HST SERVICING MISSION 3B

The Hubble Space Telescope (HST) is the first observatory designed for extensive maintenance and refurbishment in orbit. Its science instruments and many other components were planned as Orbital Replacement Units (ORU)—modular in construction with standardized fittings and accessible to astronauts. Handrails, foot restraints and other built-in features help astronauts perform servicing tasks in the Shuttle cargo bay as they orbit Earth at 17,500 mph.

NASA plans to launch HST Servicing Mission 3B (SM3B) in early 2002. The third servicing mission (SM3), originally planned for June 2000, had six scheduled extravehicular activity (EVA) days, followed by a reboost of the Telescope. However, when the progressive failure of several Rate Sensor Unit gyros left the spacecraft unable to perform science operations, NASA split SM3 into two separate flights. The first flight, designated SM3A and manifested as STS-103, was launched in December 1999 and included four scheduled EVA days. After the flight was delayed until late December, NASA reduced the number of scheduled EVAs to three to ensure that the Shuttle would be on the ground before the year 2000 rollover.

SM3A accomplishments include replacement of all three Rate Sensor Units (six gyros), NICMOS valve reconfiguration, installation of six Voltage/Temperature Improvement Kits, replacement of the DF-224 Computer with the Advanced Computer, change-out of the Fine Guidance Sensor Unit-2 and mate of the associated Optical Control Electronics Enhancement Kit connectors, change-out of the S-Band Single Access Transmitter-2, replacement of the Engineering/Science Tape Recorder-3 with a Solid

State Recorder and installation of New Outer Blanket Layers (NOBLs) over Bays 1, 9 and 10.

SM3B is manifested as STS-109 aboard the Space Shuttle *Columbia* (OV-102) to be launched to a rendezvous altitude of approximately 315 nautical miles. During the planned 11-day mission, the Shuttle will rendezvous with, capture and berth the HST to the Flight Support System (FSS). Following servicing, the Shuttle will unberth Hubble and redeploy it to its mission orbit.

Five EVA days are scheduled during the SM3B mission. *Columbia's* cargo bay is equipped with several devices to help the astronauts:
- The FSS will berth and rotate the Telescope.
- Large, specially designed equipment containers will house the ORUs.
- Astronauts will work and be maneuvered as needed from the Shuttle robot arm.

SM3B will benefit from lessons learned on NASA's previous on-orbit servicing missions: the 1984 Solar Maximum repair mission, the 1993 HST First Servicing Mission (SM1), the 1997 HST Second Servicing Mission (SM2) and the 1999 HST Third Servicing Mission (SM3A). NASA has incorporated these lessons in detailed planning and training sessions for *Columbia* crewmembers Scott Altman, Duane Carey, Nancy Currie, John Grunsfeld, James Newman, Michael Massimino and Richard Linnehan.

Reasons for Orbital Servicing

HST is a national asset and an invaluable international scientific resource that has revolutionized modern astronomy. To achieve its full potential, the Telescope will continue to conduct extensive, integrated scientific observations, including follow-up work on its many discoveries.

Although the Telescope has numerous redundant parts and safemode systems, such a complex spacecraft cannot be designed with sufficient backups to handle every contingency likely to occur during a 20-year mission. Orbital servicing is the key to keeping Hubble in operating condition. NASA's orbital servicing plans address three primary maintenance scenarios:
- Incorporating technological advances into the science instruments and ORUs
- Normal degradation of components
- Random equipment failure or malfunction.

Technological Advances. Throughout the Telescope's life, scientists and engineers have upgraded its science instruments and spacecraft systems. For example, when Hubble was launched in 1990, it was equipped with the Goddard High Resolution Spectrograph and the Faint Object Spectrograph. A second-generation instrument, the Space Telescope Imaging Spectrograph, took over the function of those two instruments—adding considerable new capabilities—when it was installed during SM2 in 1997. A slot was then available for the Near Infrared Camera and Multi-Object Spectrometer (NICMOS), which expanded the Telescope's vision into the infrared region of the spectrum. In addition, on both SM2 and SM3A a new state-of-the-art Solid State Recorder (SSR) replaced an Engineering/Science Tape Recorder (E/STR). Similarly, during SM3A the original DF-224 Computer was replaced with a faster, more powerful Advanced Computer based on the Intel 80486 microchip.

Component Degradation. Servicing plans take into account the need for routine replacements, for example, restoring HST system redundancy and limited-life items such as spacecraft thermal insulation and gyroscopes.

Equipment Failure. Given the enormous scientific potential of the Telescope—and the investment in designing, developing, building and putting it into orbit—NASA must be able to correct unforeseen problems that arise from random equipment failures or malfunctions. The Space Shuttle program provides a proven system for transporting astronauts fully trained for on-orbit servicing of the Telescope.

Originally, planners considered using the Shuttle to return the Telescope to Earth approximately every 5 years for maintenance. However, the idea was rejected for both technical and economic reasons. Returning Hubble to Earth would entail a significantly higher risk of contaminating or damaging delicate components. Ground servicing would require an expensive clean room and support facilities, including a large engineering staff, and the Telescope would be out of action for a year or more—a long time to suspend scientific observations.

Shuttle astronauts can accomplish most maintenance and refurbishment within a 10-day on-orbit mission with only a brief interruption to scientific operations and without the additional facilities and staff needed for ground servicing.

Orbital Replacement Units

Advantages of ORUs include modularity, standardization and accessibility.

Modularity. Engineers studied various technical and human factors criteria to simplify Telescope maintenance. Considering the limited time available for repairs and the astronauts' limited visibility, mobility and dexterity in the EVA environment, designers simplified the maintenance tasks by planning entire components for replacement.

ORUs are self-contained boxes installed and removed using fasteners and connectors. They range from small fuses to phone-booth-sized science instruments weighing more than 700 pounds (318 kg). Figure 2-1 shows the ORUs for SM3B.

Standardization. Standardized bolts and connectors also simplify on-orbit repairs. Captive bolts with 7/16-inch, double-height hex heads hold many ORU components in place. To remove or install the bolts, astronauts need only a 7/16-inch socket fitted to a power tool or manual wrench. Some ORUs do not contain these fasteners. When the maintenance philosophy changed from Earth-return to on-orbit servicing, other components were selected as replaceable units after their design had matured. This added a greater variety of fasteners to the servicing requirements, including non-captive 5/16-inch hex head bolts and connectors without wing tabs. Despite these exceptions, the high level of standardization among units reduces the number of tools needed for the servicing mission and simplifies astronaut training.

Accessibility. To be serviced in space, Telescope components must be seen and reached by an astronaut in a bulky pressure suit, or they must be within range of an appropriate tool. Therefore, most ORUs are mounted in equipment bays around the perimeter of the spacecraft. To access these units, astronauts simply open a large door that covers the appropriate bay.

Handrails, foot restraint sockets, tether attachments and other crew aids are essential to safe, efficient on-orbit servicing. In anticipation of such missions,

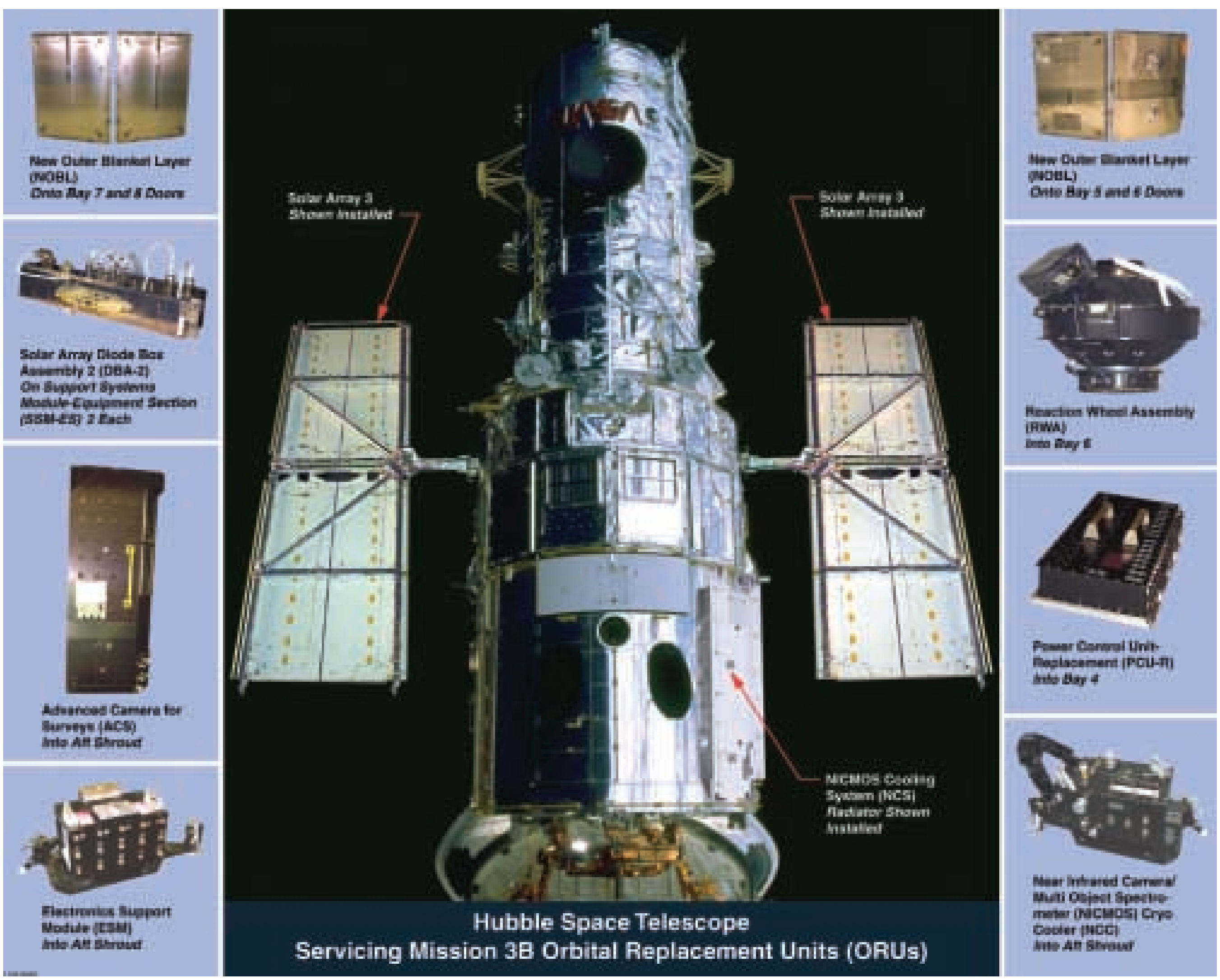

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Fig. 2-1 Hubble Space Telescope Servicing Mission 3B Orbital Replacement Units

31 foot-restraint sockets and 225 feet of handrails were designed into the Telescope. Foot restraint sockets and handrails greatly increase astronauts' mobility and stability, affording them safe worksites conveniently located near ORUs.

Crew aids such as portable lights, special tools, installation guiderails, handholds and portable foot restraints (PFR) also ease servicing of Hubble components. Additionally, foot restraints, translation aids and handrails are built into various equipment and instrument carriers specific to each servicing mission.

Shuttle Support Equipment

To assist astronauts in servicing the Telescope, *Columbia* will carry into orbit several thousand pounds of hardware and Space Support Equipment (SSE), including the Remote Manipulator System (RMS), FSS, Rigid Array Carrier (RAC), Second Axial Carrier (SAC) and Multi-Use Lightweight Equipment (MULE) carrier.

Remote Manipulator System

The *Columbia* RMS, also known as the robotic arm, will be used extensively during SM3B. The astronaut operating this device from inside the cabin is designated the intravehicular activity (IVA) crewmember. The RMS will be used to:

- Capture, berth and release the Telescope
- Transport new components, instruments and EVA astronauts between worksites
- Provide a temporary work platform for one or both EVA astronauts.

Space Support Equipment

Ground crews will install four major assemblies essential for SM3B—the FSS, RAC, SAC and MULE—in *Columbia's* cargo bay (see Fig. 2-2).

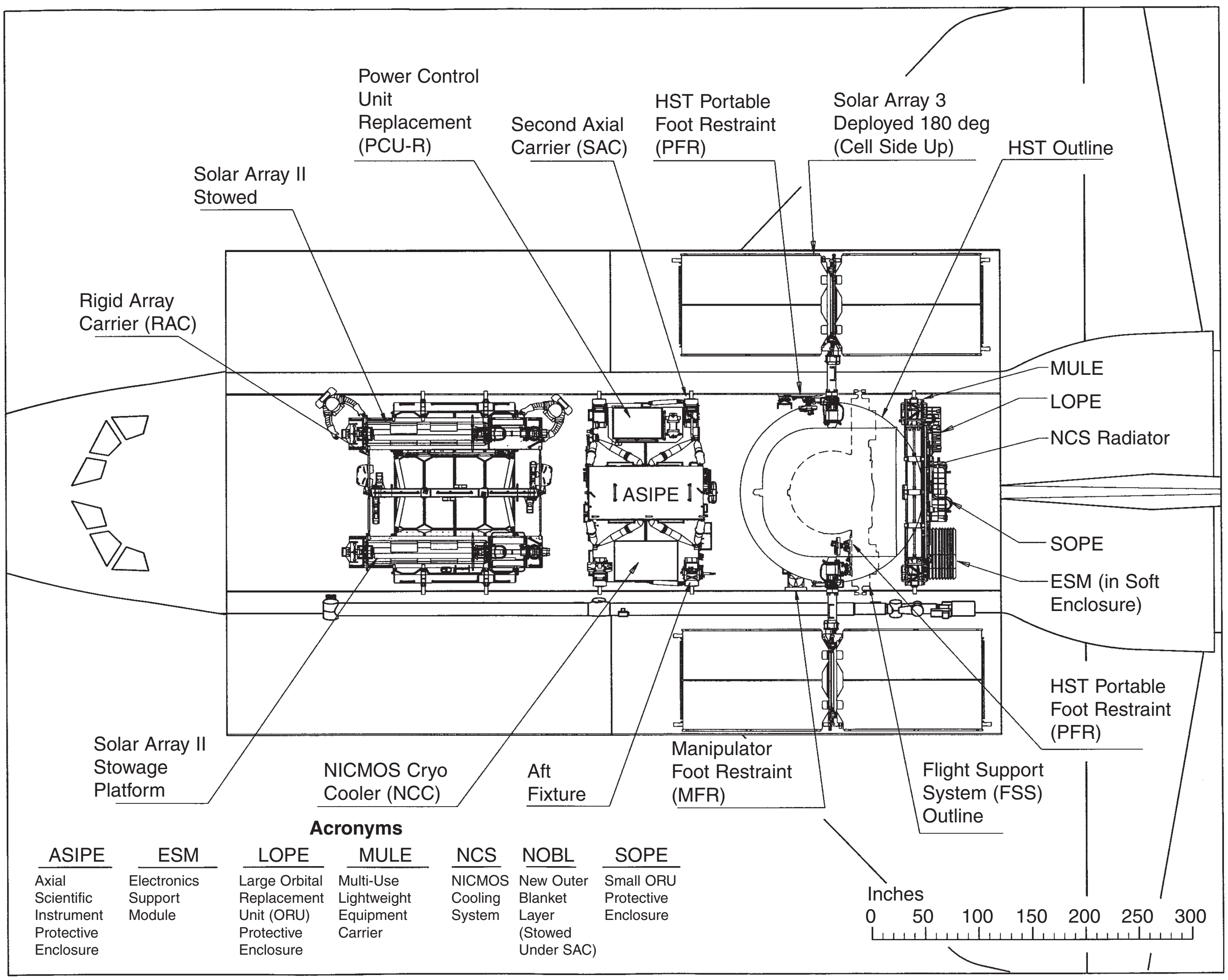
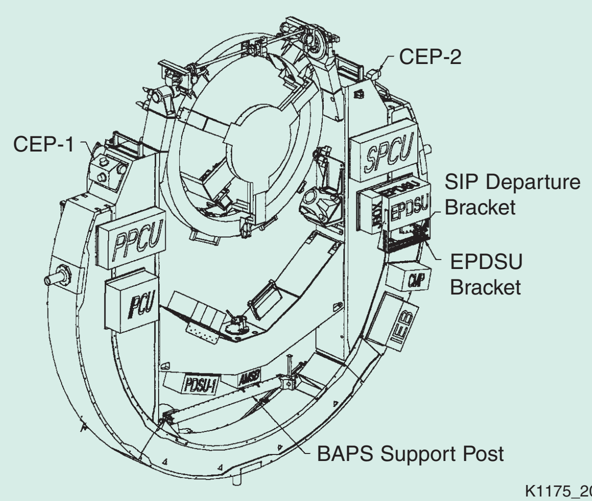


Fig. 2-2 Servicing Mission 3B Payload Bay configuration

Flight Support System

The FSS is a maintenance platform used to berth the HST in the cargo bay after the *Columbia* crew has rendezvoused with and captured the Telescope (see Fig. 2-3). The platform was adapted from the FSS first used during the 1984 Solar Maximum repair mission. It has a U-shaped cradle that spans the rear of the cargo bay. A circular berthing ring with three latches secures the Telescope to the cradle. The berthing ring can rotate the Telescope almost 360 degrees (176 degrees clockwise or counterclockwise from its null position) to give EVA astronauts access to every side of the Telescope.

The FSS also pivots to lower or raise the Telescope as required for servicing or reboosting. The FSS's umbilical cable provides power from *Columbia* to maintain thermal control of the Telescope during the servicing mission.



Acronyms

AMSB	Advanced Mechanism Selection Box
CEP	Contamination Environment Package
CMP	Contamination Monitoring Package
EPDSU	Enhanced Power Distribution and Switching Unit
IPCU	Interface Power Control Unit
PDSU	Power Distribution and Switching Unit
PPCU	Port Power Conditioning Unit
SIP	Standard Interface Panel
SPCU	Starboard Power Conditioning Unit

Fig. 2-3 Flight Support System configuration – aft view

Rigid Array Carrier

The RAC is located in *Columbia's* forward cargo bay. It has provisions for safe transport to orbit of the third-generation Solar Arrays (SA3) and associated second-generation Diode Box Assemblies (DBA2), and for return from orbit of the second-generation Solar Arrays (SA2) and their associated Diode Box Assemblies (DBA). The RAC also includes the MLI Repair Tool, two SA2 Spines, spare PIP pins, a spare DBA2, two portable connector trays, two spare SADA Clamps, the MLI Tent, Large and Small MLI Patches, four SA2 Bistem Braces, a Jettison Handle and two Auxiliary Transport Modules (ATM) to house miscellaneous smaller hardware (see Fig. 2-4).

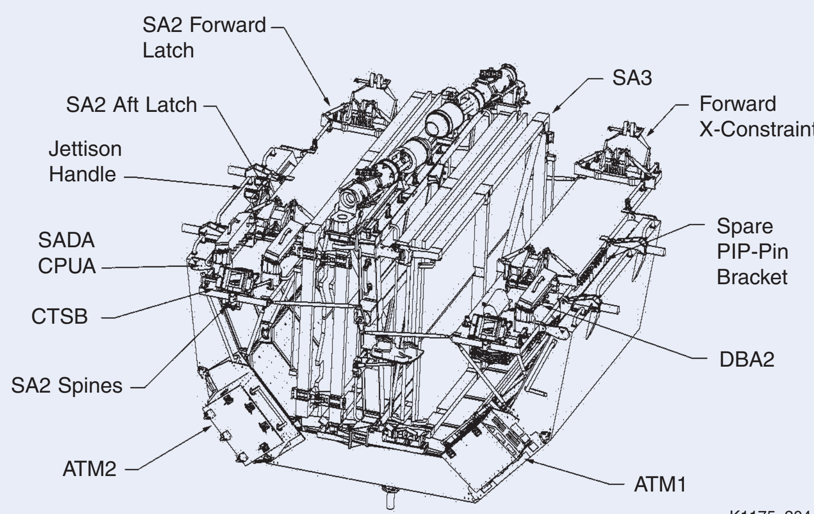


Fig. 2-4 Rigid Array Carrier configuration

Note: For clarity, MLI covers are not shown

Second Axial Carrier

The SAC is centered in *Columbia's* cargo bay. It has provisions for safe transport of ORUs to and from orbit (see Fig. 2-5). In the SM3B configuration:

- The Advanced Camera for Surveys (ACS) is stored in the Axial Scientific Instrument Protective Enclosure (ASIPE).
- The Power Control Unit (PCU) and PCU Transport Handle are stored on the starboard side.
- The NICMOS Cryo Cooler (NCC), WFPC Thermal Cover and Fixed Head Star Tracker (FHST) Covers are stored on the port side.
- The NOBL Transporter (NT) contains the new protective coverings to be installed on the Telescope equipment bay doors.
- The SAC houses other hardware, including the MLI Recovery Bag, eight Aft Shroud Latch Repair Kits, Handrail Covers and Caddies, PCU Harness Retention Device, Scientific Instrument Safety Bar, Cross Aft Shroud Harness (CASH), an Aft Fixture, two STS PFRs and an Extender, two Translation

Aids (TA), one ASIPE mini-TA and the Bays 5, 10 and DBA Thermal Covers.

The protective enclosure, its heaters and thermal insulation control the temperature of the new ORUs, providing an environment with normal operating temperatures. Struts between the ASIPE enclosure and the pallet protect Science Instruments from loads generated at liftoff and during Earth return.

Multi-Use Lightweight Equipment Carrier

The MULE is located in *Columbia's* aft cargo bay (see Fig. 2-6). It has provisions for safe transport of the NCS Radiator, Electronics Support Module (ESM), Large ORU Protective Enclosure (LOPE) and Small ORU Protective Enclosure (SOPE).

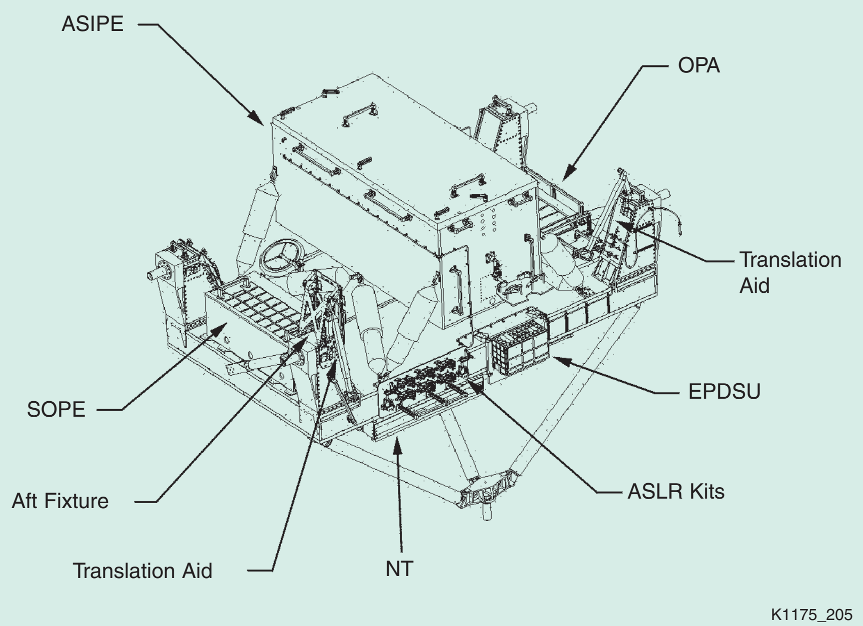


Fig. 2-5 Second Axial Carrier configuration

Astronaut Roles and Training

To prepare for SM3B, the seven-member *Columbia* crew trained extensively at NASA's Johnson Space Center (JSC) in Houston, Texas, and Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

Although there has been extensive cross training, each crewmember also has trained for specific tasks. Training for Mission Commander Scott Altman and Pilot Duane Carey focused on rendezvous and proximity operations, such as retrieval and deployment of the Telescope. The two astronauts rehearsed these operations using JSC's Shuttle Mission Simulator, a computer-supported training system. In addition, they received IVA training: helping the EVA astronauts into suits and monitoring their activities outside the *Columbia* cabin.

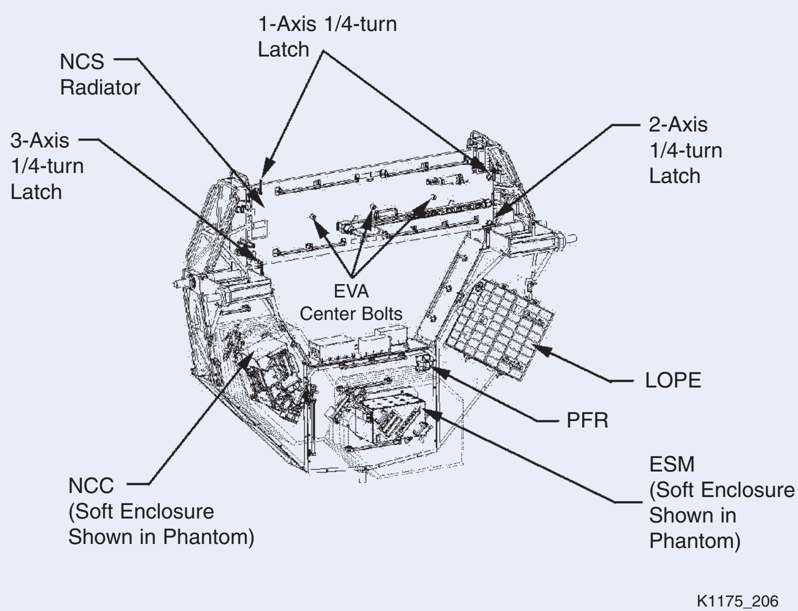


Fig. 2-6 Multi-Use Lightweight Equipment Carrier configuration

The five Mission Specialists also received specific training, starting with classroom instruction on the various ORUs, tools and crew aids, SSE such as the RMS (the robotic arm) and the FSS. Principal operator of the robotic arm is Mission Specialist Nancy Currie, who also performs IVA duties. The alternate RMS operator is Commander Altman.

Currie trained specifically for capture and redeployment of the Telescope, rotating and pivoting the Telescope on the FSS and related contingencies. These operations were simulated with JSC's Manipulator Development Facility, which includes a mockup of the robotic arm and a suspended helium balloon with dimensions and grapple fixtures similar to those on the Telescope. RMS training also took place at JSC's Neutral Buoyancy Laboratory (NBL), enabling the RMS operator and alternates to work with individual team members. For hands-on HST servicing, EVA crewmembers work in teams of two in the cargo bay. Astronauts John Grunsfeld, Richard Linnehan, James Newman and Michael Massimino logged many days of training for this important role in the NBL, a 40-foot (12-m)-deep water tank (see Fig. 2-7).

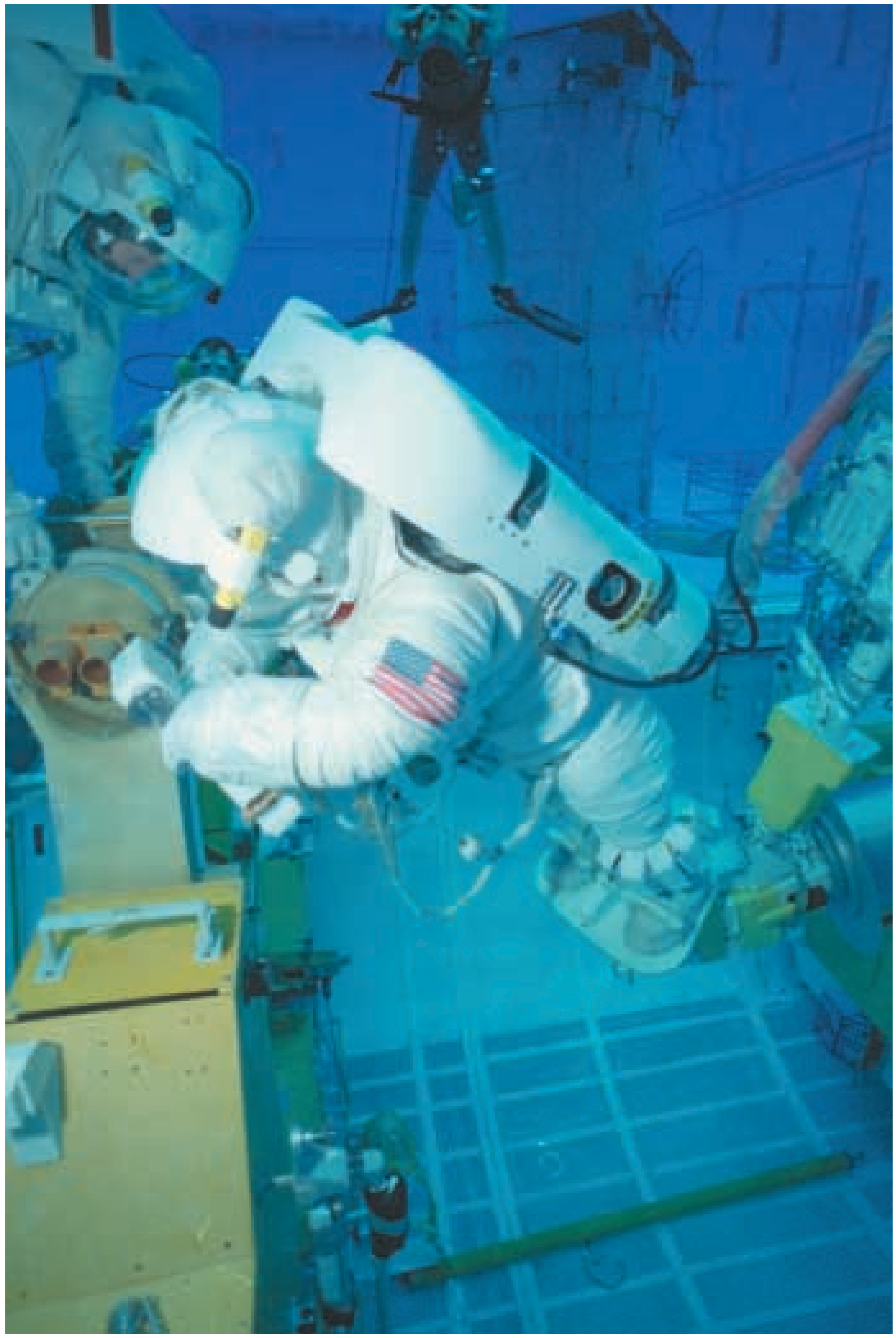


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Fig. 2-7 Neutral Buoyancy Laboratory at Johnson Space Center

In the NBL, pressure-suited astronauts and their equipment are made neutrally buoyant, a condition that simulates weightlessness. Underwater mockups of the Telescope, FSS, RAC, SAC, MULE, RMS and the Shuttle cargo bay enabled the astronauts to practice the entire SM3B EVA servicing. Such training activities help the astronauts efficiently use the limited number of days (5) and duration (6 hours) of each EVA period.

Other training aids at JSC helped recreate orbital conditions for the *Columbia* crew. In the weightlessness of space, the tiniest movement can set instruments weighing several hundred pounds, such as ACS, into motion. To simulate the delicate on-orbit conditions, models of the instruments are placed on pads above a stainless steel floor and floated on a thin layer of pressurized gas. This allows crewmembers to practice carefully nudging the instruments into their proper locations.

Astronauts also used virtual reality technologies in their training. This kind of ultrarealistic simulation enabled the astronauts to "see" themselves next to the Telescope as their partners maneuver them into position with the robotic arm.

Extravehicular Crew Aids and Tools

Astronauts servicing HST use three different kinds of foot restraints to counteract the weightless environment. When anchored in a Manipulator Foot Restraint (MFR), an astronaut can be transported from one worksite to the next with the RMS. Using either the STS or HST PFR, an astronaut establishes a stable worksite by mounting the restraint to any of

31 different receptacles placed strategically around the Telescope or 17 receptacles on the RAC, SAC, FSS and MULE.

In addition to foot restraints, EVA astronauts have more than 150 tools and crew aids at their disposal. Some of these are standard items from the Shuttle's toolbox while others are unique to SM3B. All tools are designed for use in a weightless environment by astronauts wearing pressurized gloves.

The most commonly used ORU fasteners are those with 7/16-inch, double-height hex heads. These bolts are used with three different kinds of fittings: J-hooks, captive fasteners and keyhole fasteners. To replace a unit, an astronaut uses a 7/16-inch extension socket on a powered or manual ratchet wrench. Extensions up to 2 feet long are available to extend his or her reach. Multi-setting torque limiters prevent over-tightening of fasteners or latch systems.

For units with bolts or screws that are not captive in the ORU frame, astronauts use tools fitted with socket capture fittings and specially designed capture tools so that nothing floats away in the weightless space environment. To grip fasteners in hard-to-reach areas, they can use wobble sockets.

Some ORU electrical connectors require special devices, such as a connector tool, to loosen circular connectors. If connectors have no wing tabs, astronauts use a special tool to get a firm hold on the connector's rotating ring.

Portable handles have been attached to many larger ORUs to facilitate removal or installation. Other tools and crew aids include tool caddies (carrying aids), tethers, transfer bags and a protective cover for the Low Gain Antenna (LGA).

When working within the Telescope's aft shroud area, astronauts must guard against optics contamination by using special tools that will not outgas or shed particulate matter. All tools are certified to meet this requirement.

Astronauts of Servicing Mission 3B

NASA carefully selected and trained the SM3B STS-109 crew (see Fig. 2-8). Their unique set of experiences and capabilities makes them ideally qualified for this challenging assignment. Brief biographies of the astronauts follow.

Scott D. Altman, NASA Astronaut (Commander, USN)

Scott Altman of Pekin, Illinois, is commander of SM3B. He received a bachelor of science degree in aeronautical and astronautical engineering from the University of Illinois in 1981 and a master of science degree in aeronautical engineering from the Naval Postgraduate School in 1990. Altman has logged over 4000 flight hours in more than 40 types of aircraft, and over 664 hours in space. He was the pilot on STS-90 in 1998, a 16-day Spacelab flight. He also was the pilot on STS-106 in 2000, a 12-day mission to prepare the International Space Station for the arrival of its first permanent crew. Altman was one of two operators of the robot arm transporting the EVA crew during the STS-106 space walk. Altman will command the crew of STS-109 for SM3B and serve as the alternate RMS operator.

Duane G. "Digger" Carey, NASA Astronaut (Lieutenant Colonel, USAF)

Duane Carey, *Columbia* pilot on SM3B, is from St. Paul, Minnesota. He received a bachelor of science degree in aerospace engineering and mechanics and a master of science degree in aerospace engineering from the University of Minnesota-Minneapolis in 1981 and 1982, respectively. Carey flew the A10A during tours in England, Louisiana and the Republic of Korea and the F-16 in Spain. He worked as an F-16 experimental test pilot and System Safety Officer at Edwards Air Force Base. He has logged over 3700 hours in more than 35 types of aircraft. Carey was selected as an astronaut candidate by NASA in 1996 and, having completed 2 years of training and evaluation, has qualified for flight assignment as a pilot on STS-109.

Nancy Jane Currie, Ph.D., NASA Astronaut (Lieutenant Colonel, USA)

Nancy Currie, the RMS operator on SM3B, is from Troy, Ohio. Currie received her bachelor of arts degree in biological science from Ohio State University in 1980, a master of science degree in safety from the University of Southern California in 1985 and a doctorate in industrial engineering from the University of Houston in 1997. A Master Army Aviator, she has logged 3900 flying hours in a variety of rotary and fixed wing aircraft. She was selected by NASA in 1990 and became an astronaut after completion of her training in 1991. Currie has logged over 737 hours in space. She was a mission specialist on STS-57 in 1993, STS-70 in 1995 and STS-88 in 1998.

John M. Grunsfeld, Ph.D., NASA Astronaut

John Grunsfeld is an astronomer and an EVA crewmember (EV1 on EVA Days 1, 3 and 5) on the SM3B mission. He was born in Chicago, Illinois. Grunsfeld received a bachelor of science degree in physics from the Massachusetts Institute of Technology in 1980 and a master of science degree and a doctor of philosophy degree in physics from

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Fig. 2-8 The STS-109 mission has seven crewmembers: (clockwise from top) Commander Scott D. Altman, Pilot Duane G. "Digger" Carey, Mission Specialist Nancy Jane Currie, Mission Specialist John M. Grunsfeld, Mission Specialist Richard M. Linnehan, Mission Specialist James H. Newman and Mission Specialist Michael J. Massimino.

the University of Chicago in 1984 and 1988, respectively. Grunsfeld reported to the Johnson Space Center in 1992 for a year of training and became qualified for flight selection as a mission specialist. He has logged over 835 hours in space. On his first mission, STS-67 in 1995, Grunsfeld and the crew conducted observations to study the far ultraviolet spectra of faint astronomical objects and the polarization of ultraviolet light coming from hot stars and distant galaxies. Grunsfeld flew on STS-81 in 1997 on the fifth mission to dock with Russia's Space Station Mir and the second to exchange U.S. astronauts. Grunsfeld's latest flight was aboard STS-103 in 1999 where he performed two space walks to service Hubble on SM3A.

Richard M. Linnehan, DVM, NASA Astronaut

Rick Linnehan is a doctor of veterinary medicine and an EVA crewmember (EV2 on EVA Days 1, 3 and 5) on SM3B. He was born in Lowell, Massachusetts. Linnehan received a bachelor of science degree in Animal Sciences from the University of New Hampshire in 1980 and his DVM degree from the Ohio State University College of Veterinary Medicine in 1985. Linnehan reported to the Johnson Space Center in 1992 for a year of training and became qualified for flight selection as a mission specialist. He has logged 786 hours in space. His first mission was aboard the STS-78 Life and Microgravity Spacelab, the longest Space Shuttle mission to date (17 days). This mission combined both microgravity studies and a life sciences payload. STS-90 was his second Spacelab mission. During the 16-day flight, Linnehan and the crew served as both experimental subjects and operators for 26 individual life science experiments focusing on the effects of microgravity on the brain and nervous system.

James H. Newman, Ph.D., NASA Astronaut

Jim Newman is an EVA crewmember (EV1 on EVA Days 2 and 4) on SM3B. He was born in the Trust Territory of the Pacific Islands (now the Federated States of Micronesia), but considers San Diego, California, to be his hometown. Newman received a bachelor of arts degree in physics (graduating cum laude) from Dartmouth College in 1978, and a master of arts degree and a doctorate in physics from Rice University in 1982 and 1984, respectively. Selected by NASA in 1990, Newman flew as a mission specialist on STS-51 in 1993, STS-69 in 1995 and STS-88 in 1998. He has logged over 32 days in space, including four space walks. On STS-51, Newman and the crew deployed the Advanced Communications Technology Satellite and the Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer on the Shuttle Pallet Satellite. On STS-69, Newman and the crew deployed and retrieved a SPARTAN satellite and the Wake Shield Facility. On STS-88, the first International Space Station assembly mission, Newman performed three space walks to connect external power and data umbilicals between Zarya and Unity.

Michael J. Massimino, Ph.D., NASA Astronaut

Mike Massimino is an EVA crewmember (EV2 on EVA Days 2 and 4) on the SM3B mission. He was born in Oceanside, New York. He attended Columbia University, receiving a bachelor of science degree in industrial engineering with honors in 1984. He also received master of science degrees in mechanical engineering and in technology and policy, a mechanical engineering degree and a doctorate in mechanical engineering from the Massachusetts Institute of Technology (MIT) in 1988, 1990 and 1992, respectively. Massimino was selected as an astronaut candidate by NASA in 1996 and, having completed 2 years of training and evaluation, is qualified for flight assignment as a mission specialist. STS-109 will be Massimino's first space flight, where he will perform two space walks to service the HST.

Servicing Mission Activities

After berthing the Telescope on Flight Day 3 of SM3B, the seven-person *Columbia* crew will begin an ambitious servicing mission. Five days of EVA tasks are scheduled. Each EVA session is scheduled for 6 hours (see Fig. 2-9).

Rendezvous With Hubble

Columbia will rendezvous with Hubble in orbit 315 nautical miles (504 km) above the Earth. Prior to approach, in concert with the Space Telescope Operations Control Center (STOCC) at GSFC, Mission Control at JSC will command HST to stow the High Gain Antennas (HGA) and close the aperture door. As *Columbia* approaches the Telescope, Commander Altman will control the thrusters to avoid contaminating HST with propulsion residue. During the approach the Shuttle crew will remain in close contact with Mission Control.

As the distance between *Columbia* and HST decreases to approximately 200 feet (60 m), the STOCC ground crew will command the Telescope to perform a final roll maneuver to position itself for grappling. The Solar Arrays (SA) will remain fully deployed parallel to Hubble's optical axis.

When *Columbia* and HST achieve the proper position, Mission Specialist Currie will operate the robotic arm to grapple the Telescope. Using a camera mounted at the berthing ring of the FSS platform in the cargo bay,

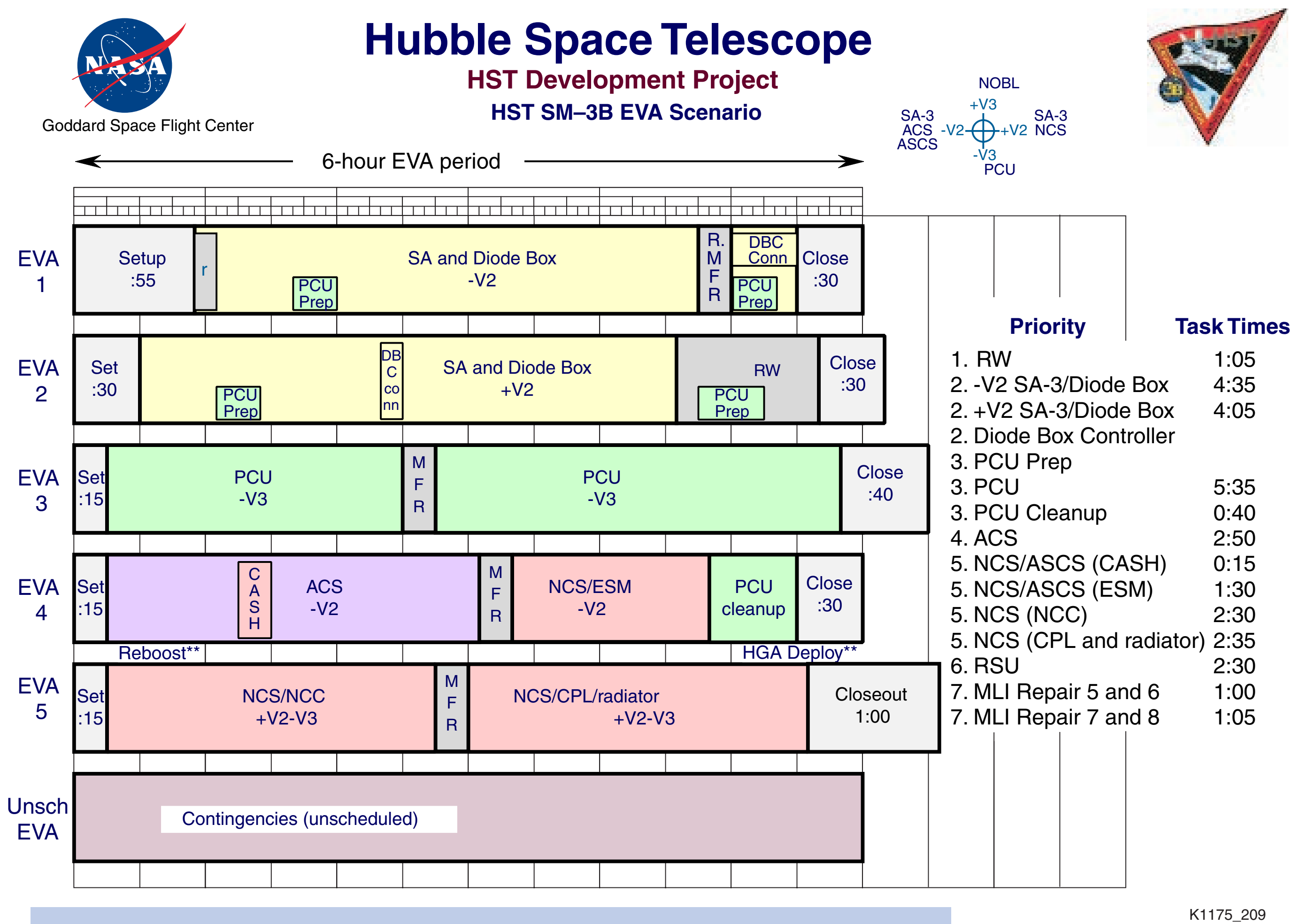

Fig. 2-9 Detailed schedule of extravehicular activities during SM3B

she will maneuver it to the FSS, where the Telescope will be berthed and latched.

Once the Telescope is secured, the crew will remotely engage the electrical umbilical and switch Hubble from internal power to external power from *Columbia.* Pilot Carey will then maneuver the Shuttle so that the HST SAs face the Sun, recharging the Telescope's six onboard nickel-hydrogen (NiH_2) batteries.

Extravehicular Servicing Activities—Day by Day

Each EVA servicing period shown in Fig. 2-9 is a planning estimate; the schedule will be modified as needed as the mission progresses. During the EVAs, HST will be vertical relative to *Columbia's* cargo bay. Four EVA mission specialists will work in two-person teams on alternate days. John Grunsfeld and Rick Linnehan comprise one team, and Jim Newman and Mike Massimino the other.

One astronaut, designated EV1, accomplishes primarily the free-floating portions of the EVA tasks. He can operate from a PFR or while free floating. The other astronaut, EV2, works primarily from an MFR mounted on *Columbia's* robotic arm (RMS), removing and installing the ORUs on the Hubble. EV1 assists EV2 in removal of the ORUs and installation of the replaced units in the SM3B carriers.

To reduce crew fatigue, EVA crewmembers swap places once during each EVA day: the free floater goes to the RMS MFR and vice versa. Inside *Columbia's* aft flight deck, the off-shift EVA crewmembers and the designated RMS operator assist the EVA team by reading out procedures and operating the RMS.

EVA Day 1: Replace –V2 Solar Array and Diode Box Assembly and install Diode Box Controller cross-strap harness.

At the beginning of EVA Day 1 (the fourth day of the mission), the first team of EVA astronauts, Grunsfeld and Linnehan, suit up, pass through the *Columbia* airlock into the cargo bay and perform the initial setup. To prevent themselves from accidentally floating off, they attach safety tethers to a cable running along the cargo bay sills.

Grunsfeld (EV1) does various tasks to prepare for that day's EVA servicing activities. These include deploying the ASIPE mini-Translation Aid (TA), deploying the port and starboard TAs as required, removing the MFR from its stowage location and installing it on the RMS grapple fixture, installing the Low Gain Antenna Protective Cover (LGAPC), removing the Berthing and Positioning System (BAPS) Support Post (BSP) from its stowage location and installing it on the FSS, and inspecting the P105 and P106 umbilical covers. Meanwhile, Linnehan (EV2) brings out of the airlock the Crew Aids and Tools (CATs) and installs the MFR handrail to the MFR on the RMS.

The BSP is required to dampen the vibration that the servicing activities will induce into the deployed SAs. Prior to the BSP installation, the IVA team commands the HST to an 85-degree pivot angle. The two center push-in-pull-out (PIP) pins are installed each day and removed each night in case the Shuttle must make an emergency return to Earth. EV1 removes the BSP from its stowage position in the FSS cradle, and then installs one end to the BAPS ring with a PIP pin and the aft end to the FSS cradle with another PIP pin. Finally the BSP is commanded to its 90-degree limit and the two center PIP pins are installed.

After the initial setup, the EVA crew will replace the –V2 Solar Array and Diode Box Assembly on the Telescope. They will also install the Diode Box Controller (DBC) cross-strap harness. First EV1, who is free floating, retrieves the HST PFR and APE and transfers them to EV2 in the MFR. EV2 moves to the HST and installs the PFR on HST foot restraint receptacle 8 for the free floater's use. EV1 translates to the RAC to retrieve the DBC cross-strap harness and a Portable Connector Tray, and temporarily stows them on the Telescope. Then he ingresses the PFR. Together the astronauts retract the –V2 SA2 Primary Deployment Mechanism (PDM). EV1 then engages the PDM lock and installs the Portable Connector Tray. While still in the PFR, EV1 demates the SA2 connectors from the DBA while EV2 retrieves the WFPC Cover and installs it on the –V3 Aft Shroud in support of the PCU change-out on EVA Day 3.

Next the astronauts remove the –V2 SA2 from the Telescope. They disengage the SADA Clamp, remove SA2, translate it to the RAC and install it on the starboard shelf via the SADA Clamp and forward constraint PIP pin mechanical attachments.

EV1 translates back to the Telescope and removes the –V2 DBA by disengaging the remaining X-connector drive mechanism and releasing the four J-hook bolts while EV2 retrieves the DBA2 from the RAC and translates it to EV1 at the Telescope worksite. The astronauts swap hardware and EV1 installs the DBA2 on the Telescope while EV2 translates to the RAC with the DBA and installs it and closes its thermal cover. EV1 installs the DBC cross-strap harness onto the Telescope and mates it to the –V2 DBA2.

With the DBA2 now installed on the Telescope, the astronauts begin the installation work for the replacement Solar Array. Both translate to the RAC. EV2 disengages Latch 5, deploys the mast and engages the two mast bolts. EV1 ingresses the aft PFR, releases and pivots Latch 3 to clear the tang, disengages the two tang bolts, stows the tang and engages the two tang bolts. EV2 disengages Latch 2. EV1 pivots Latch 3 to the stowed position and installs the PIP pin, deploys the MLI flap over the tang interface and releases Latch 4. EV1 stabilizes SA3 while EV2 releases Latch 1. The astronauts then remove SA3 from the RAC.

Both crewmembers install SA3 onto the Telescope by properly orienting SA3 and inserting the SADA into the SADA Clamp until the three soft dock tangs engage. EV1 engages the SADA Clamp closed and mates the SA3 electrical interfaces. EV2 translates back to the RAC and performs the SA2 close-out work: engaging the aft latch, the forward latch and the two forward constraint bolts.

Then the astronauts deploy the SA3 panel, engage the panel locking bolts and release the SA3 brake. EV1 routes the DBC cross-strap harness to the +V2 side, removes the HST PFR and temporarily stows it on the ASIPE, and removes and stows a Portable Connector Tray on the RAC. Meanwhile, EV2 maneuvers to the –V3 aft shroud and installs the two FHST covers in preparation for the PCU change-out on EVA Day 3.

At this time, the astronauts perform the MFR swap: Grunsfeld ingresses the MFR and Linnehan becomes the free floater. EV1 (the free floater) translates to the ASIPE, retrieves the PFR from temporary stowage and transfers it to EV2, who installs it in foot restraint receptacle 19 in preparation for EVA Day 2. EV1 retrieves the Bay 10 Thermal Cover and installs it over Bay 10 of the Telescope while EV2 disengages and removes the Telescope's +V2 trunnion EPS panel, mates the DBC cross-strap harness and installs an MLI tent over the EPS panel cavity.

For the daily close-out, EV1 inspects the FSS main umbilical mechanism, disengages the two center PIP pins on the BSP, retracts the mini-TA, retracts the port and starboard TAs if required, and takes a tool inventory. Meanwhile EV2 prepares the CATs installed on the MFR handrail for return into the airlock and egresses the MFR. EV1 releases the MFR safety tether from the grapple fixture for contingency Earth return. After completing the EVA Day 1 tasks, both astronauts return to the airlock and perform the airlock ingress procedure.

EVA Day 2: Replace +V2 Solar Array and Diode Box Assembly and Reaction Wheel Assembly – 1 (RWA-1)

During EVA Day 2, Newman (EV1) and Massimino (EV2) will replace the +V2 Solar Array and Diode Box Assembly on the Telescope and complete the DBC installation by mating it to the +V2 SA3. They also will replace the RWA-1.

Fewer daily setup tasks are required for EVA Day 2 than for EVA Day 1. After completing the airlock egress procedure, EV1 reconnects the safety strap on the MFR, installs the two BSP center PIP pins and deploys the mini-TA. EV2 exits the airlock with the EVA Day 2 required CATs installed on the MFR handrail and installs the MFR handrail.

After completing the daily setup tasks, the astronauts begin the tasks for the +V2 Solar Array and Diode Box Assembly change-outs, which are similar to the –V2 Solar Array and Diode Box Assembly change-outs performed during EVA Day 1. First EV1 and EV2 retrieve the HST PFR and APE and install them on HST foot restraint receptacle 19. EV1 translates to the RAC to retrieve a Portable Connector Tray and temporarily stows it on the Telescope. Then he ingresses the PFR.

Together the astronauts retract the +V2 SA2 PDM. EV1 then engages the PDM lock and installs the Portable Connector Tray. Still in the PFR, EV1 demates the SA2 connectors from the DBA while EV2 disengages five of six bolts on each door of Telescope Bays 2, 3 and 4 in support of the PCU change-out on EVA Day 3.

Next the astronauts remove the +V2 SA2 from the Telescope. They disengage the SADA Clamp, remove SA2, translate it to the RAC and install it on the port shelf via the SADA Clamp and forward constraint PIP pin mechanical attachments.

EV1 translates back to the Telescope and removes the +V2 DBA by disengaging the remaining X-connector drive mechanism and releasing the four J-hook bolts while EV2 retrieves the DBA2 from the RAC and translates it to EV1 at the Telescope worksite. The astronauts swap hardware and EV1 installs the DBA2 on the Telescope while EV2 translates to the RAC with the DBA and installs it and closes its thermal cover.

With the +V2 DBA2 now installed on the Telescope, they begin installation work for the replacement Solar Array. Both astronauts translate to the RAC. EV2 disengages Latch 5, deploys the mast and engages the two mast bolts. EV1 ingresses the forward PFR, releases and pivots Latch 3 to clear the tang, disengages the two tang bolts, stows the tang and engages the two tang bolts. EV2 disengages Latch 2. EV1 pivots Latch 3 to the stowed position and installs the PIP pin, deploys the MLI flap over the tang interface and releases Latch 4. EV1 stabilizes SA3 while EV2 releases Latch 1. Both remove SA3 from the RAC.

Working together, the astronauts install SA3 onto the Telescope by properly orienting SA3 and inserting the SADA into the SADA Clamp until the three soft dock tangs engage. EV1 engages the SADA Clamp closed and mates the SA3 electrical interfaces, then mates the DBC cross-strap harness to the +V2 DBA2. EV2 translates back to the RAC and performs the SA2 close-out work: engaging the aft latch, the forward latch and the two forward constraint bolts.

Both astronauts work together again to deploy the SA3 panel, engage the panel locking bolts and release the SA3 brake (see Fig. 2-10). EV1 removes the HST PFR and APE and stows them on the FSS, and removes and stows the Portable Connector Tray on the RAC.

Upon completion of the SA changeout task, the EVA crew will replace the RWA-1. EV1 translates to the LOPE on the aft starboard side of the MULE, opens the lid, removes the two RWA1-R wing tab connectors from the LOPE pouch and secures them to the RWA1-R handle Velcro, disengages the three keyway bolts, removes the replacement RWA-1 (RWA1-R) and translates to the top of the starboard MULE.

EV2 maneuvers to Bay 6 and opens the Bay 6 door, demates the two RWA-1 wing tab heater connectors from the heater bracket, demates the two RWA-1 wing tab connectors from RWA-1, disengages the three RWA-1 keyway bolts and removes RWA-1 from HST Bay 6. Then he maneuvers to the starboard MULE location and performs an RWA swap with EV2.

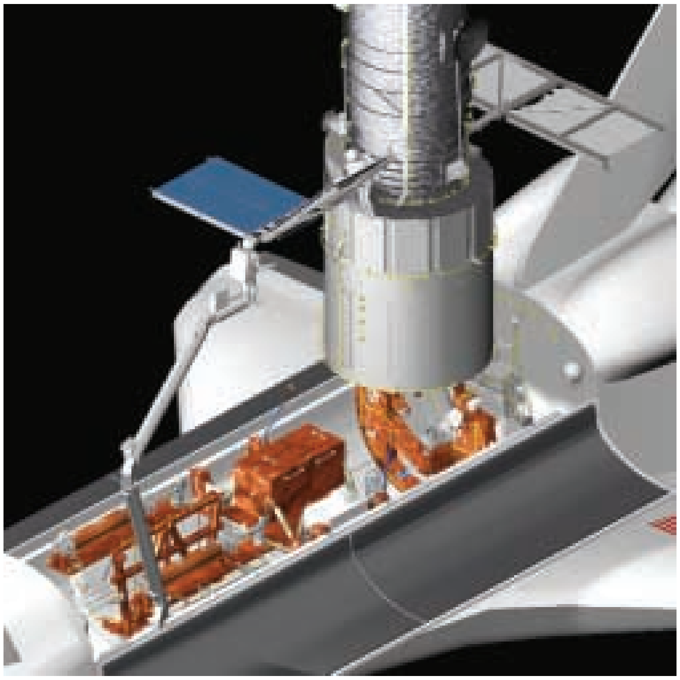
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Fig. 2-10 Deployment of new rigid solar array

EV1 maneuvers with RWA1-R to the Bay 6 worksite, installs it on HST, engages the three keyway bolts and mates the four wing tab electrical connectors. Then he closes the Bay 6 door.

After transferring the RWA1-R to EV2 and receiving RWA-1 from EV2, EV1 translates back to the LOPE, installs the RWA-1 in the LOPE, engages the three keyway bolts, stows the two wing tab connectors in the LOPE pouch and closes the LOPE lid.

EV1 retrieves the Bay 5 Thermal Cover and installs it in the retracted position on the Telescope Bay 5 in preparation for the PCU change-out on EVA Day 3. EV1 also retrieves the doorstop extensions and installs them on the +V2 aft shroud doorstops in preparation for the NCS Radiator installation on EVA Day 5.

For the daily close-out, EV1 inspects the FSS main umbilical mechanism, disengages the two center PIP pins on the BSP, retracts the mini-TA, retracts the port and starboard TAs if required and takes a tool inventory. Meanwhile EV2 prepares the CATs installed on the MFR handrail for return into the airlock and egresses the MFR. EV1 releases the MFR safety tether from the grapple fixture for contingency Earth return. After completing the EVA Day 2 tasks, both astronauts return to the airlock and perform the airlock ingress procedure.

EVA Day 3: Replace PCU.

During EVA Day 3, Grunsfeld (EV1) and Linnehan (EV2) will replace the PCU in the Telescope Bay 4. After the airlock egress procedure, EV1 reconnects the safety strap on the MFR, installs the two BSP center PIP pins and deploys the mini-TA. EV2 exits the airlock with the EVA Day 3 required CATs installed on the MFR handrail and installs the MFR handrail.

Both astronauts complete the daily setup tasks, then begin the PCU change-out. EV1 translates to the RAC to retrieve the Power Distribution Unit (PDU) fuse plug caddy and battery stringers and transfers them to EV2. EV2 translates to the Telescope Bay 3, opens the bay door, demates the three battery connectors, installs caps to deadface the battery power and temporarily closes the door. He then translates to Bay 2 and performs the same procedure for the Bay 2 battery.

Meanwhile EV1 translates to Bay 5 and deploys the thermal cover, retrieves the DBA thermal cover, translates to the +V2 DBA2 and installs its thermal cover. Then he translates to Bay 10 and deploys the thermal cover, retrieves the DBA thermal cover, translates to the -V2 DBA2 and installs its thermal cover. EV1 deploys the FHST covers on the Telescope, then translates to the SAC, retrieves the Harness Retention Device and transfers it to EV2 at the Bay 4 worksite.

EV2 opens the Bay 4 door and installs the Harness Retention Device and door stay. EV2 removes the six inboard PDU Fuse Plugs to gain sufficient access to the PCU connectors on the left side. EV1 retrieves the PCU handhold from the SAC and temporarily stows it by the +V2 trunnion. Then he translates to the airlock and recharges his suit with oxygen, enabling him to extend his EVA time. EV2 disengages seven of 10 PCU keyway bolts and demates all but the last six connectors (30).

At this point, EV1 and EV2 perform the MFR swap. EV2 completes demating the remaining PCU connectors, installs the PCU handhold, disengages the three remaining bolts, disengages the PCU groundstrap and removes the PCU from the Telescope.

EV1 translates to the starboard SAC where the replacement PCU (PCU-R) is located, ingresses the PFR, opens the thermal cover, disengages the six keyway bolts and removes the PCU-R from the SAC.

EV1 and EV2 swap boxes at the SAC worksite. EV2 translates with the PCU-R back to the Telescope worksite, installs it, engages seven keyway bolts and engages the groundstrap (see Fig. 2-11). EV1 stows the PCU on the SAC, engages the six keyway bolts, retightens the two PCU handhold wing bolts, egresses the PFR and reinstalls the PCU thermal cover. He then translates to the airlock and recharges his suit with oxygen. EV2 mates the 36 connectors on the PCR-R, a difficult and time-consuming task.

EV1 inspects the Telescope exterior handrails to be used for the ACS and NCS tasks on EVA Days 4 and 5 and, if required, installs handrail covers. EV2 reinstalls the PDU fuse plugs, removes the Harness Retention Device, removes the door stay and closes the Bay 4 door with one J-bolt. He re-opens the Bay 3 door, remates the battery connectors and closes the door with one J-bolt. Then he performs the same procedure for the Bay 2 battery. After the PDU fuse plugs are reinstalled, EV1 translates to the +V2 DBA2, retrieves the thermal cover, stows it on its Bay 5 thermal cover stowage pouch and retracts the Bay 5 thermal cover. He translates to the -V2 DBA2, retrieves the thermal cover, stows it on its Bay 10 thermal cover stowage pouch and retracts the Bay 10 thermal cover. Next EV1 retrieves the Harness Retention Device and stows it on the SAC. Then he retracts the FHST covers, receives the PDU fuse plug caddy and battery stringers from EV2, and stows them on the RAC. If time allows, EV2 removes the WFPC thermal cover and stows it on the SAC.

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Fig. 2-11 Change-out of Power Control Unit

For the daily close-out, EV1 inspects the FSS main umbilical mechanism, disengages the two center PIP pins on the BSP, retracts the mini-TA, retracts the port and starboard TAs if required and takes a tool inventory. Meanwhile EV2 prepares the CATs installed on the MFR handrail for return into the airlock and egresses the MFR. EV1 releases the MFR safety tether from the grapple fixture for contingency Earth return. After the completion of the EVA Day 3 tasks, both astronauts return to the airlock and perform the airlock ingress procedure.

EVA Day 4: Replace FOC with ACS, install ESM and perform PCU cleanup tasks.

During EVA Day 4, Newman (EV1) and Massimino (EV2) will replace the Faint Object Camera (FOC) with the ACS, install the ESM in the Telescope aft shroud and do the remaining PCU cleanup tasks. After the airlock egress procedure, EV1 reconnects the safety strap on the MFR, installs the two BSP center PIP pins and deploys the mini-TA. EV2 exits the airlock with the EVA Day 4 required CATs installed on the MFR handrail and installs the MFR handrail.

The astronauts complete the daily setup tasks, then begin the FOC/ACS change-out. EV1 deploys the aft fixture, retrieves the COSTAR Y-harness from the RAC port ATM and stows it on the Telescope aft shroud. EV2 opens the –V2 aft shroud doors. EV1 and EV2 work together to remove the FOC from the Telescope. EV1 demates the four FOC connectors, disconnects the FOC purge line and disconnects the groundstrap. EV2 disengages the FOC A-Latch and EV1 disengages the FOC B-Latch. Then EV2 removes the FOC from the Telescope and stows it on the aft fixture.

EV1 and EV2 now work together to install the CASH. Even though the CASH is part of the NCS installation, it is installed now to maximize EVA timeline efficiencies and eliminate the need to open the –V2 aft shroud doors a second time on EVA Day 5. EV1 and EV2 retrieve the CASH from the SAC and install it on handrails inside the aft shroud.
EV1 and EV2 retrieve the ACS from the ASIPE. EV1 configures the aft ASIPE PFR, opens the ASIPE lid, disconnects the ACS groundstrap and deploys the B-Latch alignment aid. EV2 disengages the A-Latch and EV1 disengages the B-Latch. They both remove the ACS from the ASIPE. EV1 closes the ASIPE lid and engages one lid latch to maintain thermal stability inside the ASIPE. The astronauts continue to work together to install the ACS into the Telescope aft shroud (see Fig. 2-12). They insert the ACS along the guiderails, deploy the B-Latch alignment aid arm,

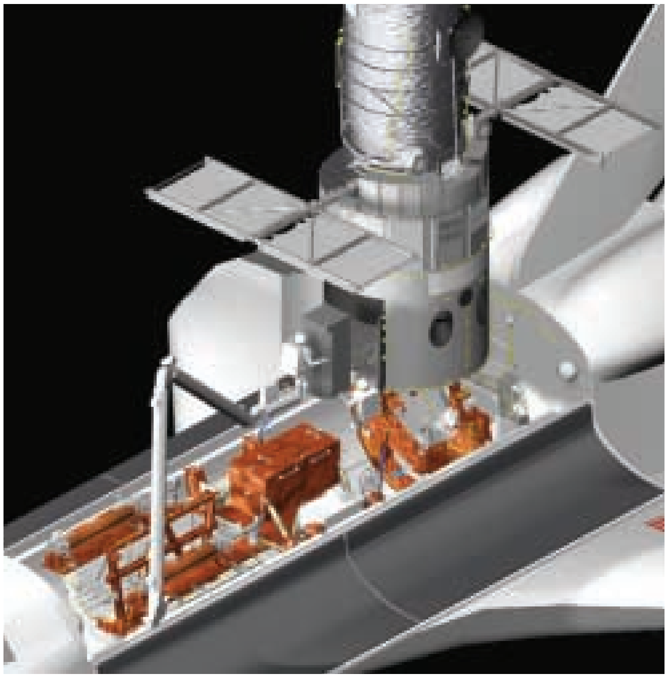

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Fig. 2-12 Installation of the Advanced Camera for Surveys

engage the B-Latch and A-Latch, stow the alignment aid, tether the ESM groundstrap to the ACS handrail, reinstall the HST groundstrap and mate the four ACS connectors.

Next the astronauts install the FOC into the ASIPE. EV2 retrieves the FOC from the aft fixture while EV1 re-opens the ASIPE lid. EV2 inserts the FOC into the ASIPE guiderails while EV1 stows the aft fixture and engages the FOC B-Latch. EV2 engages the A-Latch. EV1 disengages the FOC groundstrap bolt and installs the groundstrap on FOC, then closes the ASIPE lid and engages the five lid latches.

After completing the FOC installation into the ASIPE, the astronauts perform the MFR swap. They retrieve the ESM from the MULE and install it in the –V2 aft shroud. Then they install the ACS ESM groundstrap on the ESM, retrieve the Y-harness from temporary stowage, demate the four COSTAR connectors, mate four Y-harness connectors to the COSTAR harnesses, mate four Y-harness connectors to COSTAR and mate four Y-harness connectors to the ESM. EV2 mates the four CASH connectors to the ESM. Now they are ready to close the –V2 aft shroud doors.

The PCU cleanup task follows the FOC/ACS change-out and the ESM installation. EV1 removes the Bay 10 thermal cover and stows it on the ASIPE, then removes the Bay 5 thermal cover and stows it on the ASIPE. He also articulates the aft ASIPE PFR to its landing configuration. Meanwhile, EV2 engages the remaining five J-bolts on each door of Bays 2, 3 and 4. Then the astronauts remove the FHST and WFPC covers from the Telescope and stow them on the SAC.

For the daily close-out, EV1 inspects the FSS main umbilical mechanism, disengages the two center PIP pins on the BSP, retracts the mini-TA, retracts the port and starboard TAs if required and takes a tool inventory. Meanwhile EV2 prepares the CATs installed on the MFR handrail for return into the airlock and egresses the MFR. EV1 releases the MFR safety tether from the grapple fixture for contingency Earth return. After completing the EVA Day 4 tasks, both astronauts return to the airlock and perform the airlock ingress procedure.

EVA Day 5: Install the NCC and NCS Radiator.

During EVA Day 5, Grunsfeld (EV1) and Linnehan (EV2) will install the remaining NCS hardware. After the airlock egress procedure, EV1 reconnects the safety strap on the MFR, installs the two BSP center PIP pins and deploys the mini-TA. EV2 exits the airlock with the EVA Day 5 CATs installed on the MFR handrail and installs the MFR handrail.

Both astronauts complete the daily setup tasks, then begin the NCS installation. EV2 opens the Telescope +V2 aft shroud doors while EV1 retrieves the Cryo Vent Line (CVL) bag and NCS sock bag from the RAC port ATM and the NCC groundstrap and cryo vent insert from the RAC starboard ATM. Together the astronauts prepare the NICMOS for the NCS installation. They remove the NICMOS CVL and stow it in the CVL bag, close the NICMOS vent line valve, disengage the NICMOS groundstrap from NICMOS, install the NCC groundstrap adapter on NICMOS and install the cryo vent insert. EV1 retrieves the P600 harness from the RAC starboard ATM. EV2 retrieves the NCC from the SAC and opens the neon bypass valve while EV1 closes the NCC contamination cover.

Both astronauts install the NCC into the Telescope aft shroud. EV2 installs the NCC groundstrap on NCC and mates the four CASH connectors. EV1 translates to the MULE and releases some of the NCS Radiator latches and shear ties. At this point, they perform the MFR swap.

Next comes retrieval of the NCS Radiator. EV1 closes the left aft shroud door and together with EV2 disengages the remaining latches, removes the NCS Radiator from the MULE and opens the NCS Radiator handrail latches. They install the NCS Radiator onto the exterior of the Telescope aft shroud.

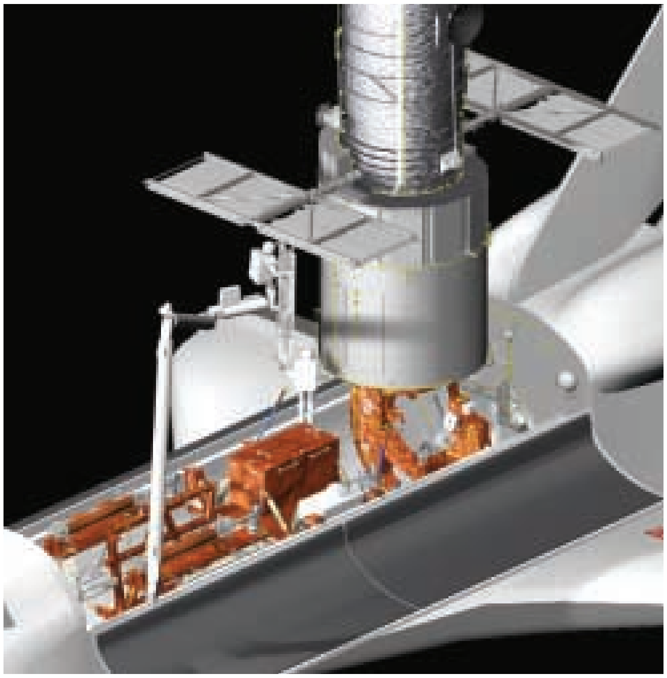

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Fig. 2-13 Installation of NICMOS Cooling System radiator

EV1 prepares the NCC by installing the coolant in and coolant out cryo valve heaters and neon lines while EV2 installs the NCC power cable to the EPS test panel and reinstalls the MLI tent. They install the NCS Radiator conduit through the cryo vent insert opening in the aft bulkhead and engage the cryo vent insert latches and locking bolts (see Fig. 2-13). Then the NCS Radiator harnesses are mated to the NCS, the NCC saddle thermal cover opened and the CPL evaporator removed from the sock and tethered to the bulkhead standoff by EV1. EV2 opens the NCS Radiator diode box, checks some LEDs and switches, and closes the diode box cover. He installs the CPL evaporator in the saddle, installs the saddle cover, engages its two bolts and closes the NCC saddle thermal cover. Together the astronauts close the aft shroud doors. The crew will then stow the CVL and NCS sock bags in the RAC port ATM.

The final close-out procedure follows the NCS installation. EV1 inspects the FSS main umbilical mechanism and the P105/P106 covers, removes the LGA protective cover from the Telescope and reinstalls it on the FSS, disengages the two center PIP pins on the BSP, retracts the mini-TA, retracts the port and starboard TAs (if required) to their landing configurations and takes a tool inventory. Meanwhile EV2 prepares the CATs installed on the MFR handrail for return into the airlock, egresses the MFR and performs the MFR stow procedure. After completing the EVA Day 5 tasks, both astronauts return to the airlock and perform the airlock ingress procedure.

Possible EVA Day 6: Replace RSU, install NOBLs 5, 6, 7 and 8, and install ASLR kits if needed.

While there is no scheduled EVA Day 6 on the manifest, if all goes well during EVA Days 1 through 5 and the *Columbia* consumables are adequate, the astronauts may execute a sixth EVA day to change out an RSU, install the Bays 5, 6, 7 and 8 NOBLs, and install repair kits on the aft shroud doors, if any of the latches exhibited excessive running torque upon examination on EVA days 4 and 5.

EVA Contingency Day. An unscheduled EVA day has been allocated for enhancing payload mission

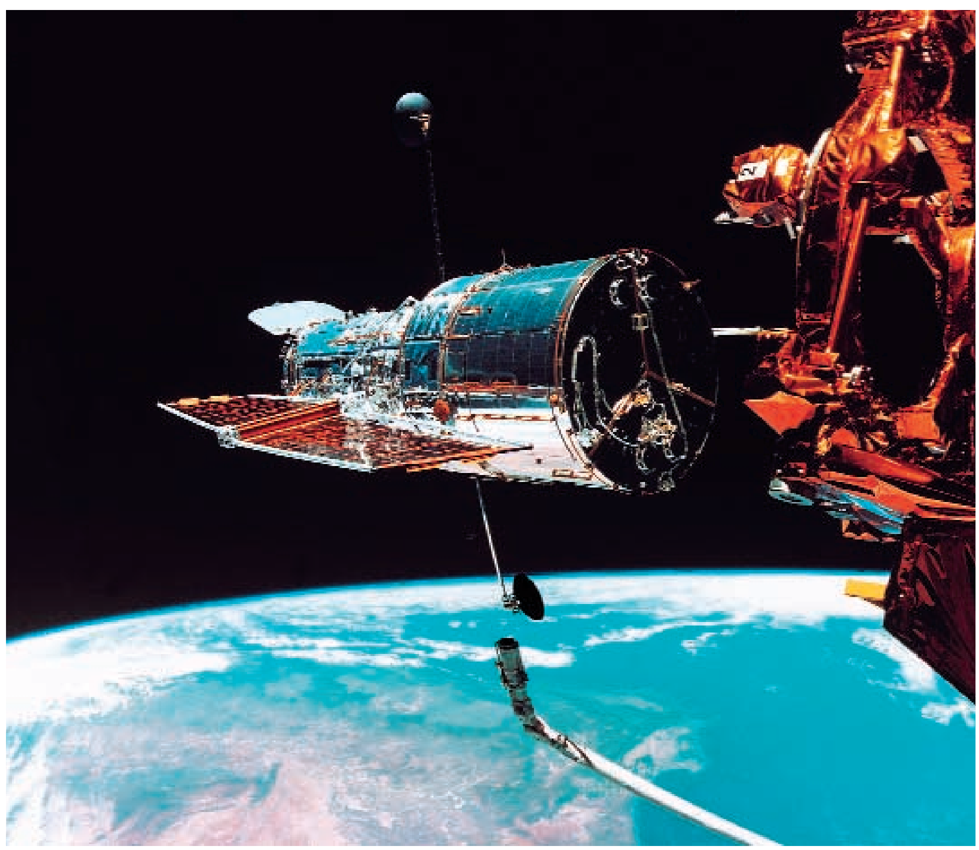

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Fig. 2-14 Redeploying the Hubble Space Telescope success and for any payload requirements on the HST redeployment day.

Redeploying the Telescope. The day following EVA Day 5 will be devoted to any unscheduled EVA tasks and redeployment of the HST into Earth orbit (see Fig. 2-14). The SAs are slewed to the Sun to generate electrical power for the Telescope and to charge the batteries, and HGAs are commanded to their deployed position. When the battery charging is complete, the RMS operator guides the robotic arm to engage HST's grapple fixture. The ground crew commands Hubble to switch to internal power. This accomplished, crewmembers command *Columbia's* electrical umbilical to demate from Hubble and open the berthing latches on the FSS. If any Telescope appendages fail to deploy properly, two mission specialists can perform EVA tasks, manually overriding any faulty mechanisms.