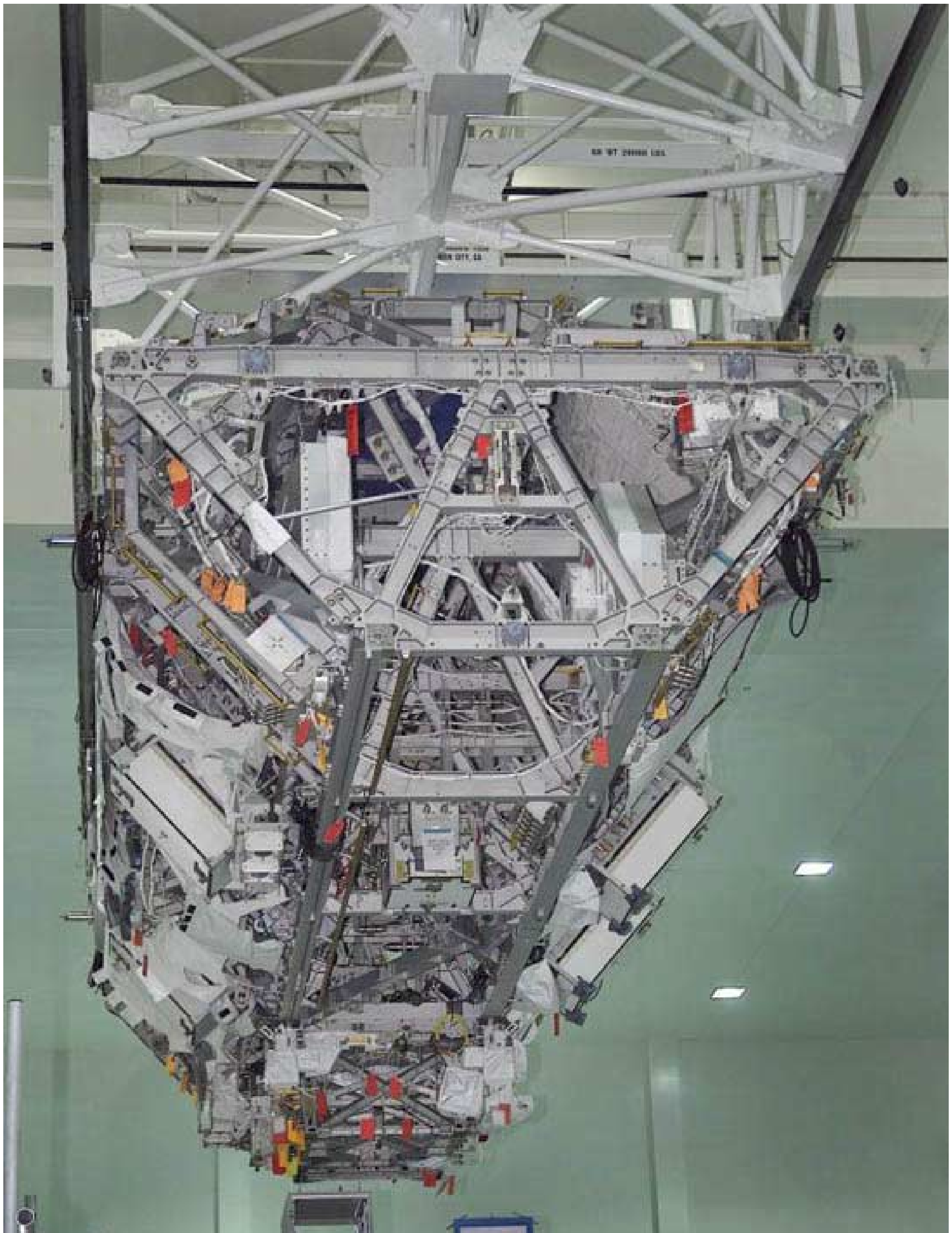
ISS004E8038

Expedition Four ISS astronauts Dan Bursch (left) and Carl Walz in the Quest Airlock before a February 20th spacewalk.

All four spacewalks will originate from the station's U.S. Joint Airlock Quest, and for all four the ISS Exercise EVA (Extravehicular Activity or spacewalk) Protocol will be used. Designed to purge nitrogen from the body, the protocol involves breathing pure oxygen while exercising vigorously. It eliminates the need to spend many hours at reduced cabin pressure. The protocol was first used during STS-104 during the first spacewalk from the Joint Airlock installed earlier during that mission.

Spacewalk 1

Before the first spacewalk, the 43.3-foot, 27,830-pound S0 truss segment is installed on the Lab Cradle Assembly, a mounting device atop the U.S. laboratory Destiny, using the station's Canadarm2. Once in place, the crew inside will command the capture latch to close. This is done to make the truss stable enough for attitude control and the small loads the spacewalkers will induce.



The S0 truss, seen from below, during processing at the Kennedy Space Center.

After leaving the airlock, Smith and Walheim will spend about 45 minutes setting up equipment and tools.

Their first task will be releasing starboard and port forward Module-to-Truss Structure (MTS) strut clamshell fasteners. Using a standard EVA power tool, they will undo a total of eight bolts, four on each side, beginning on the starboard side. Then they will release four launch restraint bolts, two on each side, from footplates.

That allows the V-shaped structures to rotate downward. Smith and Walheim will install four bolts through each footplate, securing the structures to the lab. Then each clamshell fastener will be tightened to rigidize the struts.

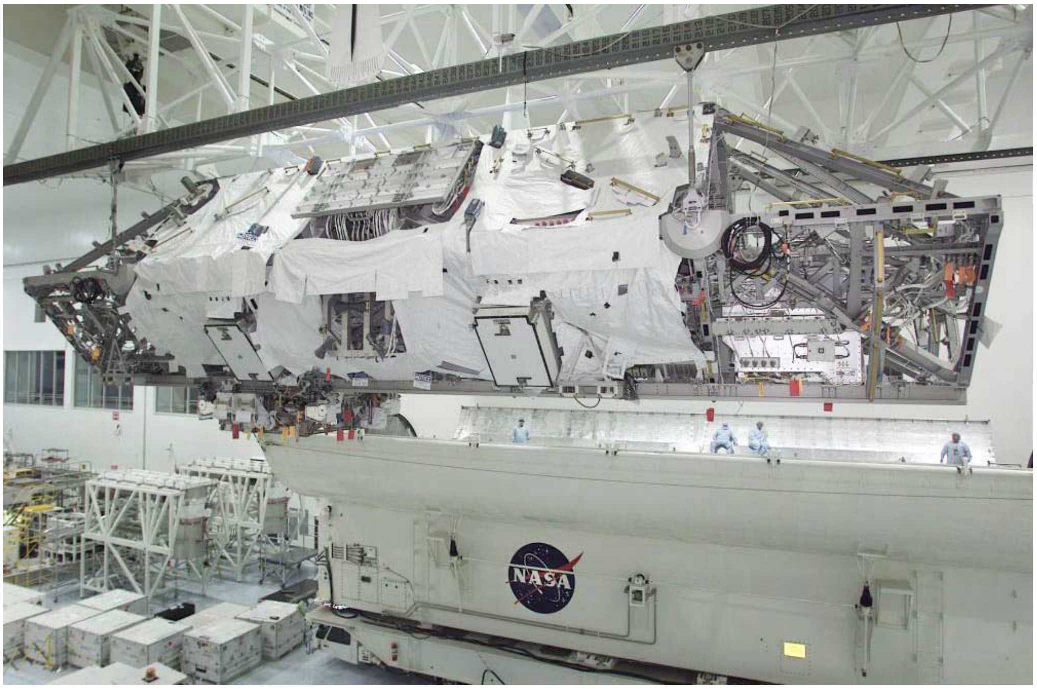
By releasing two bolts, Smith will deploy the Aft Lab Avionics Tray, which contains power, data and fluid umbilicals that will be connected to the lab, node and Z1. He will mate the avionics connectors only (not the fluid connectors) to the lab and Z1. He will pause from that task periodically to help Walheim, who is simultaneously installing and mating the Lab Forward Avionics Umbilicals on the starboard and then port side. If there is time during this spacewalk, Smith will remove the port drag link and enter the truss to install two Circuit Interrupt Devices (circuit breakers). That done, he again will team up with Walheim to install the Zenith Trailing Umbilical System Cable.

About 5 hours and 50 minutes into the spacewalk, Smith and Walheim will begin their standard cleanup and then return to the airlock.

Spacewalk 2

After leaving the airlock and standard setup activities, the first task of Ross and Morin during their flight day six spacewalk is to install the aft MTS struts, first the starboard and then the port. The aft strut groups are tripods, with three adjustable struts meeting at a common footplate that attaches to the lab structure. Ross and Morin will work together to deploy the struts, with Morin on Canadarm2 near S0 and Ross at the lab receiving the “point” of the tripod.

Each strut has two clamshell fasteners that must be released (for a total of 12 fasteners), and each strut group has five launch restraint bolts that must be released. Six bolts attach each aft MTS strut group to the lab’s aft endcone and five bolts attach each strut group to S0. This task is somewhat more difficult than other tasks because of the size of the strut groups and the specialized procedure required to torque down the bolts. Then each clamshell fastener will be tightened to rigidize the struts.



The S0 truss is loaded into its transport canister at Kennedy Space Center.

With the completion of the strut attachments, S0 is attached rigidly to the ISS, and is able to support its design loads, including the solar arrays that will be on the ends of the truss at assembly complete.

Ross, later joined by Morin, moves on to remove and stow drag links, large metal rods used to support the S0 truss during launch. They will be stowed on the truss' exterior. Ross will also remove a thermal cover from the truss and bring it into the airlock.

Next both Ross and Morin move on to mate the Trailing Umbilical System 2 nadir cable to the Mobile Transporter. Launched on the S0 Truss, the Mobile Transporter will serve as an installation point for Canadarm2's Mobile Servicing System (MSS) Base System, to be launched later this year on STS-111.

Finally, the spacewalkers remove the truss' keel pin assemblies. Like the drag links, they will be attached to the truss for long-term stowage.

Spacewalk 3

The first task of the third spacewalk, on flight day seven, after Smith and Walheim leave the airlock and complete setup, is release of the Lab Cradle Claw atop Destiny by Walheim and the installation of the J300 Panel Connectors by Smith.

The claw initially held the S0 truss to Destiny's Lab Cradle Assembly.

The J300 Connectors and subsequent reconfiguration of the J400 Power Data and Grapple Fixture (PDGF) Connectors by Smith will route power, data, and video through the S0 truss for later operation of Canadarm2 from the MSS Base System after STS-111.

If the installation of the Circuit Interrupt Devices was not completed during the first spacewalk, Walheim will install them during this spacewalk.

Smith and Walheim will then turn their attention to the Mobile Transporter, spending about 45 minutes releasing its many launch restraints and removing a small thermal cover from a radiator on the Mobile Transporter. Then they will continue work on the J400 reconfiguration for another hour and a half.

After transferring tools from the shuttle to the station’s exterior and transferring other tools on the station exterior, the spacewalkers will depress three sensors on the starboard side of S0 to test them for future mating of the S1 truss. The last task of the spacewalk is to install the Airlock Spur. The spur is a beam almost 14 feet long and fitted with handrails. The spur will help spacewalkers move more efficiently from the Quest airlock to the forward side of the S0 Truss and the Destiny laboratory.

Spacewalk 4

Tasks of the flight’s final spacewalk, on flight day nine, begin with release of Lab Cradle Assembly guide cones, used to guide the S0 Truss onto the assembly, by Morin and installation by Ross of a light on the Unity node to help future spacewalkers and robotics operators.

Those tasks complete, both spacewalkers will spend the next 30 minutes partially assembling a portable work platform, which will aid future spacewalkers in maintenance activities. They will depress three sensors on the port side of the S0 truss to test them for future installation operations of the P1 truss segment. Ross will then install a second light on Destiny.

While Ross does the 45-minute light installation, Morin will deploy the Extravehicular Charged Particle Directional Spectrometer. That instrument measures and characterizes the radiation environment outside the station for documenting crew exposure. It also can provide almost instant information on exposure rates during unexpected radiation events.

Morin's next task is to deploy the Node 1 Swing Arm. Only the beam will be deployed on this mission. Its three umbilical connectors from the S0 truss aft to the Unity Node’s endcone will be deployed on a later flight. After the beam is deployed, the crew’s outfitting of the S0 truss is complete. Ross, meanwhile, is using that hour to install Mobile Transporter Energy Absorbers, port and starboard, to provide a barrier and attach point between the Mobile Transporter and future hand-propelled carts that will be used by spacewalkers.

Other tasks on this spacewalk include installation of handrails on the S0 truss, removal of a thermal blanket from S0, and tool relocations in preparation for the next flight's spacewalkers. Additionally, Morin will be performing a checkout of a Trace Gas Analyzer that is designed to detect minute amounts of gas in the environment of space.

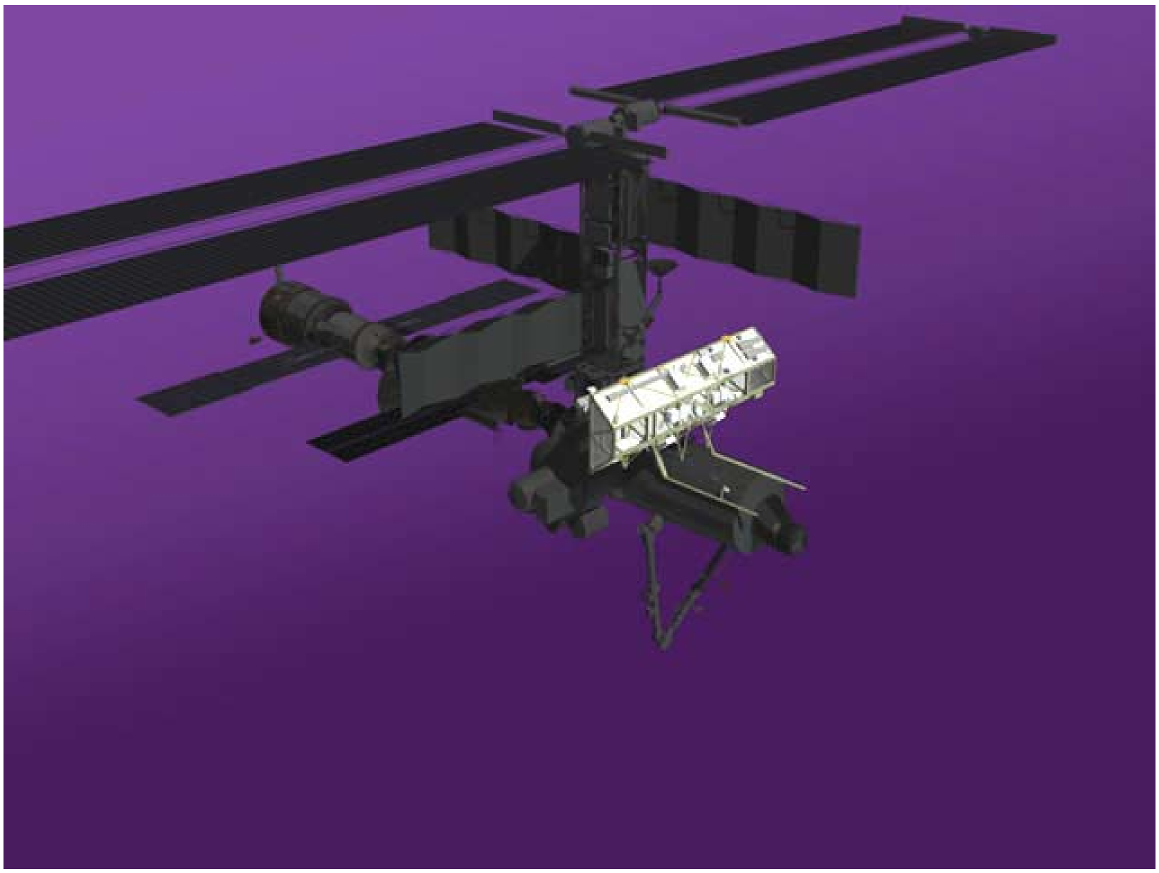
The final hour and 20 minutes before cleaning up and entering the airlock will be spent in extensive photo documentation and doing any get-ahead tasks.

Payloads

Payload Overview

As the 13th space shuttle mission in support of the assembly of the International Space Station, STS-110 is responsible for the integration of the 8A launch package with the ISS. This package includes the S0 truss segment and the Mobile Transporter (MT).

The S0 segment will be structurally attached to the U.S. Lab Module and will be the center section of the station's truss assembly. Fluid, power and data umbilicals are also attached to the S0 segment for connecting the truss-bases distributed systems with the pressurized modules. The S0 segment provides Extravehicular Activity (EVA) Airlock Spur and electrical power control and distribution; guidance, navigation and control; telemetry, command and control; video signal switching and passive and active thermal control.



This drawing highlights the S0 truss and Mobile Transporter elements that will be added to the ISS on STS-110/8A.

The MT provides the truss translation capability for the Mobile Servicing System (MSS) as well as the structural, power, data and video link between the Integrated Truss Structure Mobile Remote Servicer. It will provide the rail system for eventual movement of the station's robotic arm across the station's football-field-long truss.

The Airlock Spur will be deployed between the S0 segment and the Airlock to provide a path for EVA crewmembers to move from the Airlock to the truss segment.

In addition, five powered payloads are to be transferred to/from the shuttle middeck and the station. The five transfers are the Biomass Production System (to be taken up to the station—see "Experiments"), Biotechnology Refrigerator-2 [to be taken up and down—the crew will transfer the contents of the BTR on the ISS to the one on the shuttle to return the Cellular Biotechnology Operations Support System (CBOSS) and the yet-to-be-taken Advanced Astroculture (ADVASC) samples], Commercial Generic Bioprocessing Apparatus (to be taken up to the station only), Commercial Protein Crystal Growth—High Density (to be taken up to the ISS) and Protein Crystal Growth—Single Locker Thermal Enclosure System (two PCG-STES lockers are to be returned aboard the shuttle during STS-110). Data products and samples for other experiments also are scheduled to be returned aboard the shuttle including Renal Stone samples, Experiment of Physics of Colloids in Space (EXPPCS) data hard drives and additional ADVASC air and water samples.

Central Integrated Truss Structure (S0 Truss)

The first major element of the International Space Station's enormous backbone will bring more power supplies and data handling capabilities when it is installed during the STS-110 space shuttle mission.

The Starboard 0 (S-Zero or S0) truss segment will be delivered to the orbiting outpost on STS-110 (ISS Assembly Flight 8A). Boeing Human Space Flight & Exploration in Huntington Beach, Calif., built the truss and company operations in Florida prepared it for launch. Human Space Flight & Exploration is part of Space & Communications, a business unit of The Boeing Company, NASA's prime contractor on the space station.

The S0 truss is lowered into its transport canister at the Kennedy Space Center.

Power and data cables and the thermal control system that provides heating and cooling wind through the 44-foot by 15-foot, 27,000-pound truss segment to carry energy and information to and from the station's extremities where solar panels collect electrical energy used to power experiments, computers, life support systems and other services.

Video cameras, attached to the structure, monitor assembly operations and other activities on the station. Other instruments provide the data that astronauts and ground controllers use to maintain the station's position and orient the solar panels.

The S0 truss segment will provide the structural backbone for the power generation subsystem of the ISS electrical power system; it also will provide power conversion and routing capabilities to downstream loads.

The Integrated Truss Segment (ITS) S0 provides the capability to attach the four Photovoltaic Module truss segments to increase the ISS power production capacity. The S0 truss is launched with a complement of pre-integrated hardware to increase ISS functionality including the Mobile Transporter (MT), the Trailing Umbilical System (TUS), the Portable Work Platform, four Global Positioning System (GPS) antennas, two rate gyros, an Extravehicular Charged Particle Detection System (EVCPDS), and umbilicals for U.S. on-orbit elements. Mission 8A also delivers four Main Bus Switching Units (MBSUs), two Circuit Interrupt Devices, three Crew and Equipment Translation Aid (CETA) lights and the Airlock Spur.

The S0 is the center segment of 11 integrated trusses that provide the foundation for station subsystem hardware installation, utility distribution, power generation, heat rejection and external payload accommodations. The S0 truss acts as the junction from which external utilities are routed to the pressurized modules by means of EVA-deployed umbilicals. These utilities include power, data, video and Active Thermal Control System ammonia. The S0 truss provides a mounting point for electronic equipment such as the MBSUs, four of the DC-to-DC Converter Units (DDCUs), and four Secondary Power Distribution Assemblies. As mentioned, also mounted on S0 are the space station's four GPS antennas and two Rate Gyros.

The aft face of S0 is occupied by a 21-foot radiator panel, which radiates heat transported from S0 electronics boxes by a system of internal heat pipes. The forward facing rails of the S0 truss and the other truss assemblies form a track upon which the MT will move up and down the length of the station truss. Housed within the S0 truss structure are the MT TUS cable reels, which feed out and reel in electrical cable to the MT as it travels along the truss.

The S0 truss will connect to its neighboring truss segments (S1 and P1) by means of the Segment-to-Segment Attachment System, which consists of a remotely operated capture latch and four motorized bolt assemblies. Structural attachment to the U.S. lab is accomplished through the Module-to-Truss Structure, which consists of 10 EVA-deployed telescoping struts.

The S0 structure has an elongated hexagonal cross section with five bays arrayed along the long axis. Although S0 has a large complement of pre-integrated equipment on its structure, the frame is open enough to allow EVA operations within the spaces of the bays. The numbered faces of S0 make identification of worksites easier for EVA crews translating around the truss segment. These faces are numbered sequentially counterclockwise from the forward nadir face to the aft nadir face.

Astronauts are scheduled to make four spacewalks during the 11-day mission to install the truss. It will be installed onto the U.S. laboratory Destiny using the Module-to-Truss Segment Attach System (MTSAS), which consists of an active capture claw assembly on the Lab Cradle Assembly (LCA) and a capture bar on the passive MTSAS installed on the S0 nadir.

Module-to-Truss Segment Attach System

The MTSAS includes the MT struts and the LCA. The LCA provides a soft capture capability for mating the truss structure to the U.S. Lab as well as an adequate structural interface to allow attitude control and maneuvers after mating is complete. This allows freeing the SSRMS for other operations and would allow the orbiter to undock, if required, in a contingency situation. The MT struts are flown pre-integrated on S0 and must be deployed and attached to the U.S. Lab by EVA crewmembers. Once installed, the LCA capture latch is released. The struts will provide all of the structural support for not only S0 but also for the completed integrated truss at assembly complete post-mission 20A.

Lab Cradle Assembly

The LCA is composed of an active half, consisting of a capture claw and alignment mechanisms, and a passive half (integrated into ITS S0), consisting of additional alignment mechanisms and a rigid capture bar. During mating of S0 to the LCA, the capture claw will engage the bar on the S0 passive half, drawing the truss segment down to the LCA interface for a semi-rigid structural hold.

Umbilical Trays

S0 is outfitted with four umbilical trays (two fluid, two power and data), which will provide thermal, communications, and electrical interfaces with other elements. The port and starboard forward umbilical trays are launched on the forward starboard face.

Extravehicular Charged Particle Detection System

The EVCPDS measures and characterizes the radiation environment on the ISS for documenting crew exposure for medical records, long-term risk assessment and for mapping the radiation levels within the ISS for dose management. The EVCPDS also provides near real-time data to confirm exposure rates during an off-nominal radiation event and it will provide data for improving environmental and transport computer models. Finally, the EVCPDS is used in conjunction with the Tissue Equivalent Proportional Counter and radiation dosimeters to characterize the primary and secondary radiation field inside the ISS.

S0 Command and Data/Communication and Tracking

The S0 truss is outfitted with two Enhanced Space Station Multiplexer/ Demultiplexers or ESSMDMs. These provide control capability for each of the S0 Remote Power Distribution Assemblies and associated Remote Power Control Modules. The ESSMDMs are identical in hardware design and functionality, controlling S0 equipment.

Mobile Bus Switching Units

The Mobile Bus Switching Units or MBSUs perform power routing functions over electrical power buses within the ISS. The S0 truss is outfitted with four MBSUs located on Faces 0 and 2, Bays 1, 2 and 3.

Each MBSU accepts power input from two power channels and distributes power to module internal and truss external DDCUs. This power distribution is performed using internal Remote Bus Isolation (RBI) switches, which may be remotely commanded to provide or remove power from downstream loads. Each MBSU has an internal power supply with redundant power feeds off the channel inputs and control power provided by a single RBI on the paired MBSU. Each MBSU has two groups of six RBIs, which are each fed by a main power RBI from one of the channel inputs of the MBSU. Of these 23 RBIs, eight are allocated to provide power to downstream DDCUs. Power is supplied to the output RBIs by separate power feed switches internal to the Orbital Replacement Unit (ORU).

Global Positioning System Antennas

Four GPS antenna assemblies have been preinstalled on the exterior of the S0 truss. The GPS system on the ISS is required to prove a state vector with an accuracy of 3,000 feet (915 m) in position for a single position measurement and with an error of less than 50,000 feet (15.24 km) during 24 hours of propagation.

Rate Gyro Assemblies

The Rate Gyro Assemblies (RGAs) provide a method for the ISS Guidance and Navigation Control subsystem to perform state vector determination independent of the U.S. GPS. Two RGAs have been preinstalled on the aft port side of the S0 truss segment at the junction between Face 4 and the aft port transition face. The RGAs are composed of three ring laser gyros that determine changes in motion by measuring changes in the frequency of a reference laser beam using the Doppler effect. One ring laser gyro is assigned to measure motion in each of the three coordinate axes, with redundancy coming from the second unit in the set.

S0 Thermal Control System

Active hardware on S0 will be cooled through the use of the coldplates. The primary equipment on STS-110 that will use coldplates will be the DDCUs, but the MBSUs also are outfitted with coldplates and will be used once the units are activated. Coldplates function by running a working coolant (ammonia, for external hardware) between heat exchanger tubes beneath the ORU and a remotely located radiator.

The heat pipe radiator will provide a system for heat rejection for several of the S0 ORUs. The pipes are pre-routed on S0 and require no activation per their design.

Airlock Spur

The Airlock Spur is a structural beam outfitted with multiple EVA handrails to facilitate translation from the Joint Airlock to the forward side of S0 and the Lab module. It measures 166.9 inches in overall length from the S0 pin fitting to the airlock bolts interface. Ten handrails (seven long, three short) are installed on two faces of the beam to provide handholds for crew translation. The Airlock Spur will be launched preinstalled on the starboard aft side of S0 with a hinge pin joint attachment to S0 and will be bolted to the airlock on orbit.

Crew and Equipment Translation Aids Lights

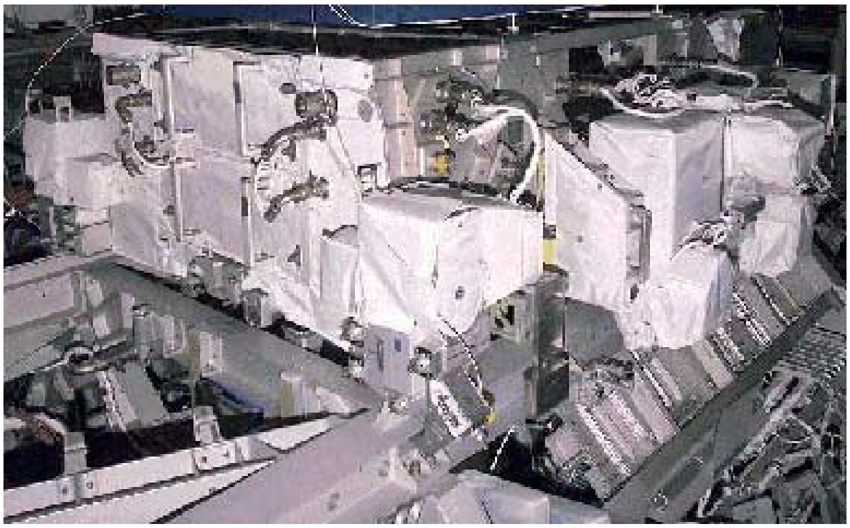
The CETA lights are halogen light assemblies mounted on boom assemblies and rated for exterior use. During the mission, two CETA lights are to aid in EVA crew activities. The first CETA light is installed on Destiny while the second is installed on the Node zenith near the aft endcone.

Future Elements

As part of Phase 3, two more truss segments, Port 1 (P1) and Starboard 1 (S1), are scheduled to be launched this year and will be attached to S0 by space-walking astronauts. Both were built and prepared for launch by Boeing Human Space Flight and Exploration. The other segments that comprise Phase 3 are P3, S3, P4, S4, P5, S5, P6 and S6. Future shuttle missions are required to transport the remaining Phase 3 truss elements.

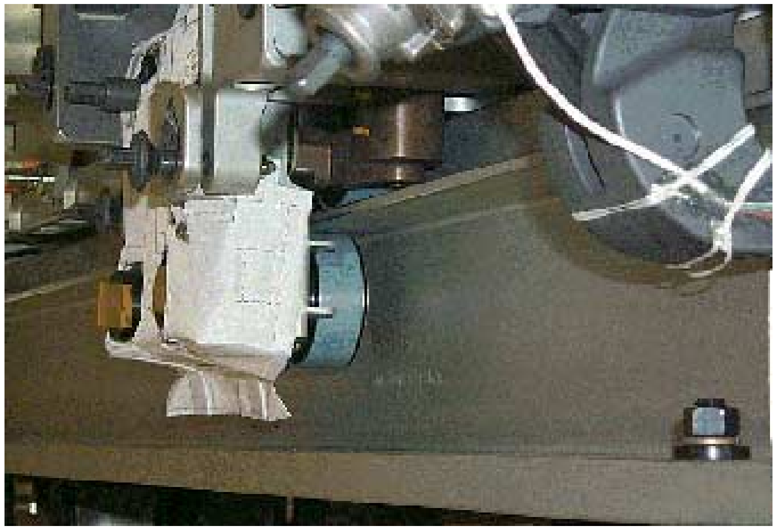
Mobile Transporter

Just as trains carried supplies to the Old West frontier, the Mobile Transporter (MT) will become the first railroad in space on the International Space Station (ISS) during STS-110/8A.



The Mobile Transporter provides mobility for the Mobile Servicing System operations along the truss segments and the solar power module rails.

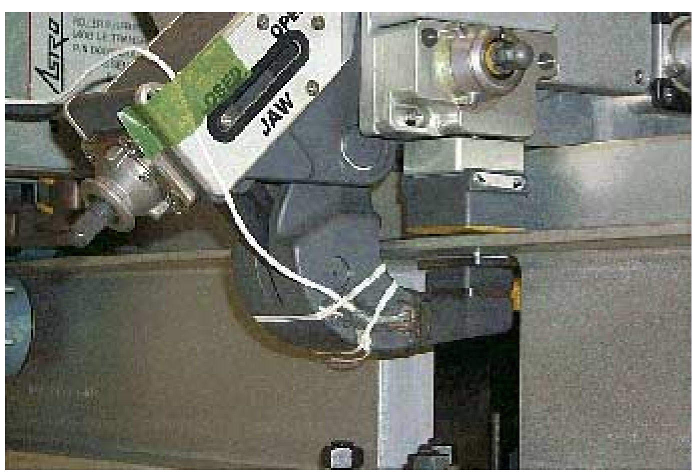
The 1,950-pound structure will travel along the rails of the Integrated Truss Structure (ITS) and, together with the Mobile Base System, will provide the work platform for the Canadian-built mechanical arm (also known as the Space Station Remote Manipulator System or Canadarm2). Strong and powerful, the high-strength aluminum transporter provides the mobility to relocate the Canadarm2 to 10 pre-designated space station worksites and helps deploy segments of the ITS with its payload capacity of 46,100 pounds. The MT will lock itself down to the rails to move the massive payloads.



The Roller Suspension Unit provides vertical and horizontal restraints for the MT.

Built for performance, the transporter measures 108 inches long, 103 inches wide and 38 inches high. It travels on a three-point suspension system: the Linear Drive Unit, which drives and supports the MT, and the two Roller Suspension Units, which provide additional support as the MT travels down the ITS rails.

During the mission, the MT will undergo a series of diagnostic tests after power and data is connected and launch restraints are removed. Three translations of the S0 truss, the first major element of the enormous ISS backbone that will be installed during STS-110, will be performed as the camera mounted on the shuttle’s Canadarm2 records the runs with speeds of 1.0, 0.4 and 0.1 inches per second.

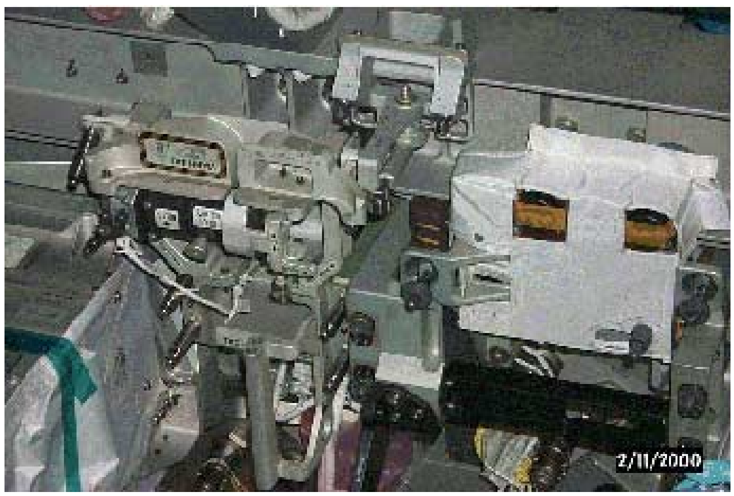


The Load Transfer Unit attaches the MT to the truss at worksites for the Mobile Remote Servicer.

The transporter will perform translations and sequential latching and unlatching at different points along the S0 Truss, testing its different functions. This is all done in preparation for the arrival of the Mobile Base System, which together with the Canadarm2, will help assemble the remainder of the integrated truss segment.

During STS-111/UF-2, the Mobile Base System will be installed onto the MT to complete the Mobile Servicing System, eventually giving Canadarm2 the capacity to move from the U.S. lab Destiny and travel the length of the ITS.

The MT is controlled by complex software. About 20 different motors are directed to run the transporter from one point to another, latch it down to the integrated truss segment for construction and plug itself into the power source, the Umbilical Mechanism Assembly port.



The Trailing Umbilical System provides data, power and video to the MT and the Mobile Servicing System.

This represents the first time that a software-controlled movable robot has ever been used on an orbiting vehicle. MT software controls the movement and thermal control of the integrated system. These functions are safety-critical hazardous functions that are essential to the assembly and operation of the International Space Station.

The MT system has been preinstalled on the forward face (Face 1) of S0, including the Trailing Umbilical System and rails required to allow the unit to move along the truss.

The MT was built in California and furnished by Boeing, the prime contractor for station construction. It is driven by dual electric motors that generate only a few hundredths of one horsepower. It moves along the rails attached to the station truss at speeds varying from one-tenth of an inch to one inch per second.

The MT will be able to stop at the 10 pre-designated worksites on the line where it can be locked down with a 7,000-pound grip to hold it in place so the robotic arm may safely maneuver cargo. Magnetic sensors locate iron strips in the aluminum rails to indicate when the MT has reached a stop.

Although it can be driven from either on board the station or from the ground, the engineers for NASA's space railroad will normally reside in Mission Control, Houston, often driving the train from thousands of miles away and hundreds of miles below.

For more on the MT hardware and software, see the Appendix.

Experiments

Science Payloads

On this mission, Atlantis will deliver science experiments to the International Space Station and many station experiments will return aboard the shuttle.

The Enhanced Gaseous Nitrogen Dewar will make its fourth trip to the space station. This low-cost facility enables scientists to grow hundreds of crystals at once and study optimum crystal growth conditions. On past missions, more than 430 teachers and students have sent samples to the space station as part of a NASA-sponsored education activity.

For this flight, the Dewar will be filled with approximately 150 samples loaded by teachers and students from Alabama, California, Florida, Indiana, Illinois, Michigan, Ohio, Texas and West Virginia, and hundreds of samples loaded by scientists at the University of California, Irvine. In May, the Space Shuttle Endeavour will return the samples to Earth, where scientists can study the crystals' structures to learn about the biochemistry of animals and plants. This experiment is sponsored by NASA's Biotechnology Program at the Marshall Center.

Two experiments sponsored by NASA's Space Product Development Program at the Marshall Center are making their second trips to the orbiting laboratory. These experiments are sponsored by two of NASA's 17 Commercial Space Centers, which are located across the country and designed to help companies carry out space research.

The Commercial Generic Bioprocessing Apparatus will study bacterial fermentation that could improve the production of antibiotics for treating cancer. This experiment is sponsored by BioServe Space Technologies in Boulder, Colo. – a NASA Commercial Space Center working with Bristol-Myers Squibb Pharmaceutical Research Institute in Wallingford, Conn.

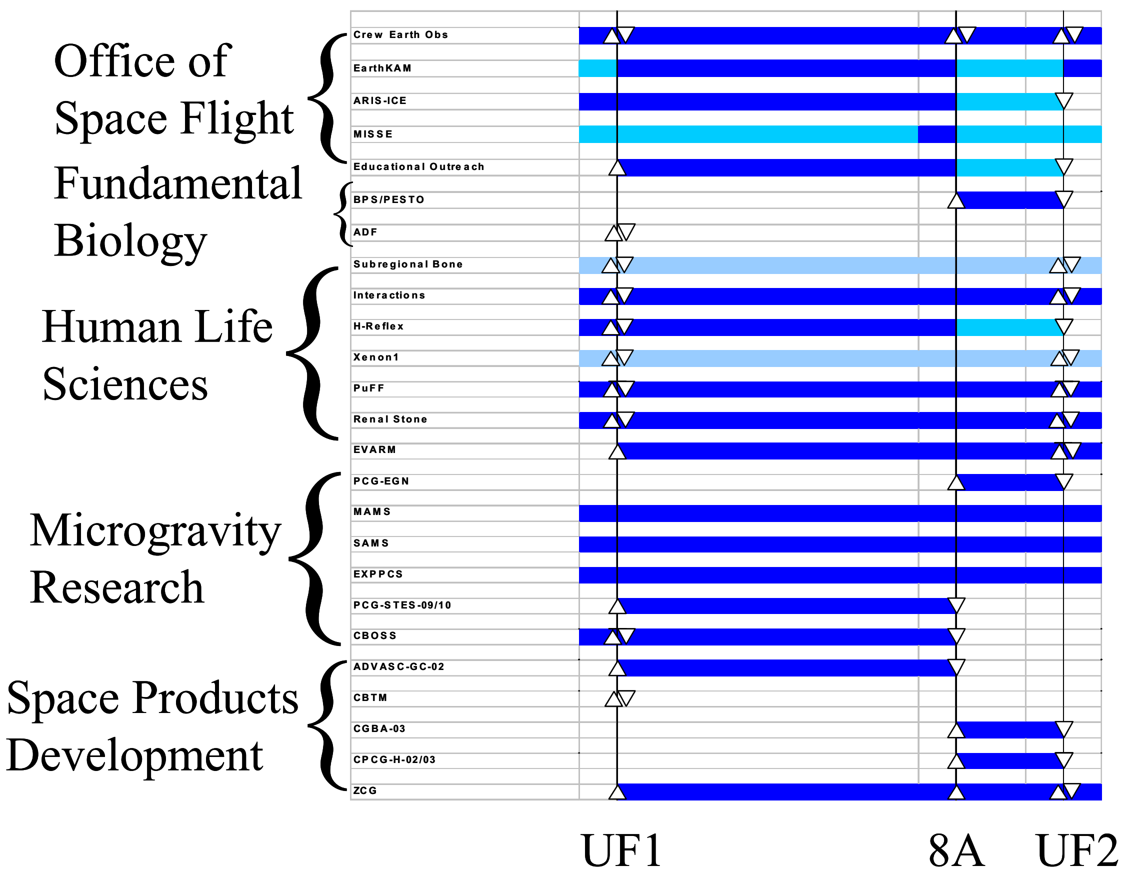
The Commercial Protein Crystal Growth-High Density experiment will grow crystals from more than a thousand different biological samples. This experiment is sponsored by the Center for Biophysical Sciences and Engineering at the University of Alabama at Birmingham. More than 50 major industrial companies work with this Commercial Space Center to study how biological crystals can be grown and then used to design new pharmaceutical products. Both these biological crystal samples and the antibiotic samples will be returned in May on Endeavour.

Also going up on STS-110 will be the first samples to be processed in the Zeolite Crystal Growth Furnace, which was delivered on an earlier flight and is also sponsored by a Commercial Space Center – the Center for Advanced Microgravity Materials Processing at Northeastern University in Boston. Zeolites are the backbone of the chemical processes industry, and virtually all the world's gasoline is produced or upgraded using zeolites. The petroleum industry is interested in growing improved zeolites in space to reduce chemical processing costs. The first set of samples will be returned to Earth in May, and another set will be delivered for processing inside the furnace, which will remain on the station.

It will be the first space station flight for the Biomass Production System and Photosynthesis Experiment and System Testing Operation – a new experiment that will help scientists at NASA's Ames Research Center in Moffett Field, Calif., develop a dedicated plant research facility for the station. Researchers will grow wheat and *Brassica* during the next month. The plants and new hardware will be returned on Endeavour in May.

Several experiments and samples will come back on Atlantis in April. These include plants, biological crystals and cell cultures. All are sponsored by NASA's Office of Biological and Physical Research in Washington.

The following chart shows the various payloads during Expedition Four—which are pre/post, which are going up/coming down on 110, and which will be operated during the 8A stage:



Expedition 4 Research Program Overview

ADVANCED ASTROCULTURE™ (ADVASC)

Principal Investigators: Tad Theno and Eric Brunsell, chief program scientists for Space Explorers Inc., and Dr. Weijia Zhou, Wisconsin Center for Space Automation and Robotics (WCSAR), University of Wisconsin-Madison

Co-Principal Investigator: Dr. Bratislav Stankovic, WCSAR

Overview

The first ADVANCED ASTROCULTURE™ plant growth unit was used successfully to grow plants during Expedition Two. These plants were returned to investigators on Earth on the STS-104 space shuttle mission in July 2001.

During their stay on the International Space Station during Expedition 2, the plants went through seed germination, plant growth and development, seed formation, and seed maturation -- completing an entire lifecycle. Of the 91 *Arabidopsis* seeds that were launched, about 90 percent germinated in space; and about 70 percent of the seeds grew to produce siliques that contained mature seeds. An average of 24 siliques per plant were produced, each containing an average of 36 seeds. The majority of siliques were rated as mature, while the others were moderately mature.

ADVANCED ASTROCULTURE™ provides a completely enclosed, environmentally controlled plant growth chamber. It requires no power during shuttle ascent and descent. Before the flight, scientists plant seeds in a root tray using a dry rooting material called Arcillite, a type of crushed clay. The seed tray is then attached to the ADVANCED ASTROCULTURE™ growth chamber. Reservoirs in the growth unit are loaded with water and nutrient solutions that plants need to live while aboard the ISS.

The equipment is configured as two single middeck lockers that insert separately into a space station EXPRESS Rack. One locker contains the support systems. The other contains the plant growth chamber and ancillary hardware. This arrangement allows the support system to remain on board, while the shuttle transports plant growth units to and from the station with different experiments.

For the Expedition Four experiment, the payload was modified. A hatch was added so the crew can remove plant tissue while the plants are growing on board the station. The plant samples have been stored in tissue fixation tubes, designed by NASA's Kennedy Space Center. Then, they were placed inside the station's Biotechnology Refrigerator. The plant tissues' RNA genetic information has been preserved to allow scientists and the commercial partner to study microgravity impact on plants' gene expression levels after the plants are returned to Earth.

The objectives of the Expedition Four ADVANCED ASTROCULTURE™ experiments are (1) to validate plant life support technologies used in the ADVASC payload; (2) to produce the second generation of seeds in space from the first generation produced during Expedition Two; and (3) to conduct a gene expression analysis to determine whether microgravity may alter plant gene expression levels.

Cellular Biotechnology Operations Support System (CBOSS)

Principal Investigators: Jeanne L. Becker, Ph.D., University of South Florida, Tampa; Timothy G. Hammond, M.B., B.S., Tulane University Medical Center, New Orleans; J. Milburn Jessup, M.D., University of Texas Health Science Center, San Antonio, Texas; Peter I. Lelkes, Ph.D., Drexel University, Philadelphia, Pa.

Program Manager: Dr. Neal Pellis, Manager, Cellular Biotechnology Program Office, NASA Johnson Space Center

Project Manager: Melody Anderson, Cellular Biotechnology Program Office, NASA Johnson Space Center

Payload Experiment Developer: Fred R. Williams, Life Sciences Systems and Services, Wyle Labs, Inc.

Overview

The objective of the Cellular Biotechnology Operations Support System (CBOSS) is to provide a controlled environment for the cultivation of cells into healthy, three-dimensional tissues that retain the form and function of natural, living tissue. CBOSS will enable investigations on normal and cancerous mammalian cells, including ovarian and colon cancer cells, neural precursor and human renal cells. The system is comprised of the Biotechnology Specimen Temperature Controller, the Biotechnology Refrigerator, the Gas Supply Module and the Biotechnology Cell Science Stowage. The crew will periodically record scientific data, add fresh media to the tissue culture modules and process samples for return to Earth. The crew also will perform preventative maintenance.

Background/Flight History

The first cellular experiment flew aboard the space shuttle in the mid-1990s during STS-70 and STS-85. Long-duration cellular biotechnology experiments also were conducted in the Biotechnology System Facility on the Russian space station Mir from 1996 through 1998. This experiment also flew on the space station during Expedition 3.

Benefits

Bioreactor cell growth in microgravity permits cultivation of *in vitro* tissue cultures of size and quantity not possible on Earth. Such a capability provides unprecedented opportunities for breakthrough research in human diseases, including various types of cancer, diabetes, heart disease and AIDS.

More information on NASA biotechnology research and other Expedition Four experiments is available at:

http://microgravity.msfc.nasa.gov

http://scipoc.msfc.nasa.gov

Commercial Generic Bioprocessing Apparatus (CGBA)

Principal Investigators: Dr. Louis Stodiek, BioServe Space Technologies, University of Colorado, Boulder, and Dr. Raymond Lam, Bristol-Myers Squibb Pharmaceutical Research Institute, Wallingford, Conn.

Project Manager: Cooperative agreement managed by John West, Office of Space Product Development, NASA Marshall Space Flight Center, Huntsville, Ala., and technical management by BioServe at the University of Colorado, Boulder

Overview

The goal of the research conducted in the Commercial Generic Bioprocessing Apparatus (CGBA) payload is to develop commercial uses of the unique microgravity environment for the field of life sciences. The CGBA hardware is able to support many standard biological laboratory techniques that have been adapted to operate in space. The experiments are designed to further our understanding of how gravity influences various biophysical and biochemical actions. Applications of this knowledge are geared toward creating or improving various biologically derived products, as well as enhancing the processes used to create them.

History/Background

The CGBA is a commercial payload sponsored by NASA's Space Product Development Program at the Marshall Space Flight Center. BioServe Space Technologies builds and manages the apparatus. BioServe is a NASA Commercial Space Center jointly located within the Aerospace Engineering Sciences Department at the University of Colorado in Boulder and the Division of Biology at Kansas State University in Manhattan. Bristol-Myers Squibb Pharmaceutical Research Institute in Wallingford, Conn., is BioServe's sponsoring commercial partner for this research. Since 1991, BioServe has flown payloads in space on 16 shuttle flights, two Mir flights and during Expedition 2 and Expedition 4.

Benefits

Gaining a better understanding of what is causing the stimulated production of antibiotics in space is helping scientists to design experiments that attempt to mimic this increase in productivity on Earth. These experimental techniques may lead to the development of methods for improving production efficiency in terrestrial pharmaceutical processing facilities.

Additional information on CGBA can be found at:

http://www.colorado.edu/engineering/BioServe/

Physics of Colloids in Space (PCS)

Principal Investigator: Prof. David Weitz, Harvard University, Cambridge, Mass.

Co-Investigator: Prof. Peter Pusey, University of Edinburgh, Edinburgh, UK

Project Manager: Michael Doherty, NASA Glenn Research Center, Cleveland, OH

Overview

A colloid is a system of fine particles suspended in a fluid. Paint, milk and ink are some common examples. Though these products are routinely produced and used, scientists still have much to learn about the underlying properties of colloidal systems. Understanding their properties may allow scientists to manipulate the physical structures of colloids -- a process called “colloidal engineering” -- for the manufacture of new materials and products.

The PCS experiment began during Expedition Two with International Space Station Mission 6A (STS-100, April 2001) and is to conclude with the return of the samples on Flight UF-2. It gathers data on the basic physical properties of colloids by studying three different colloid sample types. This experiment represents the first in-depth study of the growth and properties of colloidal superlattices -- formed from mixtures of different-sized colloidal particles -- performed in a microgravity environment. Scientists hope to better understand how colloid structures grow and behave with the long-term goal of learning how to control their growth to create new materials.

The experiment will focus on the growth and behavior of three different classes of colloid mixtures of tiny manmade particles of either polymethyl methacrylate or silica or polystyrene; these will include samples of binary colloidal crystal alloys, samples of colloid-polymer mixtures and samples of colloidal gels. Binary colloidal crystal alloys are dispersions of two different size particles in a stabilizing fluid. Colloid-polymer mixtures are solutions of mono-disperse particles mixed with a polymer in a stabilizing fluid, where the phase behavior -- solid, liquid and gas -- is controlled by the concentration of the polymer. Colloidal gels include aqueous solutions of particles, in this case aggregated on-orbit with a salt solution, to form fractal structures. The structure, stability and equilibrium properties of all the samples, as well as their structure, dynamics and mechanical properties, are being studied.

History/Background

The first generation experiments by these investigators in microgravity were glovebox experiments with binary colloidal crystal alloys and colloid-polymer mixtures, flown on the Russian space station Mir and on the STS-95 mission in October 1998.

Protein Crystal Growth— Single-locker Thermal Enclosure System (PCG-STES) Housing the Protein Crystallization Apparatus for Microgravity (PCAM)

Principal Investigators: Dr. Daniel Carter and Dr. Craig Kundrot, New Century Pharmaceuticals, Huntsville, Ala.

Project Manager: Todd Holloway, NASA's Marshall Space Flight Center, Huntsville, Ala.

Overview

The STES is an incubator/refrigerator module that can house different devices for growing biological crystals in microgravity. Each STES unit houses six Protein Crystallization Apparatuses for Microgravity (PCAM), which are designed to grow the actual crystals. The fundamental goal for growing biological macromolecular crystals is to determine their structure and the biological processes in which they are involved. Scientists select macromolecules, crystallize them, and analyze the atomic details to determine the three-dimensional atomic structure of the macromolecule. Understanding these structures may impact the studies of medicine, agriculture, the environment and other biosciences.

Background/Flight History

The STES hardware has previously flown on six shuttle missions (STS-63, 67, 73, 83, 85, 95) and during Expedition 2 and Expedition 4.

Benefits

Structural biological experiments conducted in the PCG-STES will enable the more accurate mapping of the three-dimensional structure of macromolecules. Once the structure of a particular macromolecule is known, it may become much easier to determine how these compounds function. Every chemical reaction essential to life depends on the function of these compounds.

Additional information on the STES and biological crystal growth is available at:

http://crystal.nasa.gov/

http://www.microgravity.nasa.gov/

http://www.ssl.msfc.nasa.gov/msl1/images/pcambig.jpg

Renal Stone Risk During Space Flight: Assessment and Countermeasure Validation

Principal Investigator: Dr. Peggy A. Whitson, Johnson Space Center, Houston

Project Manager: Michelle Kamman, Johnson Space Center, Houston

Overview

Exposure to microgravity results in a number of physiological changes in the human body, including alterations in kidney function, fluid redistribution, bone loss and muscle atrophy. Previous data have shown that human exposure to microgravity increases the risk of kidney stone development during and immediately after space flight. Potassium citrate, a proven Earth-based therapy to minimize calcium-containing kidney stone development, is being tested as a countermeasure to reduce the risk of kidney stone formation. This study also will assess the kidney stone-forming potential in humans based on mission duration, and determine how long after space flight the increased risk exists.

Benefits

The formation of kidney stones could have severe health consequences for ISS crewmembers and negatively impact the success of a mission. This study will provide a better understanding of the risk factors associated with kidney stone development both during and after a space flight, as well as test the effectiveness of potassium citrate as a countermeasure to reduce this risk. Understanding how the disease may form in otherwise healthy crewmembers under varying environmental conditions also may provide insight into kidney stone-forming diseases on Earth.

Commercial Protein Crystal Growth–High Density (CPCG-H)

Missions: Expedition 4, ISS Mission 8A, STS-110 for March 21, 2002; experiment will continue through Mission UF-2, STS-111 for May 2, 2002

Experiment Location on ISS: U.S. Lab EXPRESS Rack 4

Principal Investigator: Dr. Lawrence DeLucas, Director, Center for Biophysical Sciences and Engineering, University of Alabama at Birmingham

Project Manager: John West, NASA Space Product Development Program, Marshall Space Flight Center, Huntsville, Ala.

Overview

The word *protein* is coined from the Greek *proteios*, or "primary." Proteins are the primary building blocks of all life, and how they react with other biochemical compounds in living organisms determines many things, including if a creature will be healthy or become ill. First discovered in 1838, proteins are recognized as the predominant ingredients of cells. Understanding this hidden world is intensely interesting and important to scientists and physicians.

Each protein has a particular chemical structure, which means it has a favored “shape.” Researchers still lack detailed knowledge about the structures of many proteins. If they can determine the shape, or shapes, of a protein, they can learn how it works. Once this is understood, researchers can then find a way to help or hinder a given protein, and they may be able to develop new treatments that target specific human, animal and plant diseases.

One of the most widely used methods of studying protein structures is protein crystallography. Proteins can be made to crystallize in much the same way sugar crystals can be formed from sugar water to make rock candy. Scientists then use X-rays to determine the three-dimensional molecular structures of proteins.

The structures of many important proteins remain a mystery simply because researchers are unable to obtain crystals that have the quality or size required for X-ray crystallographic studies. NASA 's Protein Crystal Growth (PCG) program has been developed to learn how protein crystals grow in space and how to optimize the growth process, while producing large, high-quality crystals of selected proteins. The near-zero microgravity conditions inside an orbiting spacecraft allow crystals to grow in a more regular and perfect form because of the effects of convection and sedimentation are dampened relative to the 1-g laboratory.

The Commercial Protein Crystal Growth – High Density (CPCG-H) experiments, developed by the Center for Biophysical Sciences and Engineering at the University of Alabama at Birmingham, will launch on space shuttle flight STS-110, scheduled for launch in April 2002 as part of ISS mission 8A, and be transferred to the International Space Station. Researchers hope that these experiments will provide large, well-ordered protein crystals of several different proteins for X-ray analysis that will lead to the development of new drugs. The experiment is scheduled to return to Earth on board the shuttle STS-111 mission.

Experiment Summary

The Commercial Protein Crystal Growth-H experiment consists of 1,008 individual experiments contained in a High-Density Protein Crystal Growth Assembly. This assembly is then stored in the Commercial Refrigerator Incubator Module (CRIM) at 22 degrees Celsius (72 degrees Fahrenheit).

The space station crew will install the CRIM into a locker in the Space Station EXPRESS Rack 4 in the U.S. Lab, activate the crystal growth experiments and conduct daily status checks. These daily checks consist of checking temperature readings and cleaning the air filter. When the payload is scheduled to return to Earth, the crew will deactivate the experiments and return the module.

The protein crystals will be grown using a process known as vapor diffusion. Each experiment chamber consists of a small chamber that holds the protein crystal solution and a reservoir chamber that holds the precipitating agent solution. A small droplet of protein solution is mixed with a small amount of precipitating agent solution and placed in the protein chamber.

During activation, the protein chamber is rotated so it is in vapor contact with the reservoir. Water molecules migrate from the protein droplet through the vapor space into the more concentrated reservoir. As the volume of the protein droplet decreases, the concentration of protein increases and protein crystals form. As the experiment continues, the crystals grow larger.

Once back on Earth, the crystals will be studied using a process called X-ray diffraction. Scientists send a beam of X-rays through the crystal and measure how the atoms in the crystal scatter the X-rays. By studying the pattern made by the X-rays, scientists can map the locations of the different atoms, allowing them to create a 3-dimensional model of the protein. With this structural information, researchers determine how the protein functions and can design small molecules to aid or impede the protein’s function. This process, known as structure-based drug design, may lead to more effective drugs that target specific proteins.

Background/Flight History

Because of the enormous potential this research offers, the Center for Biophysical Sciences and Engineering (formerly the Center for Macromolecular Crystallography or CMC), a NASA-sponsored Commercial Space Center located at the University of Alabama at Birmingham, has more than 50 major industry and academic partners using the low-gravity environment of space to grow protein crystals for use in drug design.

Protein-crystal growth experiments began flying on the space shuttle in 1985. Today, more than 40 protein-crystal growth payloads have flown, producing diffraction-quality crystals of many proteins. The CPCG-H first flew aboard the ISS during Expedition 2, launching aboard STS-100 in April 2001 and returning aboard STS-105 in August 2001. The data derived from each crystal analyzed is leading researchers closer to understanding the structure and function of proteins.

Benefits

NASA's commercial research program attempts to use the materials or knowledge developed in space to develop or improve a commercial product or service on Earth. Commercial space research has the potential to create new or improved products, create jobs, give United States industry competitive advantages and improve the quality of life on Earth.

Structural studies using microgravity-grown protein crystals may provide information that can be used in the development of new drugs. With the advent of genetic information from humans and many other species, the role proteins play in diseases and degenerative conditions is becoming more clear and the need for information about the structure of these proteins more critical.

Experiments involving the crystallization of proteins and other biological macromolecules will be part of the ongoing research conducted aboard the International Space Station. The space station provides an ideal platform for growing crystals that require longer periods of microgravity than has been available on short-duration space shuttle flights.

Benefits from protein growth experiments conducted in space have already been seen. Many of the crystallization experiments conducted on the space shuttle have yielded crystals that furthered structural biology projects. For example, microgravity crystallization experiments have been conducted with recombinant human insulin. These studies have yielded X-ray diffraction data that helped scientists to determine higher-resolution structures of insulin formulations. This structural information is valuable for ongoing research toward more effective treatment of diabetes.

Other very successful microgravity crystallization experiments have provided enhanced X-ray diffraction data on a protein involved in the human immune system. These studies have contributed to the search for drugs to decrease inflammation problems associated with open-heart surgery.

The crystallization of proteins in the low-gravity environment of Earth orbit has developed into a valuable and necessary tool for the science of macromolecular crystallography.

Crystallization experiments conducted on the International Space Station involve not only human but also animal and plant proteins and promise to help answer key questions about the world around us.

Additional Information/Photos

More information on this experiment is available at:

www.scipoc.msfc.nasa.gov

http://www.microgravity.nasa.gov

http://spaceresearch.nasa.gov/

http://www.cbse.uab.edu/

www.spaceflight.nasa.gov

http://www.spd.nasa.gov

http://commercial.nasa.gov

Experiments

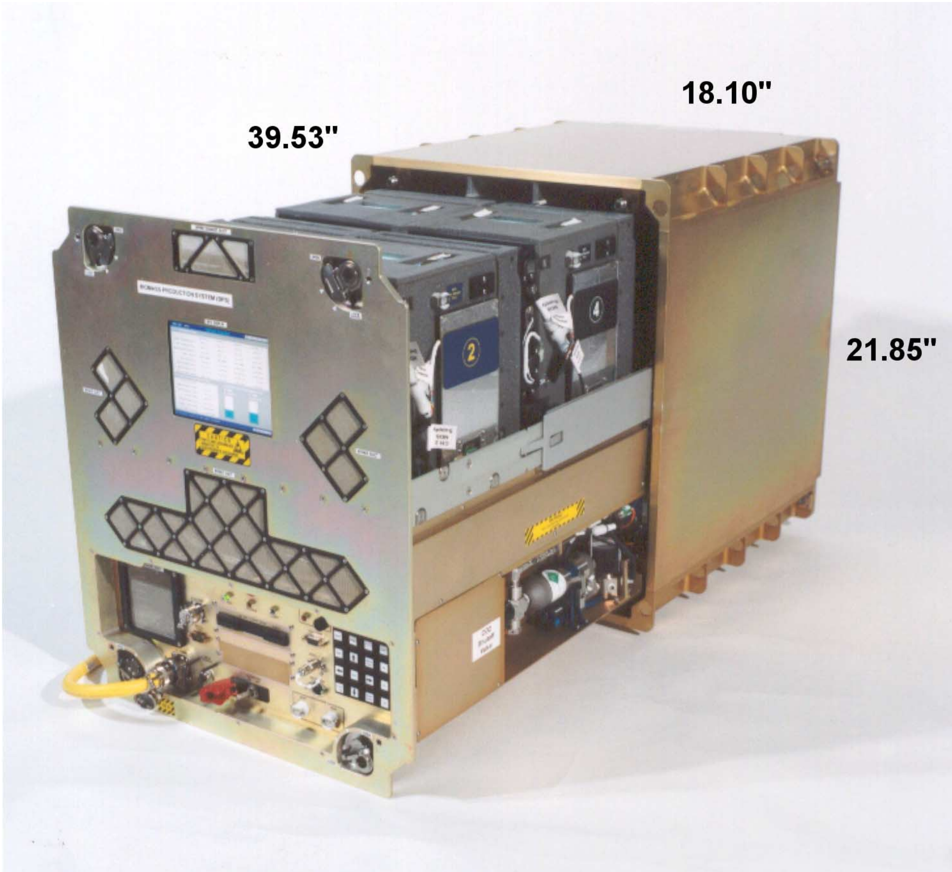
Biomass Production System (BPS) and the Photosynthesis Experiment and System Testing Operation (PESTO)

The Biomass Production System (BPS) is a test facility for a future International Space Station (ISS) plant habitat capable of supporting plant growth and botanical experimentation in microgravity for 90-day intervals or longer. The BPS will be delivered to the ISS during the STS-110 mission and then transferred to an ISS EXPRESS rack for in-flight operations.

On orbit, the BPS is designed to support the continued growth and development of plant specimens and to provide the capabilities necessary to perform scientific investigations. The BPS is one of several pieces of ISS hardware being developed by NASA's Space Station Biological Research Project (SSBRP), located at NASA Ames Research Center in California's Silicon Valley. Dr. Randall Berthold is the payload manager, and Kristina Lagel is project scientist for NASA Ames.

The primary objective of the BPS is the Technology Validation Test (TVT), which is intended to evaluate hardware performance under orbital conditions in order to select subsystems ideal for design and development of a permanent plant research unit for the ISS. The BPS also will support the Photosynthesis Experiment and System Testing Operation (PESTO), a study of the effects of microgravity on photosynthesis and metabolism in wheat plants. Some of the results from this study will be used as part of the Technical Validation Test.

Science samples will be returned to Earth from the ISS on the STS-111 space shuttle mission, currently scheduled for launch in May 2002.



Biomass Production System

Hardware Overview

The BPS is a powered, double middeck locker equivalent hardware system that includes four independent plant growth chambers, a nutrient delivery system, a temperature/humidity control system, airflow and atmospheric control systems, a video system and a data-processing system. Each plant growth chamber has a growing area of about 42 square inches (260 square centimeters) and a height of over 6 inches (15 centimeters). The BPS was developed by Orbital Technologies Corp., Madison, Wis.

Experiment Overview

The BPS will support two sets of experiments. The primary objective is to conduct the Technical Validation Test (TVT), which will evaluate the ability of the BPS and its environmental control subsystems to support plant growth and development in microgravity. Researchers will study the health and growth of the plants, facility temperature and humidity controls, nutrient delivery, lighting, plant manipulation and sample retrieval, video and data acquisition, and performance of other operations and support systems.

The TVT will use two types of plants. Chamber 4 will contain *Brassica* rapa, plants belonging to the mustard family. *Brassica* plants include such commonly grown vegetables as broccoli, cabbage, cauliflower, rutabaga and turnip. *Brassica* is a dicot – a plant with two cotyledons, or leaf-like structures, per seed -- and exhibits multiple developmental stages (growth, flowering and seedpod production) in a short time. The growth of *Brassica rapa* seedlings will test the ability of the BPS to support the growth of a developmentally complex plant. Dr. Robert Morrow, Orbital Technologies Corp., Madison, Wis., is the principal investigator for the TVT.

The TVT also will use Apogee wheat, a monocot plant with only one cotyledon, or leaf-like structure, per seed. Chamber 3 will contain wheat seedlings that will be four days old at launch. The wheat will be exposed to a variety of temperature and humidity levels in order to test the ability of the BPS to control temperature and humidity set points. In addition, water utilization and plant photosynthesis will be measured. Tissue will be harvested and frozen or fixed when the plants are 21 days old. Upon successful completion of the initial verification test, the chamber temperature and humidity will be maintained at a constant 75.2˚ F (24˚ C) and 75 percent relative humidity to conduct a 21-day microgravity test, followed by a test to grow plants that will be 12 days old at landing. Plants grown during these last two growth periods will be part of the PESTO experiments.

The second experiment set is the Photosynthesis Experiment and System Testing Operation (PESTO), which will study the growth, photosynthesis, gas exchange and metabolism of Apogee wheat in microgravity. Plants have the capability to remove carbon dioxide, generate oxygen, and purify water. This experiment will determine the ability of wheat seeds to germinate, develop and grow in microgravity conditions, measure the growth of the seedlings, and determine the effects of microgravity on photosynthesis and transpiration. The experiment will evaluate techniques for planting and watering seeds on orbit. Plants will be harvested in space and returned to Earth for detailed analysis. The PESTO principal investigator is Dr. Gary Stutte, Dynamac Corp., Kennedy Space Center, Fla.

One of the PESTO experiments will compare the effect of microgravity on Apogee wheat plants of two different ages. Chamber 1 will include 32 plants 12 days old at the time of launch. These plants will be well developed and able to photosynthesize. Chamber 2 will hold a group of 32 plants eight days old at launch. These plants will have just developed a ‘canopy’ capable of photosynthesis. Analyses of the plants’ photosynthetic development will be done three times during their development. Comparisons will be made with plants of the same age but developed under normal Earth gravity.

Another component of the PESTO experiment will germinate seeds in microgravity, and then analyze the living plants once they are returned to Earth. The plants, which will be harvested on the ground, will be 12, 19 or 24 days old at landing. The in-flight water use and photosynthetic responses of these plants will be compared to post-flight analysis of the photosynthetic apparatus. In addition, tissue will be frozen and analyzed for carbohydrate partitioning and fixed for ultrastructural analysis of the development of the photosynthetic apparatus.

System Components

Each of the BPS's four plant growth chambers includes a root module connected to a removable chamber cover. Each chamber is independently controlled for temperature, humidity, lighting, atmospheric composition (CO_2) and delivery of water. Each chamber also has its own video monitoring system. The BPS is programmed to capture still images from each chamber every two hours using this system, and recording equipment interfaced with the BPS front panel can be used to capture full-motion video footage.

Background/Flight History

Studies of the effects of microgravity on plant growth date back to the 1960s with the Biosatellite program and continued throughout the history of the Space Shuttle Program. With the addition of a stable, long-term plant research facility on the ISS, researchers will gain more reliable knowledge about the relationship between microgravity and plant growth. This research will allow the effects of microgravity on the potential of using plants to generate oxygen, remove carbon dioxide, and purify water on long-duration space missions to be evaluated under realistic conditions. This research will have direct application to future production of salad crops that the ISS crew could eat directly, such as radishes, lettuce or onions.

Benefits

The photosynthetic properties of plants are a critical component of plant-based atmospheric regeneration systems now under study for possible implementation in future long-duration space missions. Studies of photosynthesis in microgravity and determining its effects on atmosphere controls will enable NASA to make an informed decision about the feasibility and design of a self-sustaining biosphere. In such a facility, living plants will help maintain proper ship atmosphere, and reduce the air/water resupply costs associated with living and working in space. The technology used to maintain the environmental conditions necessary for plant growth also have the potential to improve environmental controls in the greenhouse and controlled-environment industries.

The BPS studies are supported by NASA's Office of Biological and Physical Research, which promotes basic and applied research to support human exploration of space and to take advantage of the space environment as a laboratory. More information is available at:

http://spaceresearch.nasa.gov/

For more information about NASA's Space Station Biological Research Project, visit:

http://brp.arc.nasa.gov/

Details about the BPS and NASA Ames' Expedition Four fundamental biology project are available at:

http://lifesci.arc.nasa.gov/UF1

Other Expedition Four experiment information can be found at:

http://microgravity.msfc.nasa.gov

http://scipoc.msfc.nasa.gov

DSOs and DTOs

Detailed Supplementary Objectives (DSOs) are space and life science investigations. Their purpose is to:

- Determine the extent of physiological deconditioning resulting from spaceflight
- Test countermeasures to those changes
- Characterize the environment of the space shuttle and/or space station relative to crew health.

Detailed Test Objectives (DTOs) are aimed at testing, evaluating or documenting space shuttle systems or hardware, or proposed improvements to the space shuttle or space station hardware, systems and operations.

Such experiments aboard Atlantis are:

DSO 493

Monitoring Latent Virus Reactivation and Shedding in Astronauts

The premise of this DSO is that the incidence and duration of latent virus reactivation in saliva and urine will increase during space flight. 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 space flight.

Space-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 70-80 percent of all adults. Its classic manifestations are cold sores, pharyngitis and tonsillitis; and it is usually acquired through contact with the saliva, skin, or mucous membranes of an infected individual. However, many recurrences are asymptomatic, resulting in the shedding of the virus.

DSO 496

Individual Susceptibility to Post-Space Flight Orthostatic Intolerance (Preflight and Postflight Only)

The occurrence of postflight orthostatic hypotension in some, but not all astronauts is contributed to by preflight, gender-related differences in autonomic regulation of arterial pressure, and space flight-induced changes in autonomic function which precipitate orthostatic hypotension in predisposed individuals. This DSO will address this hypothesis by performing a flight-related study, designed to elucidate preflight and postflight differences in susceptible and non-susceptible astronauts.

DSO 498

Space Flight and Immune Function
(Preflight and Postflight Only)

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 as the International Space Station. The effect of space flight 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 microgravity will enable researchers to develop countermeasures to minimize infection risk. DSO 498 will look at the effects of spaceflight on the neutrophils, monocytes and cytoxic cells, which play an important role in maintaining an effective defense against infectious agents. Scientists believe that space changes the way that these cells function. Researchers will analyze neutrophils and monocytes from astronaut blood samples before and after flight. They will also assess the subjects' preflight and postflight production of cytotoxic cells and cytokine. This study will complement previous and continuing immunology studies of astronauts' adaptation to space.

DSO 500

Space Flight-Induced Reactivation of Latent Epstein-Barr Virus

(Preflight and Postflight Only)

The effects of microgravity, along with associated physical and psychological stress, will decrease Epstein-Barr virus (EBV)-specific T-cell immunity and reactivate latent EBV in infected B-lymphocytes. DSO 500 will examine the mechanisms of space flight-induced alterations in human immune function and latent virus reactivation. Specifically, it will determine the magnitude of immunosuppression as a result of space flight by analyzing stress hormones, performing quantitative analysis of EBV replication using molecular and serological methods, and determining virus-specific T-cell immune function.

DSO 503-S

Test of Midodrine as a Counteractive Measure Against Postflight Orthostatic Hypotension
(Preflight and Postflight Only)

After space flight, astronauts returning to upright posture may experience the inability to maintain adequate arterial pressure and cerebral function (orthostatic or postural hypotension). This may result in lightheadedness or loss of consciousness during re-entry or egress. DSO 503-S will evaluate the efficacy of midodrine, a medicine commonly used to treat low blood pressure. It works by stimulating nerve endings in the blood pressure. The experiment will assess midodrine's effectiveness in reducing the incidence and/or severity of orthostatic hypotension in returning astronauts.

DTO 263

Shuttle Automatic Reboost Testing

The purpose of this DTO is to validate the preflight estimate of the structural natural frequencies and damping, and thus the jet firing separation time. The structural natural frequencies can be measured using the shuttle IMU downlink data, and the jet firing separation time can be implemented by display inputs by the shuttle crew. This DTO is appropriate for shuttle flight to the ISS between availability of OI-28 reboost software and availability of the vernier jet reboost capability. This is the third of approximately four flights of DTO 263.

DTO 264

Space Station RMS Dynamic Model Validation (DTO of Opportunity)

The purpose of DTO 264 is to assure stable shuttle control system performance, and acceptable loads on the space shuttle remote manipulator system (SSRMS) induced by the shuttle jet firings. During planned SSRMS handling of payloads, a brief pause is requested at a specific planned SSRMS geometric configuration in the operations preplanned 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. The SSRMS data system in the end effector will be active to measure the SSRMS transient load response. Two flights are chosen to assess SSRMS dynamic characteristics while attached to a light and a heavy payload. This is the last of two flights of this DTO.

DTO 700-14

Single-String Global Positioning System

The purpose of the Single-String Global Positioning System (GPS) is to demonstrate the performance and operations of the GPS during orbiter ascent, on-orbit, entry and landing phases. It uses a modified military GPS receiver processor and the existing orbiter GPS antennas. GPS data may be downlinked during all mission phases. This is the 23rd flight for this DTO.

DTO 805

Crosswind Landing Performance (DTO of Opportunity)

DTO 805 is to demonstrate the capability to perform a manually controlled landing in 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 substation helps provide a higher probability of a more precise landing with a crosswind of 10-15 knots as late in the flight as possible.

2. Entry: This test requires that the crew perform a manually controlled landing in a 90-degree crosswind component of 10-15 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. This DTO has been on 70 flights.

Appendix

Mobile Transporter

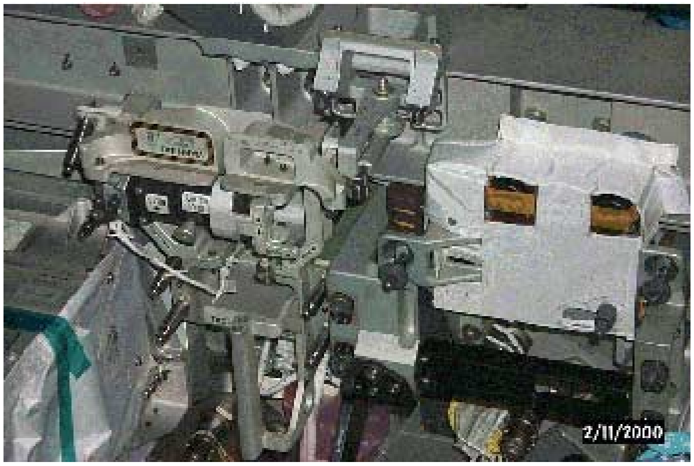
The purpose of the Mobile Transporter (MT) is to provide the following: structural attachment between the Mobile Remote Servicer Base System (MBS)/Space Station Remote Manipulator System (SSRMS) and the truss rails (MT interfaces directly with MBS); utility interfaces between the United States Orbital Segment (USOS) and the MBS/SSRMS (when parked at one of the 10 truss worksites); and the translation force for the entire Mobile Servicing System (MSS) along the International Space Station main truss structure.

The MT has a maximum velocity of 1 inch/sec (2.54 cm/sec) and the longest translation time from one end of the truss to the other (at Assembly Complete) is 50 minutes. The MT allows the MSS to accommodate payloads of up to 46,100 lbs (20,900 kg). The MT is controlled remotely (IVA) and requires no EVA support for execution of translation sequences.

The MT will be launched on STS-110/8A integrated with the S0 truss segment.

Mobile Transporter Hardware

The MT provides the primary load path between the MBS/SSRMS and the Integrated Truss Structure (ITS) rails. It is constructed of machined, aluminum-alloy space frames, which are attached with permanent Hi-Lok fasteners. The primary structure supports a number of mounted Orbital Replacement Units (ORUs) and additional components. The hardware is described below:



Trailing Umbilical System

Trailing Umbilical System (TUS)—The TUS provides all utility connections between the MT/MBS/SSRMS and the USOS. This includes all operational power during MT translation and SSRMS maneuvering (SSRMS receives no power during MT translation); a continuous command/control and telemetry data bus link; and video/sync and control lines for SSRMS video. These utilities connect the MT/MBS/SSRMS with the S0 truss and the rest of the USOS through the use of primary and redundant multi-conductor cables, which are reeled in and out along opposite sides of the ITS rails to follow the MT as it travels along the truss. The TUS is controlled by the MT software in conjunction with the concurrent MT translation sequence. Cable deployment rate can vary between 0-1 inch/sec to match the MT translation speed.

TUS Reel Assemblies—There are two TUS reel assemblies housing the two TUS cables that are to be deployed as well as additional lengths of cable for the Concentric Cable Management System (CCMS). The CCMS provides a means of managing the cable as a single continuous length, eliminating the need for slip rings. The TUS reel assembly maintains tension in the cable as it is laid in cable guides along the truss rail. This is accomplished through the use of a spring-loaded control arm. Each TUS reel assembly housing also supports a Video Signal Converter (VSC) for the SSRMS video being routed. The TUS reel assemblies are mounted on the port end of ITS S0 Bay 1. The MT is nominally parked during periods of inactivity on the adjacent ITS S0 Bay 2.

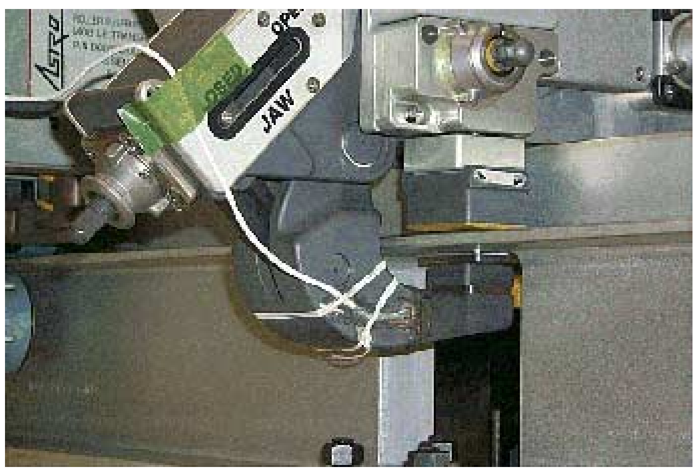
TUS Cable—The majority of the TUS cable is flat, 10 conductor design. Three central power wires are 12-gauge nickel-plated copper. Three video and two sync and control lines are 50-ohm, silver-plated copper PFM coaxial with 22-gauge center conductors. The two outer data conductors are 22-gauge, 75-ohm Twisted Shielded Pairs (TSP) of nickel-plated copper. The deployable portion of the TUS cable has additional beryllium copper stiffeners along its sides. At each end of the TUS cable, the flat cable transitions to a round, rope lay design, which is then broken out into three separate leads terminated by connectors (power, data, video). Maximum flat cable dimensions are 1.85 in. wide (1.60 in. without stiffeners) by .23 in thick. The TUS cable is considered to be an integral part of the reel assembly; thus a cable replacement on orbit, if required, may only be in the form of the entire reel assembly ORU.

TUS Cable Guides—The TUS cable guides are located intermittently along the ISS main truss structure, mounted on both the nadir and zenith MT rails. The cable guides are passive devices that constrain the location of the TUS cable within a predetermined corridor as the MT travels along the truss.

TUS Interface Umbilical Assembly (IUA)—There are two TUS IUAs mounted directly to the MT structure near the starboard-nadir and port-zenith corners. The IUAs provide for the attachment of the TUS cables to the MT and also for the insertion or removal of the TUS cable into or out of the TUS cable guides by means of a guide shoe as the MT translates. In addition, each IUA houses a TUS cable cutter assembly and an Impedance Matching Unit (IMU). The cable cutter assembly allows for remote disconnection of a TUS cable in a contingency situation. In the event of a reel assembly failure or a TUS cable jam, the cable cutter can be used to sever the TUS cable, which would allow the MT to safely reach the nearest worksite and receive power to prevent freezing hardware. The cut sequence is manually initiated by the IVA MT operator and controlled via the MT software. Power is removed from the problem TUS and the cable cutter is powered by the opposite TUS.

Umbilical Mechanism Assembly (UMA)—The UMA provides the capability to transfer USOS power to the MT at specific utility ports located along the main truss structure for stationary operation of the SSRMS. The UMA can only be connected to these ports when the MT is at one of the 10 MSS worksites. The UMA passes dual 6.0 kW 120V dc power feeds to the MBS, SSRMS and any attached payloads. A UMA is comprised of two halves. The active half, attached directly to the MT primary structure, contains primary and redundant mechanisms to physically drive its power connectors to mate with the fixed, passive UMA half, located on the main truss structure at each MSS worksite location. There are two active UMA halves on the nadir side of the MT, and each MSS worksite contains a pair of corresponding passive UMA halves. The active UMA half can be operated using an EVA manual override, if required.

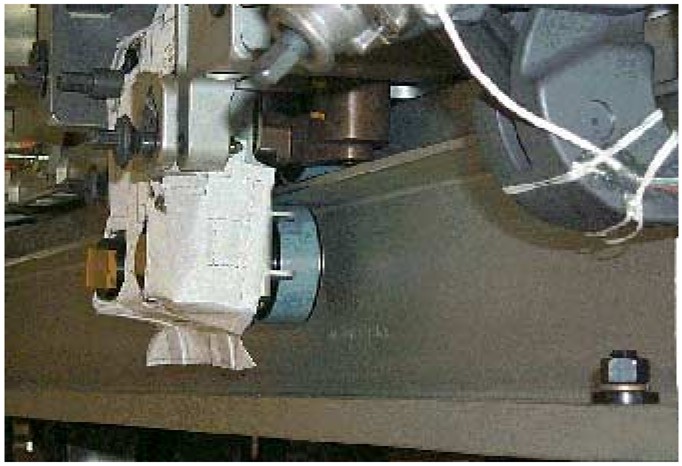
Remote Power Controller Module (RPCM)—The MT contains two RPCMs mounted on its zenith side for distributing USOS power to its various loads. Each RPCM receives 120 V dc power from a separate TUS via the TUS IUAs and distributes the power to the MT Electrical Power Consuming Equipment (EPCE) under control of MT software. S0 power allocation to the MT is 6 kW, which supplies all MT power-consuming components and the MT heater network. Power for the TUS reel assemblies is not included in this allocation.



Load Transfer Unit

Load Transfer Unit (LTU)—There are four LTUs—one mounted in each corner of the MT—for restraining the MSS at any of the various truss worksites. The four LTUs latch to hardened fittings at each worksite with holes on the ITS rails to provide a clamping force for distribution of the load between the MSS and the rails.

Linear Drive Unit (LDU)—The LDU provides the MT translation drive force and supports the zenith side of the MT during translation. The LDU contains a friction brake system for use as a parking brake at the various worksites and as an emergency brake in the event of an LDU or MT system failure.



Roller Suspension Unit

Roller Suspension Unit (RSU)—There are two RSUs mounted on the nadir side of the MT for restraint and support during MT translation along the truss rails. Each passive RSU interfaces to the nadir ITS rail through two sets of plastic wheels supported with spring-loaded compliance to allow the RSU to cross all rail joints. When the MT is parked at a worksite with latched LTUs, the RSUs are effectively suspended and are not part of the MSS load path.

MT/CETA Energy Absorber—The MT contains two MT/Crew and Equipment Translation Aid (CETA) energy absorbers, located respectively on its port and starboard sides. These ORUs will provide latching and collision energy absorption between the MT and the two CETA carts, once they are delivered on Missions 9A and 11A, respectively. Both the port and starboard energy absorbers terminate with a passive coupler half that connects to an active coupler half on the port or starboard tongue of the respective CETA cart. The active coupler half contains the mechanism which allows capture, locking and release of the passive half. The coupler is EVA operated, and both energy absorbers will be installed on the MT during Mission 8A.

End Stop Unit (ESU)—The MT also contains two ESUs, located respectively on its port and starboard sides. The ESUs interact with MT stops built into the main truss structure to prevent the MT from running off the ITS rails in the emergency event of multiple failures during MT translation. Each ESU consists of a cylinder and piston and a crushable aluminum honeycomb core, which absorbs the energy of an impact so as not to damage the MT primary structure or violate the loads at the MT/MBS interface. The ESUs are On-Orbit Maintainable Items (OMI) with a replaceable crush core and are thus intended for emergency use only.

Heaters—Thermal control of the various MT components is provided by a network of primary and redundant thermal resistive heaters. All MT heaters are passive, thermostatically controlled with no monitoring capability. The heaters are applied in pairs, and nominal operation has both heaters operating simultaneously.

Mobile Transporter Software

The MT software controls all functions of the MT and TUS required for translation across the ITS and parking at any of the MSS worksites. The software provides for automated or manual translation and can automatically detect MT component failures and route the failure event data to the operator.

The Amplifier Orbital Replacement Unit buffers and amplifies data signals between the Mobile Transporter and Trailing Umbilical System and between the Mobile Remote Servicer and Trailing Umbilical System.

Software Modes

The MT software modes are Idle, Standby, Translate and Manual. Idle mode is the default mode that results upon powering the external Multiplexer/Demultiplexer, where no data input or output occurs with the lower tier MT components. Idle mode also occurs when the MT is commanded to shutdown from Standby mode after successfully latching down the MT at the worksite. Translate mode is the automated commanding mode used by the MT operator to perform automated command, sequencing, and monitoring of MT translation. Upon completion or failure of an automated translation sequence between worksites, the MT software automatically transitions to Standby mode. Manual mode is the low level mode used by the MT operator to perform direct, low-level commands (e.g., manually command translation components after an MT sequence failure) or RPCM commands (e.g., to override the inhibit and cut the TUS cable after a cable jam or reel assembly failure). Manual mode can only be reached by operator command from Standby mode.

Shuttle Reference 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.

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 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 (RTLS).

Return to Launch Site

The RTLS 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 RTLS 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 RTLS 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 RTLS phase begins with the crew selection of the RTLS abort, which is done after solid rocket booster separation. The crew selects the abort mode by positioning the abort rotary switch to RTLS and depressing the abort push button. The time at which the RTLS is selected depends on the reason for the abort. For example, a three-engine RTLS is selected at the last moment, approximately three minutes 34 seconds into the mission; whereas an RTLS 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).

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 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 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 Ti

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 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.

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 gimbaled 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.

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.

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.

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 sevoactuator 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.

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.

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 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.

Acronyms and Abbreviations

A/L	Airlock
AA	Antenna Assembly
AAA	Avionics Air Assembly
ABC	Audio Bus Couplers
ACBM	Active Common Berthing Mechanism
ACH	Assembly Console Handbook
ACS	Assembly Contingency System
	Atmosphere Control and Supply
	Attitude Control System
ACSM	Attitude Control System Moding
ACU	Arm Computer Unit
AD	Active Device
AEA	Antenna Electronics Assembly
AFD	Aft Flight Deck
AOH	Assembly Operations Handbook
APAS	Androgynous Peripheral Attachment System
APCU	Assembly Power Converter Unit
APDS	Androgynous Peripheral Docking System
APFR	Articulating Portable Foot Restraint
APM	Attached Pressurized Module
APPCM	Arm Pitch Plane Change Mode
APS	Automated Payload Switch
AR	Atmosphere Revitalization
ARC	Ames Research Center
ARCU	American-to-Russian Converter Unit
ARR/DPTR	Arrival/Departure
ASCR	Assured Safe Crew Return
ASK	Ames Stowage Kit
ATA	Ammonia Tank Assembly
ATCS	Active Thermal Control System
ATU	Audio Terminal Unit
	Audio Thermal Unit
AUAI	Assembly Contingency System / UHF Audio Interface
AVU	Artificial Vision Unit
BBC	Bolt Bus Controller
BBS	Bolt Back Switch
BC	Bus Controller
BCDU	Battery Charge/Discharge Unit
BCU	Bus Controller Unit
BDU	Backup Drive Unit
BGA	Beta Gimbal Assembly
BIT	Built-In Test

BITE	Built-In Test Equipment
BMRRM	Bearing Motor Roll Ring Module
BMS	Bristol-Myers Squibb
BPS	Biomass Production System
BRS	Backup Restraint System
BSP	Baseband Signal Processor
C&C	Command and Control
C&DH	Command and Data Handling
C&M	Control and Monitor
C&T	Communication and Tracking
C&W	Caution and Warning
C/A-code	Coarse/Acquisition-code
C/L	Crew Lock
CA	Control Attitude
CAB	Chamber Access Bay
CAM	Centrifuge Accommodations Module
CAS	Common Attach System
CBC	Common Booster Core
CBM	Common Berthing Mechanism
CCAA	Common Cabin Air Assembly
CCD	Cursor Control Device
CCS	Command and Control Software
CCTV	Closed-Circuit Television
CDR	Commander
CDRA	Carbon Dioxide Removal Assembly
CDS	Command and Data Software
CETA	Crew and Equipment Translation Aid
CEU	Control Electronics Unit
CGBA	Commercial Generic Bioprocessing Apparatus
CHeCS	Crew Health Care System
CHX	Condensing Heat Exchanger
CI	Configuration Item
CID	Circuit Interrupt Device
CIOB	Cargo Integration and Operations Branch
CIR	Cargo Integration Review
CMB	Common Berthing Mechanism
CMG	Control Moment Gyro
COTS	Commercial-Off-the-Shelf
CO_2	Carbon Dioxide (di-molecular)
CPA	Control Panel Assembly
CPCG-H	Commercial Protein Crystal Growth – High Density Protein Growth
CRIM	Commercial Refrigerator Incubator Module
CRIM-M	Commercial Refrigerator Incubator Module - Modified
CRV	Crew Return Vehicle
CSA	Computer Systems Architecture

CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CTB	Crew Transfer Bag
CTRS	Conventional Terrestrial Reference System
CVIU	Common Video Interface Unit
CVT	Current Value Table
CVV	Carbon dioxide Vent/Valve
CWC	Contingency Water Collection
DAIU	Docked Audio Interface Unit
DAP	Double Adapter Plate
DC	Direct Current
	Docking Compartment
DCAM	Diffusion-controlled Crystallization Apparatus for Microgravity
DCP	Display and Control Panel
DCSU	Direct Current Switching Unit
DDCU	DC-to-DC Converter Unit
DDCU-E	DC-to-DC Converter Unit – External
DMCU	Docking Mechanism Control Unit
DMS-R	Data Management System-Russian
DOF	Degrees of Freedom
DPA	Digital Pre-Assembly
DPS	Data Processing System
DSO	Detailed Supplementary Objective
DTO	Detailed Test Objective
DSM	Docking and Stowage Module
E/D	Electrodynamics
	Engage/Disengage
E/L	Equipment Lock
E-Stop	Emergency Stop
EACP	Extravehicular Audio Control Panel
EAIU	EMU Audio Interface Unit
EAS	Early Ammonia Servicer
EATCS	External Active Thermal Control System
ECLSS	Environmental Control and Life Support System
ECU	Electronics Control Unit
EDDA	EMU Don/Doff Assembly
EE	End Effector
EEATCS	Early External Active Thermal Control System
EET	Experiment Elapsed Time
EETCS	Early External Thermal Control System
EF	Exposed Facility
EFGF	Electrical Flight Grapple Fixture
EIA	Electrical Interface Assembly
ELM	Experimental Logistics Module

EMU	External Maneuvering Unit Extravehicular Mobility Unit
EPG	Electrical Power Group
EPS	Electrical Power System
ERA	Electrical Replaceable Assembly
ES	Escape System
ESP	External Stowage Platform
ESSMDM	Enhanced Space Station Multiplexer/Demultiplexer
ETCS	External Thermal Control System
ETI	Elapsed Time Indicator
ETSD	EVA Tool Storage Device
EUE	Experiment Unique Equipment
EV	Extravehicular
EVA	Extravehicular Activity
EVCPDS	Extravehicular Charged Particle Directional Spectrometer
EVR	Extravehicular Robotics
EVSU	External Video Switch Unit
EVSWS	Extravehicular Support Work Station
EXPRESS	Expediting the Process of Experiments to the Space Station
EXT	Experimental Terminal
FC	Firmware Controller
FCC	Flat Collector Circuit
FCS	Fluid Circulation System
FCV	Flow Control Valve
FD	Flight Day
FDA	Fault Detection and Annunciation
FDIR	Failure, Detection, Isolation, and Recovery
FDS	Fire Detection Suppression
FGB	Functional Cargo Block
FPU	Fluid Pumping Unit
FRGF	Flight Releasable Grapple Fixture
FSEGF	Flight Support Equipment Grapple Fixture
FSS	Fluid System Servicer
FT	Fault Tolerant
GC	Growth Cell
GFE	Government Furnished Equipment
GLONASS	Russian Global Navigation Satellite System
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
GPS	Global Positioning System
GUI	Graphical User Interface
HC	Hand Controller
HCU	Headset Control Unit

HCS	Humidity Control System
HDPCG	High Density Protein Crystal Growth
HDR	High Data Rate
HGA	High Gain Antenna
HEC	Headset Extension Cable
HEPA	High Efficiency Particulate Air
HGA	High Gain Antenna
HP	Heat Pipe
HPGT	High Pressure Gas Tank
HRDL	High Rank Data Link
HRFM	High Rate Frame Multiplexer
HRM	High Rate Modem
I/F	Interface
I/O	Input/Output
IAC	Internal Audio Controller
IAS	Internal Audio System
	Internal Audio Subsystem
ICC	Integrated Cargo Carrier
ICM	Isothermal Containment Module
ICS	Intersatellite Communication System
IDA	Integrated Diode Assembly
IEA	Integrated Equipment Apparatus
IFHX	Interface Heat Exchanger
IFM	In-Flight Maintenance
IMCA	Integrated Motor Controller Assembly
IMCS	Integrated Mission Control System
IMV	Intermodule Ventilation
INCO	Instrumentation and Communication Officer
INS	Inertial Navigation System
INT	Integrated
IOCU	Input/Output Controller Unit
IP	International Partner
IRU	In-flight Refill Unit
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSSH	International Space Station Systems Handbook
ITCS	Internal Thermal Control System
ITS	Integrated Truss Segment
IUA	Interface Umbilical Assembly
IV	Intravehicular
IVA	Intravehicular Activity
IVCPDS	Intravehicular Charged Particle Directional Spectrometer
IVSU	Internal Video Switch Unit

JEM	Japanese Experiment Module
JEU	Joint Electronic Unit
KBAR	Knee-Brace Assembly Replacement
KFT	Kennedy Space Center Fixation Tube
km	Kilometer
KSC	Kennedy Space Center
LA	Lab Assembly
Lab	U.S. Laboratory Module
LAB	Lower Avionics Bay
LAN	Local Area Network
LB	Local Bus
LCA	Lab Cradle Assembly
	Loop Crossover Assembly
LCD	Liquid Crystal Display
LDA	Launch Deployment Assembly
LDR	Low Data Rate
LDU	Linear Drive Unit
LED	Light Emitting Diode
LEE	Latching End Effector
LFDP	Load Fault Detect/Protect
LGA	Low Gain Antenna
LLA	Low-Level Analog
LTA	Launch to Activation
LTL	Low Temperature Loop
LTU	Load Transfer Unit
LVLH	Local Vertical/Local Horizontal
m	Meter
MA	Mechanical Assembly
MAM	Manual Augmented Mode
MAX	Maximum Time Estimate
MBM	Manual Berthing Mechanism
MBS	Mobile Base System
	Mobile Remote Servicer Base System
MBSU	Main Bus Switching Unit
MCA	Major Constituent Analyzer
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MCC-M	Mission Control Center-Moscow
MCDS	Multifunction Cathode Ray Tube Display System
MCS	Motion Control System
MDL	Middeck Locker
MDM	Multiplexer/Demultiplexer
MELF	Metal Electrical Face
MER	Mission Evaluation Room

METOX	Metal Oxide
MFCV	Manual Flow Control Valve
MILA	Moding Indicator Light Assembly
MLI	Multilayer Insulation
Mm	Millimeter
MM/OD	Micrometeoroid/Orbital Debris
MOD	Mission Operations Directorate
MPEV	Manual Pressure Equalization Valve
MPLM	Minipressurized Logistics Module Multipurpose Logistics Module
MPM/MRL	Manipulator Positioning Mechanism/Manipulator Retention Latch
ms	millisecond
MSD	Mass Storage Device
MSFC	Marshall Space Flight Center
MSS	Mobile Servicing System
MT	Mobile Transporter
MTL	Moderate Temperature Loop
MTS	Mobile Tracking Station Module-to-Truss Structure
MTSAS	Module-to-Truss Segment Attach System
MUP	Mission Unique Process
MWA	Maintenance Work Area
N_2	Nitrogen (di-molecular)
NASA	National Aeronautics and Space Administration
NCS	NICMOS Cooling System Node Control Software
NDS	Nutrient Delivery System
NGTC	Next Generation Thermal Carrier
NIV	Nitrogen Isolation Valve
NTA	Nitrogen Tank Assembly
O_2	Oxygen (di-molecular)
OCA	Orbital Communications Adapter
OCAD	Operational Control Agreement Document
OCJM	Operator Commanded Joint Position Mode
OCPM	Operator Commanded Point of Reference Mode
OCS	Operations and Control Software
ODIN	Onboard Data Interfaces and Networks
ODS	Orbiter Docking System
OIU	Orbiter Interface Unit
OIV	Oxygen Isolation Valve
OPP	Orbiter Space Vision System Patch Panel
OPS	Operations
ORBITEC	Orbital Technologies Corporation
ORCA	Oxygen Recharge Compressor Assembly
ORU	Orbital Replacement Unit

OSE	Orbital Support Equipment
OSO	Operations Support Officer
OSVS	Orbiter Space Vision System
OSVU	Orbiter Space Vision Unit
OTD	Orbital Replacement Unit Transfer Device
P&S	Pointing and Support
P/L	Payload
P-Code	Precision Code
PB	Power Bus
PBA	Portable Breathing Apparatus
PC	Personal Computer
PCA	Pressure Control Assembly
PCAM	Protein Crystallization Apparatus for Microgravity
PCG	Protein Crystal Growth
PCG-STES	Protein Crystal Growth, Single-locker Thermal Enclosure System
PCMCIA	Personal Computer Memory Card International Adapter
PCMMU	Pulse Code Master Modulation Unit
PCN	Page Change Notice
PCP	Pressure Control Panel
PCR	Portable Computer Receptacle
PCS	Portable Computer System
PD	Physical Device
PDGF	Power and Data Grapple Fixture
PDI	Payload Data Interface
PDIP	Payload Data Interface Panel
PDRS	Payload Deployment and Retrieval System
PEHG	Payload Ethernet Hub Gateway
PESTO	Photosynthesis Experiment and System Testing and Operations
PFCS	Pump and Flow Control Subassembly
PFE	Portable Fire Extinguisher
PGSC	Payload General Support Computer
PGT	Pistol Grip Tool
PIHPC	Permanent International Human Presence Capability
PJAM	Pre-stored Joint Position Autosequence Mode
PL	Payload
PLB	Payload Bay
PLS	Primary Landing Site
PMA	Pressurized Mating Adapter
PMCU	Power Management Controller Unit
PMP	Payload Mounting Payload
POR	Point of Reference
	Point of Resolution
POST	Power On Self-Test
PPA	Pump Package Assembly
PPAM	Pre-stored Point of Reference Autosequence Mode
PPRV	Positive Pressure Relief Valve

PRD	Payload Retention Device
PRLA	Payload Retention Latch Assembly
PS	Power Supply
PSP	Payload Signal Processor
PSRP	Payload Safety Review Panel
PTCS	Passive Thermal Control System
PTT	Push-To-Talk
PTU	Pan/Tilt Unit
PV	Photovoltaic
PVCU	Photovoltaic Control Unit
PVM	Photovoltaic Module
PVRGF	Photovoltaic Radiator Grapple Fixture
PWP	Portable Work Platform
PWR	Portable Water Reservoir
QD	Quick Disconnect
R&R	Remove and Replace
R/P	Receiver/Processor
RACU	Russian-to-American Conversion Unit
RAIU	Russian Audio Interface Unit
RAM	Random Access Memory
RAMV	Rheostat Air Mix Valve
RBI	Remote Bus Isolation
RCU	Remote Control Unit
RF	Radio Frequency
RFCA	Rack Flow Control Assembly
RFG	Radio Frequency Group
RGA	Rate Gyro Assembly
RHC	Rotational Hand Controller
RHX	Regenerative Heat Exchanger
RIC	Rack Interface Controller
RJAM	Prestored Joint Position Autosequence Mode
RM	Research Module
RMS	Remote Manipulator System
ROS	Russian Orbital Segment
RPC	Remote Power Controller
RPCM	Remote Power Control Module
RPDA	Remote Power Distribution Assembly
RS	Russian Segment
RSA	Russian Space Agency
RSP	Resupply Stowage Platform
RSR	Resupply Stowage Rack
RSU	Roller Suspension Unit
RT	Remote Terminal
RTL	Ready to Latch
RU	Rigid Umbilical

RWS	Robotic Workstation
S0	Starboard Zero
SA	Solar Array
SABB	Solar Array Blanket Box
SASA	S-band Antenna Support Assembly
SAW	Solar Array Wing
SCA	Switchgear Controller Assembly
SCU	Service and Cooling Umbilical
	Sync and Control Unit
	Signal Conditioning Unit
SD	Smoke Detector
SDMS	Structural Dynamics Measurement System
SDO	Solenoid Driver Input
SDS	Sample Delivery System
SFA	Sunfinder Assembly
SFCA	System Flow Control Assembly
SGANT	Space-to-Ground Antenna
SHOSS	SpaceHab Oceaneering Space System
SIGI	Space Integrated Global Positioning System/Inertial Navigation System
SJRM	Single Joint Rate Mode
SLP	Spacelab Pallet
SM	Service Module
SMCC	Shuttle Mission Control Center
SMTC	Service Module Terminal Computer
SOC	State of Charge
SPCE	Servicing Performance and Checkout Equipment
SPEC	Specified
SPD	Serial Parallel Digital
SPDA	Secondary Power Distribution Assembly
SPDC	Secondary Power Distribution Control
SPDM	Special Purpose Dexterous Manipulator
SPP	Science Power Platform
SRMS	Shuttle Remote Manipulator System
SSAS	Segment-to-Segment Attachment System
SSBRP	Space Station Biological Research Project
SSC	Station Support Computer
	Subsystem Computer
SSMDM	Space Station Multiplexer/Demultiplexer
SSOR	Space-to-Space Orbiter Radio
SSP	Space Shuttle Program
	Standard Switch Panel
SSRMS	Space Station Remote Manipulator System
SSSR	Space-to-Space Station Radio
SSU	Sequential Shunt Unit
SVS	Synthetic Vision System

TA	Thruster Assist
TC	Terminal Computer
TCS	Thermal Control System
TCCS	Trace Contaminant Control Subassembly
TCCV	Temperature Control and Check Valve
TD	Translation Drive
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TEPC	Tissue Equivalent Proportional Counter
THC	Translational Hand Controller
	Temperature and Humidity Control
THOR	Thermal Operations and Resources
TORU	Teleoperator Control Mode
TRC	Transmitter Receiver Controller
TRRJ	Thermal Radiator Rotary Joint
TSA	Tool Storage Assembly
TUS	Trailing Umbilical System
TV	Television
TVIS	Treadmill Vibration Isolation and Stabilization
UAB	Upper Avionics Bay
UB	User Bus
UDG	User Data Generation
UDM	Universal Docking Module
UF	Utilization Flight
UHF	Ultra High Frequency
UIA	Umbilical Interface Assembly
UIP	Utility Interface Panel
ULC	Unpressurized Logistic Carrier
ULCAS	Unpressurized Logistic Carrier Attach System
UMA	Umbilical Mechanism Assembly
UOP	Utility Outlet Panel
URL	Uniform Resource Locator
USA	United Space Alliance
USOS	United States On-Orbit Segment
USS	United States Segment
VAJ	Vacuum Access Jumper
VBSP	Video Baseband Signal Processor
VDA-2	Vapor Diffusion Apparatus – Second Generation
VDS	Video Distribution System
VDU	Video Distribution Unit
VES	Vacuum Exhaust System
VGS	Video Graphics Software
VPMP	Vented Payload Mounting Panel
VRCS	Vernier Reaction Control System
VRCV	Vent/Relief Control Valve

VRIV	Vent/Relief Isolation Valve
VRS	Vacuum Resource System
VRV	Vent/Relief Valve
VSC	Video Signal Controller
VSU	Video Switch Unit
VSW	Video Switch
VTR	Video Tape Recorder
WHS	Workstation Host Software
WRM	Water Recovery and Management
WS	Water Separator
WVA	Water Vent Assembly
WVS	Wireless Video System
XCF	X-ray Crystallography Facility
ZSR	Zero-g Stowage Rack

RUSSIAN Acronyms and Abbreviations

АСА-Г	Active/Hybrid Docking Assembly
АСП-Б	Passive Docking Assembly
АСПП	Androgynous Peripheral Docking System (APDS)
ГА	Pressurized Adapter
ПГО	Instrumentation Cargo Compartment
ПГО1	Instrument Module 1
ПГО2	Instrument Module 2
ПГО3	Instrument Module 3
ПрК	Transfer Tunnel
ПхО	Transfer Compartment
РО	Working Compartment
ТОРУ	Teleoperator Control Mode

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, Fla.; Marshall Space Flight Center, Huntsville, Ala.; Dryden Flight Research Center, Edwards, Calif.; Johnson Space Center, Houston, Texas; 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 news center.

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

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.

Media Contacts

Dwayne Brown
NASA Headquarters
Washington
Dwayne.brown@hq.nasa.gov
Space Shuttle/Space Station Policy
202-358-1726

Debbie Rahn
NASA Headquarters
Washington
Debbie.rahn@hq.nasa.gov
International Partners
202-358-1638

Donald Savage
NASA Headquarters
Washington
donald.savage@hq.nasa.gov
Space Science Policy, Budget
202-358-1727

Eileen Hawley
Johnson Space Center
Houston
Eileen.hawley1@jsc.nasa.gov
Astronauts/Mission Operations
281-483-5111

George Diller
Kennedy Space Center
Kennedy Space Center, Fla.
George.Diller-1@ksc.nasa.gov
Space Shuttle Launch Operations
321-867-2468

Bruce Buckingham
Kennedy Space Center
Kennedy Space Center, Fla.
Bruce.Buckingham-1@kmail.ksc.nasa.gov
Launch Operations
321-867-2468

Kari Kelley Allen
The Boeing Company
Houston
Kari.k.allen@boeing.com
International Space Station
281-226-4844

Glen Golightly
The Boeing Company
Huntington Beach, Calif.
Robert.g.golightly@boeing.com
Space Shuttle
714-372-4742

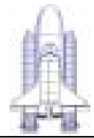
Dan Beck
Boeing Rocketdyne
Canoga Park, Calif.
Daniel.c.beck@boeing.com
Space Shuttle Main Engines
818-586-4572

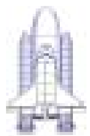
Jack King
United Space Alliance
Kennedy Space Center, Fla.
KingJW@usafoo.unitedspacealliance.com
Shuttle Processing
321-861-4358

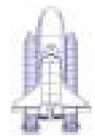
Dave Drachlis
Marshall Space Flight Center
Huntsville, Ala.
Dave.Drachlis@msfc.nasa.gov
Space Shuttle
256-544-0034

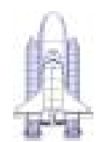
SHUTTLE FLIGHTS AS OF APRIL 2001

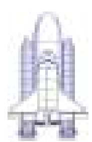
108 TOTAL FLIGHTS OF THE SHUTTLE SYSTEM -- 83 SINCE RETURN TO FLIGHT











		STS-105 08/10/01 – 08/22/01		
		STS-102 03/08/01 – 03/21/01		
		STS-92 10/11/00 - 10/24/00		
STS-109 03/01/02 – 03/12/02		STS-103 12/19/99 - 12/27/99		
STS-93 07/23/99 - 07/27/99		STS-96 05/27/99 - 06/06/99		
STS-90 04/17/98 - 05/03/98		STS-95 10/29/98 - 11/07/98		
STS-87 11/19/97 - 12/05/97		STS-91 06/02/09 - 06/12/98	STS-104 07/12/01 – 07/24/01	
STS-94 07/01/97 - 07/17/97		STS-85 08/07/97 - 08/19/97	STS-98 02/07/01 - 02/20/01	
STS-83 04/04/97 - 04/08/97		STS-82 02/11//97 - 02/21/97	STS-106 09/08/00 - 09/20/00	
STS-80 11/19/96 - 12/07/96		STS-70 07/13/95 - 07/22/95	STS-101 05/19/00 - 05/29/00	
STS-78 06/20/96 - 07/07/96		STS-63 02/03/95 - 02/11/95	STS-86 09/25/97 - 10/06/97	
STS-75 02/22/96 - 03/09/96		STS-64 09/09/94 - 09/20/94	STS-84 05/15/97 - 05/24/97	
STS-73 10/20/95 - 11/05/95		STS-60 02/03/94 - 02/11/94	STS-81 01/12/97 - 01/22/97	
STS-65 07/08/94 - 07/23/94		STS-51 09/12/93 - 09/22/93	STS-79 09/16/96 - 09/26/96	STS-108 12/05/01 – 12/17/01
STS-62 03/04/94 - 03/18/94		STS-56 04/08/83 - 04/17/93	STS-76 03/22/96 - 03/31/96	STS-100 04/19/01 – 05/01/01
STS-58 10/18/93 - 11/01/93		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-55 04/26/93 - 05/06/93		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-52 10/22/92 - 11/01/92		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-50 06/25/92 - 07/09/92		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-40 06/05/91 - 06/14/91		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-35 12/02/90 - 12/10/90	STS-51L 01/28/86	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-32 01/09/90 - 01/20/90	STS-61A 10/30/85 - 11/06/85	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-28 08/08/89 - 08/13/89	STS-51F 07/29/85 - 08/06/85	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-61C 01/12/86 - 01/18/86	STS-51B 04/29/85 - 05/06/85	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-9 11/28/83 - 12/08/83	STS-41G 10/05/84 - 10/13/84	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-5 11/11/82 - 11/16/82	STS-41C 04/06/84 - 04/13/84	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-4 06/27/82 - 07/04/82	STS-41B 02/03/84 - 02/11/84	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-3 03/22/82 - 03/30/82	STS-8 08/30/83 - 09/05/83	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-2 11/12/81 - 11/14/81	STS-7 06/18/83 - 06/24/83	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-1 04/12/81 - 04/14/81	STS-6 04/04/83 - 04/09/83	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 (27 flights)	**OV-099 Challenger (10 flights)**	**OV-103 Discovery (30 flights)**	**OV-104 Atlantis (24 flights)**	**OV-105 Endeavour (17 flights)**

Table prepared by Richard W. Orloff, 06/02/2002