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International Space Station

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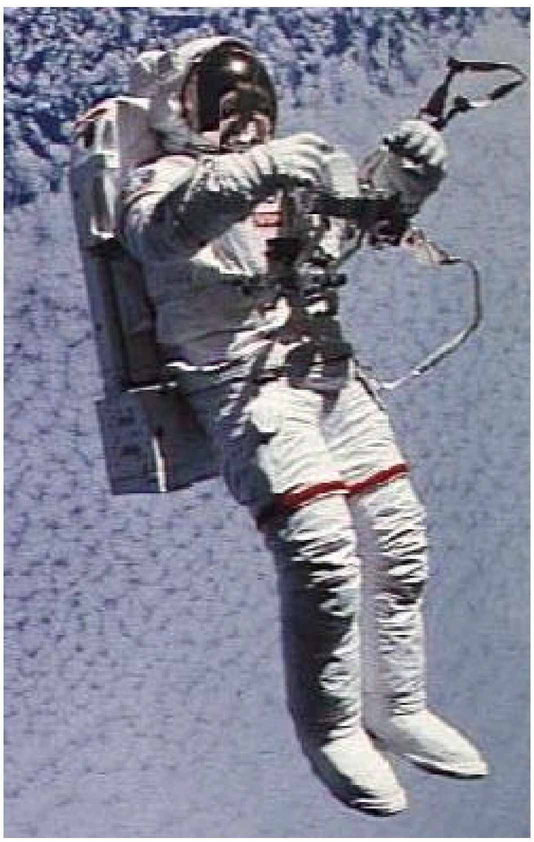
International Space Station Assembly: *A Construction Site in Orbit*

With precise grace, an overhead crane swings a 10-ton building block into position. Then, workers move in, climbing on to the structure and using hand and power tools to bolt the pieces together. It is a workaday scene that could be found on almost any city street corner, but this construction site is 250 miles up – in the airless reaches of space, where conditions alternate hourly between freezing and searing. The construction workers are astronauts, the cranes are a new generation of space robotics and the skyscraper taking shape is the International Space Station.



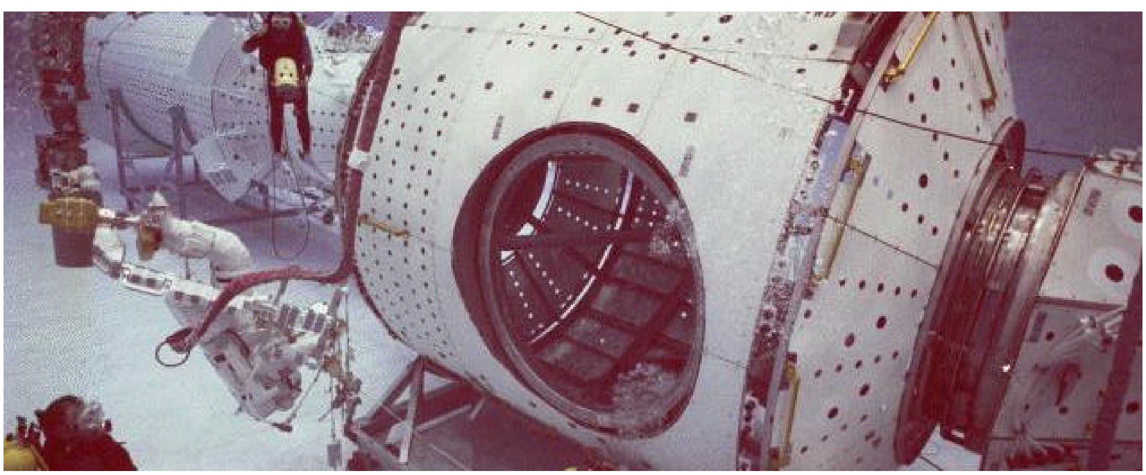
Astronaut Mark Lee test flies a jet-pack "life jacket" for spacewalkers during a 1994 Shuttle mission, one of a dozen past missions where spacewalking tests were conducted to prepare for International Space Station assembly

To assemble the 1-million pound International Space Station, Earth orbit has become a day-to-day construction site for the next five years. Humankind has begun a move off of the planet Earth of unprecedented scale. Astronauts will perform more spacewalks in the next five years than have been conducted since space flight began, more than two and half times as many. They will be assisted by an "inch-worming" robotic arm; a two-fingered "Canada hand;" and maybe even a free-flying robotic "eye" that can circle and inspect the station. Before the station's assembly is completed, more than 100 different components launched on about 46 space flights – using three different types of rockets – will have been bolted, latched, wired, plumbed and fastened together.

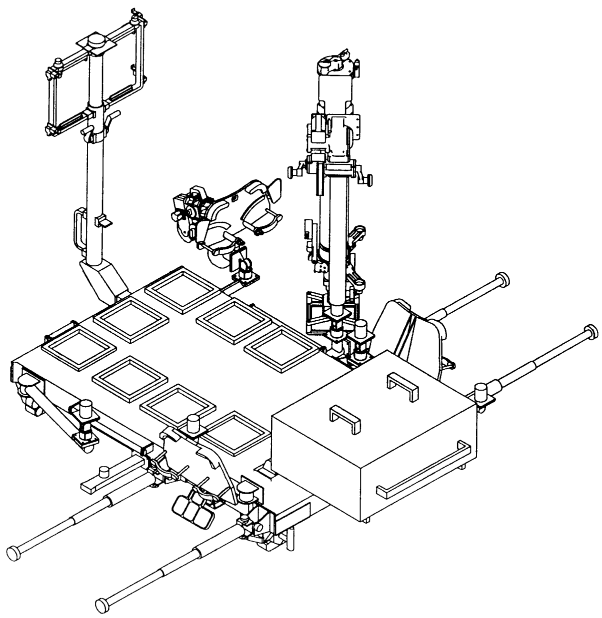
Because of the unprecedented complexity, NASA expects to encounter surprises during the orbital construction work. But to prepare for the challenges, engineers and astronauts have been methodically practicing procedures, preparing tools, testing equipment and building experience during more than a decade of spacewalking flight tests. A total of 37 Space Shuttle missions are scheduled to assemble, outfit and begin research use of the station from 1998 to 2004. Two of those have been completed. About 160 spacewalks – four already completed -- totaling 960 clock hours, or 1,920 man-hours, will be performed during that time to assemble and maintain the station. Since astronaut Ed White stepped out of an orbiting Gemini spacecraft in 1964 to become the first American to walk in space, NASA has conducted about 377 hours of spacewalks. A cooperative effort by 16 nations, the International Space Station will provide living quarters and science labs for stays by up to seven astronauts. In building, operating, and performing research on the station, humanity also gains experience needed for future travels beyond Earth orbit.

Preparing for Hands-On Construction in Space

Recognizing the challenge and complexity of building the International Space Station, NASA has made a concerted effort for more than a decade to develop and flight test the spacewalk equipment needed; refine spacewalk training; and build spacewalk, or extravehicular activity (EVA), experience for astronauts, engineers and flight controllers. Since 1991, more than a dozen "practice" spacewalks have been conducted during Space



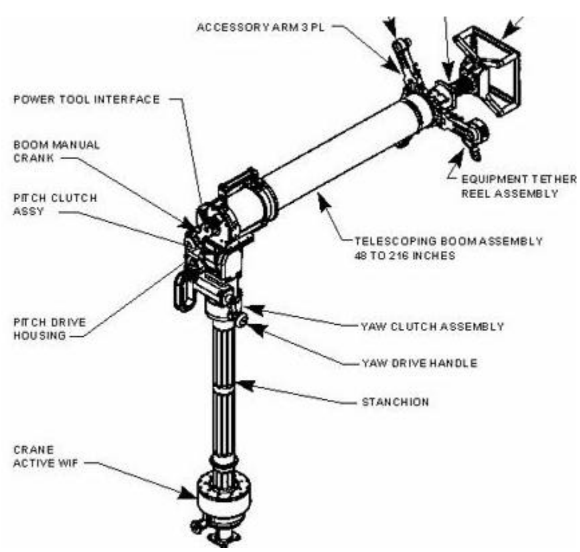
Neutral Buoyancy Laboratory: Dress Rehearsal for Spacewalking -- *The 6.5-million-gallon Neutral Buoyancy Laboratory (NBL) pool is the primary facility used to train spacewalkers for station assembly. Neutral buoyancy means an object, or person, neither floats nor sinks, imitating weightlessness. Opened in 1997 at the Johnson Space Center in Houston, the NBL replaced a smaller facility which could not hold the giant station components. But even at 202 feet long, 102 feet wide and 40 feet deep, the new pool still cannot hold a fully assembled International Space Station mockup.*



CETA cart flight-tested on STS-37 in 1991

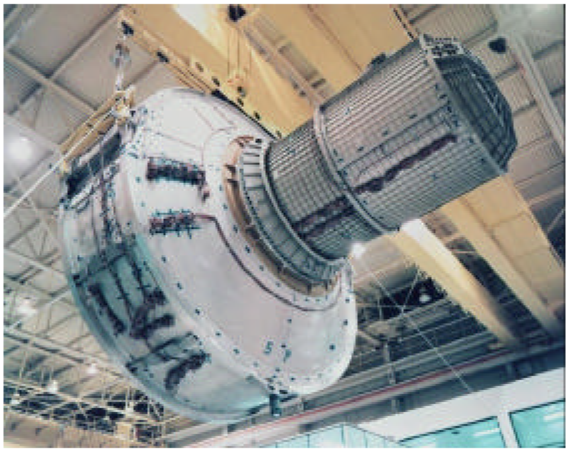
Shuttle flights as part of NASA's preparations. In addition, two servicing missions for the Hubble Space Telescope have helped prepare for the intricate work needed to build the station. Many of the astronauts who gained experience during these "practice" spacewalks will bring that knowledge to bear during future spacewalks as the station's orbital assembly begins. The flight-testing of EVA equipment designed for use aboard the International Space Station began on the first spacewalk NASA conducted after the Space Shuttle's return to flight following the Challenger accident. On Shuttle mission STS-37 in April 1991, astronauts Jerry Ross and Jay Apt performed a spacewalk to test a Crew and Equipment Translation Aid (CETA) cart designed for use in assisting astronauts to move about the football field-long truss of the completed station. Two such carts are now planned for launch to the station during its assembly. Ross served as the lead spacewalker on the first station assembly mission, Shuttle mission STS-88 in December 1998. Since 1991, other spacewalks have evaluated new tethers, tools, foot restraints, handling large masses, a jet pack "life jacket," spacesuit enhancements and even the planned station lettering and toolboxes.

To prepare for International Space Station assembly in earnest, NASA announced the first International Space Station EVA assembly crew, Ross and Jim Newman on STS-88, in August 1996. In June 1997, five more crews of station assembly spacewalkers were named to complete the first six Shuttle assembly missions, some of them more than two years ahead of their scheduled mission, much earlier than is traditional. The early naming of crew members has allowed the astronauts additional time to train for their complex and crucial missions.



"Crane" for handling large station pieces

__Taking a Walk: Working Outside the International Space Station__

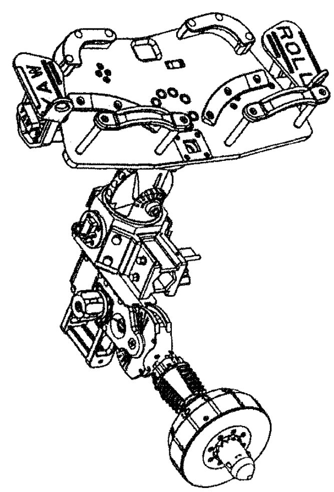


Station airlock under construction

During the first nine Shuttle assembly missions, there is no U.S. capability for spacewalks to be conducted from the station without the Space Shuttle present. The Russian Service Module provides a capability for station-based Russian spacewalks using only Russian spacesuits, but the U.S. capability will not be available until the Joint Airlock Module is attached to the station during the ninth Space Shuttle assembly mission, STS-104.

The Joint Airlock Module, which has the capability to be used by both Russian and U.S. spacesuit designs, consists of two sections, a "crew lock" that is used to exit the station and begin a spacewalk and an "equipment lock" used for storing gear. The equipment lock also will be used for overnight "campouts" by the crew, during which the pressure in the Joint Airlock Module is lowered to 10.2 pounds per square inch (psi), while the rest of the station remains at the normal sea level atmospheric pressure of 14.7 psi.

The night spent at 10.2 psi in the Airlock purges nitrogen from the spacewalkers' bodies and prevents decompression sickness, commonly called "the bends," when they go to the 4.3 psi pure oxygen atmosphere of a spacesuit. Station crew members could perform a spacewalk directly from the 14.7 psi cabin atmosphere, but they would have to go through a several hours-long prebreathe of pure oxygen first. The Airlock "campout" shortens the pure oxygen prebreathe time to only minutes for the crew. The protocol is similar to a procedure commonly used in advance of Space Shuttle spacewalks in which the Shuttle's cabin pressure is lowered to 10.2 psi at least a day ahead of the EVA.



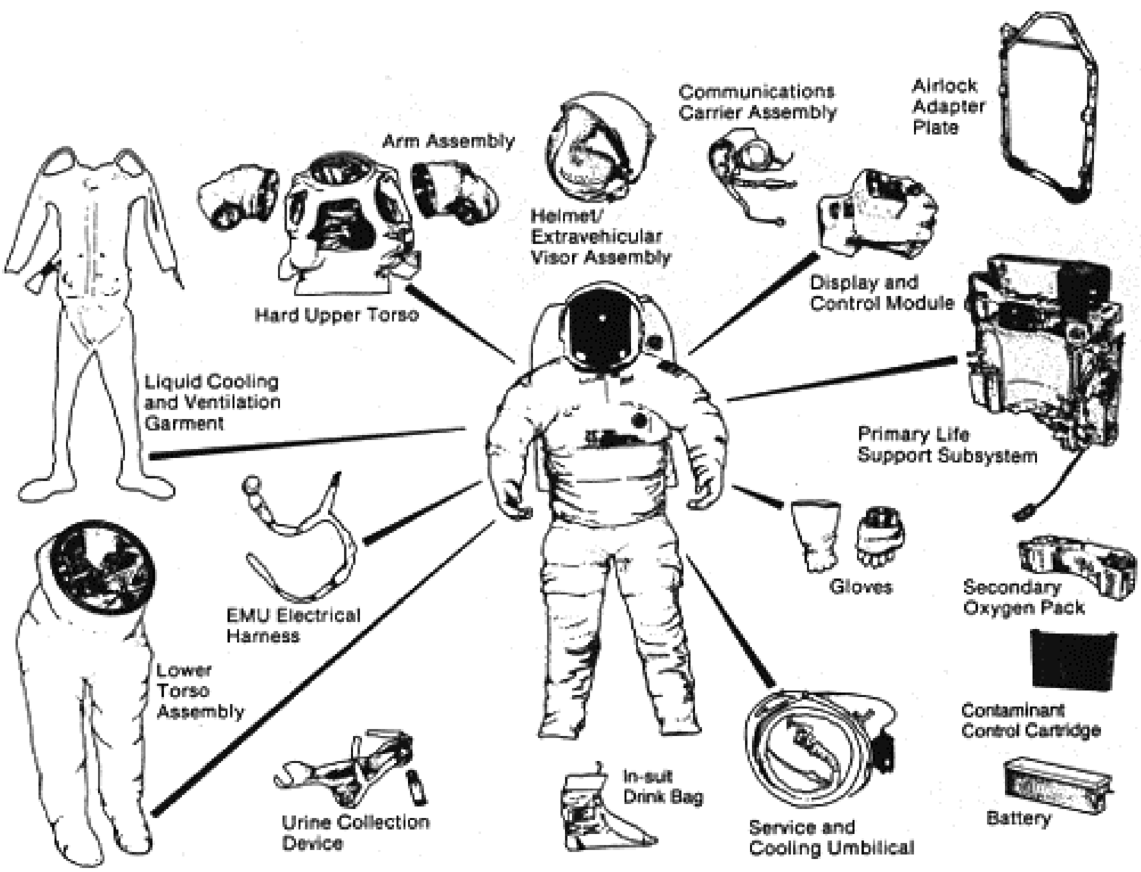
Swiveling foot platform for spacewalkers

After the Joint Airlock Module is operational, the philosophy of spacewalk training will shift due to the increasing complexity of the station and the ability of the station crew to perform spacewalks. Rather than attempting to train station crew members for every EVA task they may be called upon to perform during a mission, training will increasingly aim toward providing crew members with a general suite of EVA skills. The station's growing size and complexity will make it virtually impossible for astronauts to train for every possible contingency and maintenance EVA, as is the case in training for Shuttle missions.

Workclothes for Orbit: Spacesuit Enhancements for the International Space Station

In addition to new spacewalking tools and philosophies for assembly of the International Space Station, spacewalkers will have an enhanced spacesuit. The Shuttle spacesuit, or Extravehicular Mobility Unit (EMU) as it is technically called, is designed for sizing and maintenance between flights by skilled specialists on Earth, a difficult if not impossible requirement for astronauts aboard the station. The International Space Station spacesuit will be stored in orbit and be certified for up to 25 spacewalks before it must be returned to Earth for refurbishment. It will be able to be adjusted in flight to fit different astronauts and be easily cleaned and refurbished between spacewalks onboard the station. In addition, assembly work on the station will be done in much colder temperatures than most Space Shuttle spacewalks. Unlike the Shuttle, the station cannot be turned to provide the most optimum sunlight to moderate temperatures during an EVA.

Enhancements to the suit to better prepare it for assembly and use aboard the station include: easily replaceable internal parts; reusable carbon dioxide removal cartridges; metal sizing rings that allow in-flight suit adjustments to fit different crew members; new gloves with enhanced dexterity; a new radio with more channels to allow up to five people to talk at one time; warmth enhancements such as fingertip heaters and a cooling system shutoff; new helmet-mounted flood and spot lights; and a jet-pack "life jacket" called SAFER to



From more warmth to the ability to alter sizes, spacesuits have been redesigned for assembly work

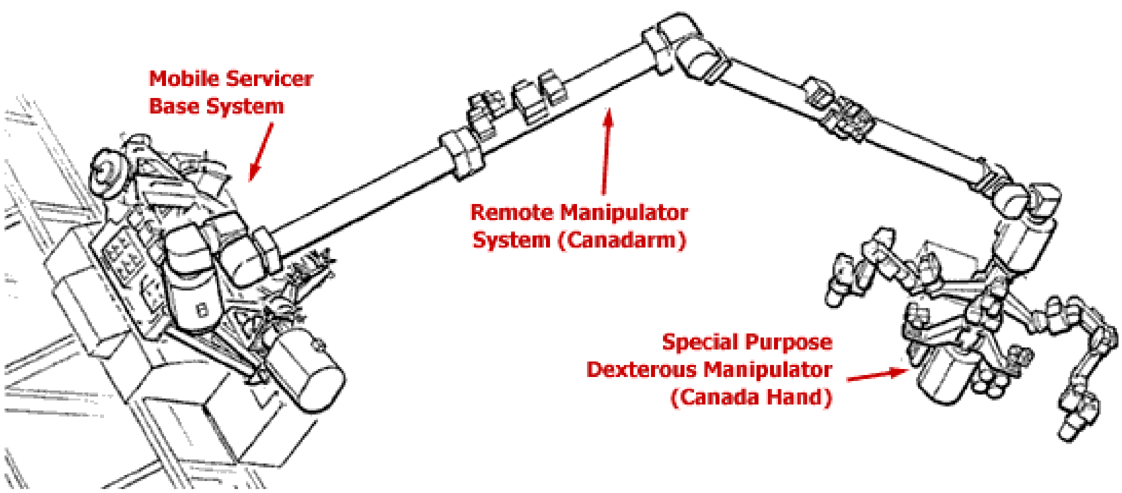
allow an accidentally untethered astronaut to fly back to the station in an emergency.

A New Generation of Space Robotics

To build and maintain the International Space Station, spacewalking astronauts will work in partnership with a new generation of space robotics. The Space Shuttle's mechanical arm and a new Space Station arm will operate both as "space cranes" to precisely maneuver large modules and components and also as space "cherry pickers" to maneuver astronauts to work areas.

The Shuttle's Canadian-built mechanical arm has been enhanced with a new "Space Vision System" (SVS) that will help the operator literally see around corners. Tested on past Space Shuttle missions STS-74, STS-80 and STS-85, the SVS uses video image processing and a series of markings on the objects being maneuvered to develop a graphical laptop computer display to assist the arm operator. It allows the Shuttle arm to be operated with great precision even when visibility is obstructed, and the system was used operationally for the first time during the first assembly mission as astronaut Nancy Currie, with her view partially obstructed, attached the first station component, the Zarya control module, to the second component, the Unity connecting module.

Canada also is building the new station mechanical arm. Called the Space Station Remote Manipulator System (SSRMS), the 55-foot-long arm will be launched in 2000, early in the



Space Station Remote Manipulator System: a new generation of space robotics

station's assembly sequence. The station arm will have the new capability to move around the station's exterior like an inchworm, locking its free end on one of many special fixtures, called Power and Data Grapple Fixtures (PDGF), placed strategically around the station, and then detaching its other end and pivoting it forward. In addition, the station arm eventually will be able to ride on a Mobile Servicing System (MSS) platform that will move on tracks along the length of the station's 360-foot truss, putting much of the station within grasp of the arm.

Canada also is providing a new robotic "Canada Hand" for the station, called the Special Purpose Dexterous Manipulator (SPDM), scheduled to be launched in 2002. The "hand" consists of two small robotic arms that can be attached to the end of the main station arm to conduct more intricate maintenance tasks.

Two other robotic arms will be on the International Space Station. A European Robotic Arm (ERA) built by the European Space Agency will be used for maintenance on the Russian segment of the station and the Japanese laboratory module will include a Japanese robotic arm that will tend exterior experiments mounted on a "back porch" of the lab.

In addition to mechanical arms, other robotics that may be used aboard the station include a free-flying robotic camera, a prototype of which was tested during a 1997 Space Shuttle mission, may be used to inspect the exterior of the station, including the acre of solar panels. Called the AERCam, more flight tests may be planned on future Shuttle missions.

Unity and Zarya modules as seen from the crew cabin of the Space Shuttle Endeavour in December 1998 during the first Space Shuttle mission to assemble the International Space Station, mission STS-88. 35 more Space Shuttle flights and eight Russian launches will follow, joining more than 100 different components together in orbit to complete the station in 2004.

Extravehicular Activities Planned for International Space Station Assembly

STS-88/ISS-2A, First Shuttle Assembly Flight: Jerry Ross and James Newman, Dec. 4-15, 1999

Veteran EVA astronauts Ross and Newman performed three spacewalks totalling 21 hours, 22 minutes over five days to finish connections between the Zarya control module and Unity, a station connecting module. Ross became the most experienced U.S. spacewalker ever with a career total of 44 hours and nine minutes on seven spacewalks. The three spacewalks made 40 different electrical and data connections between the Zarya module, the Unity module and the two attached mating adapters. They also installed U.S. early communications system components on the exterior of Unity and freed two stuck navigation antennas on the exterior of Zarya.

STS-92/ISS-3A, Fourth Space Shuttle Assembly Flight: Leroy Chaio, Jeff Wisoff, Michael Lopez-Alegria, and Bill McArthur

The fourth International Space Station assembly flight (the second assembly mission, STS-96/ISS 2A.1, included one spacewalk dedicated to equipment transfer and logistics for ISS) includes four EVAs over four days to complete the connection of an early station exterior framework, called the Z1 truss, and a third pressurized mating adapter (PMA-3) to Unity. The Z-1 truss contains gyroscopes to assist in maintaining the station's orientation and communications equipment, both systems that will be activated later in assembly. Two teams of two spacewalkers each will alternate so each team gets a day off. This approach was recommended by the STS-37 and STS-49 crews and first implemented on STS-61.

- EVA 1 **-** Chiao and Wisoff will relocate the S-band antennas installed by Ross and Newman to their permanent place on truss Z1. They then will remove Z1 thermal shrouds, connect umbilicals linking Unity and the Z1 Truss and install power converters and the Ku-band antenna on its folded boom.

- EVA 2 **-** Lopez-Alegria and McArthur will monitor as the Shuttle robotic arm grasps PMA 3 and prepares to unberth it from the carrier in the Shuttle's cargo bay. After the latching mechanisms holding the mating adapter in place are released, the spacewalkers will monitor as the arm lifts PMA 3 from the orbiter's bay to ensure that it does not bump into either the station or Shuttle structures. The Shuttle arm then berths PMA 3 to Unity where it will become the future docking port for the Shuttle on the fourth and fifth station assembly missions. The astronauts will then connect the primary umbilical bundle linking the two station components.

- EVA 3 **-** Chiao and Wisoff will connect the redundant umbilical linking PMA 3 with Unity and unfold the Ku-band antenna boom. They will remove tool boxes from the Spacelab pallet in the shuttle cargo bay and install them on the Z1 truss. They will also remove launch locks from the Z1 truss and take photos of their work to aid the fourth station assembly crew (flight 4A).

- EVA 4 **-** Lopez-Alegria and McArthur will deploy a tray holding cables and hoses for Z1 truss utilities and then store tools to be used on assembly mission 4A. They also will remove launch restraints from the umbilicals that will link the Z1 truss to the Lab module during assembly flight 5A and snap photos to familiarize upcoming crews with the worksite.

STS-97/ISS-4A, Fifth Shuttle Assembly Flight: Joe Tanner and Carlos Noriega

On the fifth International Space Station assembly flight, the first large U.S. solar arrays will be attached to the station. The Shuttle arm will be used to hoist a new truss segment, designated P6, into place on top of truss segment Z1, installed on STS-92. The new truss carries the two folded solar arrays and three thermal radiators that will extend by remote command after the truss is installed.

- EVA 1 **-** Tanner and Noriega will monitor as the Shuttle arm berths truss segment P6 on top of the Z1 framework, and they then will make structural attachments; connect power, data, communications and utility cables between the two segments; and remove launch restraints to prepare to deploy the solar arrays.

- EVA 2 **-** The astronauts will reconfigure the P6 power system to provide power to the International Space Station. They will then prepare and monitor deployment of the Photovoltaic thermal radiator, remove shrouds and relocate equipment.

STS-98/ISS-5A, Sixth Shuttle Assembly Flight: Mark Lee and Tom Jones

This mission adds the U.S. Laboratory module, maneuvered into place to berth to Node 1 by the Shuttle's mechanical arm. The arm also will maneuver one of the pressurized mating adapters (PMA) to attach it to the end of the U.S. Lab. Lee and Jones will conduct three EVAs in five days to complete the connections.

- EVA 1 **-** Lee and Jones will monitor as the Shuttle arm transfers PMA-2 to a temporary holding place, then will configure Node 1 and the Lab for berthing. They will stand by as the arm hoists the bus-sized Lab into place, then will connect umbilicals from Node 1 and the power system to the U.S. Lab.

- EVA 2 **-** Lee and Jones will connect umbilicals from the Z-1 framework to the Lab, remove a vent cover, and install a Power and Data Grapple Fixture (PDGF) on the Lab. The PDGF provides an initial attachment point for the Space Station Remote Manipulator System mechanical arm, which will be installed on mission 6A.

- EVA 3 **-** The astronauts will prepare the Lab to receive PMA 2. After the Shuttle arm reberths PMA 2 to the end of the Lab, the astronauts will connect umbilicals between the adapter and Lab. They then will prepare radiators for deployment and install a shutter mechanism on the Lab window.

STS-100/ISS-6A, Eighth Shuttle Assembly Flight: Chris Hadfield and Robert Curbeam

Curbeam and Canadian astronaut Hadfield will perform three EVAs to install an Ultra-High Frequency radio antenna and the Canadian-contributed SSRMS robot arm. The SSRMS will grapple the PDGF attachment point installed on the Lab during assembly mission 5A.

STS-104/ ISS-7A, Ninth Shuttle Assembly Flight: Mike Gernhardt and James Reilly

U.S. station-based EVAs will become possible following this assembly flight. Gernhardt and Reilly will perform three spacewalks to install the station's Joint Airlock Module and High Pressure Gas Assembly on Node 1. Prior to this mission, U.S. spacewalks were only possible from the Space Shuttle when docked to the International Space Station. With the station Airlock in place, U.S. spacewalks can be performed by station resident crews. Spacewalks will be possible using Russian equipment from the Russian segment with the arrival of the Service Module, however. With the arrival of the U.S. airlock, the philosophy of spacewalks for station assembly becomes more flexible.

Additional International Space Station Assembly Sequence Highlights: EVA and Robotics

Shuttle Assembly Mission 8A/STS-108
Astronauts add the airlock spur, a "bridge" for access between the Airlock and station truss.

Shuttle Utilization Flight (UF)-2/STS-109
The Shuttle delivers the Mobile Base System, making the station arm mobile on the truss. This lays the groundwork for future assembly of the 350-foot-long truss.

Shuttle Assembly Mission 9A/STS-111
The astronauts install the first of two CETA carts that assist them in moving along the truss.

Shuttle Assembly Mission 11A/STS112
The Shuttle delivers the second CETA cart.

Shuttle Assembly Mission 9A.1/STS-114
The Shuttle delivers Russia's Science Power Platform (SPP). The station arm inchworms to an attachment point on Zarya. The shuttle arm then hands the SPP to the station arm to install it.

Shuttle Utilization Flight (UF)-4/STS-127
The Canadian Special Purpose Dexterous Manipulator (SPDM), "Canada Hand" is delivered.

Shuttle Assembly Mission 14A/STS-130
The Shuttle delivers the Cupola to aid robotics and EVA visibility, as well as provide views of Earth.

History of Extravehicular Activity Preparations for Assembly of the International Space Station

STS-37, April 5-11, 1991: Jerry Ross and Jay Apt

Astronauts Jerry Ross and Jay Apt performed an unplanned EVA to free a stuck antenna crippling the $500-million Gamma Ray Observatory. The next day they tested the Crew Equipment and Translation Aid (CETA) in Atlantis payload bay. CETA is a manually operated cart capable of transporting up to 1200 pounds along the station’s truss. Two CETA carts will be added to the International Space Station during the year 2000. Ross and Apt also measured the stress astronauts at work place on station structure - important because an astronaut masses about 375 pounds while wearing the Extravehicular Mobility Unit (EMU) space suit. Linda Godwin moved equipment and astronauts using Atlantis' Shuttle Remote Manipulator System (SRMS) robot arm. Adding the unplanned EVA while still carrying out planned EVA objectives showed that NASA plans adequate margins to accomplish EVA goals in spite of contingencies.

STS-49, May 7-16, 1992: Tom Akers, Pierre Thuot, Rick Hieb, and Kathy Thornton

After two failed attempts to retrieve the Intelsat IV satellite, astronauts Tom Akers, Pierre Thuot, and Rick Hieb performed the first 3-person EVA, successfully capturing the 32,000-pound satellite by hand. During a fourth EVA, Akers and Kathy Thornton practiced building a truss structure and moving large masses representing space station replacement parts. Originally STS-49 was to have included only three EVAs, of which only one was devoted to Intelsat VI. STS-49 pointed up NASA's need to expand its EVA experience base, but also demonstrated its built-in EVA margins and ability rapidly replan complex EVAs in the face of unexpected events. Bruce Melnick operated Endeavour’s robot arm.

STS-54, January 13-19, 1993: Greg Harbaugh and Mario Runco

Greg Harbaugh and Mario Runco gathered astronaut performance data during a 4 hour, 28 minute EVA in Endeavour’s payload bay. They tested transporting large objects by carrying each other, demonstrated large tool use by manually positioning a satellite table, and tested their ability to align heavy objects by placing each other in the bracket that holds the Shuttle space suit in the airlock. They repeated their tasks in the Weightless Environment Training Facility (WETF) water tank at NASA's Johnson Space Center in Houston after the flight to show that underwater training adequately duplicates actual EVA experience.

STS-57, June 21-July 1, 1993 G. David Low and Peter Wisoff

Astronauts G. David Low and Peter Wisoff experimented with tools, safety tethers, and large mass handling during a 5 hour, 50 minute EVA in Endeavour’s payload bay. Their EVA was originally intended to last just 4 hours, 20 minutes, but was extended to allow them to repair a stuck antenna on the EURECA satellite, again demonstrating NASA's ability to modify EVAs rapidly to take into account problems and take advantage of built-in margins. Nancy Sherlock operated the SRMS robot arm.

STS-51, September 12-22, 1993: James Newman and Carl Walz

In Discovery's payload bay astronauts James Newman and Carl Walz tested tools and foot restraints with application to both space station assembly and Hubble Space Telescope servicing. They also tested the thermal characteristics of the space suit gloves. On previous EVAs, astronauts reported numb fingers and shivering during cold orbital night. Because astronauts will frequently work in shadow on the International Space Station, NASA began work to modify the Shuttle suit to keep the astronauts warm.

STS-61, Dec. 2-13, 1993: Story Musgrave, Jeffrey Hoffman, Tom Akers, and Kathy Thornton

The first Hubble Space Telescope Servicing Mission demonstrated NASA's ability to carry out a mission including a complex series of Shuttle-based EVAs on the scale of the missions planned for the first phase of International Space Station assembly. Veteran EVA astronauts Story Musgrave, Jeffrey Hoffman, Kathy Thornton, and Tom Akers performed five complex EVAs without a hitch, showing the benefits of EVA experience and the maturity of NASA EVA training, planning, and operations. Had they experienced problems, the STS-61 EVA crew had sufficient margins available to carry out a total of eight spacewalks. Claude Nicollier operated the Shuttle arm.

STS-64, September 9-29, 1994
Mark Lee and Carl Meade

In the first untethered EVA since the Manned Maneuvering Unit flights in 1984, astronauts Mark Lee and Carl Meade tested the Simplified Aid for EVA rescue (SAFER) device, a “life jacket” for astronauts who become detached from the International Space Station, which is unable to maneuver to rescue them. Susan Helms operated Discovery’s robot arm.

STS-63, February 3-February 11, 1995
Michael Foale and Bernard Harris

STS-63 was the first EVA Development Flight Test mission, in which testing EVA for the International Space Station was a high-priority activity. Soon after Discovery completed proximity operations with Russia’s Mir space station, Michael Foale and Bernard Harris performed a 6 hour, 51 minute EVA to test large mass handling and space suit thermal modifications. They became very cold, so Mission Control terminated the EVA early. Russian cosmonaut Vladimir Titov operated the SRMS.

STS-69, September 7-18, 1995
James Voss and Michael Gernhardt

For this second EVA Development Flight Test, James Newman operated Endeavour’s SRMS robot arm. Astronauts James Voss and Michael Gernhardt tested suit enhancements, including fingertip heaters, and remained comfortably warm. They also tested planned International Space Station fasteners, power tools, tools for replacing station meteoroid and orbital debris shields and insulation blankets, and new space suit helmet lights for working at night and in shadow.

STS-72, January 11-20, 1996
Leroy Chiao, Daniel Barry, and Winston Scott

The third EVA Development Flight Test spanned two EVAs outside Endeavour. Leroy Chaio and Daniel Barry performed the first EVA; Chiao and Winston Scott performed the second. Japanese astronaut Koichi Wakata operated the RMS. They tested space suit thermal modifications, including a bypass system for shutting off coolant to the space suit; the Portable Work Platform - an astronaut tool holder and positioning aid; a rigid umbilical of the type that will carry fluid and electrical lines between International Space Station modules and trusses; connection of fluid and electrical lines between panels simulating adjacent truss segments; contingency EVA tools for the International Space Station, including an Orbital Replaceable Unit (ORU) changeout tool; an electrical line replacement kit; and the Body Restraint Tether (BRT). Turning a collar makes the BRT rigid, holding the astronaut or tool firmly in place.

STS-76, March 22- 31, 1996
Linda Godwin and Richard Clifford

The fourth EVA Development Test Flight was the first U.S. EVA outside a space station since the Skylab program in 1974. Astronauts Linda Godwin and Rich Clifford installed experiments outside Mir's Docking Module. They also tested new "interoperable" EVA equipment usable by U.S. and Russian spacewalkers wearing either U.S. EMU or Russian Orlan-M space suits. For example, Interoperable foot restraints can clamp onto both round U.S. and square Russian handrails. The International Space Station will carry sufficient interoperable hardware to allow a cosmonaut in a Russian Orlan-M space suit to assist U.S. EVA astronauts on the U.S. segment.

STS-82, February 11-21, 1997: Mark Lee, Steve Smith, Greg Harbaugh, and Joe Tanner

The second Hubble Servicing Mission gave NASA additional complex EVA experience. Astronauts Mark Lee, Steve Smith, Greg Harbaugh, and Joe Tanner performed four planned EVAs to install new components resembling the large ORUs planned for the International Space Station. An unplanned fifth EVA to mend Hubble's cracked insulation again demonstrated NASA's ability to adapt and built-in EVA margins. The astronauts tested the Shuttle space suit enhanced for use on the International Space Station. Steve Hawley operated the SRMS.

STS-86, September 25 -October 5, 1997
Scott Parazynski and Vladimir Titov

During the fifth EVA Development Flight Test, Scott Parazynski and Russian cosmonaut Vladimir Titov tested the flight model SAFER, a foot restraint usable by both U.S. and Russian space suits, and other equipment outside the Mir space station. Titov became the first non-U.S. space traveler to perform an EVA in a U.S. space suit. Russia joined the International Space Station partnership in 1993, bringing with it two decades of nearly continuous space station experience, including varied experience in EVA assembly and maintenance. Russian cosmonauts have performed more than 80 EVAs outside the Mir space station.

STS-87, November 1997:
Takao Doi and Winston Scott

During the sixth EVA Development Flight Test, Takao Doi (representing Japan's space agency, NASDA) and Winston Scott ventured outside Columbia to test techniques and equipment for handling large and small Orbital Replaceable Unit (ORU) components installed on the International Space Station's exterior. They used the ORU Transfer Device, a portable crane. Doi and Scott simulated one of the most challenging ORU transfer tasks planned for the International Space Station - moving a bulky battery. They also tested sockets and handles for manipulating and positioning equipment and new rigid tethers for restraining astronauts and equipment

Astronauts have been flight-testing tools and procedures for more than a decade in preparation to become orbital construction workers assembling the International Space Station on about 160 planned spacewalks.