The Hubble Space Telescope (HST) is the first observatory designed for extensive maintenance and refurbishment in orbit. While other U.S. spacecraft have been retrieved or repaired by astronauts, none was so thoroughly designed for orbital servicing as HST. Its science instruments and many other components were designed as Orbital Replacement Units (ORU) – modular in construction with standardized fittings and accessible to spacewalking astronauts. Features such as handrails and foot restraints are built into the Telescope to help astronauts perform servicing tasks in the Shuttle cargo bay as they orbit Earth at 17,500 mph.

For Servicing Mission 3A (SM3A), the *Discovery* cargo bay is equipped with several devices to help the astronauts. The Flight Support System (FSS) will berth and rotate the Telescope. Large, specially designed equipment containers house the ORUs. Astronauts can work and be maneuvered as needed from the Shuttle robot arm.

SM3A will benefit from lessons learned on NASA's previous on-orbit servicing missions, ranging from the 1984 Solar Maximum repair mission to the 1993 HST First Servicing Mission (SM1) and the 1997 Second Servicing Mission (SM2). NASA has incorporated these lessons in detailed planning and training sessions for astronauts Curtis Brown, Jr., Scott Kelly, Jean-François Clervoy, Steven Smith, John Grunsfeld, Michael Foale, and Claude Nicollier. All of NASA's planning and the astronauts' skills will be put to the test during the SM3A mission in 1999. Four extravehicular activity (EVA) days are scheduled for the servicing.

2.1 Reasons for Orbital Servicing

The Hubble Telescope is a national asset and an invaluable international scientific resource that has revolutionized modern astronomy. To achieve its full potential, HST 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 20-year life, scientists and engineers will upgrade the science instruments. 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 – and added considerable new capability – when it was installed during the Second Servicing Mission in February 1997. This left open a slot for the Near Infrared Camera and Multi-Object Spectrometer (NICMOS), which expanded the Telescope's vision into the infrared region of the spectrum. Additionally, on SM2 a new Solid State Recorder (SSR) replaced an Engineering/Science Tape Recorder (E/STR).

Component Degradation. Servicing plans take into account the need for routine replacement of some items, for example, restoring HST system redundancy and limited-life items such as tape recorders 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 to the Telescope fully trained for its on-orbit servicing.

Originally, planners considered using the Shuttle to return the Telescope to Earth approximately every five 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.

2.2 Orbital Replacement Units

Advantages of ORUs include modularity, standardization, and accessibility.

Modularity. Engineers studied various technical and human factors criteria to simplify Telescope maintenance. Due to 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.

The modular ORU concept is key to successfully servicing the Telescope on orbit. 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 lb (318 kg). Figure 2-1 shows the ORUs for SM3A.

Standardization. Standardized bolts and connectors also simplify on-orbit repairs. Captive bolts with 7/16-in., double-height hex heads hold many ORU components in place. To remove or install the bolts, astronauts need only a 7/16-in. socket fitted to a power tool or manual wrench. Standardization limits the number of crew aids and tools.

Some ORUs do not contain these fasteners. When the maintenance philosophy changed from Earth-return to on-orbit-only 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-in.-head bolts and connectors without wing tabs. Despite these exceptions, the high level of standardization among units reduces

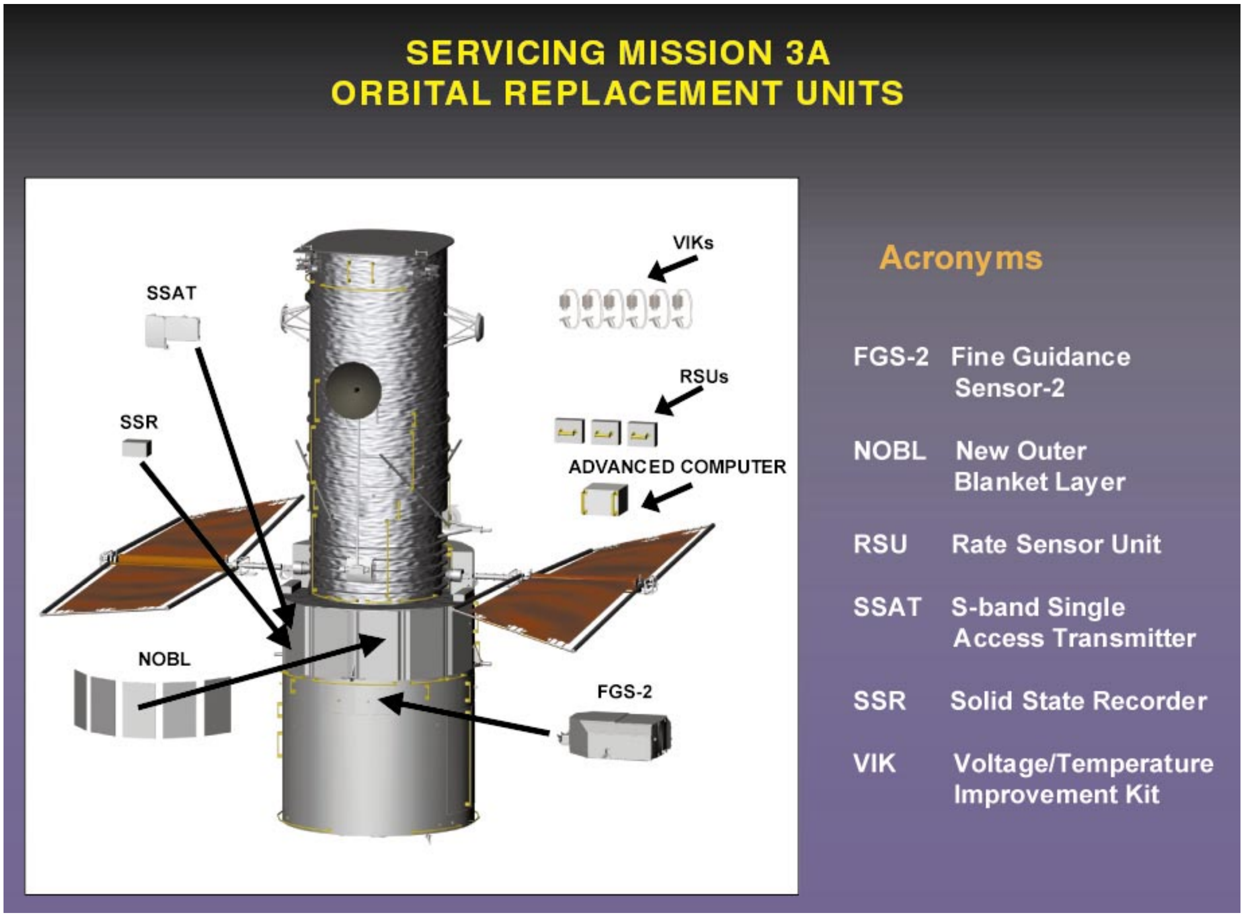

Fig. 2-1 Hubble Space Telescope Servicing Mission 3A Orbital Replacement Units

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 the 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 efficient, safe on-orbit servicing. In anticipation of servicing missions, 31 foot restraint sockets and 225 ft of handrails were designed into the Telescope. The foot restraint sockets and handrails greatly increase the mobility and stability of EVA astronauts, giving 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 the telescope components. In addition, foot restraints, translation aids and handrails are built into various equipment and instrument carriers specific to each servicing mission.

2.3 Shuttle Support Equipment

To assist the astronauts in servicing the Telescope, *Discovery* will carry into orbit several thousand pounds of hardware and Space

Support Equipment (SSE), including the Remote Manipulator System (RMS), FSS, and ORU Carrier (ORUC).

2.3.1 Remote Manipulator System

The *Discovery* RMS, also known as the robotic arm, will be used extensively during SM3A. The astronaut operating this device from inside the cabin is designated intravehicular activity (IVA) crew member. 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.

2.3.2 Space Support Equipment

Ground crews will install two major assemblies essential for SM3A – the FSS and ORUC – in Discovery's cargo bay. Figure 2-2 shows a cargo bay view of these assemblies.

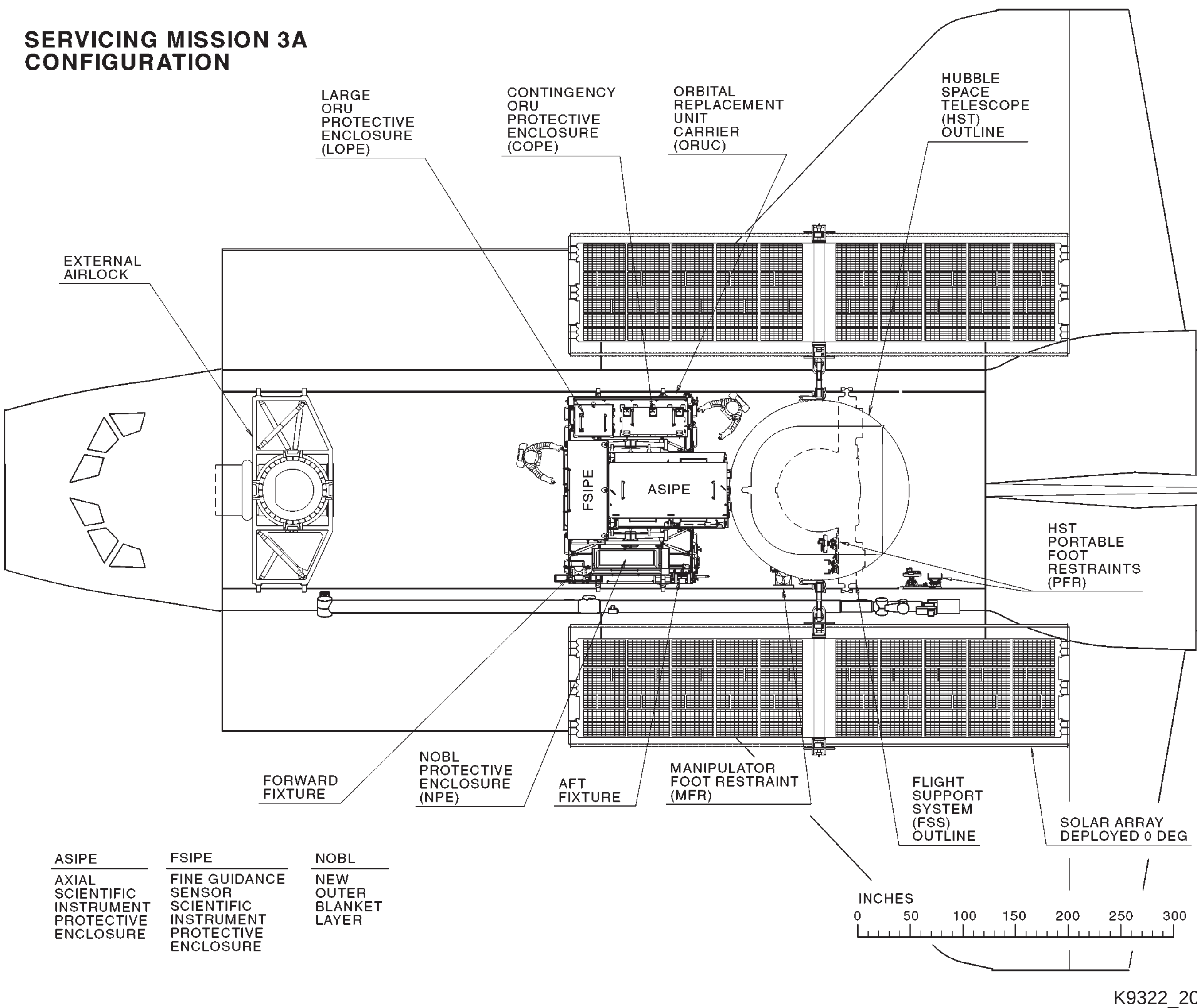

Fig. 2-2 Servicing Mission 3A Payload Bay configuration

Flight Support System. The FSS is a maintenance platform used to berth the HST in the cargo bay after the *Discovery* 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 *Discovery* to maintain thermal control of the Telescope and permits ground engineers to test and monitor Telescope systems during the servicing mission.

2.3.3 Orbital Replacement Unit Carrier

The ORUC is centered in *Discovery's* cargo bay. A Spacelab pallet modified with a shelf, it has provisions for safe transport of ORUs to and from orbit (see Fig. 2-4). In the SM3A configuration:

- The Fine Guidance Sensor (FGS) #2 is stored in the Fine Guidance Sensor Scientific Instrument Protective Enclosure (FSIPE).
- The Large ORU Protective Enclosure (LOPE) contains the Advanced Computer and two Y-harnesses (going up), two spare Voltage/Temperature Improvement Kits (VIK), and the DF-224 computer and co-processor (returning from orbit).
- The Contingency ORU Protective Enclosure (COPE) houses three Rate Sensor Units (RSU), the Solid State Recorder (SSR) (going up), the S-band Single Access Transmitter

FSS – AFT VIEW

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

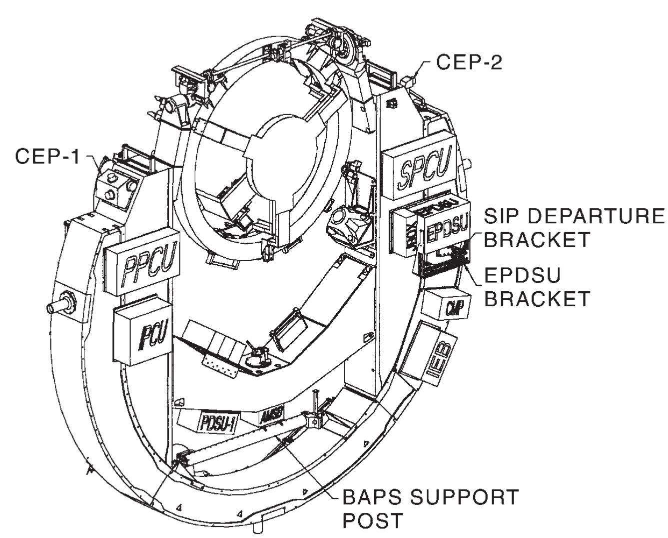

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Fig 2-3 Flight Support System configuration

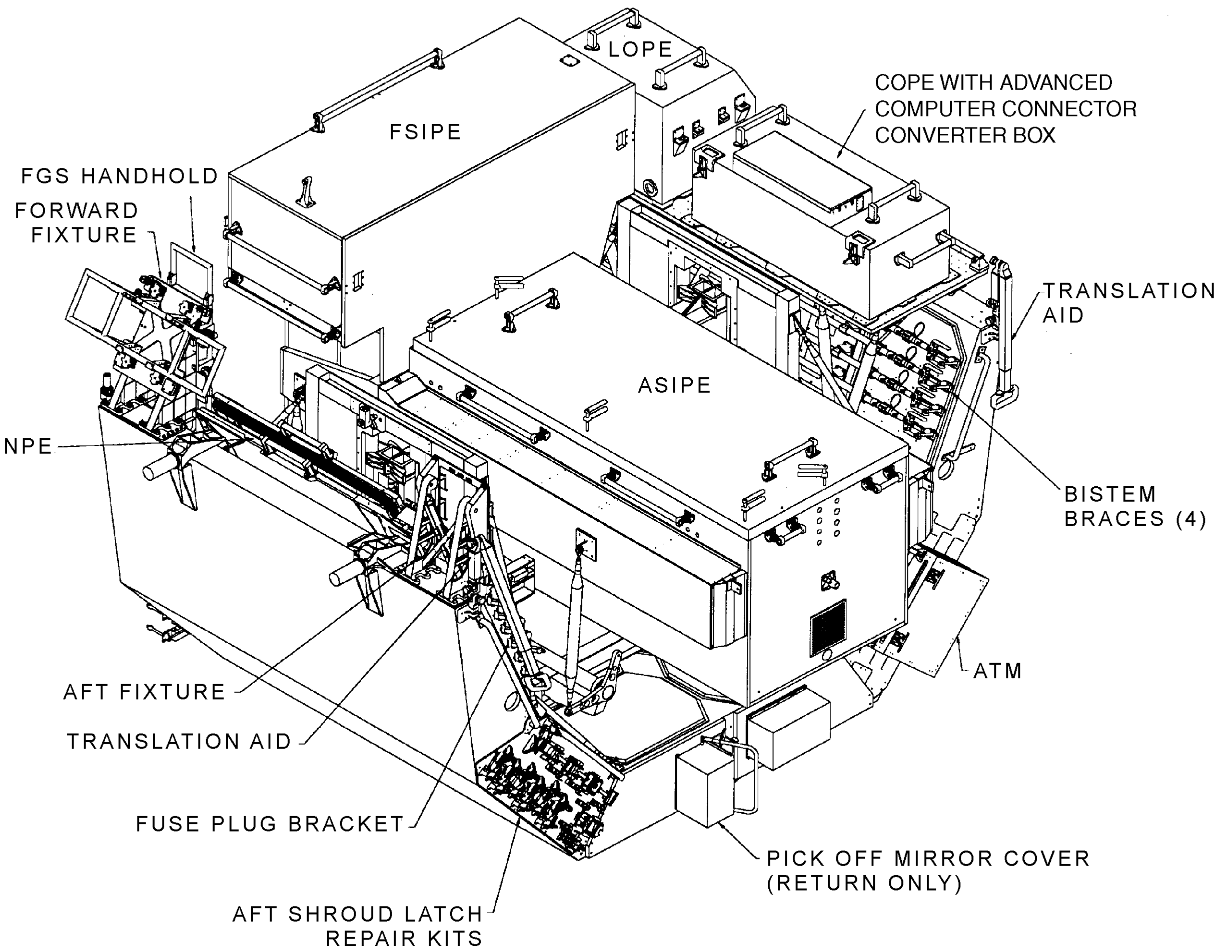

Fig. 2-4 Orbital Replacement Unit Carrier

(SSAT), the Engineering/Science Tape Recorder (E/STR) (coming back), and additional harnesses. Contingency hardware including the Electronics Control Unit (ECU), the spare Optics Control Electronics Enhancement Kit (OCE/EK), and the Power Distribution Unit (PDU) connector covers are stowed in the COPE.

- Connector converters for the Advanced Computer are on the COPE lid.
- The Axial Scientific Instrument Protective Enclosure (ASIPE) shelf contains the spare Advanced Computer, the spare RSU, six Multi-Layer Insulation (MLI) patches (two large and four small), seven Shell/Shield Replacement Fabrics (SSRFs), and six SSRF rib clamps.
- The New Outer Blanket Layer (NOBL) Protective Enclosure (NPE) contains the new protective coverings to be installed on the Telescope equipment bay doors.
- The Auxiliary Transport Module (ATM) houses MLI Recovery Bags, the Data Management Unit (DMU)/Advanced Computer contingency cables, a debris bag, and a spare SSAT coaxial cable.

The protective enclosures, their heaters, and thermal insulation control the temperature of the new ORUs and provide an environment equivalent to that inside the Telescope. Struts, springs, and foam between the enclosures and the pallet protect the ORUs from the loads generated at liftoff and during Earth return.

2.4 Astronaut Roles and Training

To prepare for SM3A, the seven-member *Discovery* 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 Brown and Pilot Kelly 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 *Discovery* cabin.

The five Mission Specialists also received specific training, starting with classroom instruction on the various ORUs, tools and crew aids, Space Support Equipment (SSE) such as the RMS (the robotic arm), and the FSS. Principal operator of the robotic arm is Mission Specialist Clervoy, who also performs IVA duties. The alternate operators are mission specialists Claude Nicollier and John Grunsfeld.

Clervoy trained specifically for capture and redeployment of the Telescope, rotation and pivoting of 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 Smith, Grunsfeld, Foale, and Nicolier logged many days of training for this important role in the NBL, a 40-ft (12-m)-deep water tank (see Fig. 2-5).

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

Other training aids at JSC helped recreate orbital conditions for the *Discovery* astronauts. In the weightlessness of space, the tiniest movement can set instruments weighing several hundred pounds, such as FGS #2, 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.

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Fig. 2-5   Neutral Buoyancy Laboratory at NASA Johnson Space Center

2.5 Extravehicular Crew Aids and Tools

Astronauts servicing HST use three different kinds of foot restraints to counteract their 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 strategically placed on the Telescope or 16 receptacles on the ORUC and the FSS.

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 this servicing mission. All tools are designed to be used in a weightless environment by astronauts wearing pressurized gloves.

The most commonly used ORU fasteners are those with 7/16-in., double-height hex heads. These bolts are used with three different kinds of fittings: J-hooks, captive fasteners, and key-hole fasteners. To replace a unit, the astronauts use a 7/16-in. extension socket on a powered or manual ratchet wrench. Extensions up to 2 ft long are available to extend an astronaut's 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, the crew can use wobble sockets.

Some ORU electrical connectors require special tools, such as a torque tool to loosen coaxial connectors. If connectors have no wing tabs, astronauts use another special tool to get a firm hold on the rotating ring of the connector.

Portable handles have been attached to many larger ORUs to facilitate removal or installation. Other tools and crew aids used during the servicing mission are tool caddies (carrying aids), tethers, transfer bags, and protective covers for the Low Gain Antenna (LGA).

When astronauts work within the Telescope's aft shroud area, they 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.

2.6 Astronauts of the Servicing Mission 3A

NASA carefully selected and trained the SM3A STS-103 crew (see Fig. 2-6). Their unique set of experiences and capabilities makes them eminently qualified for this challenging assignment. Brief biographies of the STS-103 astronauts follow.

Curtis L. Brown, Jr., NASA Astronaut (Lieutenant Colonel, USAF). Curtis Brown of Elizabethtown, North Carolina, is commander of SM3A. He received a bachelor of science degree in electrical engineering from the Air Force Academy in 1978. His career highlights include: 1992 – pilot of STS-47 Spacelab-J, an eight-day cooperative mission between the United States and Japan; 1994 – pilot of STS-66, the Atmospheric Laboratory for Applications and Science-3 (ATLAS-3) mission; 1996 – pilot of STS-77, whose crew performed a record number of rendezvous sequences (one with a SPARTAN satellite and three with a deployed Satellite Test Unit) and approximately 21 hours of formation flying in close proximity of the

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Fig. 2-6 *The STS-103 mission has seven crewmembers. They are (from left) Mission Specialist C. Michael Foale, Mission Specialist Claude Nicollier, Pilot Scott J. Kelly, Commander Curtis L. Brown, Jr., Mission Specialist Jean-François Clervoy, Mission Specialist John M. Grunsfeld, and Mission Specialist and Payload Commander Steven L. Smith.*

satellites; 1997 – commander of STS-85, a 12-day mission that included deployment and retrieval of the CRISTA-SPAS payload; 1998 – commander of STS-95, a nine-day mission during which the crew supported a variety of research payloads including the Hubble Space Telescope Orbital Systems Test Platform and deployment of the Spartan solar-observing spacecraft.

Scott J. Kelly, NASA Astronaut (Lieutenant Commander, USN). Scott Kelly, *Discovery* pilot on SM3A, is from Orange, New Jersey. He received a bachelor of science degree in electrical engineering from the State University of New York Maritime College in 1987 and a master of science degree in aviation systems from the University of Tennessee, Knoxville, in 1996. Kelly became a naval aviator in 1989 and served in the North Atlantic, Mediterranean Sea, Red Sea and Persian Gulf. He graduated from the U.S. Naval Test Pilot School in 1994, then worked as a test pilot, logging over 2,000 flight hours in more than 30 different aircraft. After completing two years of training and evaluation at Johnson Space Center in 1998, he qualified for flight assignment as a pilot. Before his selection for the SM3A crew, Kelly performed technical duties in the Astronaut Office Spacecraft Systems / Operations Branch.

Jean-François Clervoy, ESA Astronaut. Jean-François Clervoy, the RMS operator on SM3A, is from Toulouse, France. Clervoy received his baccalauréat from Collège Militaire de Saint Cyr l' Ecole in 1976 and graduated from Ecole Polytechnique, Paris, in 1981. He was selected as a French astronaut in 1985 and became a flight test engineer in 1987. Clervoy served as chief test director of the Parabolic Flight Program at the Flight Test Center, Brétigny-sur-Orge, where he was responsible for testing and qualifying the Caravelle aircraft for microgravity. He also worked at the Hermes Crew Office, Toulouse, supporting the European Manned Space Programs. Clervoy trained in Star City, Moscow, on the Soyuz and Mir systems in 1991. He was selected for the astronaut corps of the European Space Agency (ESA) in 1992. After a year of training at the Johnson Space Center, he qualified as a mission specialist for Space Shuttle flights. Clervoy flew twice aboard Space Shuttle *Atlantis* and has logged over 483 hours in space. He served as a mission specialist on STS-66 in 1994 and as the payload commander on STS-84 in 1997.

Steven L. Smith, NASA Astronaut. Steven Smith is payload commander and EVA crewmember (designated EV1 on EVA Days 1 & 3). He was born in Phoenix, Arizona, but considers San Jose, California, to be his hometown. He received both bachelor and master of science degrees in electrical engineering and a master's degree in business administration from Stanford University. Smith served as a mission specialist aboard the Space Shuttle *Endeavour* on STS-68 in 1994. His responsibilities during the 11-day flight included Shuttle systems and Space Radar Lab 2 (the flight's primary payload). Smith flew as an EVA crew member on STS-82, the HST Second Servicing Mission, in 1997. He made two 6-hour space walks while installing new science instruments and upgraded technology. From November 1994 until March 1996, Smith was assigned to the astronaut support team at Kennedy Space Center. The team was responsible for Space Shuttle prelaunch vehicle checkout, crew ingress and strap-in, and crew egress post landing.

John M. Grunsfeld, Ph.D., NASA Astronaut. John Grunsfeld is an astronomer and an EVA crewmember (EV2 on EVA Days 1 & 3) on the SM3A mission. He was born 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 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. A veteran of two space flights, he has logged over 644 hours in space. On his first mission, STS-67 in March 1995, Grunsfeld and the crew conducted observations around the clock 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 1991 on the fifth mission to dock with Russia's Space Station Mir and the second to exchange U.S. astronauts.

C. Michael Foale, Ph.D., NASA Astronaut. Michael Foale is an EVA crewmember (EV1 on EVA Days 2 & 4) on SM3. He was born in Louth, England, but considers Cambridge, England, to be his hometown. He attended the University of Cambridge, Queens' College, receiving a bachelor of arts degree in physics, with first-class honors, in 1978. He completed his doctorate in Laboratory Astrophysics at Cambridge in 1982. NASA selected Foale as an astronaut candidate in 1987 and he completed astronaut training and evaluation in 1988. A veteran of four space flights, Foale has logged over 160 days in space including 10-1/2 hours of EVA. He was a mission specialist on STS-45 in 1992 and STS-56 in 1993, the first two ATLAS missions to address the atmosphere and its interaction with the Sun. He was a member of the first Shuttle crew (STS-63) to rendezvous with Russia's Mir Space Station in 1995. Foale spent four months aboard Mir in 1997, conducting various science experiments and helping the crew resolve and repair numerous malfunctioning systems. He arrived May 17 on Space Shuttle *Atlantis* (STS-84) and returned October 6, also on *Atlantis* (STS-86).

Claude Nicollier, ESA Astronaut. Claude Nicollier is an EVA crewmember (EV2 on EVA Days 2 & 4) on SM3A. A native of Vevey, Switzerland, he received a bachelor of science degree in physics from the University of Lausanne in 1970 and a master of science degree in astrophysics from the University of Geneva in 1975. He became a Swiss Air Force pilot in 1966, an airline pilot in 1974, and a test pilot in 1988. In July 1978 ESA selected Nicollier as a member of the first group of European astronauts. Under agreement between ESA and NASA, he joined the NASA astronaut candidates selected in 1980 for training as a mission specialist. A veteran of three space flights, Nicollier has logged more than 828 hours in space. He participated in the deployment of the European Retrievable Carrier (EURECA) science platform on STS-46 in 1992. He was the RMS operator on STS-61 in 1993, the first HST servicing and repair mission. He also served as a mission specialist on STS-75 aboard *Columbia* in 1996 – the reflight of the Tethered Satellite System and the third flight of the United States Microgravity Payload.

2.7 Servicing Mission Activities

After *Discovery* berths the Hubble Space Telescope in Fall of 1999, the seven-person crew will begin an ambitious servicing mission. Four days of EVA tasks are scheduled. Each EVA session is scheduled for six hours.

2.7.1 Rendezvous With the Hubble Space Telescope

Discovery will rendezvous with Hubble in orbit 320 nautical miles (512 km) above the Earth.

Prior to approach, in concert with the Space Telescope Operations Control Center (STOCC) at GSFC, Mission Control will command HST to stow the High Gain Antennas (HGA) and close the aperture door. As *Discovery* approaches the Telescope, Commander Brown will control the thrusters to avoid contaminating HST with propulsion residue. During this approach the Shuttle crew will be in close contact with Mission Control at JSC.

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

When *Discovery* and HST achieve the proper position, Mission Specialist Clervoy 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, he will maneuver HST 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 *Discovery*. Pilot Kelly also will maneuver the Shuttle so that the SAs face the Sun to recharge the Telescope's six onboard nickel-hydrogen (NiH_2) batteries.

2.7.2 Extravehicular Servicing Activities – Day by Day

Figure 2-7 shows the schedule for four planned six-hour EVA servicing periods. These time spans are planning estimates; the schedule will be modified as needed as the mission progresses. During the EVAs, HST will be vertical relative to *Discovery's* cargo bay. Four EVA mission specialists will work in two-person teams on alternate days. One team is Steve Smith and John Grunsfeld; the other is Mike Foale and Claude Nicollier.

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 *Discovery'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 SM3A 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 *Discovery'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.

At the beginning of EVA Day 1 (the fourth day of the mission), the first team of EVA astronauts suit up and pass through the *Discovery* airlock into the cargo bay. To prevent themselves from accidentally floating off, they attach safety tethers to a cable running along the cargo bay sills. EV1 accomplishes a variety of specific tasks to prepare for that day's EVA servicing activities. These include removing the MFR from its stowage location and installing it on the RMS grapple fixture, installing the Low Gain Antenna Protective Cover (LGA PC), deploying the Translation Aids (TA), and removing the Berthing and Positioning System (BAPS) Support Post from its stowage location and installing it on the FSS with the assistance of EV2.

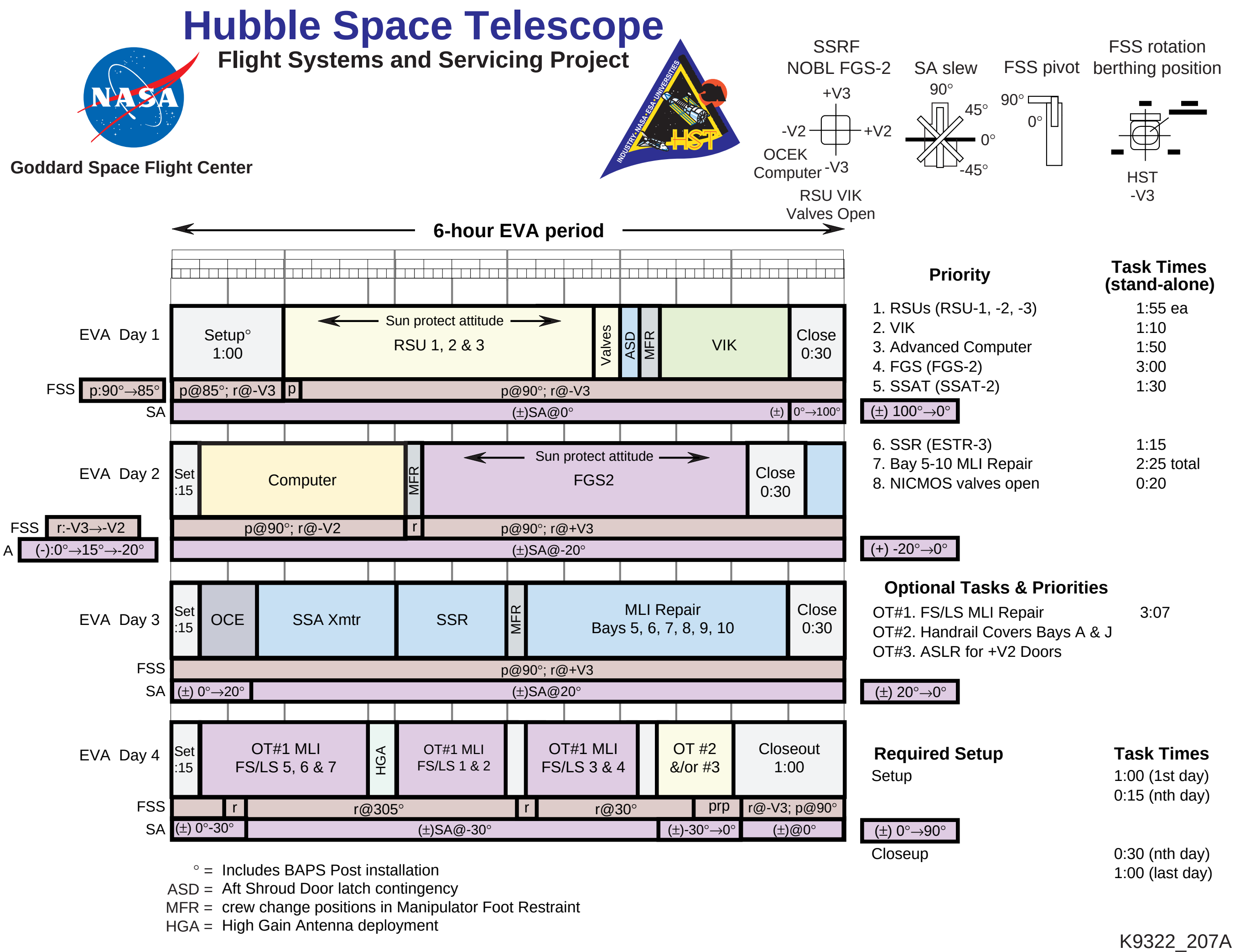

Fig. 2-7 Detailed schedule of extravehicular activities and SA and FSS positions during SM3A

Meanwhile, EV2 brings out of the airlock the Crew Aids and Tools (CATs) that will be attached to the handrails of the RMS. He installs the CATs handrail to the RMS and the color television camera (CTVC) on the MFR. The IVA RMS operator then moves EV2 to the BAPS Support Post (BSP) installation worksite to install the BSP forward end on the BAPS.

EVA Day 1: Change out three RSUs. Remove caps and open the NICMOS "Coolant In" and "Coolant Out" valves. Install VIK on HST batteries.

During EVA Day 1, Smith and Grunsfeld are scheduled to replace three new RSUs in the Telescope. They will also remove caps from the NICMOS "Coolant In" and "Coolant Out" valves. Any ice contained within those valves will sublimate in the vacuum of space and facilitate installation of a replacement cooler for NICMOS on SM3B. Additionally, the astronauts will install VIKs on the six batteries aboard HST.

Once in the payload bay, the astronauts begin the initial setup, which includes installation of the LGA protective cover, TA deployments, and installation and deployment of the BSP.

The BSP is required to dampen the vibration that the servicing activities will induce into the deployed SAs. Prior to the BSP installation on

EVA Day 1, 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 the event that the Shuttle must make an emergency return to Earth. Steve Smith (EV1) removes the BSP from its stowage position in the cradle of the FSS and hands the forward end to John Grunsfeld (EV2) who installs his end to the BAPS ring with a PIP pin. Smith then installs the aft end of the BSP to the FSS cradle with a PIP pin. Finally the BSP is commanded to its 90-degree limit and the two center PIP pins are installed.

After the BSP is installed and other initial setup tasks are completed, the crew starts the specific tasks for the RSU change-outs. First Smith, who is free floating, retrieves the STS PFR and Articulating Socket and temporarily stows them at the aft ORUC. Smith and Grunsfeld (in the MFR), move to the COPE to retrieve the replacement RSU-2. To accomplish the removal, they open three COPE T-handle lid latches and the COPE lid, then release the transport module T-handle latch and open it. They remove the replacement RSU-2 and stow it in the ORU transfer bag. Next they close the transport module and the COPE lid and engage two T-handle latches.

The astronauts then translate to the aft shroud. They inspect the area for excessive particulates or debris and when satisfied that the area is clear, Smith and Grunsfeld open the HST –V3 aft shroud doors by retracting two Fixed Head Star Tracker (FHST) seals and disengaging four door latches.

Smith then installs the PFR and articulating socket in the HST aft shroud and ingresses. Smith and Grunsfeld remove the old RSU-2 by demating two wing tab connectors and disengaging three 7/16-in. hex-head captive spring-loaded fasteners. Smith and Grunsfeld remove the RSU-2 replacement from the ORU transfer bag. They remove the two connector caps and install the replacement RSU-2 in HST, engaging three fasteners and mating the two connectors (see Fig. 2-8). Finally, they replace the old RSU-2 in the ORU transfer bag.

Smith steps out of the PFR, reconfigures it for the RSU-3 position, and gets back into the PFR. Meanwhile, Grunsfeld maneuvers to the COPE and opens the lid, stowing the old RSU-2 and retrieving the RSU-3 replacement. He stows it in the ORU transfer bag, then temporarily closes the COPE lid (two latches) and maneuvers back to the aft shroud.

Smith and Grunsfeld remove the old RSU-3 by demating two wing tab connectors and disengaging three 7/16-in. hex captive spring-loaded fasteners. They then remove the replacement RSU-3 from the ORU transfer bag and install it, first removing the two connector caps, then seating it in HST. They engage three fasteners, mate the two connectors and place the old RSU-3 in the ORU transfer bag.

Smith exits the PFR and reinstalls it in the aft shroud door closing position. Grunsfeld performs a video close-out on the two newly installed RSUs. He then maneuvers to the COPE and stows RSU-3. He retrieves the replacement RSU-1 and stows it in the ORU transfer bag. He temporarily closes the COPE lid (one latch) and maneuvers back to the aft shroud.

Grunsfeld, on the MFR at the end of the RMS, removes the old RSU-1 by demating two wing tab connectors and disengaging three 7/16-in. hex captive spring-loaded fasteners. They install the replacement RSU-1 by removing the two connector caps, removing the replacement from the ORU transfer bag, seating it in HST

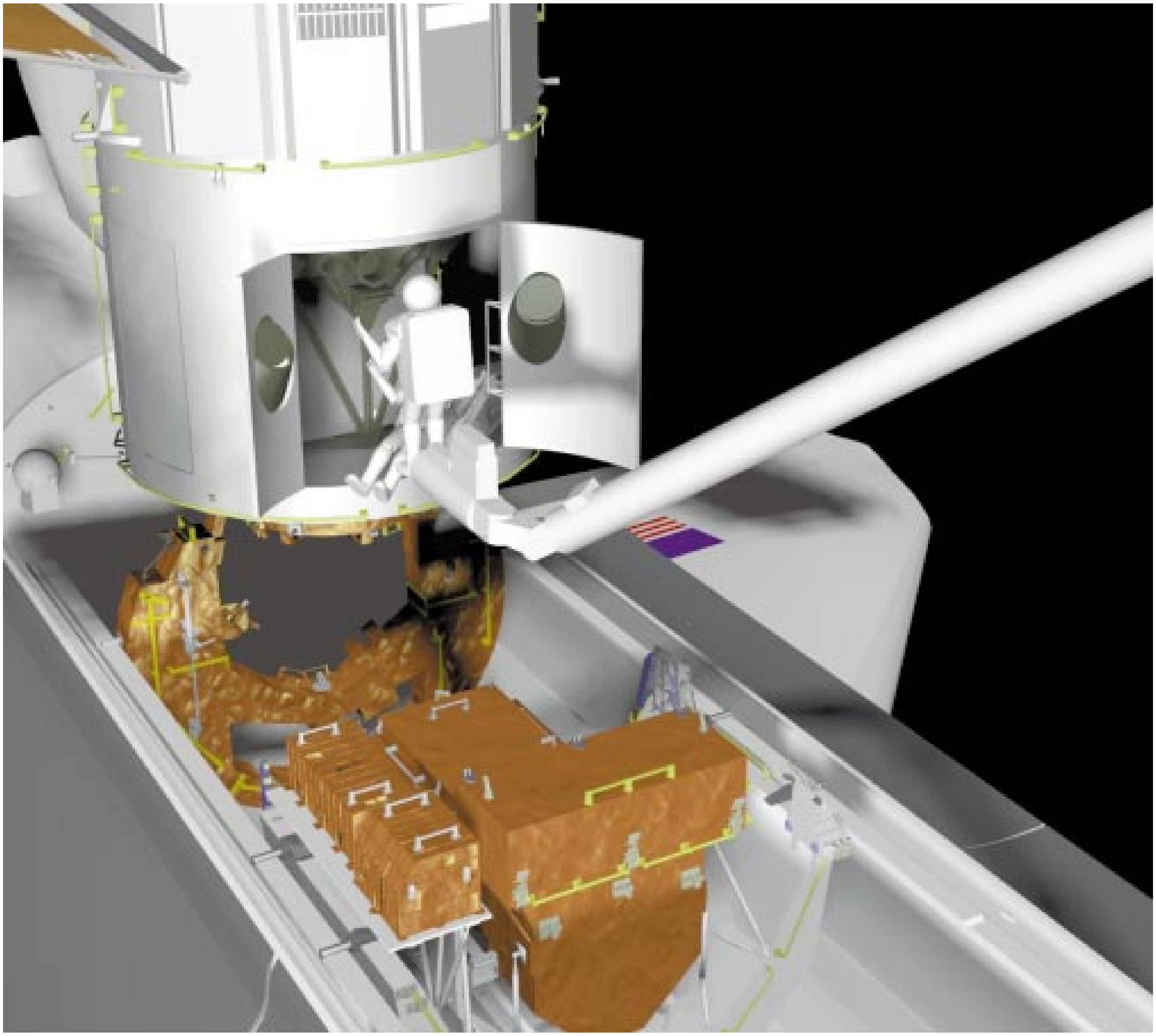

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Fig. 2-8 Change-out of Rate Sensor Unit

and engaging three fasteners, and mating two connectors. After the old RSU-1 is stowed in the ORU transfer bag, Grunsfeld performs the replacement RSU-1 video close-out.

While positioned at the Aft Shroud, Smith and Grunsfeld then perform the NICMOS valve reconfiguration. They remove two "Coolant In" and "Coolant Out" bayonet caps and open the "Coolant In" and "Coolant Out" valves. Grunsfeld performs the NICMOS valve reconfiguration video close-out.

Grunsfeld partially closes the –V3 Aft Shroud doors as Smith ingresses the PFR. With Smith's assistance, Grunsfeld closes the left and right doors, engages the four door latches, checks the door seals, and extends the two FHST light seals. Smith egresses the PFR/Articulating Socket, removing it from HST and restowing it in cargo bay. Grunsfeld maneuvers to the COPE and stows the old RSU-1 in the transport module, closes the transport module lid, then fully closes the COPE lid, engaging all three latches.

Smith and Grunsfeld now prepare to install VIKs on the HST batteries. Smith takes Grunsfeld's place on the MFR and Grunsfeld becomes the free floater after the MFR swap.

Grunsfeld translates to airlock, retrieves the VIK Caddy, translates to Bay 3, and transfers the VIK Caddy to Smith. Smith (in the MFR) opens the Bay 3 door by disengaging six J-hooks. Grunsfeld retrieves the handrail cover caddy, inspects the handrails around Bays 2 and 3, and installs the handrail covers if needed. Smith demates three Bay 3 battery connectors (one at a time) and installs a VIK in-line with each battery connector (see Fig. 2-9). Smith performs the Bay 3 VIK video close-out, closes the door, and engages the six door J-hooks.

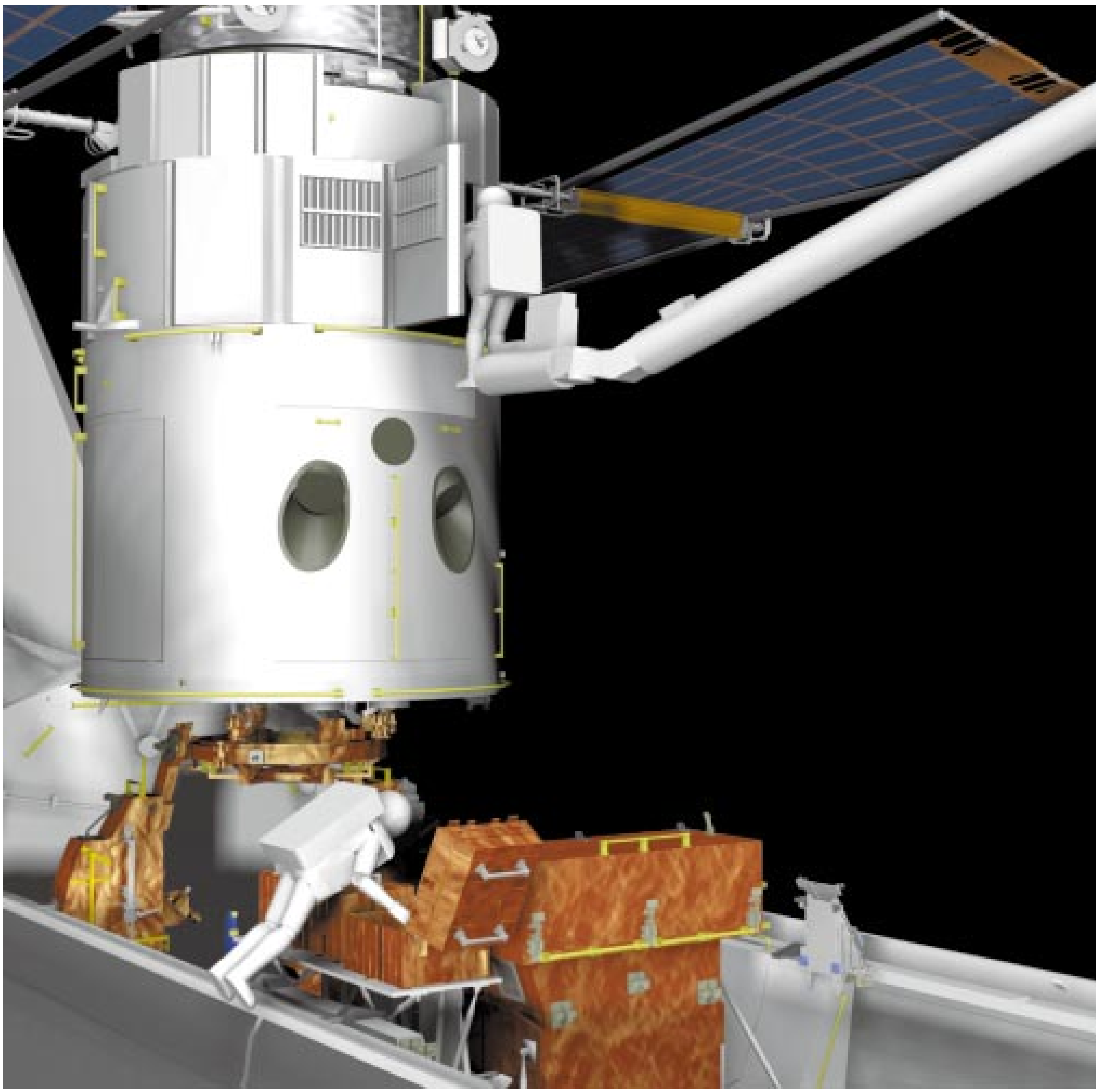

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Fig. 2-9 Voltage/Temperature Improvement Kit installation

Smith then opens Bay 2 door by disengaging six J-hooks. He demates three Bay 2 battery connectors (one at a time) and installs a VIK in-line with each battery connector. He performs the Bay 2 VIK video close-out, closes the door, engages the six door J-hooks, and stows the VIK Caddy on the MFR.

For the daily close-out, Grunsfeld removes the center pins on the BSP, inspects the FSS main umbilical, and retracts the TAs while Smith prepares the CATs installed on the MFR handrail for return into the airlock. Additionally, Smith releases the MFR safety tether from the grapple fixture for contingency Earth return and releases the lower CTVC cable. After the completion of EVA Day 1, both astronauts return to the airlock with the Day 1 CATs installed on the MFR handrail.

EVA Day 2: Replace DF-224 computer with Advanced Computer and install Bay 1 NOBL. Change out FGS-2.

During EVA Day 2, EVA astronauts Nicollier (EV1) and Foale (EV2) are scheduled to replace HST's DF-224 computer with a faster, more powerful unit called the Advanced Computer. They will also change out a degraded FGS in position number 2 (see Fig. 2-10).

Fewer daily setup tasks are required for EVA Day 2 than for EVA Day 1. Foale exits the airlock with the EVA Day 2 required CATs installed on the MFR handrail. Nicollier reconnects the safety strap on the MFR and connects the CTVC cable to the RMS end effector. Foale then installs the MFR handrail and the CTVC on the RMS. Nicollier deploys the TAs and installs the BSP center PIP pins.

The astronauts' first servicing task for the day is to change out the DF-224 computer with the new Advanced Computer. Foale (in the MFR) maneuvers to the COPE Converter Transport Module and retrieves the Connector Converter Caddy. Foale then maneuvers to the Bay 1 worksite and installs handrail covers on the handrails adjacent to the Bay 1 door if he deems them necessary.

Meanwhile, Nicollier (free floating) translates to the LOPE and opens the LOPE lid by disengaging four J-hook bolts. He removes the Y-harness and mates one end of it to the Advanced Computer. Nicollier also prepares the Advanced Computer for Foale to remove from the LOPE , releasing five of its six J-hooks and temporarily closing the LOPE lid and engaging a single J-hook.

Foale opens the Bay 1 door by disengaging six J-hooks and sets the integral door stay. Nicollier translates back to Bay 1 to assist Foale with the computer swap. Foale removes the DF-224 computer by demating its nine electrical connectors and disengaging six J-hooks. He transfers it to Nicollier positioned at the MFR stanchion. Foale then installs the seven connector converters on the HST harnesses.

Nicollier transfers the DF-224 computer to Foale for the maneuver to the LOPE worksite. Foale transfers the DF-224 computer back to Nicollier and opens the LOPE lid by disengaging one J-hook. Foale removes the Advanced Computer from the LOPE by disengaging one J-hook, then maneuvers back to Bay 1.

Meanwhile, Nicollier installs the DF-224 computer in the LOPE, engaging six J-hooks, then closes the LOPE lid and engages four J-bolts. Nicollier translates back to the Bay 1 worksite to assist Foale. Foale installs the Advanced Computer in Bay 1 by engaging six J-hooks, mating two remaining Y-harness connectors,

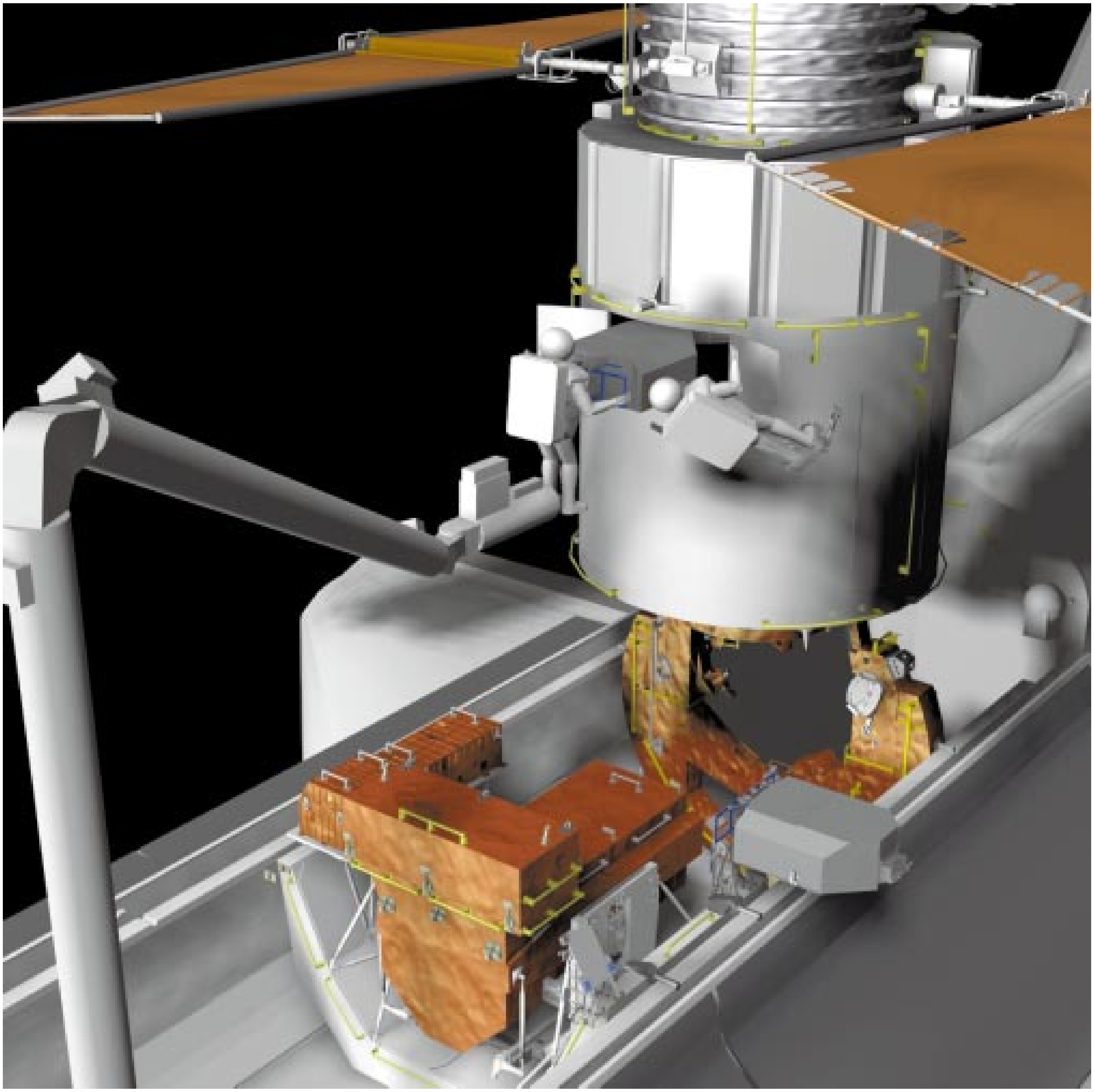

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Fig. 2-10 Fine Guidance Sensor change-out

and mating seven harnesses. He then performs the Advanced Computer video close-out, releases the door stay, and closes the Bay 1 door, engaging six J-hooks.

After the computer change-out, Nicollier and Foale open the NPE, retrieving the Bay 1 NOBL and NOBL plug stringer from the NPE and closing it. They install the Bay 1 NOBL on the Bay 1 door by installing four NOBL vent hole plugs and connecting the NOBL ground cap to the door J-bolt.

As the astronauts prepare to undertake the FGS-2 change-out, Nicollier replaces Foale on the MFR and Foale becomes the free floater.

Nicollier and Foale retrieve a PFR/PFR Extender and set it up on the HST in Foot Restraint 11. Nicollier retrieves the outboard FGS handhold from the ORUC forward fixture and installs handrail covers at FGS-2 worksite as needed. Foale deploys the aft fixture.

The astronauts open and secure the FGS bay doors and demate the FGS connectors and ground strap. Nicollier installs four guide studs on the FGS, then installs the FGS handhold and loosens the A latch. The FGS is now ready to be removed.

With Foale in the PFR and Nicollier holding the FGS handhold, the team removes the FGS as Foale gives clearance instructions. To ensure successful installation of the replacement FGS, the team may practice reinsertion of the old FGS back into the HST guiderails without latching the latches or mating the connectors for mass handling evaluation.

After this practice insertion, Nicollier removes the FGS and stows it on the aft fixture. Foale then conducts a bay inspection. Next, Foale translates to the ORUC FSIPE, opens the lid, latches the lid in the open position, and demates and secures the ground strap. In parallel, Nicollier retrieves the other FGS handhold from the ORUC forward fixture and positions himself for its installation on the replacement FGS in the FSIPE.

After installing the handhold on the replacement FGS, Nicollier loosens the A latch. Then, with instructions and assistance from Foale, Nicollier removes the replacement FGS from the FSIPE and translates with it to the HST. Foale closes the FSIPE lid and engages one lid latch. He then ingresses the PFR mounted on the HST and prepares to remove the FGS mirror cover. Nicollier presents the FGS to Foale so that the FGS mirror cover can be removed. Foale tethers to the cover, releases the slide lock lever, and operates the handle to remove the mirror cover. When the mirror cover is removed, IVA repositions Nicollier on the MFR so the FGS can be installed.

Nicollier inserts the FGS with assistance from Foale (see Fig. 2-10). Nicollier tightens the A latch, removes the FGS handhold, and stows it temporarily on the MFR, then installs the ground strap and electrical connectors. After the electrical connectors are mated, IVA informs Mission Control to perform an aliveness test. Nicollier takes the close-out photographs (video), closes and latches the doors, and checks the door seals. He then retrieves the HST PFR and stows it for later reinstallation in the cargo bay. Foale stows the mirror cover on the ORUC.

Nicollier retrieves the FGS from the aft fixture. Foale stows the aft fixture, translates to the FSIPE, and opens the lid. Nicollier translates to the FSIPE with the FGS. Foale assists Nicollier during the FGS insertion into FSIPE. After full insertion, Nicollier tightens the A latch while Foale mates the ground strap. Foale releases the FSIPE on-orbit latches and closes and secures the lid. Nicollier stows the replacement FGS handhold in the forward fixture. Foale retrieves the PFR that was used for the FGS change-out and reinstalls it on the Shuttle bay adaptive payload carrier.

For the EVA Day 2 daily close-out, Foale removes the center pins on the BSP, inspects the FSS main umbilical mechanism, and retracts the TAs while Nicollier prepares the CATs installed on the MFR handrail for return to the airlock. Foale releases the MFR safety tether from the RMS in the event of contingency Earth return. Both astronauts return to the airlock with the MFR handrail and its installed CATs.

EVA Day 3: Mate additional OCE-EK connectors for the new FGS-2. Change out SSAT. Replace E/STR #3 with SSR #3. Repair MLI.

On EVA Day 3, EVA astronauts Smith and Grunsfeld are scheduled to mate additional OCE-EK connectors to allow for the on-orbit alignment optimization of the replacement FGS adjustable, articulated, fold flat #3 mirror. They will replace an S-band single access transmitter (SSAT) that failed in 1998. An identical backup transmitter has functioned perfectly and HST's observing program has not been affected. The astronauts also will install an SSR in place of an E/STR. Finally, they will undertake MLI repairs over the doors on Bays 5 through 10.

The daily setup for EVA Day 3 is identical to EVA Day 2. Smith still exits the airlock with the required CATs and CTVC installed on the MFR handrail and transfers them to Grunsfeld. He reconnects the safety strap on the MFR/RMS and connects the CTVC to the RMS end-effector. Grunsfeld installs the MFR handrail and the CTVC on the RMS. Smith deploys the TA and installs the BSP center PIP pins.

The first task of the day is the mating of the OCE-EK connectors. Grunsfeld on the RMS translates to the Optical Telescope Assembly (OTA) Bay C door and opens the door via the three J-hooks. He then demates the P11 connector from the OCE, and mates the OCE-EK J/P11 A with the OCE J11 and HST P11 connectors. The close-out photographs are taken and the Bay C door is secured with its three J-hooks.

Grunsfeld on the MFR then opens the Bay 5 door by disengaging six J-hooks, then secures the door in the open position. He prepares the old SSAT-2 for removal by demating two circular connectors and three coaxial connectors. He installs a fastener retention block, removes eight non-captive bolts/washers, and removes the old SSAT-2. Grunsfeld transfers the SSAT-2 to Smith, who is free floating.

Smith brings the old SSAT-2 to the COPE, opens it, and retrieves the replacement SSAT. He stows the old SSAT in the COPE, closes it, and translates back to Bay 5. Grunsfeld receives the replacement SSAT-2 from Smith, installs it on the Bay 5 door by engaging seven bolts, removing the two connector caps, mating two circular connectors, and mating three coaxial connectors (see Fig. 2-11). Grunsfeld then performs the video close-out. Because the SSR installation is the next task, the Bay 5 door is left open.

The next change-out task is replacement of the E/STR-3 with a newer technology SSR-3. Grunsfeld demates the T-harness installed during SM2 and two other E/STR-3 connectors, being careful not to allow the powered-on P1 connector to touch structure ground. He secures the P1 connector behind the cable harness along the side wall, demates the four keyhole fasteners, and removes the E/STR.

Smith and Grunsfeld translate to the COPE with the E/STR-3. Smith releases the COPE lid latches and opens the lid. Smith and Grunsfeld remove SSR-3 from the COPE transport module and install the E/STR-3 into the COPE transport module. Grunsfeld translates back to the Bay 5 worksite. Smith stows the T-harness in the COPE lid, retrieves the J-harness, then closes and latches the lid. He then translates with the J-harness to Bay 5 to assist with the SSR installation.

In parallel to Smith's closure of the COPE, Grunsfeld installs the SSR into the #3 position (see Fig. 2-12). SSR-3 is mounted via four keyhole bolts. The SSR-3 connector caps are removed and the connectors mated, then the

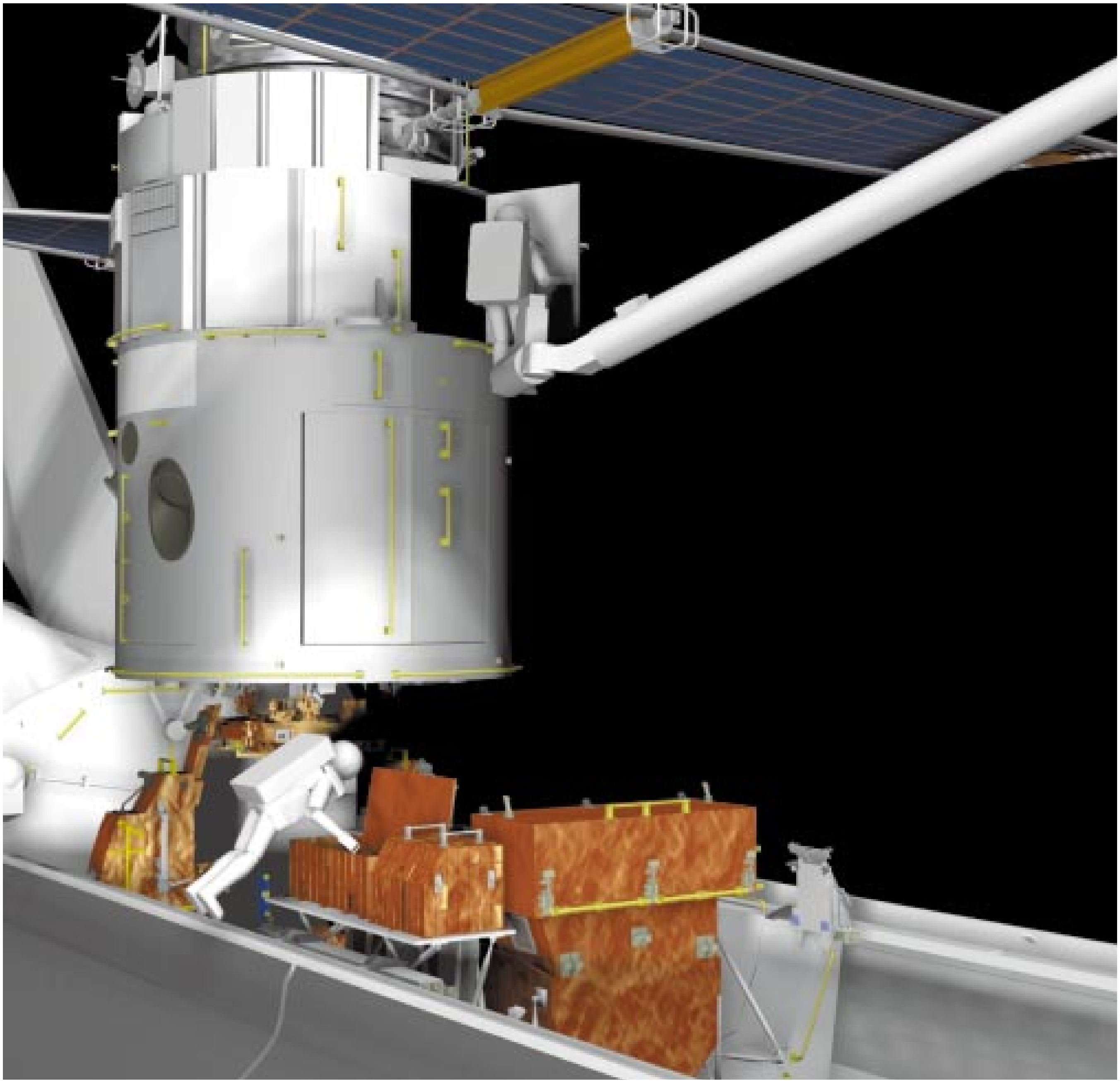
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Fig. 2-11 S-Band Single Access Transmitter change-out

J-harness is mated to the J-4 connectors on SSR-3 and SSR-1. The J-harness provides increased capability for the SSR and HST. Grunsfeld takes the close-out video. With the assistance of Smith, Grunsfeld closes the door and secures it with the six J-hooks.

The crewmembers now swap roles: Smith moves to the MFR and Grunsfeld becomes free floating. Grunsfeld retrieves the MLI recovery bags from ORUC ATM. Smith opens the NPE and retrieves the NOBLs for Bays 5 and 6 and a single NOBL plug stringer. He temporarily closes the NPE by securing one latch.

Grunsfeld assists Smith throughout the NOBL installation process. Smith installs the Bay 6 NOBL to the door stop and secures the handle

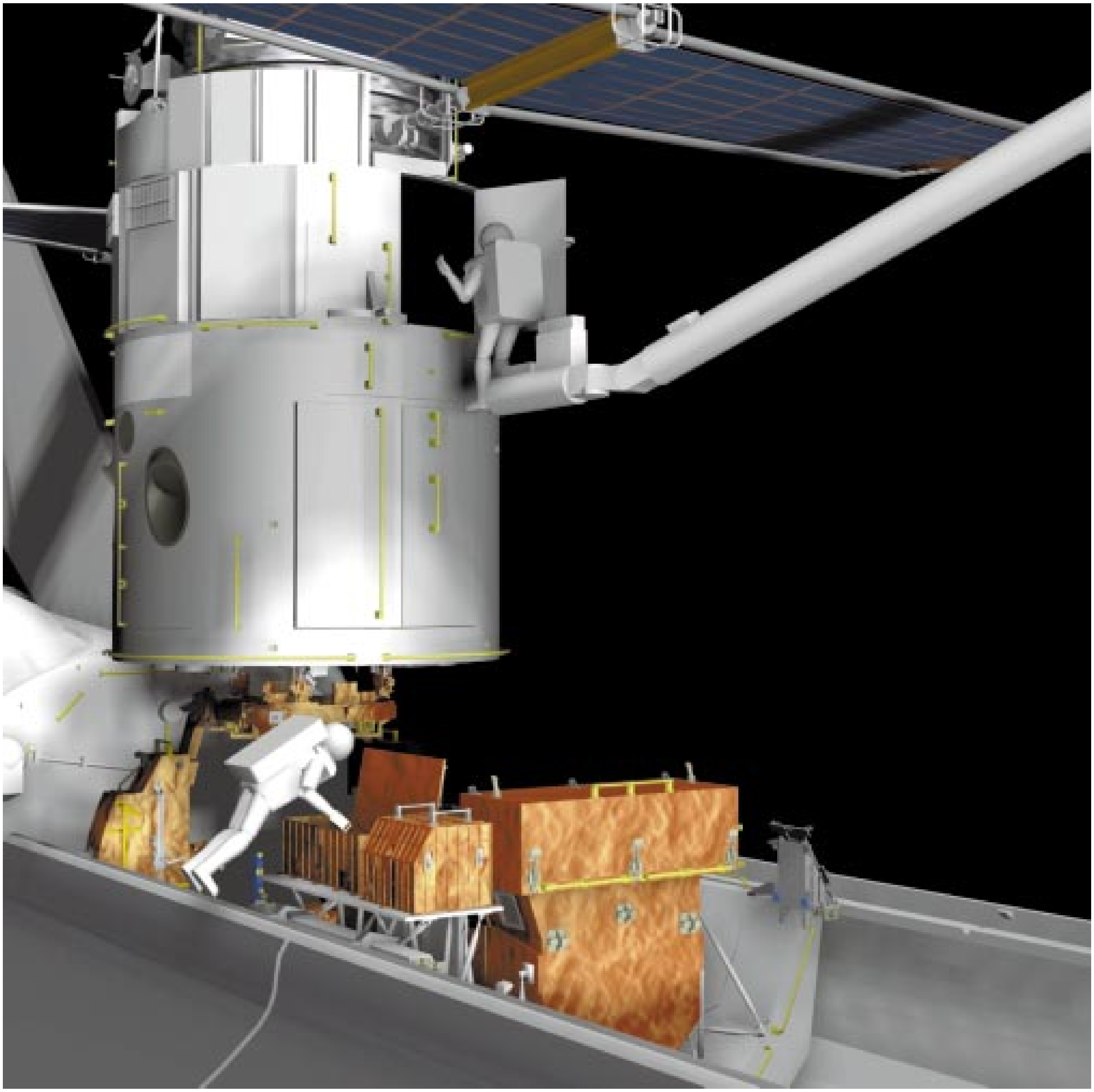

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Fig. 2-12   Installation of Solid State recorder

attachment to the door handle. He removes the two Bay 7 tie wraps and stows them in the trash bag, then removes the two Bay 8 patches and stows them in an MLI recovery bag. The patches were installed during SM2.

Smith removes the original Bay 5 door MLI and stows it in an MLI recovery bag. He installs the Bay 5 NOBL and secures it with the four NOBL plugs, then connects the NOBL ground cap to a J-bolt (see Fig. 2-13).

Smith retrieves the Bay 7 and Bay 8 NOBL and two vent plug stringers from the NPE and temporarily closes the NPE, securing a single latch. He installs the Bay 7 NOBL, securing it

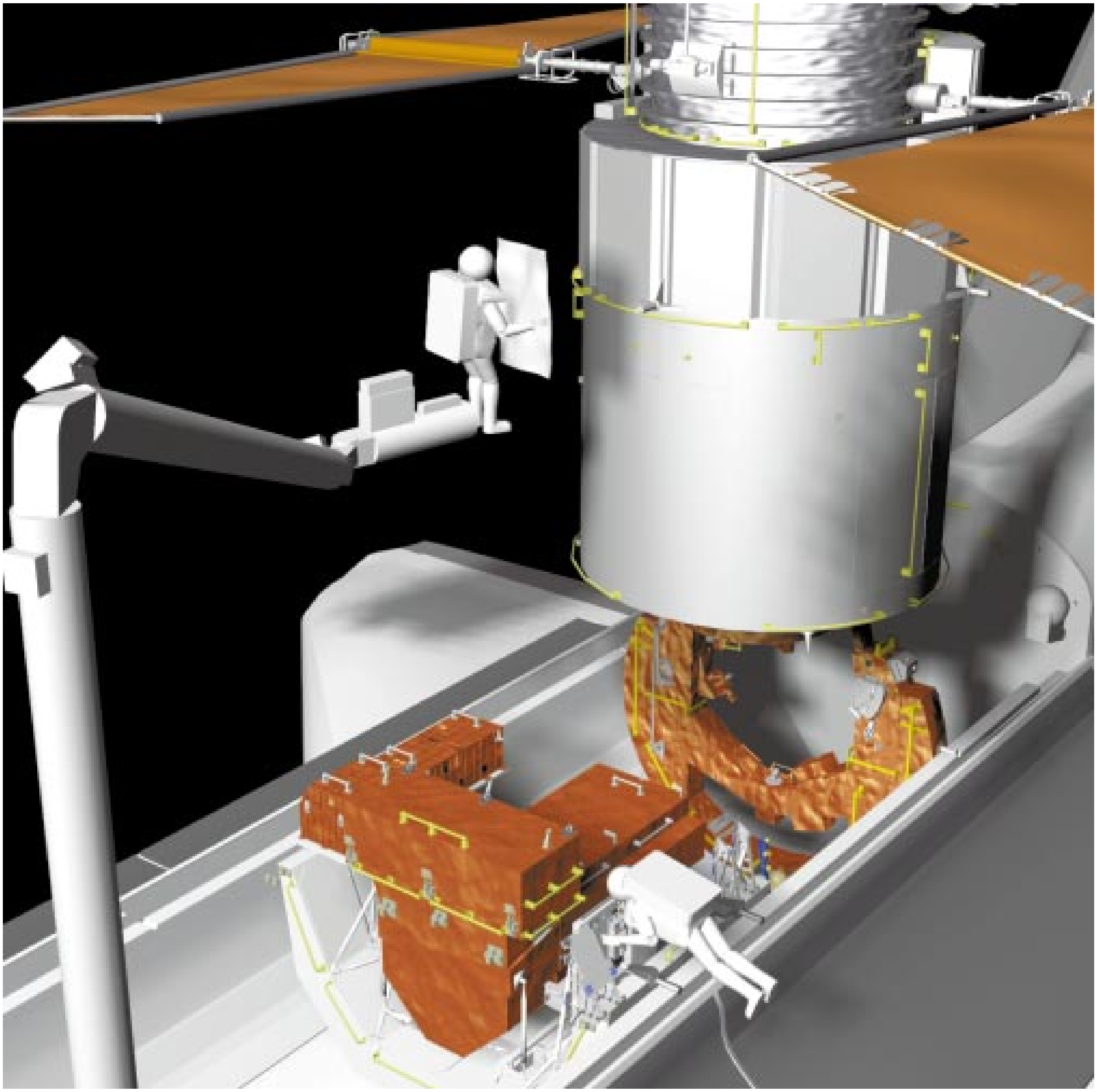

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Fig. 2-13   New outer blanket layer installation

with the four NOBL plugs, then connects the NOBL ground cap to a J-bolt.

Smith installs the Bay 8 NOBL and secures it with the NOBL plugs, then connects the NOBL ground cap to a J-bolt. He removes the two MLI patch kits installed on Bay 10 during SM2 and stows them in an MLI recovery bag, then removes the two original Bay 10 door MLI pieces and stows them in an MLI recovery bag.

Smith retrieves the Bay 9 and Bay 10 NOBL and NOBL plugs from the NPE and closes the NPE, securing all three latches. He installs the Bay 9 NOBL to the door stop and secures the handle attachment to the door handle. Smith then installs the Bay 10 NOBL and secures it with the four NOBL plugs, then connects the NOBL ground cap to a J-bolt.

For the Day 3 EVA close-out, Grunsfeld removes the center pins on the BSP, inspects the FSS main umbilical mechanism, and retracts the TAs while Smith prepares the CATs installed on the MFR handrail for return into the airlock. Smith releases the MFR safety tether from the RMS in the event of contingency Earth return. After completion of the EVA Day 3 close-outs, both astronauts return to the airlock with the MFR handrail and its installed CATs.

EVA Day 4: EVA Day 4 consists of a series of scheduled and optional tasks: Install SSRFs on the forward shell/light shield. Install handrail covers on the Bays A and J handrails. Install Aft Shroud Latch Repair (ASRL) Kits on the +V2 aft shroud doors.

EVA crewmembers Foale and Nicollier are scheduled to install new insulation material on the outer surfaces of the Telescope where MLI has become degraded. Optional tasks are to install handrail covers where the paint covering has debonded and install repair kits to functionally replace the degraded aft shroud door latches.

EVA Day 4 has a daily setup similar to that of the prior EVA days. Nicollier starts the day in the MFR. Foale exits the airlock with the required CATs installed on the MFR handrail and the CTVC and transfers them to Nicollier. Nicollier reconnects the safety strap on the MFR/RMS and connects the CTVC cable to the RMS end-effector. Nicollier then installs the MFR handrail and the CTVC to the RMS. Foale deploys the TAs and installs the BSP center PIP pins.

Foale opens the ORUC ASIPE by disengaging the five lid latches. Nicollier opens the lid. Foale retrieves the five SSRF rib clamps and Nicollier retrieves SSRFs 5, 6, and 7. Nicollier closes the ASIPE lid temporarily by engaging a single lid latch.

Foale and Nicollier install the five SSRF rib clamps on the HST station 358 rib. Working as a team, Foale and Nicollier install SSRFs 5, 6, and 7.

Nicollier opens the ASIPE and retrieves SSRFs 1, 2, 3, and 4. He then fully closes the ASIPE, engaging the five lid latches. Nicollier and Foale translate to HST and installs SSRFs 1 and 2.

When that task is complete, the IV crew rotates the FSS to the HST 30-degree position. Nicollier and Foale install SSRFs 3 and 4. Both then install two ASLR Kits on the two degraded +V2 door latches if needed. The handrail covers also can be installed, if needed, at this time.

For the final daily close-out, Foale stows the TAs, removes and stows the LGAPC, inspects the FSS main umbilical mechanism, and inspects the P105/P106 connector covers. Nicollier installs the CATs on the MFR handrail for return to the cabin and demates and stows the MFR from the RMS. When the tasks are complete, both crewmembers enter the airlock with the CATs-laden MFR handrail.

EVA Contingency Day. An unscheduled EVA day has been allocated for enhancing payload mission success and for any payload requirements on the HST redeployment day.

Redeploying the Telescope. The day following EVA Day 4 will be devoted to any unscheduled EVA tasks and redeployment of the HST into Earth orbit (see Fig. 2-14).

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Fig. 2-14 Redeploying the Space Telescope

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, crew members command Discovery'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 on the redeployment day, manually overriding any faulty mechanisms.

2.8 Future Servicing Plans

As the Hubble Space Telescope enters the 21st century, other enhancements are planned. A third-generation instrument, the Advanced Camera for Surveys (ACS), will greatly enhance HST's imaging capabilities. Shuttle astronauts plan to install the camera during SM3B.

ACS is truly an advanced camera, with predicted performance improvements one to two orders of magnitude over current Hubble science instruments. Its unique characteristics and dramatically improved efficiencies will exploit the full potential of the Telescope to serve the needs of the science community.

Periodic upgrades and servicing will ensure that Hubble continues to yield remarkable advances in our knowledge of the universe.