

STS-61

PRESS INFORMATION

December 1993



Rockwell International
Space Systems Division

Office of Media Relations

PUB 3546-V Rev 12-93

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MISSION OVERVIEW

This is the 5th flight of Endeavour and the 59th for the space shuttle.

The flight crew for the 11-day mission is commander Richard (Dick) O. Covey, pilot Kenneth (Ken) Bowersox, and mission specialists F. Story Musgrave, Thomas (Tom) D. Akers, Jeffrey (Jeff) A. Hoffman, Kathryn (Kathy) C. Thornton, and Claude Nicollier of the European Space Agency (ESA).

STS-61's primary objective is to carry out the first in a series of planned missions to perform on-orbit servicing of the Hubble Space Telescope, an international cooperative program between NASA and ESA. This will be accomplished through rendezvous, proximity operations, docking and retrieval, and a record five scheduled extravehicular activities (EVAs) to service the HST (two unscheduled EVAs and a contingency EVA are also possible, if required). Once the telescope has been serviced, it will be redeployed.

The first HST servicing mission has three primary objectives: restoring the planned scientific capabilities, restoring the reliability of HST systems, and validating the HST on-orbit servicing concept.

The primary servicing tasks include the installation of the following items:

- Two new solar arrays, which provide the telescope with electrical power (the current arrays jitter due to excessive flexing that occurs when the telescope passes from cold darkness into warm daylight, compromising their structural integrity)
- An operational wide-field/planetary camera (WF/PC-II) to compensate for the telescope's mirror's spherical aberration
- P16 fuse plugs (to correct sizing and wiring discrepancies)

- Rate sensor units (RSUs) 2 and 3 (gyroscopes required to point and track the telescope—three of the six on board the HST have failed)
- Electronics control unit (ECU) 3 (one of the three electrical brains for the RSUs will be replaced to increase reliability)
- Magnetic sensing system (MSS) 1 (one of the two magnetometers that help measure HST's position relative to Earth's magnetic field will be replaced with an improved MSS)
- Solar array drive electronics (one of HST's two SADEs, which transmit positioning commands to the wing assembly, has failed and will be replaced)
- Replacement of the current high-speed photometer with the corrective optics space telescope axial replacement (COSTAR) to compensate for the mirror's spherical aberration

Activities that will be performed on a best-effort, time-available basis include the following:

- Installation of the DF-224 coprocessor, which will restore HST's degraded memory redundancy and augment its memory capacity and speed
- Replacement of P15 fuse plugs (to correct sizing and wiring discrepancies)
- ECU 1
- MSS 2
- Repair of the Goddard high-resolution spectrometer, one of whose detector systems is not operating due to power supply problems

The servicing activities will be performed by two teams. Mission specialists Jeff Hoffman and Story Musgrave form one spacewalk team, and Kathy Thornton and Tom Akers the other. All have previous EVA experience.

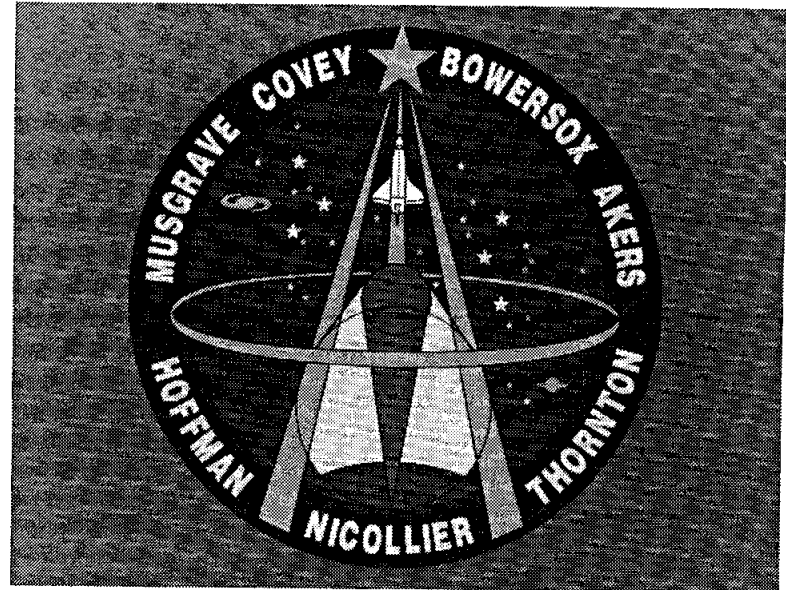
The payload complement for this mission includes the flight support system (FSS), the orbital replacement unit carrier (ORUC), and the solar array carrier (SAC). The FSS provides a maneuverable servicing platform for the HST and electrical power interfaces to the orbiter. ORUC will carry both the WF/PC and the COSTAR in scientific instrument protective enclosures (SIPEs). The MSS's are stowed on the aft end of the ORUC. The ORUC also carries a large ORU protective enclosure to transport an HST DF-224 coprocessor and new DF-224 computer and the small ORU protective enclosure (SOPE) to transport three RSUs, two ECUs, and the HRS repair kit. The contingency ORU protective enclosure is carried on the SAC and will contain the SADE and spare fuse plugs.

STS-61's secondary objectives are to perform the attached cargo operations of the IMAX cargo bay and in-cabin cameras and the Air Force Maui Optical Site calibration test.

The IMAX in-cabin camera is a 70mm motion picture camera system located in the cabin of the orbiter. The system consists of the IMAX camera, lenses, rolls of film, two magazines with film, a cassette recorder, blank cassette tapes, window mounting bracket, photoflood light, power cables, and a black changing bag. Operation of the camera will be controlled by the crew. IMAX scenes include Hubble Space Telescope retrieval, maintenance, and release and Earth views.

The IMAX cargo bay camera is a 70mm color motion picture camera system consisting of a camera, 30mm lens, and a film magazine containing approximately 3,520 feet of film for 10-1/2 minutes of filming. The camera is housed in an insulated, pressurized enclosure with a movable lens window cover. This container is mounted in bay 13 on the port side of the aft payload bay on a getaway special

beam. The payload is controlled from the aft flight deck with the autonomous payload controller. Scene opportunities will be provided to the crew both before the flight and during the flight in real time and will include HST retrieval, maintenance, and release and Earth views.



Crew Insignia

The Air Force Maui Optical Site (AMOS) uses the orbiter during cooperative overflights of Maui, Hawaii, and Arecibo, Puerto Rico, to obtain imagery and/or signature data to support the calibration of ground-based sensors and to observe plume phenomenology. No unique on-board hardware is associated with the AMOS test; however, crew and orbiter participation may be required to establish controlled conditions for the cooperative overflights. AMOS is manifested on STS-61 as a target of opportunity. Cooperative

overflights requiring crew and orbiter participation may be scheduled in real time if resources become available. Any necessary crew procedures will be uplinked in real time.

Twelve development test objectives and 12 detailed supplemen-

tary objectives are scheduled to be flown on STS-61, including DTO 700-8, which will demonstrate the performance and operation of the Global Positioning System (GPS) during orbiter ascent, on-orbit, entry, and landing phases using a modified military GPS receiver processor and the existing orbiter GPS antennas.

MISSION STATISTICS

Vehicle: Endeavour (OV-105), 5th flight

Launch Date/Time:

12/1/93 4:57 a.m., EST (night)
 3:57 a.m., CST
 1:57 a.m., PST

Launch Site: Kennedy Space Center (KSC), Fla.—Launch Pad 39B

Launch Window: 1 hour, 7 minutes (determined by planar conditions)

Mission Duration: 10 days, 22 hours. The capability exists for two additional days to perform contingency operations and avoid inclement weather.

Landing: Nominal end-of-mission landing on orbit 165

12/12/93 2:57 a.m., EST (night)
 1:57 a.m., CST
 11:57 p.m., PST (12/11/93)

Runway: Nominal end-of-mission landing on runway 15, KSC, Fla. Alternates are Edwards Air Force Base (EAFB), Calif., and Northrup Strip (NOR), White Sands, N. M.

Transatlantic Abort Landing: Banjul, The Gambia; alternates: Ben Guerir, Morocco; Moron, Spain

Return to Launch Site: KSC

Abort-Once-Around: EAFB; alternates: KSC, NOR

Inclination: 28.45 degrees

Ascent: The ascent profile for this mission is a direct insertion. Only one orbital maneuvering system thrusting maneuver, referred to as OMS-2, is used to achieve insertion into orbit. This direct-insertion profile lofts the trajectory to provide the earliest opportunity for orbit in the event of a problem with a space shuttle main engine.

The OMS-1 thrusting maneuver after main engine cutoff plus approximately two minutes is eliminated in this direct-insertion ascent profile. The OMS-1 thrusting maneuver is replaced by a 5-foot-per-second reaction control system maneuver to facilitate the main propulsion system propellant dump.

Altitude: 310 nautical miles (357 statute miles) (shuttle altitude to meet HST); 317 nautical miles (365 statute miles) (HST operations)

Space Shuttle Main Engine Thrust Level During Ascent: 104 percent

Space Shuttle Main Engine Locations:

No. 1 position: Engine 2019
No. 2 position: Engine 2033
No. 3 position: Engine 2017

External Tank: ET-60

Solid Rocket Boosters: BI-063

Mobile Launcher Platform: 2

Cryo Tank Sets: 5 (fully loaded)

Software: OI-22 (4th flight)

Editor's Note: The following weight data are current as of November 17, 1993.

Total Lift-off Weight: Approximately 4,515,150 pounds

Orbiter Weight, Including Cargo, at Lift-off: Approximately 250,314 pounds

Orbiter (Endeavour) Empty and 3 SSMEs: Approximately 173,267 pounds

Payload Weight Up: Approximately 17,662 pounds

Payload Weight Down: Approximately 17,662 pounds

Orbiter Weight at Landing: Approximately 211,210 pounds

Payloads—Payload Bay (* denotes primary payload): Hubble Space Telescope (HST) Servicing Mission 01 (SM-01) (Includes solar array carrier [SAC], flight support system [FSS], orbital replacement unit carrier [ORUC], Hubble Space Telescope tool box and tools, scientific instrument protective enclosures [SIPes]. HST replacements include solar array [SA] II, wide-field/planetary camera [WF/PC] II, rate sensor units [RSUs] 1, 2, and 3; electronic control units [ECUs] 1 and 3; magnetic sensing systems [MSS's] 1 and 2; corrective optics space telescope axial replacement [COSTAR]; solar array drive electronics [SADE]); IMAX cargo bay camera (ICBC)

Payloads—Middeck: HST EVA tools, IMAX in-cabin camera, Air Force Maui Optical Site (AMOS) calibration test

Flight Crew Members (Single Shift):

Commander: Richard (Dick) O. Covey, fourth space shuttle flight

Pilot: Kenneth (Ken) Bowersox, second space shuttle flight

Mission Specialist 1: Kathryn (Kathy) C. Thornton, third space shuttle flight

Mission Specialist 2: Claude Nicollier, European Space Agency, second space shuttle flight

Mission Specialist 3: Jeffrey (Jeff) A. Hoffman, fourth space shuttle flight

Mission Specialist 4: F. Story Musgrave, fifth space shuttle flight

Mission Specialist 5: Thomas (Tom) D. Akers, third space shuttle flight

Ascent and Entry Seating:

Ascent:

Flight deck, front left seat, commander Richard O. Covey

Flight deck, front right seat, pilot Kenneth Bowersox

Flight deck, aft center seat, mission specialist Claude Nicollier

Flight deck, aft right seat, mission specialist Kathryn C. Thornton

Middeck, mission specialist F. Story Musgrave

Middeck, mission specialist Thomas D. Akers

Middeck, mission specialist Jeffrey A. Hoffman

Entry:

Flight deck, front left seat, commander Richard O. Covey

Flight deck, front right seat, pilot Kenneth Bowersox

Flight deck, aft center seat, mission specialist Claude Nicollier

Flight deck, aft right seat, mission specialist Thomas D. Akers

Middeck, mission specialist Kathryn C. Thornton

Middeck, mission specialist F. Story Musgrave

Middeck, mission specialist Jeffrey A. Hoffman

Extravehicular Activity Crew Members, if Required:

Extravehicular (EV) astronaut 1 (EVAs 1, 3 and 5): mission specialist Jeffrey A. Hoffman

EV-2 (EVAs 1, 3 and 5): mission specialist F. Story Musgrave

EV-3 (EVAs 2 and 4): mission specialist Kathryn C. Thornton

EV-4 (EVAs 2 and 4): mission specialist Thomas D. Akers

Two unscheduled EVAs are also possible to service Hubble Space Telescope components. A contingency EVA may be performed to close and/or latch the payload bay doors; realign the Ku-band antenna; perform an RMS joint alignment, tie-down, manipulator positioning mechanism deployment, shoulder brace release, MPM stow; or manually release the RMS grapple fixture in support of the HST deployment.

Entry: Automatic mode until subsonic, then control stick steering

Flight Directors:

Ascent/entry: Rich Jackson

Orbit 1 team (rendezvous/deploy): Bob Castle

Orbit 2 team/lead (EVA): Milt Heflin

Orbit 2 team (orbiter operations): Jeff Bantle

Planning team: John Muratore

Notes:

- The remote manipulator system is installed in Endeavour's payload bay for this mission.
- The shuttle orbiter repackaged galley, middeck accommodations rack, and middeck utility panel are installed in Endeavour's middeck.
- STS-61 marks the first time Endeavour will fly with five nitrogen tanks and five cryo tank sets.
- This is the first mission to fly with three high-accuracy inertial navigation system inertial measurement units.



STS-61 CREW—The seven astronauts assigned to this mission include (seated, left to right) pilot Kenneth Bowersox and mission specialists Kathryn C. Thornton, F. Story Musgrave, and Claude Nicollier. Standing are mission commander Richard Covey and mission specialists Jeffrey Hoffman and Thomas Akers.

MISSION OBJECTIVES

- Primary objective
 - Retrieval, servicing, and redeployment of the Hubble Space Telescope (HST first servicing mission)
- Secondary objectives
 - Middeck
 - IMAX in-cabin camera
- Air Force Maui Optical Site (AMOS) calibration test
 - Payload bay
 - IMAX cargo bay camera (ICBC)
- 12 development test objectives/12 detailed supplementary objectives

FLIGHT ACTIVITIES OVERVIEW

Flight Day 1

Launch
OMS-2 burn (310 nmi by 297 nmi)
Payload bay doors open
ICBC activation
Unstow cabin
NC-1 burn (310 nmi by 302 nmi)

Flight Day 2

RMS checkout
Cabin pressurization to 10.2 psi
Space support equipment checkout/survey
Configure flight servicing structure
NPC burn (310 nmi by 302 nmi)
NSR burn (310 nmi by 304 nmi)
Extravehicular mobility unit checkout
NC-2 burn (317 nmi by 305 nmi)

Flight Day 3

HST rendezvous operations
NH burn (320 nmi by 305 nmi)
NC-3 burn (320 nmi by 310 nmi)
NCC burn (320 nmi by 310 nmi)
TI burn (320 nmi by 312 nmi)
HST grapple (320 nmi by 313 nmi)
HST berth
HST survey
Priority Group B power-down

Flight Day 4

HST EVA 1 (Hoffman/Musgrave: two rate sensor units/secondary servicing list items)

Flight Day 5

HST EVA 2 (Thornton/Akers: solar array changeout)

Flight Day 6

HST EVA 3 (Hoffman/Musgrave: wide-field/planetary camera; two magnetic sensing systems)

Flight Day 7

HST EVA 4 (Thornton/Akers: corrective optics space telescope axial replacement/secondary servicing list items)

Flight Day 8

HST reboost burns (320 nmi by 313 nmi)
HST EVA 5 (Hoffman/Musgrave: solar array drive electronics/secondary servicing list items)

Flight Day 9

Priority Group B power-up
HST grapple
HST unberth
HST release (320 nmi by 313 nmi)
Separation burns 1, 2, and 3 (320 nmi by 311 nmi)
Priority Group B power-down

Flight Day 10

Cabin pressurization to 14.7 psi
Off-duty half day

Flight Day 11

Priority Group B power-up
FCS checkout
RCS hot fire
Cabin stow

Flight Day 12

Space support equipment power-down
Deorbit preparations
Deorbit burn
Entry
Landing

Notes:

- Each flight day includes a number of scheduled housekeeping activities. These include inertial measurement unit alignment, supply water dumps (as required), waste water dumps (as

required), fuel cell purge, Ku-band antenna cable repositioning, and a daily private medical conference.

- On every shuttle mission, some day-to-day replanning takes place to adjust crew and event time lines in response to unforeseen developments or simply to optimize the use of time in orbit. During STS-61, the bulk of the daily replanning will be done by the planning shift in mission control while the crew sleeps. During the EVA days, this team will play a crucial role in making the most of the astronauts' time in Endeavour's payload bay. To maximize crew productivity and to adapt to any unexpected challenges, the planning team will have the ability to reorder the sequence of individual tasks within any given spacewalk or to shift tasks from one day's agenda to another. Each day's replanning effort will produce an execute plan defining the approach for the next day's activities in space and on the ground.
- All planned burns are recalculated in real time after the flight is under way based on the latest information for the position of HST and will likely change slightly. Depending on how accurate the orbiter's navigation and course are at certain times, some smaller burns may not be required. However, the times for major burns and events are unlikely to change by more than a few minutes.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

DTOs

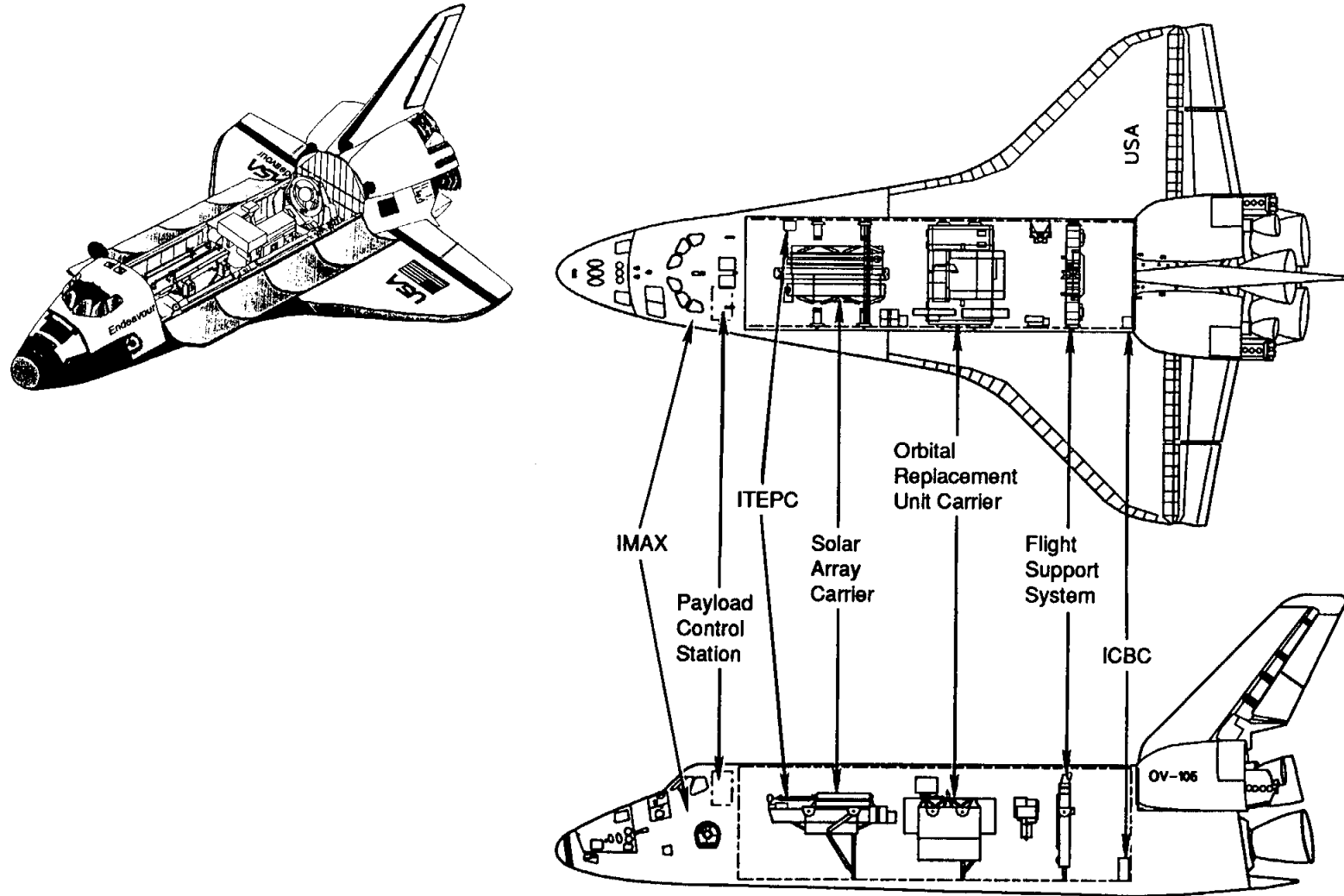
- Ascent structural capability evaluation (DTO 301D)
- Ascent compartment venting evaluation (DTO 305D)
- Entry compartment venting evaluation (DTO 306)
- Entry structural capability evaluation (DTO 307D)
- ET TPS performance (methods 1, 2, and 3) (DTO 312)
- Orbiter drag chute system (DTO 521)
- Electronic still camera photography test (with downlink) (DTO 648)
- PGSC single-event upset monitoring (DTO 656)
- Portable in-flight landing operations trainer (DTO 667)
- Laser range and range rate device (DTO 700-2)
- Global Positioning System (GPS) development flight test (DTO 700-8)
- Waste and supply water dump at 10.2 psia (DTO 1211)

DSOs

- Window impact observations (target of opportunity) (DSO 326)
- In-flight radiation dose distribution (TEPC only) (DSO 469)
- Back pain pattern in microgravity (DSO 483)
- Inter-Mars tissue equivalent proportional counter (ITEPC) (DSO 485)
- Immunological assessment of crew members (DSO 487)
- EVA dosimetry evaluation (DSO 489*)
- Visual-vestibular integration as a function of adaptation (DSO 604 OI-3*)
- Cardiorespiratory responses to submaximal exercise (DSO 624*)
- Cardiovascular and cerebrovascular responses to standing before and after space flight (DSO 626*)
- Documentary television (DSO 901)
- Documentary motion picture photography (DSO 902)
- Documentary still photography (DSO 903)

*EDO buildup medical evaluation

STS-61 PAYLOAD CONFIGURATION



FIRST HUBBLE SPACE TELESCOPE SERVICING MISSION

STS-61 is the most extensive and perhaps the most difficult servicing mission NASA has ever attempted. Over seven days of this 11-day flight, the astronauts will rendezvous with the Hubble Space Telescope; capture and berth the bus-size, 13-ton spacecraft in Endeavour's cargo bay; and perform five spacewalks totaling more than 30 hours, more than on any previous mission, to repair and service the telescope so that it can continue its 15-year mission.

Although the astronauts will have a limited amount of time to perform many complex tasks, the astronomical satellite they will be working on has been designed to make their job easier. The first spacecraft to be thoroughly designed for on-orbit servicing, the Hubble Space Telescope has 49 standardized, easily accessible, replaceable modules and about 100 handholds and footholds for the astronauts.

The primary objectives of the mission are to restore the telescope's ability to image individual objects in crowded fields and allow it to see very faint objects so far away in distance and time that they appear as they looked when the universe was 1/10th its current age, restore the reliability of the spacecraft's systems, and validate the concept of on-orbit servicing.

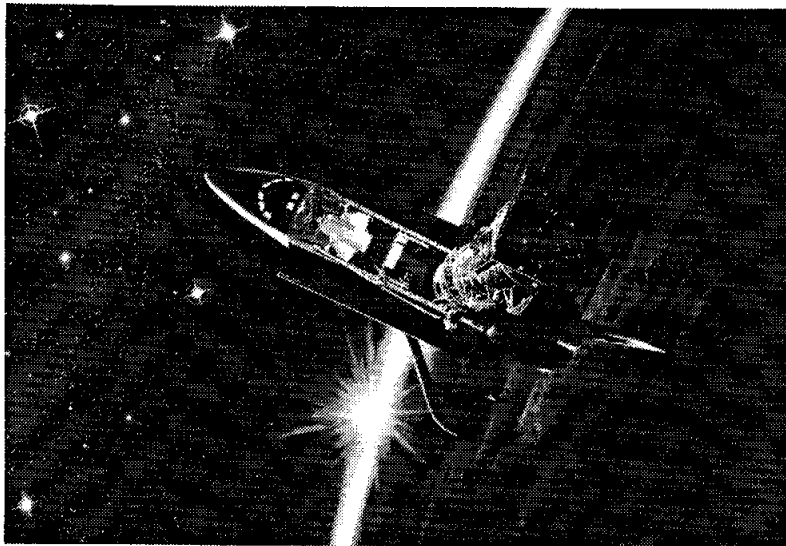
For the first servicing mission to be considered fully successful, the following top-priority items must be accomplished: installation of the replacement solar arrays; two rate sensing units, one with an electronics control unit; the wide-field/planetary camera and fuses; the corrective optics space telescope axial replacement; at least one new magnetometer; and a new solar array drive electronics unit. In addition, other tasks may be performed if time is available. The minimum criterion for mission success is to leave Hubble with three newer-design gyroscope systems and either an operational WF/PC or COSTAR.

Two months after the Hubble Space Telescope was launched in 1990, scientists detected a flaw in the telescope's primary mirror. Subsequent image analysis showed that the surface of the mirror was too flat near the edge by an amount equal to 1/50th the width of a human hair. The result was a spherical aberration: only 16% of the light was brought to focus within a 0.2-arc-second-diameter circle, rather than the specified 70%. A NASA investigative board later determined that the flaw was caused by the incorrect adjustment of a testing device used to check the mirror's curvature during manufacture.

Even though a flaw in its 7-foot primary mirror has blurred the telescope's vision, the telescope is producing a flow of unparalleled measurements that scientists believe no other instrument can match. Positioned above the Earth's atmosphere, the Hubble Space Telescope enables astronomers to view the universe with unprecedented clarity and observe 10 times more detail and stars 50 times fainter than those detectable by ground-based optical telescopes. Astronomers are gaining a new understanding of distant galaxies-immense congregations of billions of stars that sweep across the unmeasured distances of the universe hundreds of millions of light-years away. Astronomers will, in fact, be able to measure those cosmic distances with greater accuracy than ever before. They will be able to see into the uncharted region of ultraviolet, where many stellar objects lie hidden, and conduct deep-sky surveys to search for clues to the very fabric of the universe itself.

Why, then, has a mission been planned to repair an instrument that is already established as the world's best in its category?

First, although the telescope mirror itself cannot be fixed or changed, corrective optics can be added to the telescope's instruments to compensate for the aberration, much like glasses correct



Scott Kahler, Ball Aerospace

This artist's conception of the Hubble servicing mission shows an astronaut positioned to the left of the telescope preparing to install the corrective optics space telescope axial replacement designed and built by Ball Aerospace and Communications

human eyesight. The new optics should allow Hubble to accomplish most, if not all, of its originally planned objectives.

Second, servicing has always been part of NASA's plan for ensuring that the telescope reaches at least its 15-year lifetime and achieves its scientific goals. Originally, NASA planned to return the telescope to Earth every five years, refurbish it, and return it to space in addition to servicing it in space every 2-1/2 years. But concerns about contamination and the possible effects of structural loading on the satellite when it returned to Earth on board the shuttle caused NASA to drop that idea and adopt a three-year cycle of service missions.

NASA was already planning the first servicing mission before the telescope was launched. When problems were found in the telescope's optical system and solar arrays after it was placed in orbit in 1990, NASA and the European Space Agency, NASA's partner in the Hubble mission, decided to fix them during the first servicing mission.

The purpose of servicing missions is to modernize the scientific instrumentation and to replace any defective elements. On-orbit servicing occurred to NASA planners soon after they first began to study the idea of placing a telescope in space. They realized that on-orbit servicing would considerably reduce the recurring costs of developing and launching replacement spacecraft and would allow them to enhance the capabilities of the scientific instruments and control systems on board the telescope. Furthermore, the space shuttle afforded astronomers an efficient system for servicing the telescope.

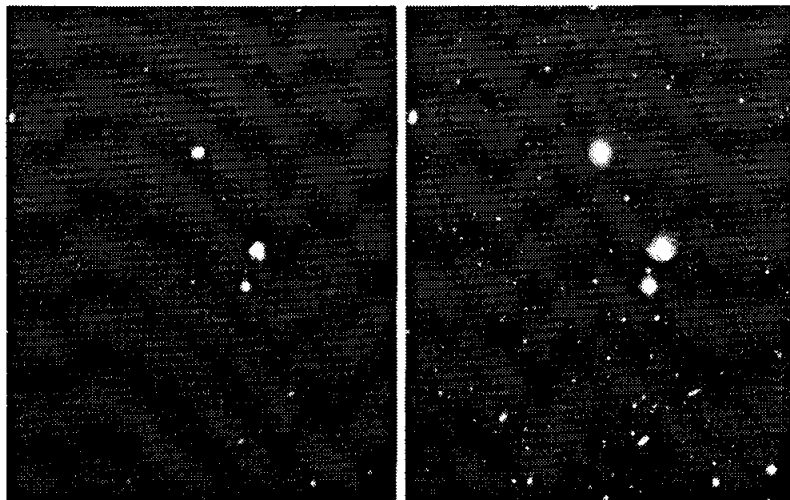
Second, repairs have indeed become necessary, though not sooner than expected. After three years in orbit, the telescope has suffered considerable wear. It has lost three of its six original gyroscopes, leaving it with the minimum number required for pointing control. Of the three fine guidance sensors, which lock on to celestial objects, one is out of action, and one of the two electronic systems that control the deployment of the solar arrays is also showing signs of wear.

So far, the deterioration that has occurred is having little effect on the program's overall performance. Backups for all of the satellite's sensitive elements were installed, but, in the case of the gyroscopes, there are no usable spares left. In other words, restoring redundancy on board is becoming a matter of urgency to make sure that the mission can continue with maximum reliability and effectiveness.

Finally, this rendezvous will be very beneficial scientifically. "The (telescope) is admittedly suffering from impaired vision," said Duccio Macchetto, ESA's man at the Space Telescope Science

Institute in Baltimore, Md., who for 15 years led the European team in charge of developing ESA's faint-object camera for the Hubble Space Telescope. "It cannot see as clearly or as far as expected. Nevertheless, it has demonstrated its extraordinary capabilities. It is producing first-class observations day after day, in a limited portion of the universe. Any improvement is therefore worthwhile, and installation of the corrective optics is certainly going to be a paying proposition. The slightest progress—even if it does not quite attain the standards originally expected—will enable us to make significant strides in the quality and quantity of data and ultimately in our knowledge of the cosmos."

Macchetto added that the scientific instrument that will benefit most from the corrective optics will be the faint-object camera,



Space Telescope Science Institute

The simulated image on the right shows a tenfold improvement in sensitivity—a telescope's ability to detect faint objects. The corrective optics for the Hubble Space Telescope are expected to produce this same improvement in the telescope's instruments.

which was designed and built by European scientists to explore the most distant regions of the universe.

Without this mission, it would be impossible to correct the two manufacturing faults discovered after the launch. Worse, with normal wear and tear on the satellite, the program might run into serious difficulties within the next few years.

HISTORY OF THE TELESCOPE

The Hubble Space Telescope, a joint cooperation between NASA and ESA, was launched on April 24, 1990, and deployed in a 28.45-degree orbit 337 nautical miles above the Earth's surface from the shuttle Discovery on April 25. It orbits the Earth once about every 90 minutes.

The scientific objectives of the astronomical observatory are to determine the constitution, physical characteristics, and dynamics of celestial bodies; the nature of the processes that occur in the extreme physical conditions existing in stellar objects; the history and evolution of the universe; and whether the laws of nature are universal in the space-time continuum.

The Hubble telescope has been designed and developed to achieve the following specific scientific objectives:

- Precise determination of distances to galaxies out to expansion velocities of 1×10^4 km/sec and calibration of distance criteria applicable at cosmologically significant distances
- Determination of the rate of deceleration of the Hubble expansion of the universe, its uniformity in different directions, and possibly its constancy with time
- Testing of the basic reality of the universal expansion by determining the surface brightness versus red-shift relation of distant galaxies

- Establishment of the history of the star formation and nuclear processing of matter as a function of position in nearby galaxies and determination of the variations from galaxy to galaxy
- Determination of the nature of stellar populations in the early stages of the galactic evolution, based on “look-back” observation of distant galaxies
- Estimation of the He/H ratio in quasars by observing red-shifted He I and He II resonance lines
- Search for multiple-red-shift absorption line groups in the ultraviolet spectra of low-red-shift quasars
- Intercomparison of total spectra of high-red-shift quasars, low-red-shift quasars, and active galactic nuclei
- Resolution of densely packed nuclei of globular star clusters in search of massive black holes
- Identification and flux measurement in ultraviolet and optical wavelengths of faint X-ray sources and radio pulsars
- Resolution of the complex internal structure of Herbig-Haro objects to investigate their possible links to star formation
- High spatial resolution, infrared observations of protostars
- Direct imaging and astrometric search for planetary companions of nearby stars
- Determination of bolometric luminosities of faint, hot stars for studies of stellar evolution
- Determination of the composition, temperature, density, and ionization structure of the gas in the galactic halo, in high-velocity clouds, and intergalactic medium

- Precise mapping of the 100-micrometer flux sources in compact H II regions
- Determination of the composition of clouds in the atmospheres of Jupiter, Saturn, Uranus, and Neptune
- Resolution of surfaces of minor planets and asteroids
- Synoptic mapping of atmospheric features on Venus, Jupiter, Saturn, and Uranus for the study of atmospheric dynamics
- Intensity measurements of atomic and molecular ultraviolet emission lines important to understanding the chemistry of comets

The telescope and its imaging instruments will study objects ranging from asteroids, comets, and planets within our solar system to galaxies and quasars at the farthest reaches of the universe until the year 2005. The telescope’s wide-field/planetary camera detects objects 100 times fainter than those visible from Earth-based telescopes, with about 10 times greater spatial resolution. The largest Earth-based telescopes can detect objects at a distance of about 2 billion light-years, or about 12 billion trillion miles; the Hubble space telescope extends our vision to about 16 billion light-years.

The space telescope is 43.5 feet long and 14 feet in diameter, about the size of a railroad tank car. It weighs 26,000 pounds-about as much as eight automobiles.

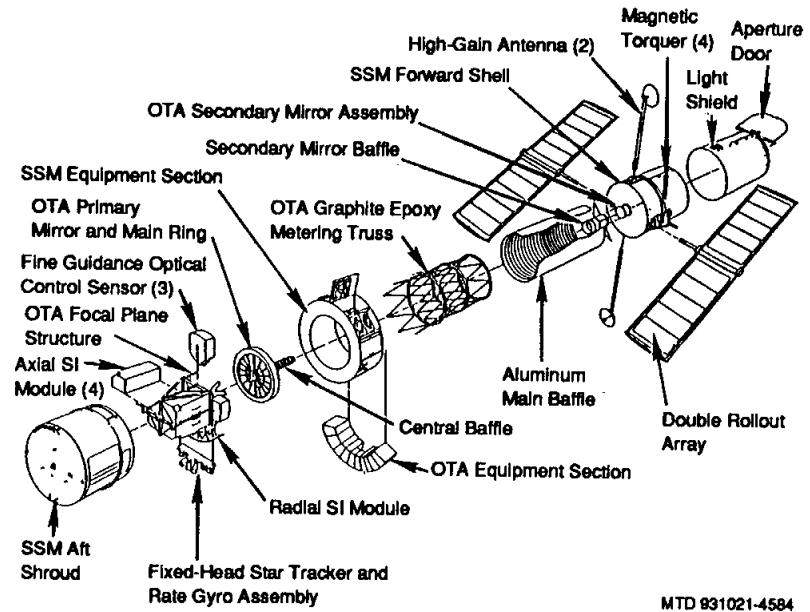
The major elements of the Hubble Space Telescope are the support systems module (SSM), the optical telescope assembly (OTA), the scientific instruments, the scientific instrument control and data handling subsystem, and the solar arrays.

The spacecraft portion of the telescope is the support systems module. It supports all other elements of the vehicle and contains all interfaces to the orbiter. The SSM also provides the structural and electrical interface to the flight support system for orbital servicing.

*Hubble Space Telescope Characteristics
Before First Servicing Mission*

Parameter	Dimension
Stowed configuration • Length • Diameter	43 ft 6 in. 14 ft
Deployed configuration • Length (aperture door opened) • Diameter (solar arrays and high-gain antenna deployed)	53 ft 10 in. 41 ft 10 in.
Weight of spacecraft	24,255 lb
Orbit altitude Orbit inclination	330±5 nmi 28.45 deg
Propulsion	None
Attitude control • Slew rate • Settling time • Pointing stability	Reaction wheels Magnetic torquers 6 deg/min 2 min 0.007 arc sec
Solar arrays • Length • Width • Power	39 ft 9 in. 9 ft 6 in. 4,400 W
High-gain antennas (two) (+V3, -V3) • Dish diameter (effective) • Boom length (from HST centerline) • LHC polarization	4 ft 2 in. 19 ft 4 in.
Low-gain antennas (two) (forward, aft) • Small spiral cone • LHC polarization	
Science data storage	1 x 10 ⁹ bits
Data rate (baseband modulation) • Science data (HGA-to-TDRSS) • Engineering data	1 Mbps (3.072 Mbps encoded) 500 bps (LGA-to-TDRSS) 4, 32 kbps, 1 Mbps* (HGA-to-TDRSS or LGA-to-GSTDN)
Transmitter frequency • S-band multiaccess (2) • S-band single access (2)	2,287.5 MHz 2,255.5 MHz
Receiver frequency • S-band MA (low-gain antenna) • Command receive rate	2,106.4 MHz 1 kbps, 125 bps
*Recorder dump rate.	

The SSM contains a very precise pointing and stabilization control subsystem, thermal control subsystem, data management subsystem, electrical power subsystem, and communication subsystem.



MTD 831021-4584

Major Structural Elements of Hubble Space Telescope

The optical telescope assembly (OTA) is an $f/24$ Ritchey-Chretien Cassegrain-type telescope with a usable field of view of 14 arc minutes half-angle. The focal plane is divided among four axial scientific instruments and one radial instrument, three optical control sensors, and three fine guidance sensors. The major elements of the OTA include the primary mirror and main ring, which provide the primary structural interface to the SSM; the focal plane structure, which provides precise optical alignment of the scientific instruments and fine guidance sensors; the main, secondary, and central light baffles for absorbing stray light; the metering truss and secondary mirror; and the equipment section, housing most of the OTA

Hubble Space Telescope Initial Complement of Scientific Instruments

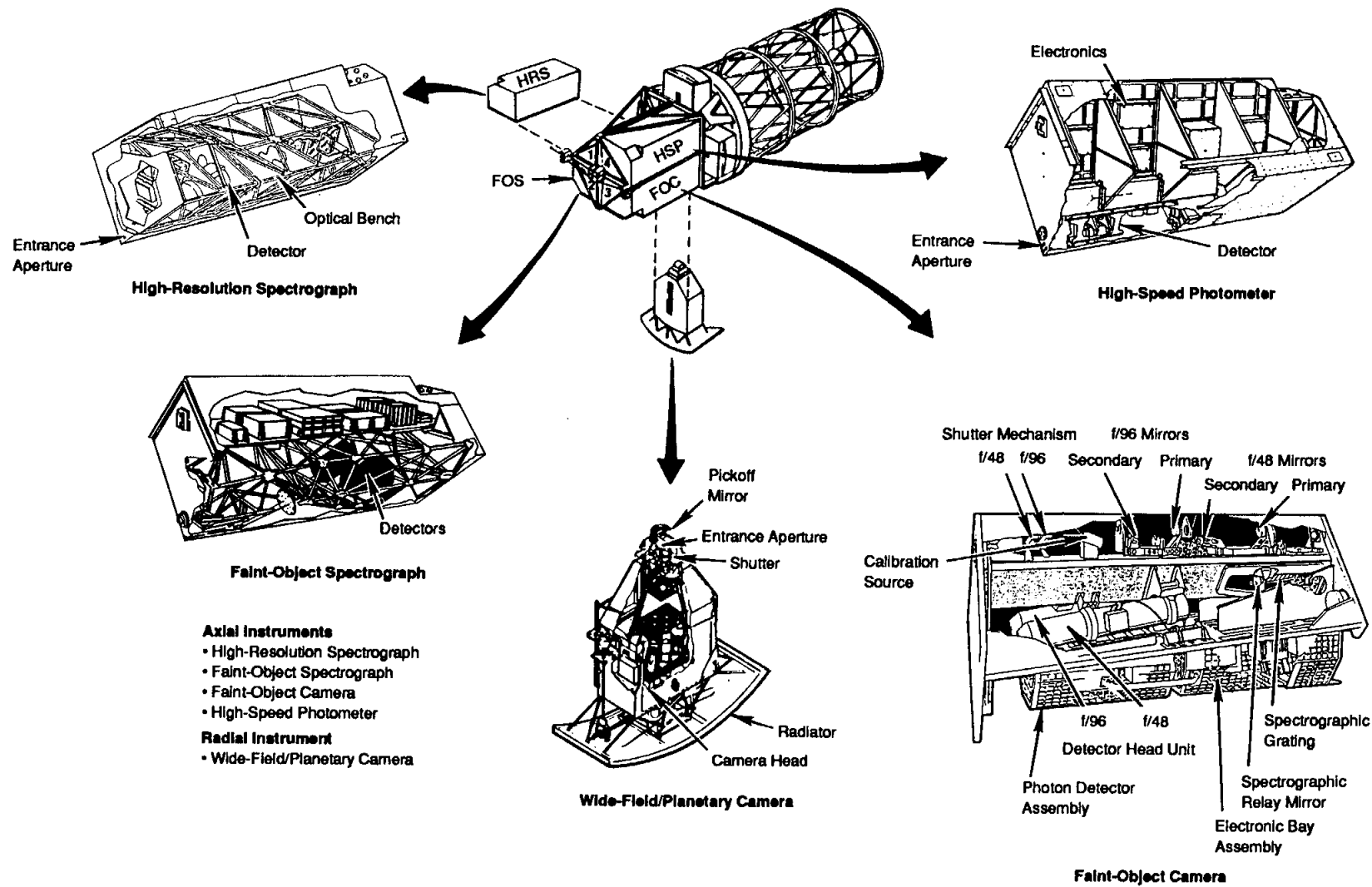
Instrument (Principal Investigator)	Contractor	SSM Location	Characteristics
Wide-field/planetary camera (Prof. J.A. Westphal, California Institute of Technology)	Jet Propulsion Laboratory, Calif.	Radial (-V ₃)	2 cameras + ascent/entry Purge gas Carousel of 50 filters/polarizers Far UV (1,160 Å) to near IR (11,500 Å)
Faint-object camera (Dr. F.D. Macchetto, European Space Agency)	Dornier Systems/Matra/ British Aerospace	Axial (-V ₂) (Pos 3)	For 10-hour exposure: S/N ≥ 4 for M = 28 S/N = 15 for M = 21/arc sec Pixel size = 0.002 arc sec for f/96 mode
Faint-object spectrograph (Dr. R.J. Harms, University of California, San Diego)	Martin-Marietta	Axial (+V ₂) (Pos 2)	FOV = 10 arc sec Modest spectral resolution across UV and visible wavelengths for faintest limiting magnitude
High-resolution spectrograph (Dr. J.C. Brandt, GSFC)	Ball Brothers	Axial (+V ₂) (Pos 1)	FOV = 10 arc sec for two modes R = 2 × 10 ⁴ in 105-320 nm (UV) (up to 15 km/sec equivalent speed) should see M _v = 17 R = 1.2 × 10 ⁵ in 110-320 nm (UV) (up to 2.5 km/sec equivalent speed)
High-speed photometer/polarimeter (Dr. R.C. Bless, University of Wisconsin)	University of Wisconsin	Axial (-V ₂) (Pos 4)	3 aperture diameters: 2.9 arc sec 1.4 arc sec 0.7 arc sec Filter plate and four polarizers (45 deg apart) Time resolution: 1 msec and longer for rapidly varying objects 16 μsec and longer for signals

electronics. The OTA equipment section mounts to the exterior of the SSM equipment section. An SSM equipment shelf is provided with the focal plane structure for mounting the fixed-head star trackers and rate sensor units. All of the focal plane sensors and the majority of the OTA electronics are orbital replacement units.

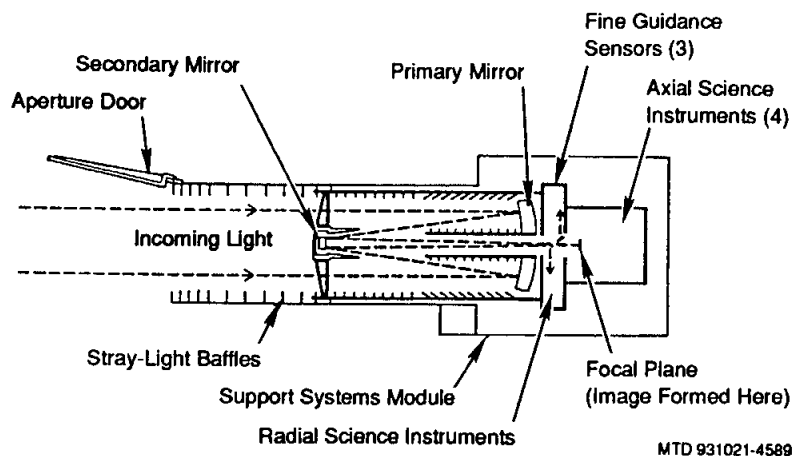
The primary mirror contains push-pull actuators to correct the shape of the mirror's surface. This system of actuators is controlled from the Space Telescope Operations Center at the Goddard Space Flight Center, based on analysis of optical control subsystem data. The secondary mirror's position can also be adjusted by ground command for tip, tilt, decenter, and despace.

Light from distant space objects enters the telescope's tube at one end and strikes the primary mirror, which is 7.8 feet in diameter. The light reflected from that mirror hits the secondary mirror, located 16 feet in front of the primary mirror. The secondary mirror is 12 inches in diameter. From there, the beam of light narrows and intensifies, passing through a 2-foot hole in the center of the primary mirror.

The light is then used by one of the five science instruments. Four of the instruments are mounted directly behind and perpendicular to the focal plane and the fifth is mounted radially in the telescope.



Location of Scientific Instruments in the Optical Telescope Assembly



Light Path for the Main Telescope

The five science instruments are the wide-field/planetary camera, the faint-object camera, the faint-object spectrograph, the high-resolution spectrograph, and the high-speed photometer.

The WF/PC is a general-purpose camera that covers the red and near-infrared regions. It can photograph the entire facing hemisphere of planets in our solar system in a single exposure with an image sharpness equivalent to reading a license plate from about 30 miles away.

The scientific objectives of the WF/PC include the following:

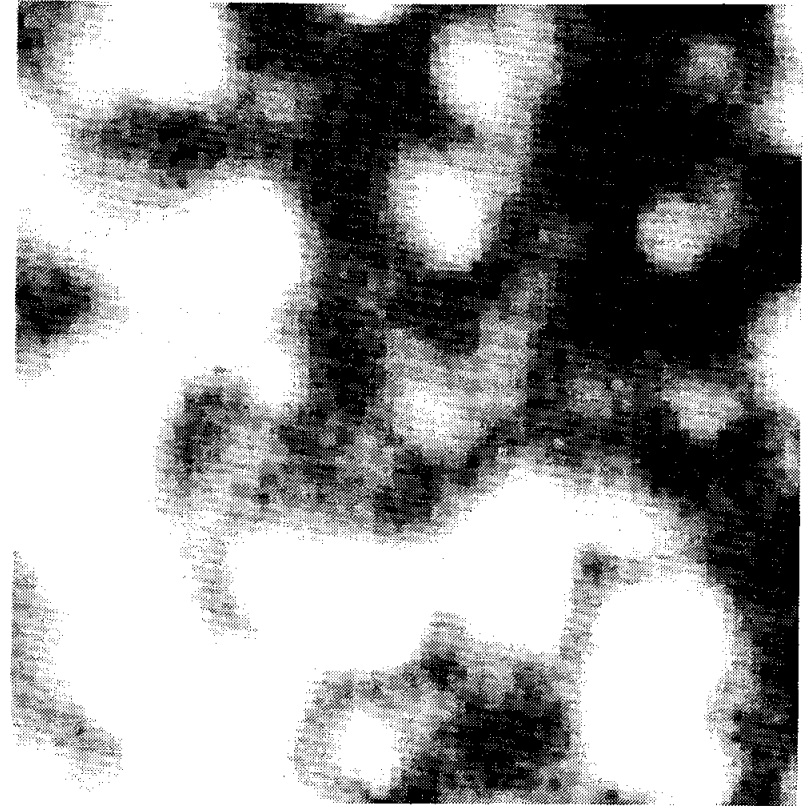
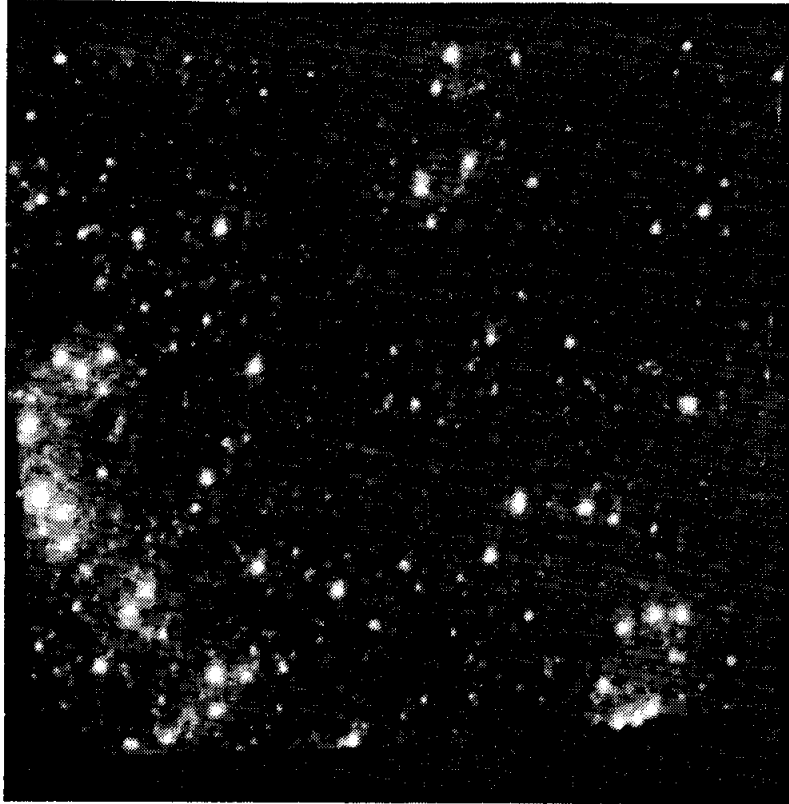
- Determination of the cosmic distance scale over distances larger by a factor of 10 than possible from the ground
- Tests of world models and cosmic evolution
- Comparative evolutionary studies of distant and local galaxies
- Stellar population studies to very faint levels

- High-resolution luminosity profiles of galactic nuclei
- Energy distribution of stars and compact sources
- Dynamic motions in supernova remnants and protostars
- Synoptic studies of planetary atmospheres
- Search for extrasolar planets
- High-resolution and ultraviolet studies of comets

The ESA-provided faint-object camera, which was designed to study extremely distant stars and galaxies, can record such fine detail that it could discern the head or tail on a nickel 6 miles away. It intensifies images to 100,000 times their original brightness. That is equivalent to increasing the light of a candle to the brightness of the noonday sun.

The main scientific objectives of the FOC include the following:

- Study of the physics of planets
- Search for planets and protoplanetary condensations around nearby stars
- Search for massive black holes in globular clusters
- High-spatial-resolution studies of very young stars
- Measurements of distances to the Coma Cluster galaxies
- Observation of optical emissions associated with radio lobes and jets in galaxies
- Study of gravitational lenses



NASA Photo

The image on the right of a nearby globular cluster shows the Hubble Space Telescope's current ability to distinguish individual objects in crowded fields. Although these objects can be "resolved," or separated, quantitative scientific measurements of each star are difficult to obtain because the spherical aberration in the Hubble's primary mirror creates a "fuzz" around the brightest stars that overlaps the fainter stars. After the corrective optics are installed during the first Hubble servicing mission, it will be possible to do photometry and radiometry and make other quantitative measurements of stars in crowded fields.

History of Payload Anomalies

Failure/Anomaly	Cause	Response	Comments
Spherical aberration	Primary mirror ground to wrong prescription	WF/PC and COSTAR with corrective optics	Correction necessary to meet level I requirements
Solar array orbital structural deformation and jitter	Thermal deformations of solar array structure	Solar array with thermal shielding and improved mechanical design	Solar array experiencing deformations outside of design envelope
Gyro failures	Gyros 4 and 6: Generic problem with Bendix pulse rebalance loop hybrid circuits Gyro 6 motor spindown: Random failure of spin motor power phase-open circuit most likely originating in electronics Gyro 1 shutdown: Short circuit causing fuse to open, most likely originating in ECU	Retrofit of spare rate-sensing units with Teledyne hybrids Changeout of RSUs 2 and 3 Changeout of ECU 3 Changeout of RSU 1, ECU 1, and fuse plugs (PDUs 1 and 2)	Three of six gyros necessary to conduct science mission Five post-FSMs necessary to ensure adequate failure tolerance Changeout of RSU 3 already planned
DF-224 memory unit failures	Memory unit 3: Open of plated-through hole on seven-layer board Memory unit 4: Failure of ready write enable circuitry	Augment memory with coprocessor/shared memory unit Coprocessor/shared memory augmentation	Could be generic board problem Stress cycling of spare boards proved tolerance Not believed to be a generic problem
Magnetometer anomalies	Intermittent open on signal path of V2 on MSS-1 Variable resistance loading of analog output to PSEA on MSS-2	Replace MMS-1 None	Attitudinally/thermally induced Not generic problems
Gyro fuse derating	Improper fusing for gyro power circuits	Replace fuse plugs in PDU for gyro circuits	3-amp fuse must carry 2 to 3.3 amps for 27 sec
Gyro low-voltage power supply failure	Intermittent open of lug solder joint	Science data cross-strapping via relay box	Use of built-in redundancy requires switch-over of entire HST data management system
Fine guidance sensor 12 star selector servo anomaly	Degradation of Teflon toroids or loss of lubrication in bearing	Under review	Anomaly investigation is continuing
Five percent array capability loss	Catastrophic failure of solar array in PCU	None	Bypass relay could be exercised to restore capability if necessary
Solar array temperature sensor and tension monitor anomalies	Potentiometer failure is likely cause of tension monitor anomaly Short circuits of power and signal lines on solar array blanket are likely causes of temperature sensor anomalies	None	Deployment control electronics and data interface unit absolved as possible causes Solar array being replaced due to jitter problems
DIU bilevel monitor anomalies	Circuit lockup as a result of PCU trim relay K16 failure	None	Power cycling of DIU in August 1992 as a result of safe mode entry restored nominal operation

- Spatial distribution of density, temperature, and chemical abundance of gas in gaseous nebulae

The high-resolution spectrograph and the faint-object spectrograph provide a wide range of spectral resolutions that would be impossible to cover with a single instrument. The HRS studies faint objects in the ultraviolet portion of the light spectrum. The FOS examines the chemistry of extremely faint objects in the visible and red regions of the spectrum.

The HRS obtains data at time intervals of as little as 1/20th of a second. It can take five separate data samples in the blink of an eye. The FOS resolves objects separated by as little as 0.1 arc-second. That is the same as distinguishing a car's left and right headlights at a distance of 2,500 miles.

The HRS will obtain very high resolution spectrographic analysis in the ultraviolet region and will be used to study the following:

- Supernovae, active galaxies, bright quasars, and phenomena in the Earth's solar system
- The physical composition of exploding galaxies, quasars, and other dense objects
- The loss of mass of one star to another in binary systems
- Measurements of the total amount of matter expelled in stellar explosions
- The physical composition of gas clouds

The basic scientific objectives of the FOS are as follows:

- High-spatial-resolution spectroscopic observations of active galaxies

- Measurement of chemical abundances in galaxies
- Observation of physical conditions in quasars
- Ultraviolet observations of the central stars of planetary nebulae
- Study of quasars embedded in galaxies and the nature of their associated wisps and jets
- Cometary observations much farther from the sun than before and in the ultraviolet

The high-speed photometer is a relatively simple device that measures rapid brightness variability over time intervals as frequent as every 1/100,000th of a second. It will be removed from the telescope and replaced by the corrective optics space telescope axial replacement unit, which will correct the telescope's spherical aberration.

Typical scientific objectives of the HSP are as follows:

- Observation of rapidly pulsing compact objects, variable stars, and binary systems
- Calibration of faint stellar objects
- Examination of specific spikes or flickers of light transmitted from stellar objects, including compact stars and supernovae
- Searches for optical counterparts to radio pulsars
- Determination of magnitude scales in the visual and ultraviolet regions to the faintest magnitudes observable by the Hubble Space Telescope
- Ultraviolet polarimetric observations of interstellar grains, especially in the vicinity of the 200-nm extinction hump

The Man Behind the Name
Edwin Hubble, 1889–1953

Edwin P. Hubble, the man for whom the space telescope is named, has been called the most influential astronomer since Galileo, Kepler, and Newton. He is credited with initiating studies of the universe beyond the Milky Way Galaxy, which supported the notion of an expanding universe and, later, the Big Bang theory of creation.

Although astronomy was a lifelong interest for Hubble, it was certainly not his only interest. A native of Marshfield, Mo., he lettered in basketball and track at the University of Chicago while majoring in astronomy and mathematics. He played on the school's 1909 national championship and 1910 Big Ten championship basketball teams. He was also a talented enough heavy-weight boxer that a promoter urged him to challenge the current world champion.

But Hubble went to England as a Rhodes scholar and studied law. He came home, passed the Kentucky bar exam, and began teaching Spanish and physics at a high school in Indiana. The following year, he returned to the University of Chicago and the Yerkes Observatory in Williams Bay, Wis., where he worked until he received his Ph.D. in 1917. He served as an infantryman in France during World War I and then went to work at the Mount Wilson Observatory in California.

Hubble was particularly interested in nebulae, glowing clouds within and outside of our galaxy, some of them billions of light-years away. Often these luminous clouds were found to be galaxies, which he classified by shape. From his analysis of their radial velocities, Hubble concluded that these galaxies are speeding away from us at a rate that can be determined by their distance from Earth. This ratio of speed to distance is still fundamental to calculations in modern astronomy.

The five instruments generate data in digital form and transmit it to the ground at a rate of up to 1 million bits per second. At that rate the entire contents of a 30-volume encyclopedia would be transmitted in 42 minutes. On the ground the data is converted to pictures and other usable forms.

The space telescope receives electrical power through two ESA-provided deployable solar arrays of 48,000 solar cells positioned like a pair of wings on either side of the telescope's main tube. Power is stored in six nickel-hydrogen batteries so that operations can continue even when the telescope is in the Earth's shadow.

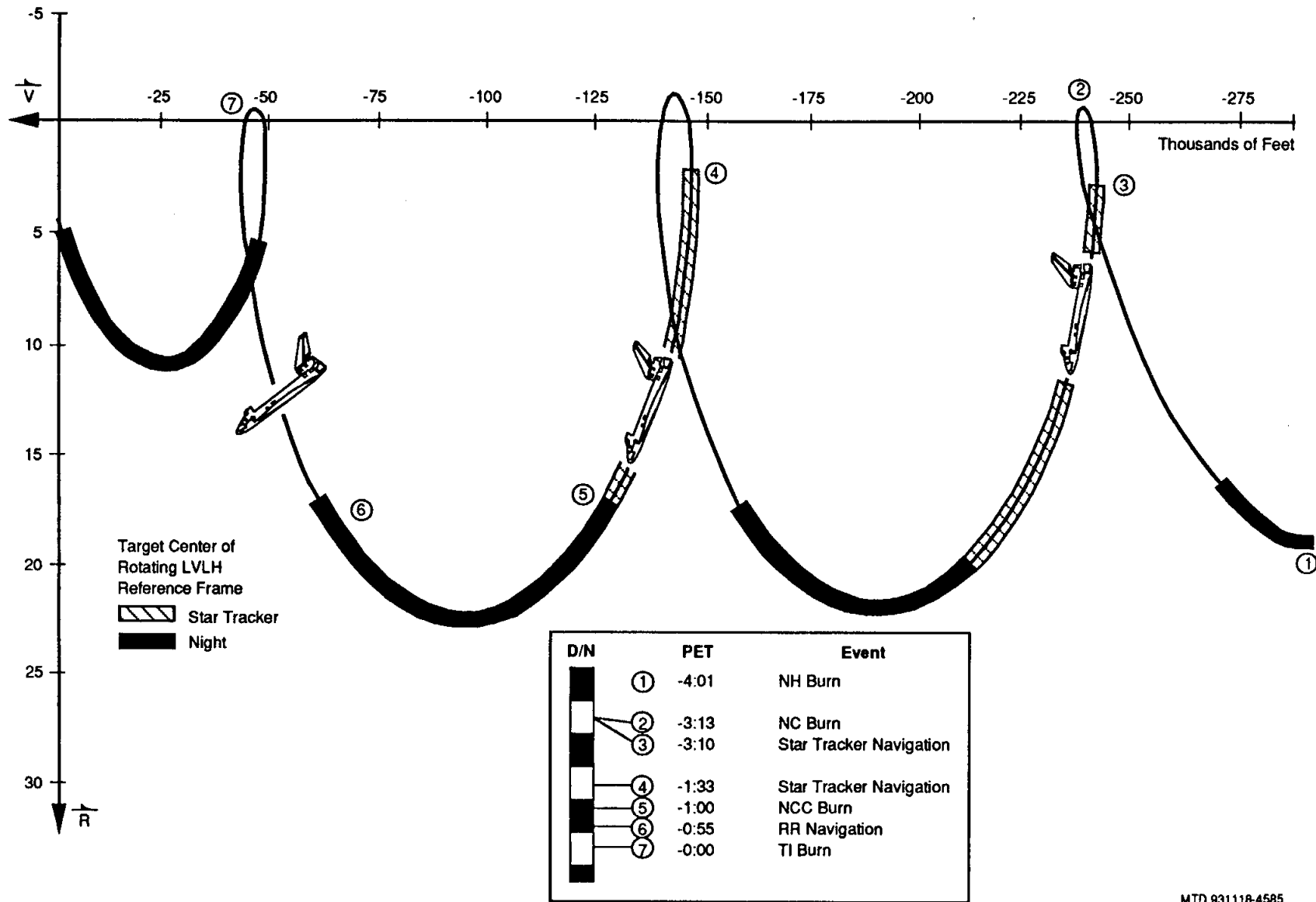
The telescope's pointing control system moves the telescope and points it at the celestial object selected for study. This system is made up of gyroscopes, momentum wheels, magnetic torquers, and star trackers that can keep the telescope pointed to within 0.007 of an arc-second—the equivalent of locking onto a dime in San Francisco from Los Angeles.

Other support systems include the space telescope's main computer, which controls the overall spacecraft; high-gain antennas, which receive ground commands and transmit data back to Earth; a thermal control system, which uses thermal blankets and a network of tiny heaters to keep the telescope within an acceptable temperature range; and a safing system, designed to take control of the telescope in case of serious computer problems or loss of communication with ground controllers at the Space Telescope Operations Center at the Goddard Space Flight Center, Greenbelt, Md., which manages Hubble.

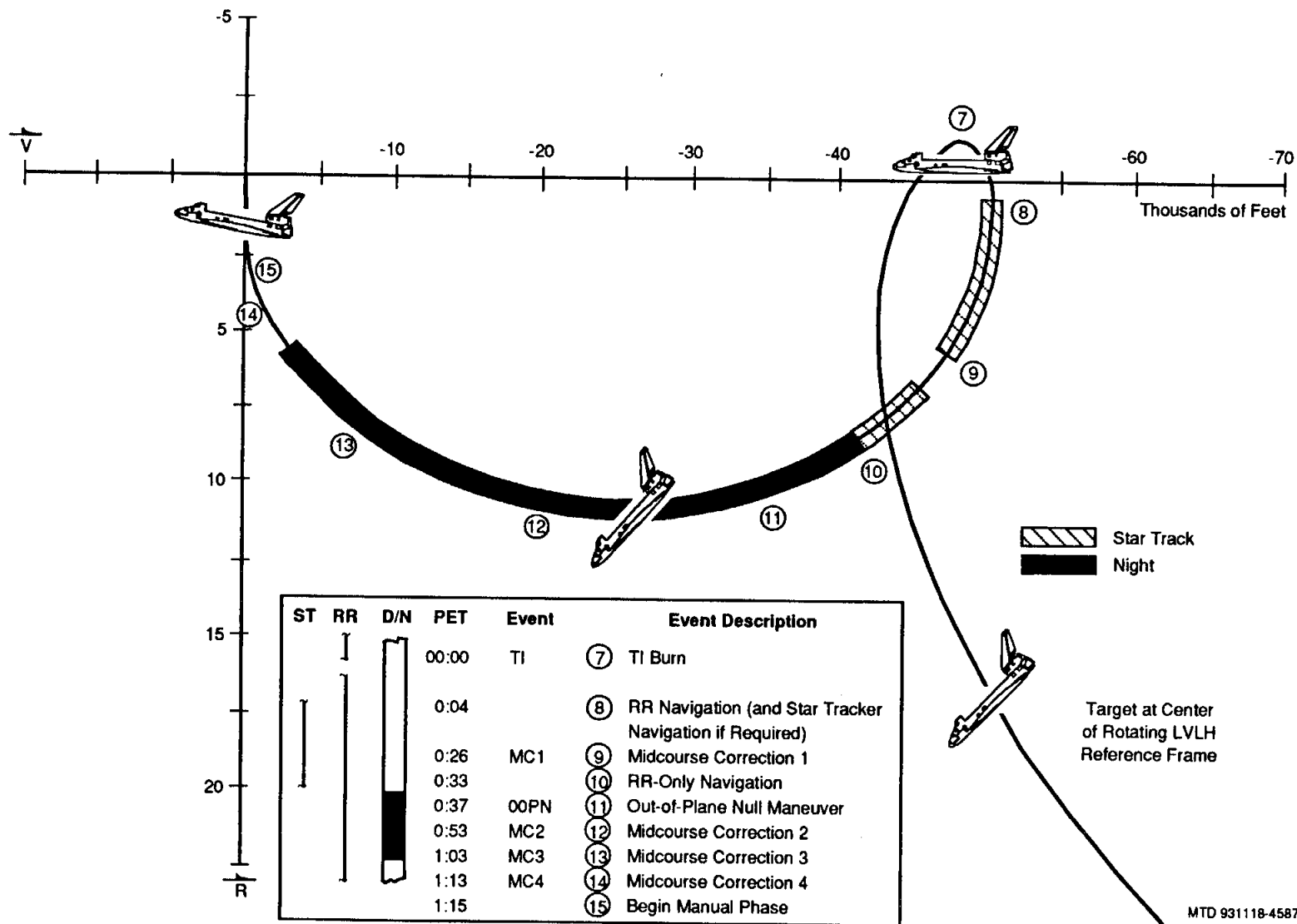
MISSION OVERVIEW

STS-61 is scheduled as an 11-day mission to accommodate a record five spacewalks plus an additional two, if they are needed.

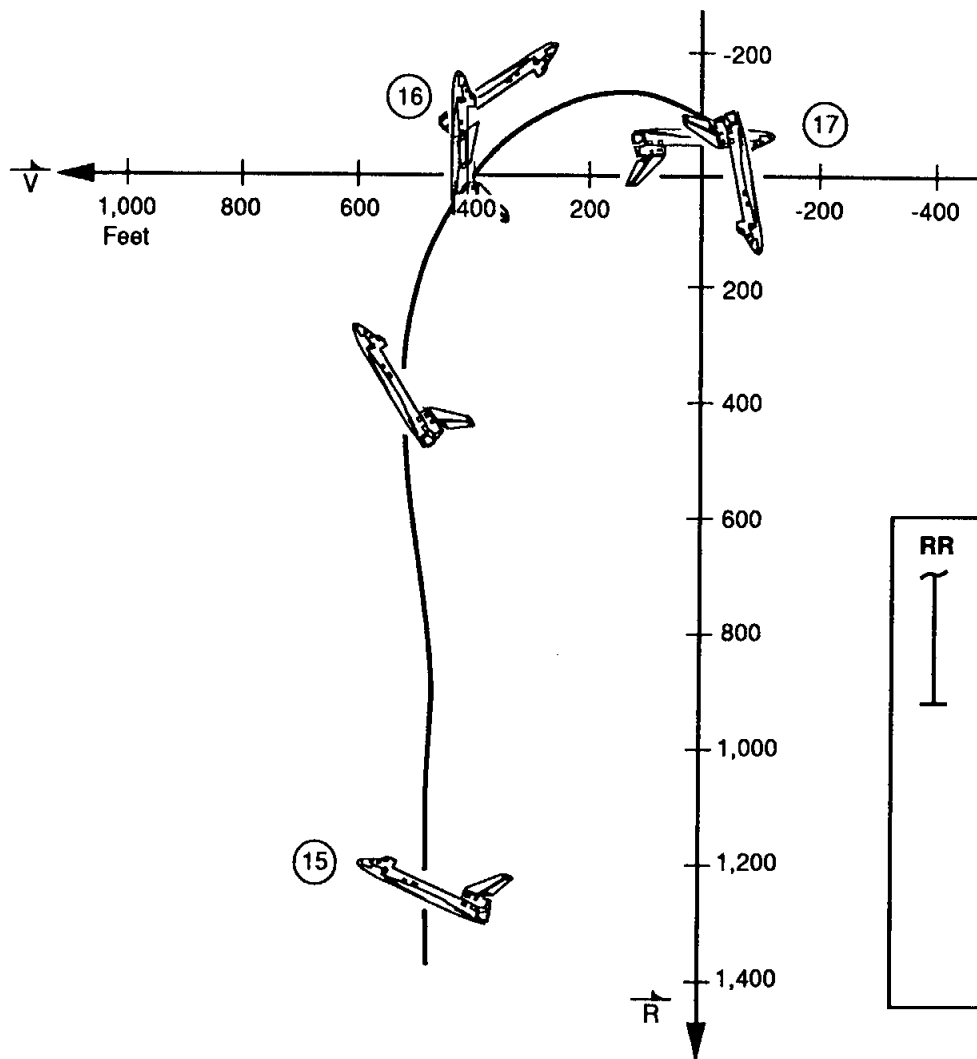
The shuttle crew will spend the first two days on orbit checking out and activating the 16,000 pounds of servicing hardware and equipment the astronauts will use during the servicing mission and



Rendezvous Profile



Post-TI Profile



RR	D/N	Time	Event Description
	15		Continuation of Manual Phase
	16	~1:36	V Bar Crossing
			Continue Inertial Approach
	17	~1:59	Arrive at 35 Feet
		2:11	Sunset

MTD 931118-4586

Manual Phase Profile

maneuvering Endeavour to rendezvous with the Hubble Space Telescope. These activities include activating the flight support system and orbital replacement unit carrier heaters and checking out the shuttle's remote manipulator system, Ku-band antenna, and ground command system.

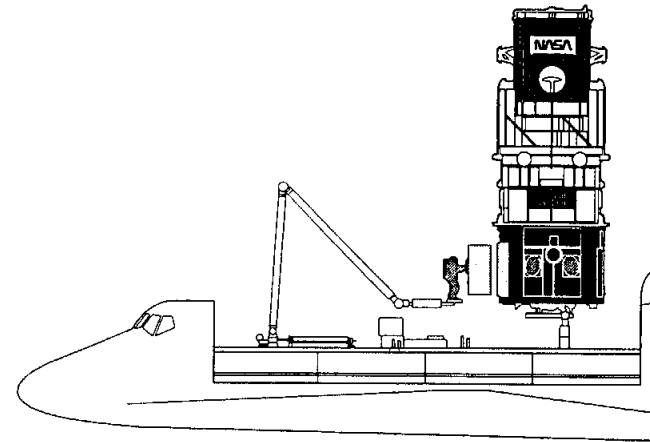
On the third day, the crew will perform a terminal initiation burn about 2 hours before capture when the shuttle is approximately 40,000 feet in front of the telescope. Several small midcourse correction burns follow before the commander takes over manual control of the shuttle about 1,200 feet below and 500 feet behind the telescope.

The orbiter will approach Hubble from underneath just after orbital sunset. This approach technique is designed to minimize potential contamination from the shuttle's thruster firings.

Before capture, the telescope will perform a ground-commanded maneuver to align its grapple fixture with Endeavour's robot arm. The size of the maneuver will depend on the angle to the sun and ranges from about 70 degrees to 180 degrees.

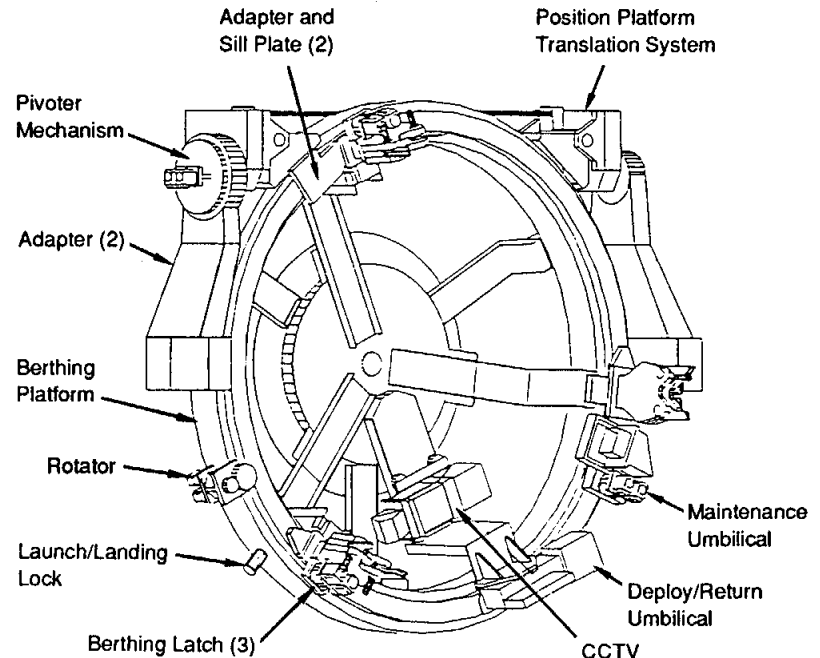
After the telescope has been grappled by the robotic arm's end effector, it will be lowered into the payload bay and berthed in the flight support system, a turntable that has been likened to a lazy susan because of its ability to rotate and tilt to assist in the servicing tasks. An electrical cable provides orbiter power to the telescope.

The unprecedented five spacewalks will take place over the next five days. The astronauts will replace two rate sensor units, one with an electronics control unit, and one of two magnetic sensor systems during the first spacewalk on day four. On day five, the solar arrays will be replaced. During the third spacewalk on the following day, the crew will replace the wide-field/planetary camera and four secondary-objective instrument fuse plugs and install the high-resolution spectrograph redundancy kit (secondary objective). The corrective optics space telescope axial replacement will be installed in



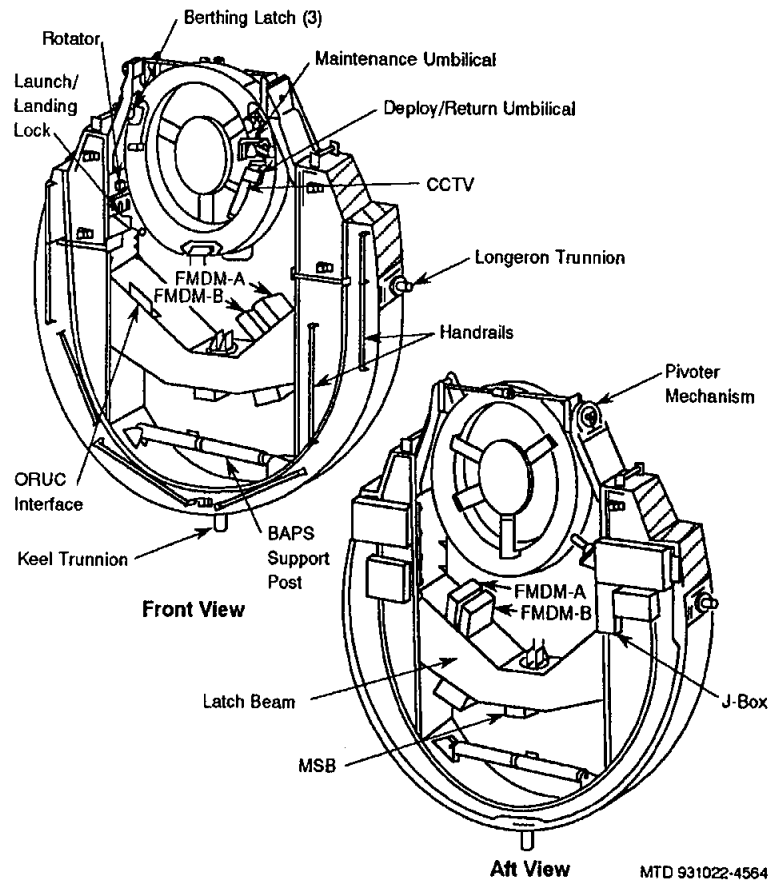
MTD 931021-4573

Artist's drawing shows astronaut installing corrective optics in Hubble Space Telescope, which is secured upright in the shuttle cargo bay.



Berthing and Positioning System

MTD 931021-4565



Flight Support System

place of the high-speed photometer on the seventh day. During the fifth and final scheduled spacewalk on the eighth day, astronauts will replace one solar array drive electronics unit and the second magnetic sensing system (secondary objective), install circuit fuses and a computer coprocessor (secondary objective), and deploy the new solar arrays. A third rate sensor unit is being carried in the payload bay for use if needed.

The serviced and repaired telescope will be deployed on the ninth day of the mission.

After the servicing is complete, the telescope will be redeployed. Part of the activities involved in configuring the telescope for deployment will occur on the FSS and part will occur on the shuttle's remote manipulator system (RMS).

The solar arrays and high-gain antennas will be deployed while the telescope is berthed to the FSS. The orbiter will assume an attitude that will allow the batteries on the telescope to charge. After the batteries have reached the required state of charge, the RMS will grapple the telescope and the crew will transfer power from the orbiter to the telescope's batteries. The umbilical will be removed when the Hubble Space Telescope is verified on internal power. The telescope will be unberthed from the FSS and maneuvered to the release position.

When the telescope is in the release position, the STOCC will command the telescope's aperture door to open and enable the pointing and safe mode electronics assembly. The telescope will be released, and after the first separation burn, the crew will command it to S/W sun point. The STOCC will regain control of the telescope and configure it for orbital operations.

The spacewalks will be performed by STS-61 extravehicular crew members Jeff Hoffman, Story Musgrave, Kathy Thornton, and Tom Akers, all of whom have prior EVA experience. Each spacewalk will be performed by two crew members, one of whom will be in a foot restraint mounted at the end of Endeavour's mechanical arm. During all EVAs, the crew member mounted at the end of the arm will be referred to as extravehicular crew member 2, or EV2. The other spacewalker will be designated EV1.

The EVA crew members can be distinguished by markings on the legs of their space suits. Hoffman will have a solid red stripe around the legs of his suit, Musgrave will have no stripes, Thornton

will have a dashed red stripe, and Akers will have a diagonal, broken red stripe.

The spacewalks have been designed to take into account the possibility that crew members may encounter unforeseen difficulties, either in performing their tasks or with the equipment, that could cause the preplanned schedule to change. All four EVA crew members have been cross-trained so that each of them is capable of performing any task.

During all of the tasks, the flight support structure on which the telescope will be mounted will be rotated so the area being worked on faces forward to give the astronauts better visibility.

The decision to schedule five extravehicular activities (EVAs) was reached following extensive evaluations of underwater training, maneuver times required using the shuttle's robot arm based on software simulations, and EVA tasks performed on previous missions.

"Basically, what we've done by going to five EVAs rather than three is to repackage our margin so that we have the capability to respond to the dynamics, or unknowns, of spacewalks," Mission Director Randy Brinkley said. "It improves the probabilities for mission success while providing added flexibility and adaptability for reacting to real-time situations."

In laying out the specific tasks to be completed on each of the spacewalks, officials have determined that changing the gyroscopes, solar arrays, and the WF/PC and fuses and installing the corrective optics space telescope axial replacement, at least one new magnetometer, and a new solar array drive electronics unit are priority objectives during the mission.

"When we looked at accomplishing all of the tasks, highest through lowest priority, and recognizing that the major tasks . . . would consume most of the time set aside for each spacewalk, five

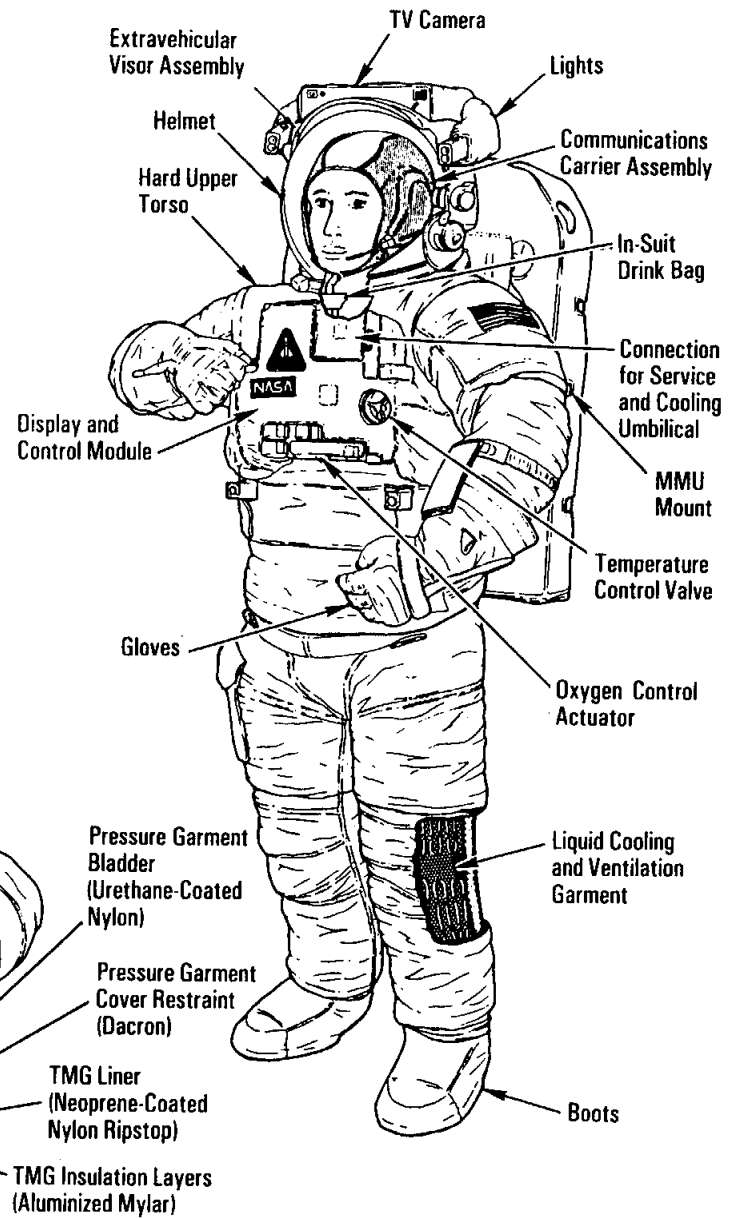
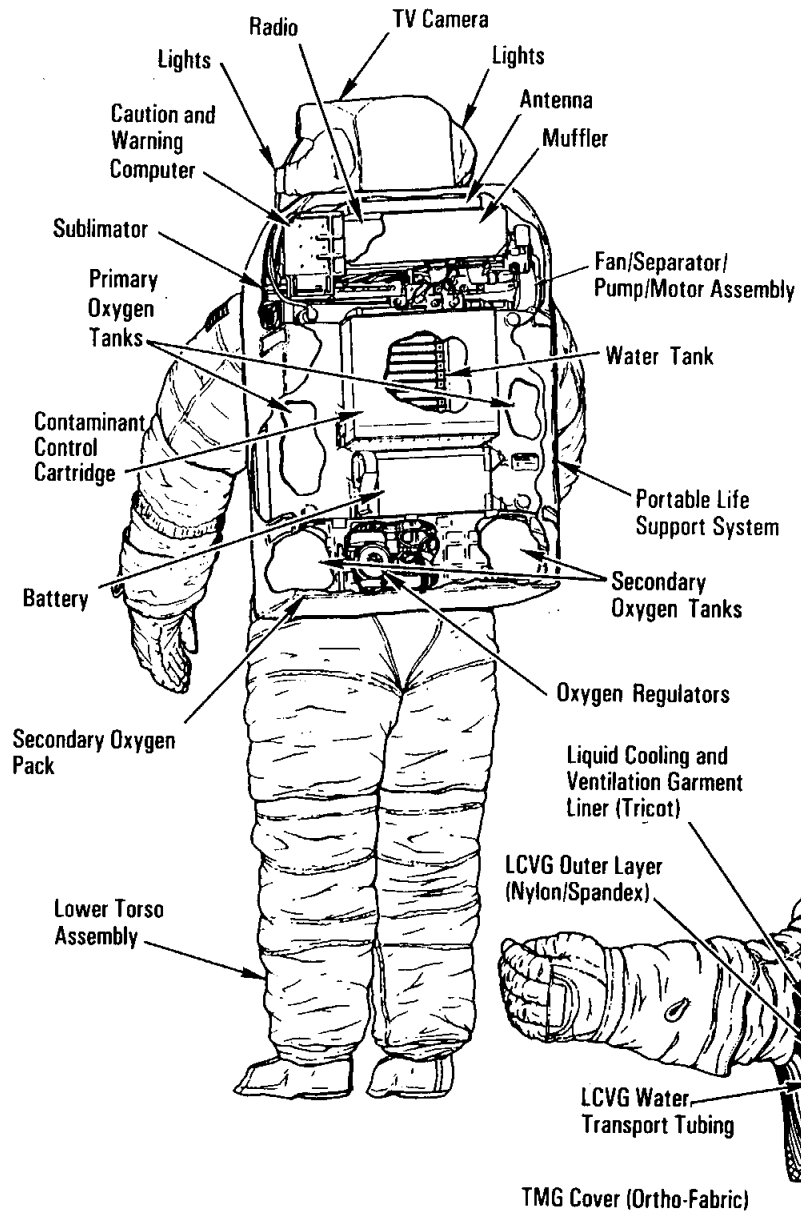
EVAs were deemed appropriate," said Milt Heflin, lead flight director for the mission.

Spacewalks were included on the June flight of Endeavour and Discovery's September mission so that NASA could evaluate some of the more than 200 unique tools and crew aids (space support equipment) to be used on this mission. The evaluations gave the agency a better understanding of the differences between working in the weightlessness of space and the ground training in the water tanks at the Johnson Space Center in Houston and the Marshall Space Flight Center in Huntsville, Ala. The spacewalks also gave NASA more insight into the time required for the various tasks and expanded the experience levels of the astronauts, flight controllers, and trainers.

During the EVAs, the astronauts will wear the extravehicular mobility unit, a combination space suit and portable life support system that allows crew members to work outside the shuttle. The pressurized suit supplies the astronauts with oxygen, removes carbon dioxide, controls temperature, and protects them against micrometeoroids. Expendable supplies-oxygen, battery, water, and lithium hydroxide for carbon dioxide removal-last for seven hours, and there is an extra 30-minute supply of emergency oxygen.

It takes about 15 minutes for a crew member to put on the EMU, which weighs 250 pounds on Earth. During the donning procedure, the EMU is attached to a mounting fixture in the orbiter's airlock. First, the astronaut puts on the liquid cooling and ventilation garment, then the lower torso assembly with the boots attached. The astronaut then slides up into the hard (fiberglass) upper torso and life support backpack, which are mounted on a special fixture in the airlock, and connects the two halves of the space suit with a waist ring. The gloves and helmet are donned last, and then the entire EMU is released from the mounting fixture.

In preparation for an EVA, the astronauts breathe pure oxygen for one hour to remove nitrogen from their bodies before donning their EMUs. The shuttle cabin pressure is then lowered from 14.7 to



Extravehicual Mobility Unit

10.2 psia. After 12 to 14 hours in this low-pressure environment, they put on their EMUs and breathe pure oxygen again for 40 minutes before leaving the spacecraft.

In addition to the expendables in the life support system, the space suit contains a bag with 21 ounces of drinking water and a urine collection device that is disposed of after each EVA. A micro-processor in the EMU monitors vital functions and automatically warns the astronaut if a system malfunctions or expendables are running low.

COST TO TAXPAYERS

NASA has some good news for American taxpayers. It will not cost any more to repair the Hubble Space Telescope than the originally planned servicing mission.

NASA remained within budget by trimming the \$86.3-million cost of correcting the telescope's optical problems from other areas of the mission. Some replacement instruments, such as the near-infrared camera multiobject spectrometer, were scaled back and the development of others, such as the space telescope imaging spectrograph, was delayed.

These actions resulted in a savings of about \$84.2 million. The rest of the cost overrun was made up by reducing administrative operations, deferring the development of operations computer software, and making other changes.

NASA has spent \$251 million for instruments, ground operations, and related activities since the agency began planning for the servicing mission in fiscal year 1990. The shuttle flight itself costs \$378 million.

REPLACEMENT HARDWARE AND INSTRUMENTS

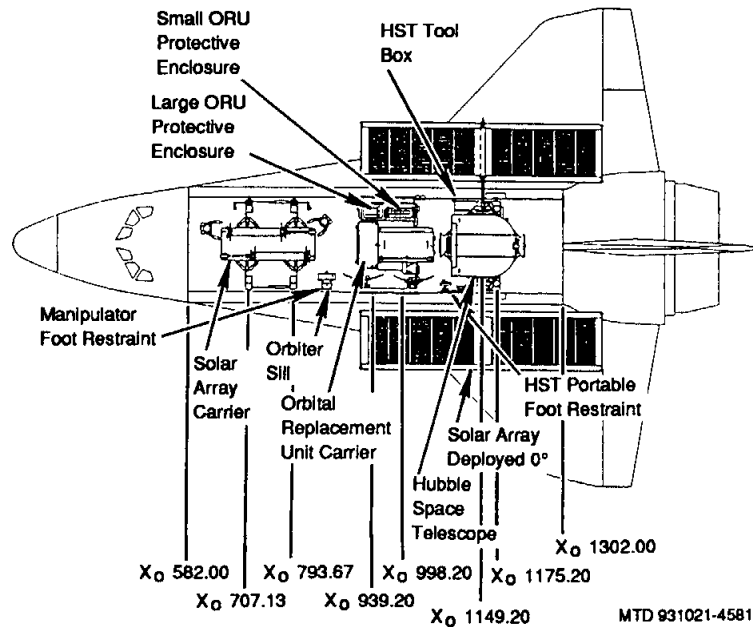
The payload complement for the servicing mission comprises the flight support system (FSS), the orbital replacement unit carrier (ORUC), and the solar array carrier (SAC). The FSS provides a maneuverable servicing platform for the space telescope and electrical power interfaces to the orbiter. The ORUC will carry both the wide field/planetary camera and the corrective optics space telescope axial replacement in scientific instrument protective enclosures (SIPes). The ORUC will also provide a large ORU protective enclosure (LOPE) to transport a DF-224 coprocessor and modification kit and a small ORU protective enclosure (SOPE) to transport three rate sensor units, two electronics control units, and a Goddard high-resolution spectrometer repair kit. Two magnetic sensing system units will be transported on the lower aft ORUC pallet structure. The ORUC will provide a load isolation system for the ORUs and scientific instruments. The SAC will provide load isolation for two new solar arrays and a contingency ORU protective enclosure (COPE). The COPE will transport a replacement solar array drive electronics unit, fuse plugs, and power tools. Tools and crew aids will be carried in the Hubble tool box and on the FSS, ORUC, and SAC.

The FSS is a modified configuration of the FSS flown on the Solar Max repair mission (STS 41-C). It consists of the A cradle and a berthing and positioning system (BAPS) with additional servicing mission avionics. The FSS will provide the platform for the Hubble Space Telescope during the servicing mission. Interfaces for orbiter support services are provided with the general-purpose computer data bus interfaces to a set of standard interface panels (port and starboard) just aft of the FSS.

The ORUC is a modified Spacelab pallet that is held in the orbiter payload bay by four payload retention latch actuators and an active keel latch. The mission-specific complement of ORUs, EVA tools, and other crew aids is stored on the ORUC.

The SAC is an isolated carrier system that consists of the fixed assembly, a pallet assembly, the solar array support structure

(SASS), and the COPE. The fixed assembly is the lower fixed structure which attaches to the shuttle payload bay. The pallet assembly is attached to the fixed assembly and provides the flat pallet structure to which the load isolation system, the SASS, and the COPE are mounted. A tripod of load isolators is located at each corner of the SASS between the SASS and the pallet assembly. The solar array attach points and latches are mounted on the SASS. The SAC is located forward of the ORUC and FSS in the payload bay.



Payload Configuration, HST Berthed, Solar Array Deployed Zero Degrees

NASA's Goddard Space Flight Center is responsible for the components that will be serviced or replaced on the Hubble Telescope. Goddard has devised a list of primary servicing tasks to be carried out during the mission and a list of secondary tasks to be undertaken if time and conditions allow.

The mission's primary objective is to restore the Hubble telescope's science capabilities with the wide-field/planetary camera II and the corrective optics space telescope axial replacement, both of which will compensate for the spherical aberration of the primary mirror. However, the replacement of the spacecraft's solar arrays, the telescope's major source of electrical power, tops the primary servicing task list because solar array jitter, or excessive flexing, may be compromising the structural integrity of the arrays. Replacing the arrays first will allow the observatory to perform science even if an emergency causes the mission to be called off and forces the astronauts to release the telescope from the space shuttle before the optics packages are installed. Similarly, the replacement of one gyro pair is second on the primary task list because the pointing of the spacecraft at science targets cannot be accurately controlled if more gyros fail.

The primary servicing task lists include the following:

- Solar arrays
- Gyro pair 2
- WF/PC II and four instrument fuse plugs
- COSTAR
- Magnetometer system 1
- Gyro pair 3 with electronics control unit
- Solar array drive electronics 1

The secondary servicing task list includes the following:

- A redundancy kit for the Goddard high-resolution spectrograph
- The 386 coprocessor on the spacecraft's primary computer

- Magnetometer system 2
- Four gyro fuse plugs
- Electronics control unit for gyro pair 1

CORRECTIVE OPTICS SPACE TELESCOPE AXIAL REPLACEMENT

The COSTAR, invented by the Hubble Space Telescope Strategy Panel and built by Ball Aerospace and Communications Group in Boulder, Colo., for NASA's Goddard Space Flight Center, is designed to significantly restore the Hubble Space Telescope to its original imaging capabilities. Once installed and aligned, COSTAR will provide correction for the faint-object camera, the faint-object spectrograph, and the high-resolution spectrograph. This correction will allow these instruments to analyze more distant stellar objects within a shorter time period without computer enhancement.

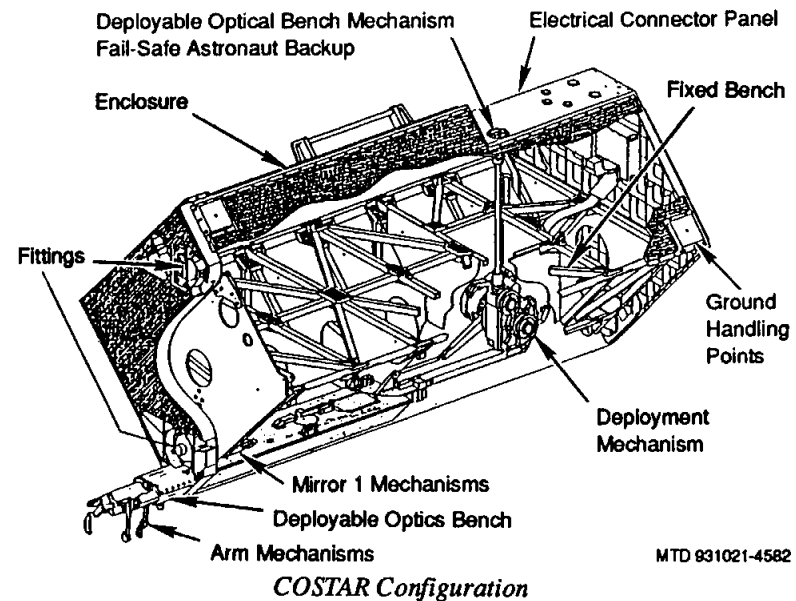
The FOC, provided by the ESA, is designed to detect very low luminosity celestial bodies and provide the most detailed images from the telescope. It consists of an electronic conventional scanning camera (of the television type), whose front part is a powerful image-intensifier tube. Its performance has been degraded by the spherical aberration, but the sharp image cores still allow the camera to detect details not seen by ground-based telescopes.

The FOS analyzes the light from very faint objects in the visible and ultraviolet spectral regions. While the faintest objects now cannot be reached, observations of brighter sources are only moderately degraded.

The HRS is intended for very detailed analysis of ultraviolet radiation. The instrument now loses spectral resolution on the faintest objects, but observations of brighter sources are only moderately degraded.

COSTAR will be installed in the aft area of the telescope during one of the five planned spacewalks. The COSTAR module weighs approximately 640 pounds and is more than 7 feet long. It is a composite and aluminum structure that supports five pairs of mirrors on a deployable optical bench. Once installed in the telescope's axial bay, the optical bench is extended into the telescope through an opening in the COSTAR module.

Because the space telescope's primary mirror was accidentally figured incorrectly and the secondary mirror has the correct shape, the two mirrors are not a matched set and do not produce a correctly focused image. The technical term for this anomaly is spherical aberration, which is a relatively simple geometrical effect. Light rays that strike the primary mirror at different radii from the center travel different distances before they come to a final focus. Because they do not all come to a focus at the same point, there is no one location where all are in focus, and some rays are always out of focus at any one location. This blurring can be corrected if all rays are brought to focus at the same distance behind the primary mirror.



COSTAR corrects the spherical aberration and provides significantly improved images to the FOC, FOS, and HRS by placing pairs of small mirrors, ranging from about the size of a dime to a quarter, in front of each instrument. The first mirror reflects light from the primary mirror to a second mirror that contains the correction. The second mirror then reimages the light at the instrument to correct the aberration. The fundamental improvement is a much tighter point spread function with most of the light energy focused within a 20-micron-diameter area.

This improves performance in several areas. Because a larger fraction of the light is focused onto a smaller detector area, the count rate per pixel increases, and much less energy spills onto neighboring detector elements. The FOC will be better able to separate closely spaced objects, resolve fine detail, and detect fainter signals. The amount of light energy the small entrance slits of the FOS and HRS collect will be increased, which will make sources appear brighter and shorten exposure times. More importantly, the images of neighboring objects will no longer overlap, and the spectra of closely spaced sources can be recorded without contamination. All three instruments will be able to detect and analyze the light from faint objects very near to much brighter sources.

The mirrors are mounted on small mechanical arms as part of the deployable optical bench. The arms are folded up inside the optical bench during launch. On orbit, the optical bench extends into the focal plane and deploys its arms to place the mirrors in front of the science instruments. Small actuators make fine adjustments to the alignment and focus of the mirrors to optimize the correction for each instrument.

COSTAR will have three side effects. An increase in magnification will reduce the area of sky covered by each instrument, and the orientation of the image of the sky on the instruments will be reversed. This means that operational procedures used to point the telescope will have to be modified. Finally, no mirror reflects 100%

of the light that hits it, and two additional reflections will increase the amount of light lost.

The benefits of COSTAR, however, greatly outweigh these side effects. An important goal of the optically corrected telescope will be to find, classify, and study extremely faint and distant galaxies. The FOC will be able to detect Cepheid variable stars in distant galaxies that are not detectable by ground-based telescopes. The cosmic distance scale calibrated from Hubble Space Telescope data can help determine the size of the observable universe, the rate and uniformity of expansion, and the possible fate of the universe a billion years from now. The corrected FOS and HRS will be able to record the spectra of fuzz around quasars and examine the morphology, environment, and stellar content of the host galaxy. The existence of black holes may be proven because the velocities of regions very close to the central engine should be observable. The most important, interesting, and even controversial issues in modern astronomy can be tackled-and resolved.

COSTAR will be carried into orbit in Endeavour's cargo bay inside the science instrument protective enclosure, which will keep the instrument warm and provide some protection during the launch. On the seventh day of the mission, a team of astronauts will remove the high-speed photometer (HSP) from the aft end of the Hubble Space Telescope and insert COSTAR in its place. The photometer will be placed in the SIPE and returned to Earth.

Through a servicing bay door, astronauts will pull out the 487-pound, phone booth-size HSP and install the identically sized COSTAR in its place. Once in place, COSTAR will deploy a set of mechanical arms, no longer than a human hand, that will place corrective mirrors in front of the openings that admit light into the faint-object camera, the faint-object spectrograph, and the Goddard high-resolution spectrograph. COSTAR's corrective mirrors will refocus light relayed by the telescope's primary mirror before it enters these three instruments. COSTAR will restore the optical performance of these instruments very close to the original expectations.

To install COSTAR, the spacewalking astronauts first will loosen several bolts and open the doors to the bay that encloses the HSP. Once the doors are open, they will loosen latches that hold the HSP in place and disconnect four electrical connectors and a ground strap from the instrument.

The astronauts will then lower the HSP from its position to guide rails. The arm-mounted crew member will slide the photometer out while his fellow spacewalker, standing in a foot restraint attached to the telescope, will ensure that it is aligned with the guide rails.

Once the HSP has been removed, the crew member standing on the end of the arm will hold the photometer while the arm is positioned so the unit can be placed in a temporary parking fixture mounted in the cargo bay. After the HSP has been temporarily stowed, the astronauts will attach a handhold to COSTAR and lift it from its protective enclosure. While the arm-mounted astronaut lifts COSTAR out, his crew mate will make sure it is squarely aligned with the enclosure as it is extracted.

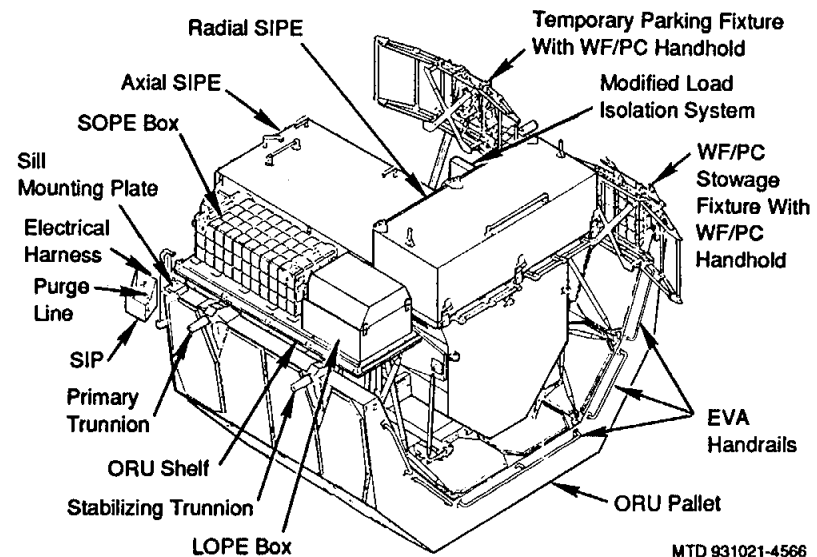
The arm-mounted crew member will then be moved to the installation area with COSTAR while the other astronaut moves to the site using handrails on the telescope. The arm-mounted spacewalker will align the upper left-hand corner of COSTAR with a guide rail, and his counterpart will check the alignment with a rail at the lower right corner.

When COSTAR is in place, the astronauts will connect the four electrical connections and the grounding strap disconnected from the HSP to COSTAR and tighten the latches that hold COSTAR in place.

During training, the removal of the HSP and installation of COSTAR took about 3 hours and 15 minutes.

NASA is confident that COSTAR will fit in the Hubble telescope because the space agency verified the instrument in the same simulators used to verify the telescope's original hardware. Furthermore, COSTAR and the wide-field/planetary camera were placed in a high-fidelity replica of the Hubble Space Telescope at the Goddard Space Flight Center to ensure that they fit.

Before COSTAR is launched, NASA will have gone to some lengths to make sure that it is the right prescription for fixing the space telescope's vision problem. First, experts determined the exact error in the primary mirror. Then the new optical elements were subjected to two different and independent tests to verify the correctness of the prescription. Next, the correct placement and shape of the COSTAR mirrors were determined. Finally, COSTAR was tested in a device that simulated the aberrant Hubble telescope optical system. Images that matched the aberrant HST images were fed into



Orbital Replacement Unit Carrier

COSTAR, and it produced corrected images, demonstrating that the instrument has the proper correction and alignment.

WIDE-FIELD/PLANETARY CAMERA II

The WF/PC-II, designed and built by the California Institute of Technology's Jet Propulsion Laboratory under contract to NASA, occupies the center of the space telescope's focal plane and is made up of four camera systems: three wide-field cameras and one planetary camera. The wide-field cameras provide the greatest sensitivity for the detection of distant objects, and the planetary camera facilitates high-resolution studies of individual objects, including planets, galaxies, and stellar objects. By the time this multipurpose camera

was launched, a replacement instrument was in the early stages of construction.

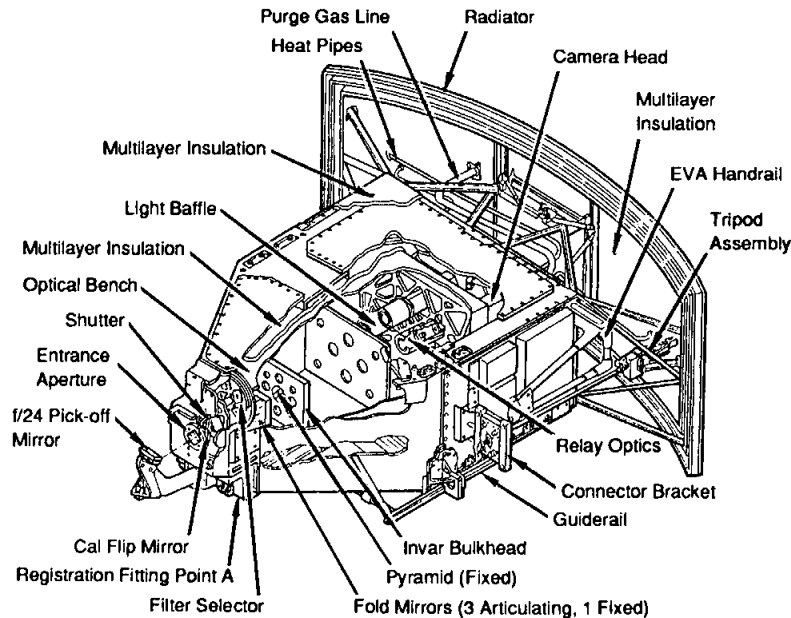
As a result of the flaw in the primary mirror, starlight was spread over a larger area in a fuzzy halo, causing a blurred rather than sharp image to arrive at all of the science instruments. Images that require a great deal of clarity and detail, such as images of binary stars circling each other at close range or star clusters containing thousands of individual stars inside an envelope of dust and gas, suffered from the loss of resolution. For compact bright objects, computer image processing has been used to return some of this light to its intended position. However, for faint or diffuse objects, computer processing is difficult or impossible, and these objects cannot be imaged satisfactorily by the current WF/PC.

To correct this aberration, the WF/PC will be replaced with a new camera to regain nearly all of the original imaging capability. To do this, slight modifications were built into the WF/PC-II's relay optics to refocus the blurred incoming light.

Several other design changes were made to enhance the camera's overall imaging capability. The WF/PC-II incorporates a revised filter set, including a far-ultraviolet filter; a flat-field calibration system; current-technology charge-coupled devices; fold mirrors on three of the four light pathways inside the camera; and a new mechanism on the pick-off mirror to ensure optical alignment of the camera with the telescope.

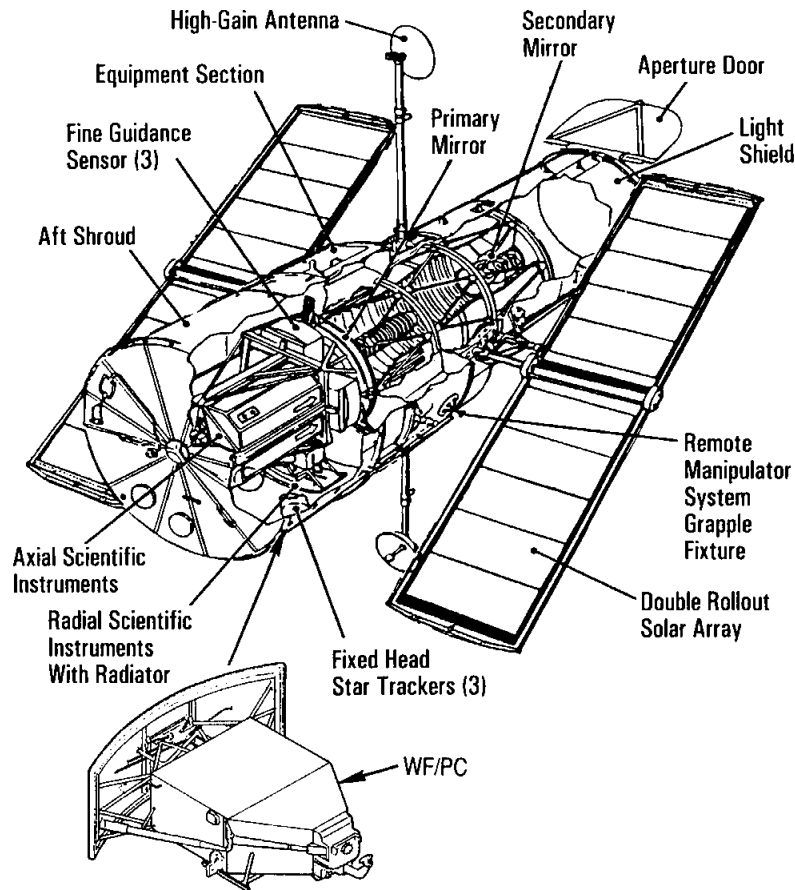
Once these changes are made, astronomers will be able to recover most of the telescope's original capability and pursue the full range of their proposed investigations. The capability to finally obtain crisp images from the near infrared to the far ultraviolet promises to revitalize the Hubble Space Telescope science community with its diverse interests, which range from observations of nearby planets to the most distant objects in the universe.

Although the second wide-field/planetary camera was still about four years away from completion when the aberration in the



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Replacement Wide-Field/Planetary Camera



Hubble Space Telescope and Replacement WF/PC

primary mirror was discovered, the schedule to complete the new camera was accelerated, and a requirement was added that the camera's internal optical system correct for the telescope's spherical aberration to the fullest extent possible.

The solution was to change the existing mirrors in the WF/PC's relay optics to include aberration—or curvature—corrections equal to and opposite the flaw in the telescope's primary mirror. To do this,

a previously flat “fold” mirror was polished slightly convex so that the space telescope's primary mirror would be focused precisely on that relay optic's secondary mirror. However, the corrected imaging performance of the telescope requires 10 times more precise alignment than the current camera requires. The space telescope's primary mirror images formed on the corrective relay elements have to be precisely centered to within less than 1% of the diameter of these dime-sized mirrors. If this pupil alignment is not maintained, another aberration—coma—would be introduced, defeating the purpose of the corrective optical design and destroying the ability of the space telescope to detect and resolve the faintest astronomical sources.

The other essential ingredient of the optical fix was an alignment capability that could be controlled from the ground. The fixed, immobile pick-off mirror and three of four fixed fold mirrors in the current WF/PC were replaced on the WF/PC-II with articulated, adjustable mirrors that can be tipped and tilted to ensure that the light beam from the telescope falls precisely on the center of the secondary relay mirrors. That alignment capability is necessary after the vibrations and jitters of launch and installation and also provides a means for guaranteeing on-orbit alignment later on.

During its lifetime, the Hubble Space Telescope will see distant galaxies and quasars, the planets of our solar system, and their moons. The WF/PC-II will be able to track the orbits of comets around the sun and search for planetary systems around other stars.

While solar system studies will contain treasures of new information, the real gold for celestial prospectors is expected to lie in distant fields. The WF/PC program has embarked on an unprecedented contamination control program to ensure far-ultraviolet imaging capability. Since ultraviolet imaging from ground-based telescopes is impossible due to atmospheric effects, the WF/PC-II will be uniquely capable of imaging in this scientifically fascinating region.

Astronomers have set for themselves three major tasks in the field of cosmology: to determine the cosmic distance scale, to under-

stand the evolution of the universe, and to test "world models" of the expanding universe.

Currently, it is difficult-in most cases, impossible-to measure astronomical distances. Scientists search the Milky Way galaxy for unusual stars, called Cepheid variables, whose light varies in brightness in regular periods. Their distances can be measured. Then scientists look for those Cepheid variables in other galaxies. The distant stars act just like their nearby cousins and, thus, scientists try to scale the distance to that galaxy.

But in that method lies a seed of doubt: We reside in a massive cluster of galaxies, whose mutual gravitational effects introduce error-or, at least, serious doubt-into those measurements of distance. Even small gravitational effects build up respectable mistakes.

How do astronomers hope to solve the problem? The answer is to obtain even better measurements. The wide-field/planetary camera will be able to measure stars in distant galaxies 100 times fainter than those that the 200-inch Hale telescope atop Palomar Mountain near San Diego, Calif., can observe. That capability will enable astronomers to measure stars 10 times farther away and to reach and measure Cepheid variables in galaxies that, until now, have been untouchable. By doing this, it will be possible to tie local measurements of distance to the far realm of the great galaxy clusters.

The wide-field/planetary camera supports many other investigations across a diverse range of astronomical fields. The science team hopes to determine the cosmic distance scale, with an expected sevenfold improvement in current estimates; test models of the universe and cosmic evolution; compare evolutionary studies of distant and local galaxies; study populations of stars at very faint levels and conduct high-resolution studies of galactic centers; examine the energy distribution of stars and compact sources, such as quasars; and search for perturbations of nearby stars that would indicate the presence of planets the size of Jupiter in orbit around them. Scien-

tists also hope to observe cloud motions and identify compositions of planetary atmospheres in our solar system and map the surfaces of moons, asteroids, and comets in our solar system.

Through a servicing bay door in the side of the Hubble telescope, the astronauts will slide out the 610-pound, wedge-shaped WF/PC and replace it with the new instrument. The old WF/PC will be returned to Earth.

The WF/PC-II has three wide-field cameras and one planetary camera instead of the eight cameras the original unit has. The WF/PC-II team reduced the number of cameras in order to develop a system that would allow them to align the corrective relay mirrors on orbit. Improved charge-coupled devices have been incorporated into the new unit to improve its sensitivity, particularly in the ultraviolet region.

To remove and replace the WF/PC, the astronauts will open the doors to the service bay at the base of the telescope and install specially designed guide rails.

After installing a temporary handhold on the WF/PC, the arm-mounted spacewalker will pull the WF/PC out while the other EVA astronaut watches the alignment of the WF/PC on the rails and makes sure that it is level as it is removed. Once he has removed it from the telescope, the arm-mounted astronaut will stow the old WF/PC in a temporary parking fixture in the shuttle's cargo bay.

The astronauts will then install a temporary handhold on the new unit, and the arm-mounted crew member will pull it from its protective enclosure. While the operator of the robotic arm moves the arm-mounted crew member and the new WF/PC to the telescope, the other spacewalker will temporarily latch the SIPE door.

Before installing the WF/PC-II in the telescope, the astronauts will remove a cover over its mirror. Then the arm-mounted astronaut will slide the instrument into the telescope while his part-

ner makes sure that it is aligned on the guide rails. When the unit is in place, the astronauts will remove the handhold and the guide rails.

Finally, the astronauts will remove the old WF/PC from temporary storage and place it in the SIPE that carried the new WF/PC for the return trip to Earth.

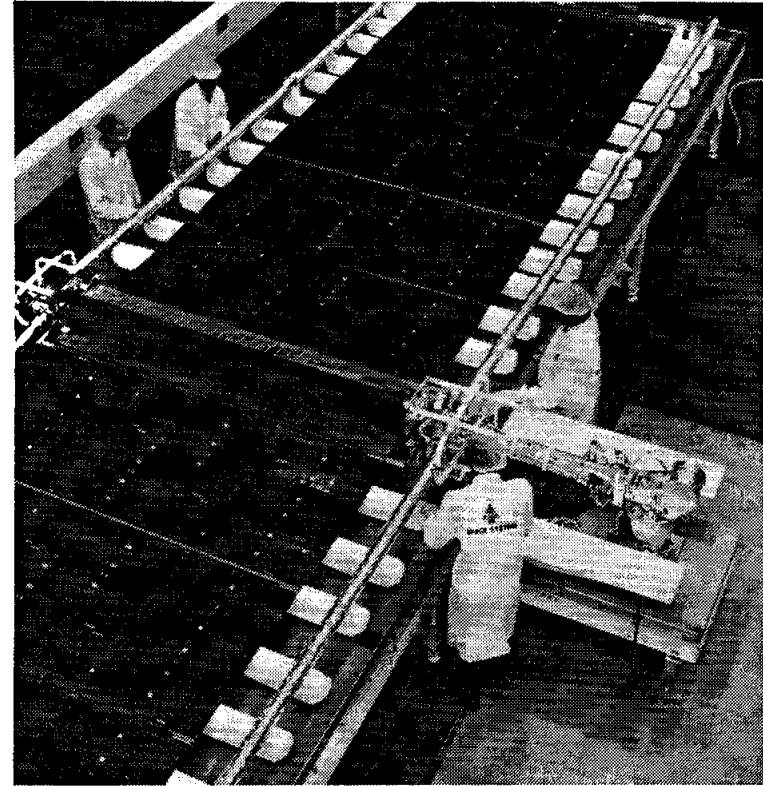
It has taken about 4 hours and 15 minutes to remove and replace the WF/PC during training.

SOLAR ARRAYS

One of the top priorities of the servicing mission is to replace both of the telescope's 352-pound solar arrays, which provide the astronomical satellite with up to 5 kW of electrical power. The solar wings, which are made of huge sheets of fiberglass-reinforced Teflon held in place by horizontal metal struts, were designed to be replaced about every five years because they are constantly being bombarded by cosmic rays and micrometeoroids and their photoelectric cells naturally degrade. However the arrays must be replaced sooner to correct an unexpected problem that has affected the telescope's pointing ability.

After the spacecraft was deployed in 1990, it was discovered that the arrays, which are provided by the European Space Agency, would expand and contract when the orbiting craft crossed the boundary between day and night every 95 minutes. The jerky, irregular movement of the solar wings caused vibration, or jitter, which degraded the precision of the telescope's pointing system.

An interim solution to the problem was to anticipate the transition from day to night and vice versa and command the spacecraft to change its line of sight to compensate for the jitter. But this procedure was extremely cumbersome and required a large amount of the satellite's on-board computer memory.



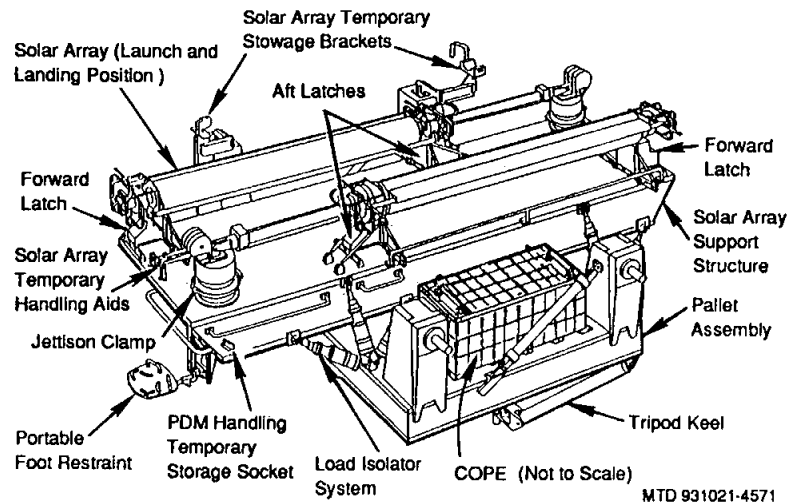
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Photo British Aerospace for ESA

One of the double rollout solar arrays that will replace similar arrays on the Hubble Space Telescope undergoes final testing at British Aerospace.

A replacement set of solar arrays was already under construction in Europe when the problem was discovered. Changes incorporated into the design of the arrays are expected to reduce jitter to an acceptable amount. The new arrays are 10% more powerful, more stable mechanically, and have extra handles to make it easier to maneuver them in space.

The spacecraft's current arrays will be command to retract by the STOCC. The arm-mounted spacewalker will then release three latching points on the first array to be removed. When the three latches



Solar Array Carrier

have been released, the array will be removed and handled using a transfer handhold mounted on the array.

The operator of the robotic arm will then move the arm-mounted astronaut and the old arrays to within reach of a temporary stowage bracket on the right-hand side of the solar array carrier. While being moved from place to place at the end of the arm, the crew member also may evaluate the handling characteristics of the arrays to prepare for carrying the new arrays to the telescope. Throughout the removal operation, the arm-mounted astronaut will be assisted by his counterpart, who will use handholds on the telescope and shuttle to move around.

The new solar arrays will be removed from the SAC by disconnecting power and data connections and then unlatching each array's three latch points, which are exactly like the latch points on the telescope. A temporary transfer handle allows the arm-mounted astronaut to carry the new arrays to the telescope. His counterpart, standing in a foot restraint mounted to the telescope near the work area, will assist with the installation.

While the arrays are being transported, the power and data connectors will be secured in temporary holding brackets on the arrays. To install a new array, it is first moved into position and seated, the three latch points are locked in place, and the connectors are plugged in.

During training, the time required to change the solar arrays was about 5 hours, and one full spacewalk is dedicated to this task. It is not planned to deploy the new arrays during the spacewalk when they are installed.

Neither NASA nor ESA suspected that the problem of jitter would arise when they were designing the solar arrays. The problem would have been discovered beforehand if the agencies had been able to test the huge arrays under weightless and solar radiation conditions, but there are no facilities anywhere in the world large enough to test the arrays.

GYROSCOPE PAIRS (RATE SENSING UNITS) AND ELECTRONICS CONTROL UNIT

Three gyroscopes (or gyros) are required to point and track the Hubble Space Telescope. Three more gyros are on board as backups. The six gyros are packaged in pairs of two, called rate sensor units (RSUs). One gyro failed in December 1990, a second in June 1991, and a third in November 1992.

Hybrid electronics in two of the three failed gyros, one located in pair 2 and the other in pair 3, are suspected as the cause of the failures. Gyro pairs 1 and 3 also have experienced a failure in one channel of their electronics control unit (ECU). The cause is thought to be a random electronic part failure. While these failures have not affected the telescope's performance, replacing the failed hardware will increase system reliability.

To replace the RSUs, which are inside the telescope's housing, one of the astronauts, standing in a foot restraint mounted on the end of the shuttle's mechanical arm, will first back out several bolts to

WHICH IS BETTER: SPACE-BASED OR EARTH-BASED TELESCOPE?

The flaw in the primary mirror of the Hubble Space Telescope has caused some to speculate that powerful new Earth-based telescopes will be able to perform as well as Hubble or better. These critics are overlooking the fact that both types of telescope have unique strengths that will benefit astronomy.

One area where an Earth-based telescope has an advantage over the Hubble Space Telescope is in light-gathering power. The Keck telescope in Hawaii, the world's largest telescope, has 17 times more area for collecting light than Hubble and can collect faint starlight much faster than the space telescope.

The Hubble telescope has the advantage in resolving power, which is the ability to produce sharp, detailed images. Hubble's resolution is 5 to 10 times better than Keck's because it does not have to contend with the blurring caused by Earth's atmosphere.

Improvements in ground-based telescopes eventually will enable them to compete with the Hubble Space Telescope's reso-

lution, but only when investigating bright starlike objects and only over small patches of sky.

Unlike Earth-bound telescopes, Hubble's images and other data are optically stable, which means it can reexamine targets at any time of the year and obtain the data of the same quality year-round. An Earth-based system that could match this ability may not be available until after the working lifetime of the Hubble Space Telescope.

The Hubble Space Telescope's location gives it other advantages. From space, it is able to view any celestial object without the Earth, sun, or moon getting in the way. No Earth-based telescope can do this. Hubble is also able to detect objects that emit ultraviolet light, such as stars more massive than our sun, white dwarfs, and hot regions of interstellar gas. The atmosphere absorbs most of the ultraviolet light from other celestial bodies before it can reach telescopes on the surface of the Earth.

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open doors covering the star tracker near the base of the telescope. One of the four bolts holding the doors must be completely removed to unlatch the doors. The second spacewalker, standing on a foot restraint attached to a support structure in the shuttle's bay, will help the arm-mounted astronaut unlatch the doors. Once the doors are unlatched, they will be swung open to provide access to the bay area.

The RSUs are located behind the cone-shaped star tracker shades in the bay area of the telescope. To replace an RSU, the astronauts may have to remove these shades. Three bolts must be loosened to allow the shades to be pulled off. The shades then can be

temporarily stowed outside the work area until they are reinstalled by pushing them back into place and retightening the three bolts.

To remove an RSU, the astronaut standing in the adjustable foot restraint attached to the telescope will loosen three bolts and disconnect two electrical plugs. The astronaut will then grasp a handrail on the top of the RSU and remove the unit. The astronaut will install the new RSU, carried in the orbital replacement unit carrier in the shuttle's bay, by sliding it into place, retightening the three bolts, and hooking up the two electrical plugs.

During these activities, the astronaut standing on the end of the arm will assist his partner from behind.

A programmable power wrench will be used to loosen and tighten all bolts during the RSU replacement.

The time required during training to set up, remove and replace two RSUs, and clean up the area has been about 3-1/2 hours, including the possible removal and reinstallation of the star tracker shades.

The ECUs, the electrical brains of the RSUs, are located in a service bay on the Hubble telescope. Once the compartment door is opened, two of the three ECUs will be removed by removing the bolts that secure the units and disconnecting each unit's electrical cable. The new units, which are stored in a protective container in the payload bay, will then be installed.

SOLAR ARRAY DRIVE ELECTRONICS (SADE)

Each solar array wing has an electronics control assembly, which includes a drive electronics unit. These units transmit positioning commands to the wing assembly. One of these SADE units failed due to transistor overheating. A replacement SADE, provided by ESA, will restore that lost capability and provide better heat protection for the transistors.

Two solar array drive electronics boxes are mounted on the inner side of one of the doors to a telescope service bay. Only one box is being replaced. Once the door is opened, the two spacewalkers—one mounted on the arm and one holding handrails on the telescope—will loosen six bolts to free the old SADE unit and disconnect electrical connectors attached to the unit. The new SADE unit is installed in a reversal of this process.

MAGNETOMETER SYSTEM 1

The space telescope's two magnetometers (also known as magnetic sensing systems) measure the spacecraft's relative orientation with respect to the Earth's magnetic field. Neither magnetometer is functioning at full capability. The replacement units have improved electronics and thermal blankets.

The magnetic sensing systems are located near the top of the telescope near the aperture door. The new units will be installed using four rotating knob connectors and will be attached directly on top of the old units by removing some insulation and removing and reinstalling the electrical cable.

FUSE PLUGS

Eight fuses for both the gyros and instruments will be replaced to correct sizing and wiring discrepancies. The fuses that will be replaced are located on the inside of a compartment door. After they have been replaced, the astronauts will check to ensure they are working properly.

SECONDARY SERVICING TASKS

Coprocessor

The DF-224 is the space telescope's flight systems computer. One of the computer's six memory units has failed and another has partially failed. Hubble requires only three memory units to fully function; so the failures have not affected the telescope's operations. However, to restore the memory redundancy and augment the telescope's memory capacity and speed, a coprocessor, based on 386-computer architecture, will be integrated into the flight systems computer, which will increase both flight computer memory and the speed of some operations.

The DF-224 coprocessor will be installed on top of the telescope's computer. The memory upgrade will be attached with four bolts.

Goddard High-Resolution Spectrograph Redundancy Kit

The HRS has two detector systems. Because of the anomalous behavior of a low-voltage power supply, the side 1 detector is no longer used. The redundancy kit consists of an externally mounted relay box that enhances system redundancy so that the side 1 detector can be used and the side 2 detectors will not be compromised if the anomaly occurs again.

Consisting of four cables and a relay box, the redundancy kit is designed to bypass an erratic detector system on the science instrument located in an instrument bay on the lower portion of the telescope. The relay box will be installed first using a power tool similar to an electric drill. This will be followed by the attachment of the four cables.

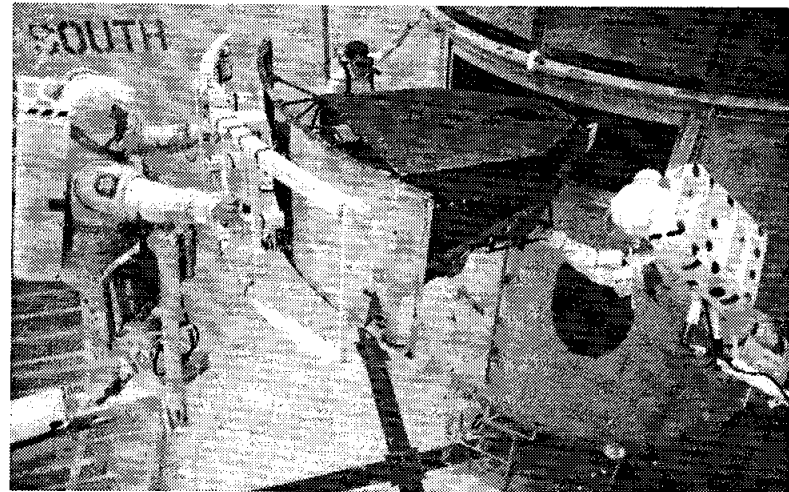
MISSION TRAINING

Training for the in-orbit repair of the Hubble Space Telescope involves three major components: simulated EVA mass handling of the large telescope elements, remote manipulator system operations, and computer graphics/virtual reality technology to integrate these crew tasks.

EVA mass handling training is conducted in several facilities to simulate on-orbit conditions. A series of underwater sessions in NASA's neutral buoyancy simulator at Marshall Space Flight Center in Huntsville and the weightless environment training facility at Johnson Space Center in Houston tested both the skill and stamina of the astronauts to conduct five consecutive six-hour EVAs. The practice sessions are scheduled for 10 to 12 days (three sessions for each EVA team). To compensate for water drag and limited weightlessness, the crew members also participated in a more realistic exercise at a JSC facility equipped with an air-bearing floor and an Apollo pogo device.

Both the MSFC and JSC water tanks contain a full-scale mockup of the orbiter, complete with remote manipulator system (or mechanical arm). NASA recently upgraded the MSFC tank to make training more realistic. A new mechanical arm has been installed that moves and responds like the real one on the shuttle. The displays and controls used by the arm operator have also been improved. Mass handling tests will simulate the arm's start/stop dynamics, in-transit motion, and bounce while the operator attempts to position and maneuver loads.

Supplementary activities included manned thermal vacuum chamber tests, visits to contractor facilities, use of the high-fidelity mechanical simulator at Goddard Space Flight Center in Greenbelt, Md., and crew equipment tests at the Kennedy Space Center in Florida to conduct flight interface fit checks and functional demonstrations. The JSC manipulator development facility, integrated water



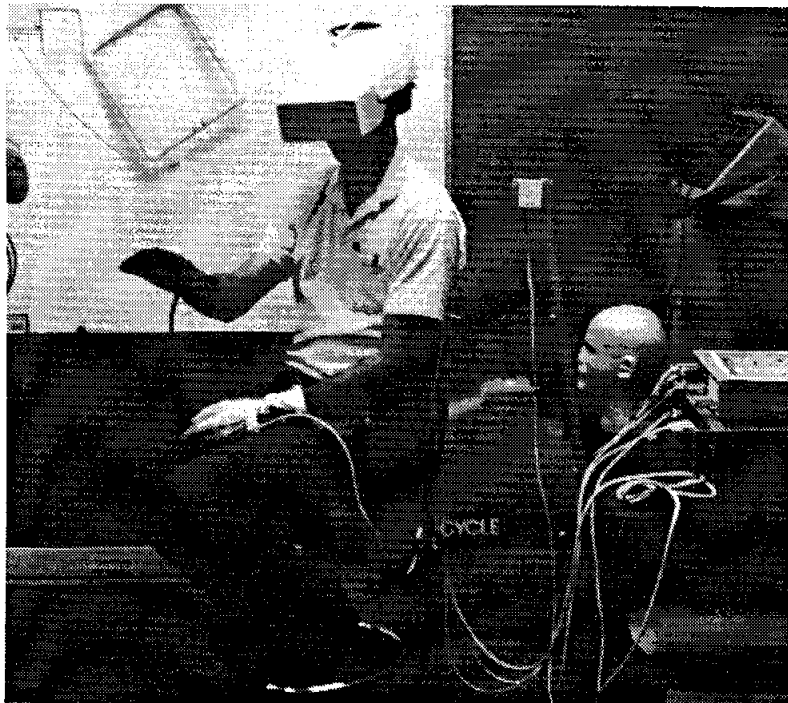
NASA Photo

Astronauts F. Story Musgrave and Jeffrey A. Hoffman rehearse for the Hubble Space Telescope repair mission in the giant pool at the Johnson Space Center's weightless environment training facility. The two are working with a full-scale training version of the wide-field/planetary camera.

tank/shuttle mission simulator tests, and virtual reality/computer simulation were used to practice integrated EVA and shuttle RMS procedures.

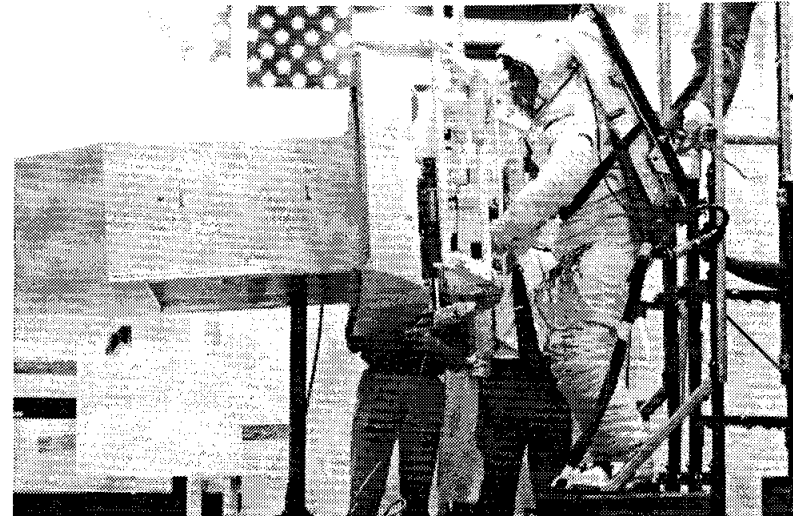
In addition to giving the astronauts experience with large components, the object of the tests was to collect instrumented data for computer analysis and validation, input the results to EVA and RMS flight procedures, and establish safe clearances for fine alignment of components.

NASA's Automation and Robotics Division at JSC has been developing a telerobotics, telepresence, and virtual reality (VR)



NASA Photo

Astronaut Jeffrey Hoffman is one of the STS-61 crew members using a new training aid called virtual reality to help refine positioning patterns for the shuttle's robotic arm when it is near the Hubble Space Telescope.



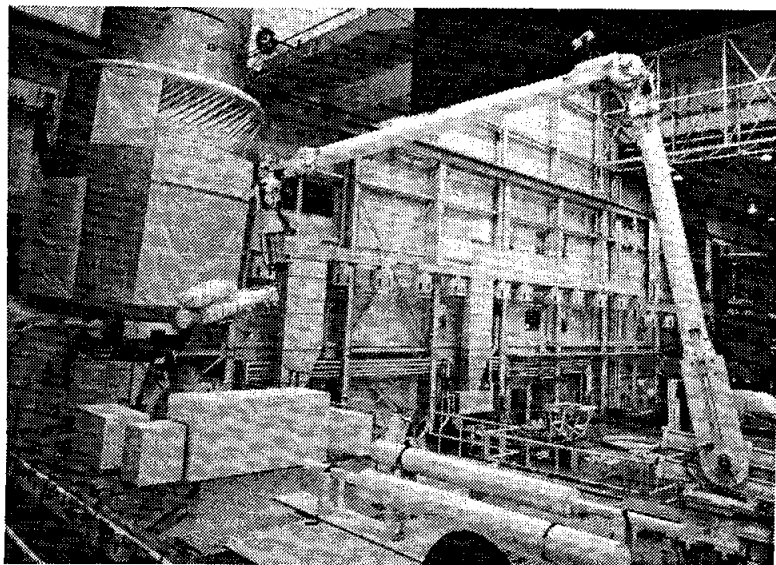
NASA Photo

Making use of the air-bearing floor in Johnson Space Center's shuttle mockup and integration laboratory, astronaut Jeffrey A. Hoffman practices working with the Hubble Space Telescope's wide-field planetary camera. Changing out the large camera is one of several chores to be performed by Hoffman and three other mission specialists.

architecture to control dexterous robotic devices during space missions. The division, which can link multiple simulations and people in a virtual environment, developed the prototype system to familiarize and train the crew for Hubble repair EVA and RMS operations.

That system applies current computer graphics with VR technology to simulate integrated tasks involving EVA crew members and the RMS operator and to tie together the training activities at a variety of facilities. In VR practice sessions, the RMS operator and the EVA astronaut standing on the end of the arm work out sets of verbal commands that they both agree to and understand.

The simulated RMS is a kinematic representation that uses the actual flight control algorithms to operate the arm. The arm is maneuvered by inputs from hand controllers and instruments on a



NASA Photo

An STS-61 mission specialist uses the training version of the shuttle's remote manipulator system to ease a space-suited mannequin into position for a Hubble Space Telescope servicing task in the space shuttle mockup and integration laboratory at the Johnson Space Center.

graphic depiction of the real on-board control panel. The operator sees changing "out of the window" scenes, simulated payload bay and RMS camera views, and overall configuration views, which include the movements of EVA crew members.

The EVA simulation is driven by the head and hand movements of the crew members practicing in the virtual environment. In a helmet-mounted display, the EVA astronaut sees a computer-generated stereo view of the surrounding environment. A number of sources supply inputs for the motion of objects in the scene: sensed head and hand motions of the EVA participants, RMS motion produced by the mechanical arm simulation, and the movement of mechanisms, doors, the flight support structure, etc., produced by integrated external simulations.

Contact, e.g., the EVA astronaut's hand touching a rail or other object in the scene, is based on collision detection routines that compare the graphic model database with graphic models of the EVA gloves. Color changes in the helmet-mounted display indicate the contact to the EVA trainee.

HUBBLE SPACE TELESCOPE TOOLS AND CREW AIDS

The crew of STS-61 has more than 200 tools and crew aids for servicing the Hubble Space Telescope. These tools and aids, known as space support equipment hardware, range from a simple bag for carrying some of the smaller tools to sophisticated, battery-operated power equipment. Tools and crew aids are provided by the Johnson Space Center, Houston, and the Goddard Space Flight Center, Greenbelt, Md.

Crew aids are items that are fixed in place and portable equipment that crew members use to accomplish servicing mission tasks. Crew aids permit the crew members to maneuver safely or restrain themselves, transfer orbital replacement units (ORUs) and other portable items, protect equipment and themselves during changeout activities, and temporarily stow or tether equipment during spacewalks.

Examples of crew aids are handrails, handholds, translation devices, transfer equipment, protective covers, tethering devices, grapple fixtures, foot restraint sockets, and stowage and parking fixtures.

Tools are devices that allow the EVA astronauts to increase their efficiency while performing intricate, labor-intensive tasks.

The tools and crew aids will be stowed on or in the solar array carrier, orbital replacement unit carrier, flight support system, tool box, sidewall-mounted adapter plates, provisions stowage assembly, an adaptive payload carrier, middeck lockers, aft flight deck, and airlock.

General tools and crew aids, which have a wide variety of uses, include the power ratchet tool, multisetting torque limiter, adjustable extension with 7/16-inch sockets, ingress aids, portable work-light receptacle, and a locking connector tool. Other general items with more specific uses are a low-gain antenna cover, umbilical connector covers, a flight support system, berthing and positioning system, support post, and a multilayer insulation repair kit.

Items that will be used for the changeout of the wide-field/planetary camera are the WF/PC handholds, WF/PC guide studs, quick-release zip nuts, WF/PC pickoff mirror cover, forward fixture, aft fixture, and the Hubble radial bay cover.

Tools and aids that will be used to replace the high-speed photometer with the corrective optics space telescope axial replacement are the COSTAR contamination cover, a COSTAR handling aid, an HSP handling aid, forward fixture, aft fixture, and an axial science instrument protective enclosure (SIPE) safety bar.

To replace the solar arrays, the astronauts will use articulating foot restraints, solar array primary drive mechanism handles, solar array temporary stowage brackets, solar array transfer handles, a solar array jettison handle, solar array spines, a portable flight release grapple fixture, and a Marmon clamp.

For the changeout of the gyro rate sensor units, crew members will use a portable foot restraint socket converter (90 degrees), fixed-head star tracker light shade covers, and a fixed-head star tracker delta plate cover.

Portable Foot Restraint

Two Hubble Space Telescope portable foot restraints were built for use on the STS-61 mission. These restraints will be used by the spacewalking astronauts during the five extravehicular activities to provide a stable platform from which to work. Both restraints are

stowed in the payload bay, one on the left side and the other on the flight support system.

Tool Box

The tool box is designed for stowing individual tools, tool boards, and tool caddies that will be used throughout the mission. The box is mounted on the right side of the payload bay. Each tool inside the box is stowed in a specific location with markings to help the astronauts retrieve and stow them.

Power Ratchet Tool

The Goddard-provided power ratchet tool is powered by a 28-volt battery. Made of titanium and aluminum, the 17-inch tool will be used for tasks requiring controlled torque, speed, or turns and can be used where right-angle access is required. It will provide 25 foot-pounds of pressure in the motorized mode and 75 foot-pounds of pressure in the manual mode. It has a speed of 10 to 30 rpm. A spare power ratchet will be carried on the mission, as will spares for all other tools to be used by the astronauts.

Mini-Power Tool

The mini-power tool is a battery-operated screwdriver that can be used when a larger power tool is not required and when work space is limited. It can be used as a power tool or manual tool. With the power off, the output shaft is locked automatically for use as a manual driver.

Multisetting Torque Limiter

This tool is used to avoid damaging hardware due to the application of torque that may exceed the design limits. Multisetting torque limiters are used in conjunction with the power tools or hand tools that interface with bolts and latches on the telescope.

Adjustable Extensions

Several extensions were designed to be adjustable to ease the movement of the astronauts and reduce the time required for tool changeouts. One of the extensions is adjustable from 12 to 16.5 inches and replaces several fixed-length extensions. Another is adjustable from 15 to 24 inches. These extensions also reduce the potential for damaging other hardware because they can be retracted when they are not being used.

SERVICING MISSION ORBITAL VERIFICATION

NASA will not be able to tell immediately whether the Hubble Space Telescope has been fixed. Verification that the telescope is working properly is a very detailed process that will take as long as 13 weeks for some instruments.

The purpose of the servicing mission orbital verification is to "recommission" the Hubble Space Telescope so that it can begin science operations as soon as possible following the servicing mission. This involves a thorough engineering checkout of all serviced subsystems, optical alignment and initial calibration of all science instruments, and the phasing in of astronomical observations. Orbital verification will begin when the telescope is released from the Shuttle.

Key activities during the orbital verification are as follows:

- Activation and engineering checkout of the science instruments
- Optical alignment and focusing of WF/PC-II and the COSTAR
- Initial calibration of WF/PC-II and the COSTAR-corrected science instruments
- Early science observations

The following engineering checkout activities are planned:

- Decontaminate the WF/PC-II detectors (charge-coupled devices) of any foreign substances by heating the detectors to "drive off" contaminants
- Establish the proper operating temperature of the WF/PC-II CCDs by monitoring ultraviolet light from a calibration star
- Monitor pressure drop (due to outgassing) until it is safe to turn on high voltage to the COSTAR-corrected science instruments
- Determine the effects of the servicing mission on the basic (pre-COSTAR) optical performance of the science instruments

The steps in focusing the scientific instruments are as follows:

- Check out the first-generation instruments and conduct pre-focusing tests
- Adjust the secondary mirror in the optical telescope assembly to set the focus of the WF/PC-II and correct for residual coma in the optical telescope assembly
- Deploy COSTAR arms
- Adjust COSTAR and WF/PC-II optics and mirrors, including mirror tilt, coarse adjustment, fine alignment, and focus

The scientific instruments will be calibrated by performing a series of tests and measurements to establish the actual performance of the instruments in the areas of sensitivity, resolution, and detector response characteristics.

It will take seven weeks to focus and align the wide-field/planetary camera and 10 weeks to focus and align the train of corrected optics in the corrective optics for the faint-object camera. Then the telescope will be able to produce acceptable images.

When the alignment of the corrective optics for the faint-object spectrograph has been completed, between nine and 13 weeks after the servicing mission, astronomers will know if they have fixed the telescope.

The new wide-field/planetary camera and the corrective optics for the faint-object camera, faint-object spectrograph, and high-resolution spectrograph contain mechanisms that tilt and move some of their mirrors so that light entering the telescope is oriented precisely and focused on the corrective optical surfaces. In order to correct for the spherical aberration in the 7.8-foot primary mirror, images from the mirror must be precisely aligned and focused onto optical sur-

faces in the WF/PC and COSTAR that are as small as a dime and no bigger than a quarter. It is a time-consuming process to achieve this precise alignment, a process that involves collecting and analyzing sequences of images that are purposely out of focus, calculating the best positions of the mirrors, and repeating the procedure to refine the trial positions.

During the alignment and focusing, the telescope will still be scientifically productive. Scientific data will continue to be taken by the telescope as it has in the past three years, and as soon as the corrective optics are aligned on one of the instruments, that instrument will begin to collect data.

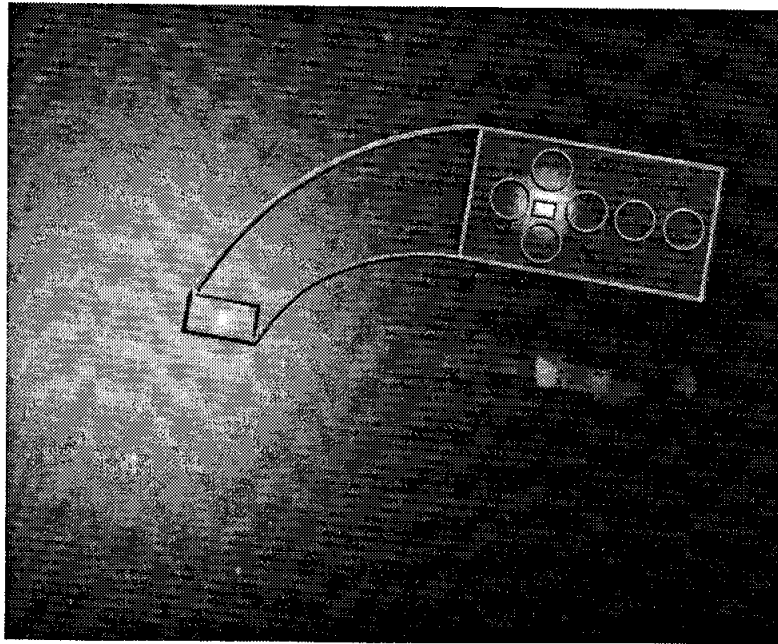
HUBBLE SPACE TELESCOPE PRODUCES AMAZING 3-YEAR HARVEST DESPITE FLAW

Despite the disappointing distortion in the Hubble Space Telescope's primary mirror, the telescope has been providing a steady flow of unparalleled observations of planets, stars, and galaxies over the last three years because of the quality of the telescope and the skill of astronomers.

One of the main areas of concentration of the telescope has been our solar system because the planets are near and bright, which makes their images ideal for computer enhancement. Hubble took more than 100 photos of unprecedented sharpness of a gigantic tornado on Saturn. Similar long-term observations of Mars and Jupiter may increase astronomers' understanding of the origins of the major storms on Mars and the Great Red Spot in Jupiter's atmosphere.

Hubble also provided astronomers with the latest breakthrough in understanding the solar system with the first images of Pluto, the farthest planet from the sun, and its moon Charon that clearly distinguish the neighboring bodies. What is more, astronomers have been able to estimate the weight of the two bodies and found that Pluto has 10 times the mass and twice the density of Charon, strongly indicating that the two had separate origins.

Within our galaxy, the space telescope has focused on the evolution of stars. It has produced images of stars that are less a million years old—very young as stars go. Astronomers studying those images discovered that about 15 of the young stars were surrounded by a cocoon of matter from which they sprang. It is thought that the sun and planets of our solar system originated from just such a cloud



The steady increase in brightness of galaxy M87 toward its center is readily apparent in this Hubble Space Telescope image. The galaxy's stars are strongly concentrated toward its core, as if drawn into the center and held there by the gravitational attraction of a massive black hole. Although it cannot be proved that there is a black hole, spectral measurements taken near the galaxy's core may provide enough evidence to suggest that it does exist. Due to the spherical aberration of the telescope's primary mirror, however, these spectral observations would take so long (hundreds of hours) as to be practically impossible. With corrective optics that compensate for the mirror's flaw, the measurements will only take a matter of hours.

Image: NASA, Tod Lauer, NOAO
Overlay: Faint-Object Spectrograph Team

of gas and dust about 4-1/2 billion years ago. Hubble also discovered young globular star clusters at the core of a peculiar galaxy. The telescope found "blue straggler" stars in the core of globular cluster 47 Tucanae, providing evidence that some stars "capture" others and merge with them.

"The discovery of rings of gas and dust around young stars is very encouraging to astronomers," said Piero Benvenuti, manager of the Hubble Space Telescope project for the European Space Agency. "It suggests that the process by which our solar system was created is a natural phenomenon which could be common throughout the cosmos."

Farther out, Hubble has uncovered circumstantial evidence for the existence of supermassive black holes of more than a million solar masses that are at the centers of galaxies. It has also observed the farthest known galaxy (10 billion light-years away) and the most distant galactic cluster (7 to 10 billion light-years away). Hubble yielded direct evidence of the evolution of galaxies by resolving the shapes of galaxies that existed long ago. It revealed that many ancient spiral galaxies have since disappeared, possibly through fading or collisions and mergers with other galaxies.

The space telescope allowed astronomers to take a major first step in determining the rate at which the universe is expanding. Hubble detected 27 stars called Cepheid variables. These stars are "standard candles" for estimating distances to galaxies. The expansion rate, known as the Hubble constant, is one of two critical numbers needed for making a precise determination of the size, age, and fate of the universe.

Hubble discovered boron, the fifth-lightest element, in a very ancient star. This star would have been one of the earliest formed after the big bang explosion that most scientists believe began the universe. If boron was produced in the first few minutes of the birth of the universe, it implies that the big bang was not a uniform explosion.

Hubble precisely determined the ratio of deuterium to hydrogen in interstellar gas clouds. This value shows that the universe has only 6% of the observable matter required to prevent itself from expanding forever.

Based on its observations of the galaxy known as IC4182, which is about 16 billion light-years away, Hubble has been able to produce a precise cosmic distance scale. It should be able to do the same thing with galaxies that are three times the distance once the primary mirror's flaw is fixed and use these measurements as a baseline for determining the distance to even more remote stars and, ultimately, the age and destiny of the universe.

All of Hubble's accomplishments so far, however, are but a harbinger of what lies ahead. After the telescope is repaired, it may be able to give astronomers their first detailed look at the surface of Pluto, explore the structure of the rings of dust around young stars, detect planetoid bodies in the process of being formed, or finally determine the true dimension of the universe.

Some of the key scientific goals following the first servicing mission are discussed below.

Hubble will determine, precisely, the expansion rate of the universe by measuring the light curve of Cepheid variable stars in galaxies out to a distance of at least 50 million light-years.

Cepheids are pulsating stars that become alternately brighter and fainter. Their periods (the duration of the states of brightness or faintness) range from 10 to 50 days. Astronomers have known for over 50 years that the periods of these stars precisely predict their total luminous power, which allows their distance to be measured.

The age of the universe can be estimated from the Hubble constant. The Hubble constant is the ratio of the recession velocities of galaxies to their distance. (Recession velocity is the speed at which a galaxy is moving away from the Earth.) The age of the uni-

verse currently is estimated to be between 10 and 20 billion years, but a more precise measurement of the Hubble constant is required to narrow this range to an accuracy of 10%.

The Hubble Space Telescope will look for the gravitational signature of massive black holes in the cores of normal and active galaxies. A black hole is a theoretical object that is so compact and dense that nothing can escape its gravitational field. The Hubble spectrographs will measure precisely the velocities of gas and stars orbiting the center of a galaxy. If the stellar velocities increase rapidly toward the galaxy's center, it would be the signature of a massive, compact central object.

Hubble will be able to determine the shapes of very distant galaxies. Because remote objects also are relics of the early universe, the telescope will be able to study how galaxies have evolved since the beginning of the universe. Nearby galaxies have spiral, elliptical, and irregular shapes; however, these shapes should have changed over time because the universe is evolving.

Hubble will be able to precisely measure the ages of globular clusters by observing the faintest stars in the clusters. Globular clusters are considered to be the oldest objects in the universe, and their ages provide insight into how stars evolve and an independent estimate of the age of the universe.

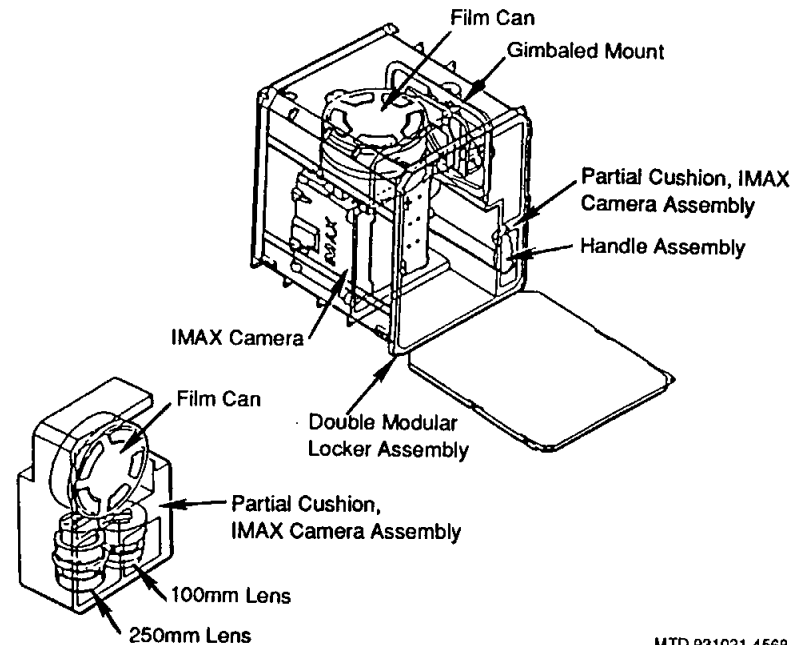
IMAX IN-CABIN AND CARGO BAY CAMERAS

The IMAX project is a collaboration between NASA, the Smithsonian Institution's National Air and Space Museum, IMAX Systems Corp., and the Lockheed Corp. to document significant space activities and promote NASA's educational goals using the IMAX film medium. This system, developed by IMAX Systems Corp. of Toronto, Canada, uses specially designed 70mm cameras and projectors to record and display very high definition color motion pictures which, accompanied by six-channel high-fidelity sound, are displayed on screens in IMAX and OMNIMAX theaters that are up to ten times larger than a conventional screen, producing a feeling of "being there."

IMAX cameras have been flown on space shuttle missions STS 41-C, 41-D, 41-G, -29, -34, -32, -31, -42, -46, and -51 to document crew operations in the payload bay and the orbiter's middeck and flight deck as well as to film spectacular views of space and Earth. Film from those missions was used as the basis for the IMAX productions "The Dream Is Alive" and "The Blue Planet." Two IMAX camera configurations are being flown: the in-cabin and cargo bay cameras.

On STS-61, IMAX will document the Hubble Space Telescope retrieval, repair, and deployment activities. IMAX's secondary objectives are to film Earth views, which may require orbiter pointing. Scene opportunities are provided to the crew both before the flight and in real time. The footage will be used in a new film dealing with our use of space to gain new knowledge of the universe and the future of mankind in space.

The in-cabin system consists of a camera, four lenses, rolls of film, two magazines with film, an emergency speed control, a Sony recorder and associated equipment, two photographic lights, mounting brackets to accommodate the mode of use, two cables, and various supplemental equipment. The camera body is stowed in a



IMAX Camera

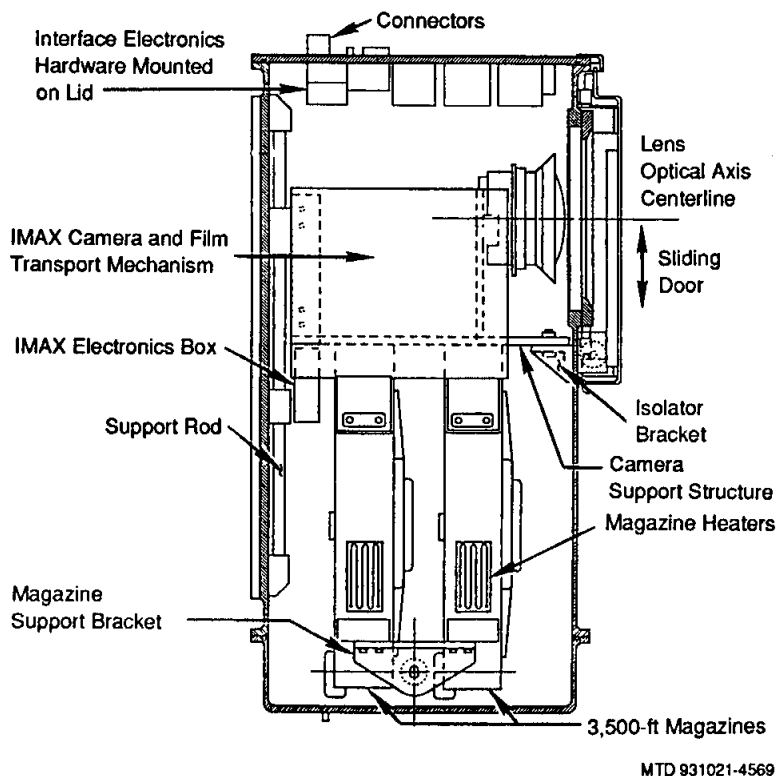
double middeck locker. Two and a half additional lockers are needed for the other IMAX equipment.

The camera may be gimbal-mounted to the orbiter's aft starboard window and both overhead windows. The starboard window is usually the overhead window used. The gimbaled mount is attached to the aft starboard and overhead windows with Velcro. The overhead window uses both the gimbaled mount and the overhead window mount. The overhead window mount utilizes the latches that hold the electromagnetic interference window shields. The gimbaled mount has adjustable motion dampers that allow the

camera to pan and tilt. The overhead window mount bracket is stowed in the window shade bag on the middeck.

The IMAX in-cabin camera uses two interchangeable film magazines which can be reloaded with film. Each magazine runs for approximately three minutes. Lenses are interchanged based on scene requirements. The IMAX will be installed in the orbiter middeck approximately seven days before the launch.

Crew members will load and unload film magazines, mount different lenses, select exposures, and position the camera for the various types of scenes required. Earth scenes are shot with ASA 25



IMAX Camera Container Equipment

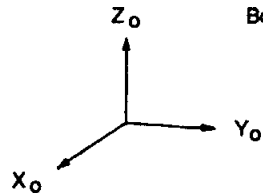
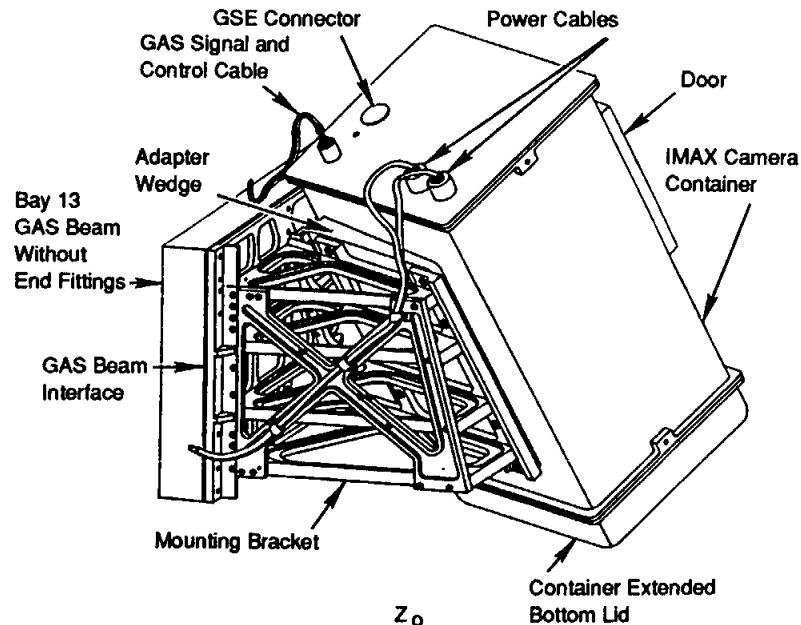
film. The 40mm lens is used for wide-angle views, and the 60mm and 110mm lenses for closer views of specific Earth features. Similarly, activities in the payload bay can be filmed using the 30mm, 40mm, 60mm, and 110mm lenses. In-cabin scenes require ASA 250 film and the 30mm lens. The crew will use additional lights in the middeck and flight deck for interior filming. A stereo cassette sound recorder and two microphones are also used by the crew to record on-orbit activities.

Several other setups are required. Window brackets and shrouds must be mounted to film out the window. Similarly, a handle is available for in-cabin shots with a hand-held camera. The photoflood lights must be set up, and spot meterings must be taken. Power cables must be connected, and any necessary malfunction procedures must be performed.

The ICBC is a 70mm camera system designed for use in the orbiter payload bay. No generic pointing requirements, orbiter maneuvers, or specially staged crew activities are needed to support the main filming objectives of the ICBC.

The ICBC is mounted in a pressure-sealed container on a small payload accommodation getaway special (GAS) beam in the payload bay. The ICBC consists of two main structures: an insulated, pressurized camera container and a mounting bracket. The camera container holds the camera, takeup and delivery reels, camera control electronics, and support hardware. It features a movable lens window cover. The mounting bracket connects the camera container to the GAS beam and orients the camera container for the proper camera field of view. Once mounted for a flight, the camera container position is fixed; no tilt or pan is possible. For STS-61, the container is tilted upward 30 degrees and panned inboard 29.7 degrees; it is mounted in bay 3 (starboard).

For STS-61, the delivery reel is loaded with 3,500 feet of film (nominally), enough for approximately 10-1/2 minutes of filming. The ICBC can also be loaded with a 2,200-foot film magazine. A



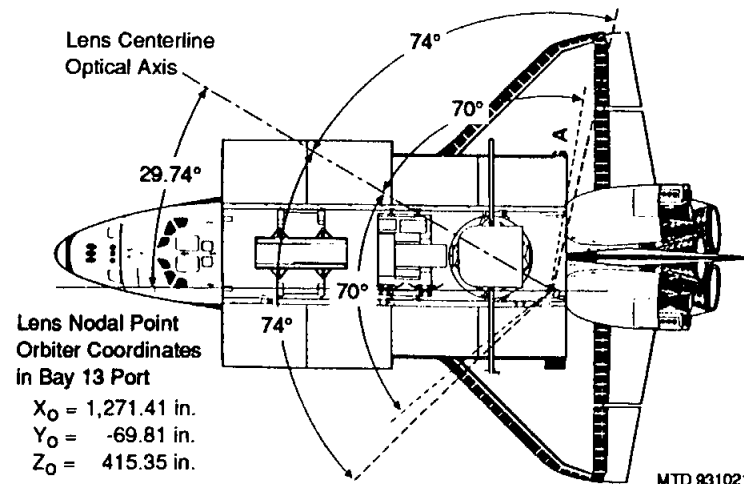
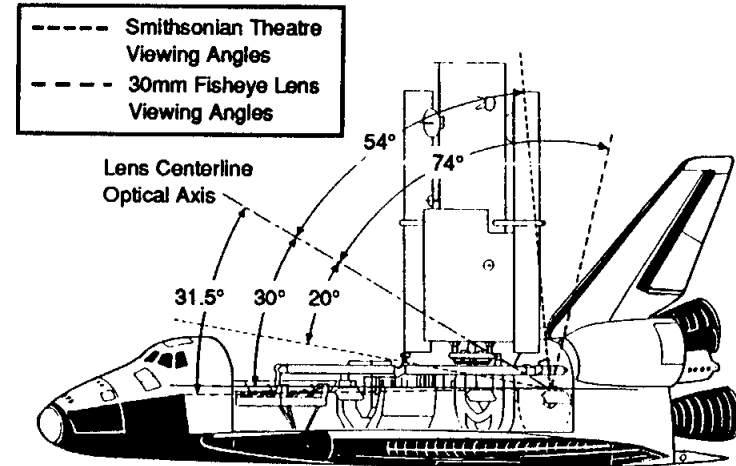
MTD 931021-4580

ICBC General Arrangement

single 30mm wide-angle lens is mounted on the camera; lenses and film cannot be changed during the flight.

The ICBC is controlled from the aft flight deck by the enhanced GAS autonomous payload controller (GAPC). The crew member can command the ICBC to turn main power on, go to a standby mode, adjust f-stop, and film a scene. By using the GAPC, the crew member can also determine the status of the camera, such as the current f-stop and the amount of film exposed. A tape recorder is

also provided for crew documentation. All the GAS hardware, such as the GAS control decoders, status responder units, GAPCs, and the GAS signal and control cable, are owned, serviced, and certified by NASA's Goddard Space Flight Center.



MTD 931021-4583

IMAX Cargo Bay Camera (ICBC) Viewing Angles on STS-61

Scene List for IMAX Cabin Camera

P/TV Scene	Activity	Subject	No. of Shots/Length*	Lens
P/TV04	Preggrapple	HST in distance, Earthlimb in frame, between R bar and V bar	1-30 sec	40mm
P/TV07	EVA 1	RSU replacement		Crew choice
P/TV07	EVA 2	Solar array replacement		Crew choice
P/TV07	EVA 3	WF/PC replacement		Crew choice
P/TV07	EVA 3	Magnetometer replacement, if visible		Crew choice
P/TV07	EVA 4	Install COSTAR		Crew choice
P/TV07	EVA 4	Install coprocessor		Crew choice
P/TV11	EVA 1-5	Suiting up for EVA	2/3-30 sec	30mm
P/TV11	EVA 1-5	Unsuiting after EVA	1/2-30 sec	30mm
P/TV12	EVA 1-5	Cutaways: RMS operator, IV crew, commander, pilot	4-30 sec	30mm
P/TV09	HST release	RMS lifting HST off FSS	1-30 sec	Crew choice
P/TV09	HST release	HST at 200 feet	1-30 sec	100mm
P/TV09	HST release	HST second shot further away without beam splitter	1-30 sec	250mm
P/TV12	Flight deck	Crew celebration	1-30 sec	30mm
P/TV15	Earth observation	Earth views if film left	As available-30 sec	40mm
*Suggested number of shots and lengths in screen time.				

Scene List for IMAX Cargo Bay Camera

P/TV Scene	Activity	Subject	No. of Shots/Length*	Lens
P/TV04	Preggrapple	HST at 100-200 feet (terminator shot; earlier if better Earth shot)	1-30 sec	30mm
P/TV04	Grapple	HST ready for grapple if light permits	As required	30mm
P/TV04	Postgrapple	RMS moves HST towards FSS if light permits	1-30 sec	30mm
P/TV07	EVA 1	105, 106 caps installed; will also see SA deformation	1-30 sec	30mm
P/TV07	WF/PC	FGS scuff plate door opening	1-30 sec	30mm
P/TV06	SA operations	SA deploy if visible, some at 3 fps	2-30 sec	30mm
P/TV09	HST release	Prerelease and release if in light	1-70 sec	30mm
P/TV09	HST release	HST moving away, 50-100 feet	1-30 sec	30mm
P/TV07	HST EVA	EVA targets of opportunity	As available-30 sec	30mm
		High-altitude Earth scenes if film left	As available-30 sec	30mm
*Suggested number of shots and lengths in screen time.				

AIR FORCE MAUI OPTICAL SITE (AMOS) CALIBRATION TEST

The AMOS tests allow ground-based electro-optical sensors located on Mt. Haleakala in Maui, Hawaii, and at Arecibo, Puerto Rico, to collect imagery and/or signature data of the space shuttle orbiters during cooperative overflights. Cooperative overflights are defined as those planned times when AMOS test conditions can be met and the STS mission timeline and propellant budget permit the requested orbiter activities to be performed.

This experiment is a continuation of tests made during the STS-29, -30, -34, -32, -31, -41, -35, -37, -43, -48, -44, -49, -56, -57, and -51 missions. The scientific observations of the orbiters during those missions consisted of reaction control system thruster firings, water dumps, activation of payload bay lights, or the phenomena of "shuttle glow," a well-documented fluorescent effect created as the shuttle interacts with atomic oxygen in Earth orbit. They were used to support the calibration of the AMOS ground-based infrared and optical sensors, using the shuttle as a well-characterized calibration target, and to validate spacecraft contamination models through observations of contamination/exhaust plume phenomenology under a variety of orbiter attitude and lighting conditions.

No unique on-board hardware is associated with the AMOS test. Crew and orbiter participation may be required to establish the controlled conditions for the Maui overflights. AMOS is being flown as a payload of opportunity and will be conducted if crew time permits.

The AMOS facility was developed by the Air Force Systems Command through its Rome Air Development Center at Griffiss Air Force Base, N.Y. It is administered and operated by the AVCO Everett Research Laboratory on Maui. The principal investigators for the AMOS tests on the space shuttle are from AFSC's Air Force Geophysical Laboratory at Hanscom Air Force Base, Mass., and AVCO.

Flight planning and mission support activities for the AMOS test opportunities are performed by a detachment from AFSC's Space Systems Division at the Johnson Space Center in Houston. Flight operations are conducted at the JSC Mission Control Center in coordination with the AMOS facilities.

DEVELOPMENT TEST OBJECTIVES

Ascent wing structural capability evaluation (DTO 301D). The purpose of this DTO is to verify that the orbiter wing structure is at or near its design condition during lift-off and ascent with near-maximum-weight payloads. The DTO will determine flight loads and structural capability and whether any unacceptable dynamic effects exist. This is a data-collection-only test and requires no specific activity other than recording and returning specified data.

Ascent compartment venting evaluation (DTO 305D). This DTO will collect data under operational conditions to validate/upgrade the ascent venting math model and verify the capability of the vent system to maintain compartment pressures within design limits.

Entry compartment venting evaluation (DTO 306). This DTO will collect data under operational conditions to validate/upgrade the descent venting math model and verify the capability of the vent system to maintain compartment pressures within design limits.

Entry structural capability evaluation (DTO 307D). This DTO will collect structure load data for different payload weights and configurations to expand the data base of flight loads during entry, approach, and landing. The data will be used to verify the adequacy of the structure at or near design conditions and to demonstrate structural system operational capability, determine flight loads, and verify the stress/temperature response of critical structural components. This is a data-collection-only test and requires no specific activity other than recording and returning specified data.

ET TPS performance, methods 1, 2, and 3 (DTO 312). This DTO will obtain photographs of the external tank after separation in order to determine TPS charring patterns, identify regions of TPS material spallation, evaluate overall TPS performance, and identify

TPS or other problems that may be sources of debris that could damage the orbiter. The cameras are located in the orbiter umbilical well and in the flight deck. Method 1 requires an ARCS +X maneuver, and methods 2 and 3 require a +pitch maneuver.

Orbiter drag chute system (DTO 521). This DTO will evaluate the orbiter drag chute system's performance through a series of landings with increasing deployment speeds. The DTO will be performed on vehicles equipped to measure drag forces imposed by the drag chute system. This DTO has two phases. Phase I consisted of two flights, with the first-flight drag chute deployment at nose gear touchdown (STS-49) and the second at initiation of derotation. Now that Phase I testing is complete, the drag chute is cleared for deployment under the same conditions for subsequent missions. Phase II consists of seven flights with deployment at gradually increasing speeds, from initiation at derotation of 185 knots equivalent air speed (KEAS) to initiation at 205 KEAS, and will use concrete runways whenever possible.

Electronic still camera photography test (with downlink) (DTO 648). Electronic still photography is a new technology that consists of using a hand-held camera to electronically capture and digitize an image with resolution approaching film quality. The digital image is stored on disks and can be converted to a format suitable for downlink transmission or enhanced using image-processing software. The ability to enhance and/or downlink high-resolution images in real time will greatly improve Earth observation. The objective of this DTO is to determine camera response to the photographic conditions encountered on orbit with a variety of lenses and camera settings. The electronic still camera was specifically manifested on STS-61 to support HST photography documentation requirements.

PGSC single-event upset monitoring (DTO 656). This DTO will evaluate the payload and general-support computer's random-

access susceptibility to single-event upset caused by cosmic radiation. This information could lead to improved procedures, hardware, or software to reduce radiation effects. This DTO will run continuously once initiated on the PGSC and will be interrupted only if the crew needs to use the PGSC for PADM operations.

Portable in-flight landing operations trainer (DTO 667). One of the challenges to flying longer-duration shuttle missions is that orbiter landing tasks require a high level of skill and proficiency but data shows that pilots' landing skills degrade when they have been away from a landing trainer, such as the shuttle training aircraft, for extended periods. The purpose of this DTO is to verify that the portable in-flight landing operations trainer (PILOT) simulator will assist the shuttle commander and pilot in maintaining the highest possible level of proficiency for the end-of-mission approach and landing task on extended-duration orbiter (EDO) flights. PILOT is an on-orbit trainer/simulator that strongly reinforces visual cues over the temporal, proprioceptive, and otolithic cues. It also gives the commander and pilot a tool for combatting degradation of motor skills used in landing while demonstrating the ability of current technology to provide a useful, portable in-flight landing simulator.

This DTO consists of a laptop PC with landing software transferred from the shuttle engineering simulator software used to validate Shuttle flight software and a spare rotational hand controller (essentially a landing simulator). PILOT is stowed in lockers on the flight deck and middeck. When a member of the crew wishes to use the system, the workstation is mounted on a console directly in front of the pilot's seat on the flight deck and the PILOT system hand controller is attached to the orbiter's hand controller. The commander and pilot will participate in this DTO on the day before entry only. The PILOT system may be integrated into the standard training activities of all shuttle crews at JSC.

This is the second flight of PILOT. Complete evaluation and refinement of PILOT require six EDO flights.

Laser range and range rate device (DTO 700-2). The laser range and range rate DTO will demonstrate the capability to provide the orbiter flight crew with range and range rate data for rendezvous, proximity operations, and deployment operations. The major objective is to show that a hand-held laser can provide accurate and reliable range and range rate information, even if the target does not have a laser reflector. The DTO will assess the best means of displaying the data, addressing location as well as update frequency. The equipment will be checked out on flight day 3 when the crew transitions to the rendezvous checklist.

Global Positioning System (GPS) development flight test (DTO 700-8). This DTO will demonstrate the performance and operation of the GPS during orbiter ascent, on-orbit, entry, and landing phases using a modified military GPS receiver processor and the existing orbiter GPS antennas. GPS will estimate the position, velocity, measurement discreets, and attitude data during ascent and entry phases. This is the first flight of this DTO.

Waste and supply water dump at 10.2 psia (DTO 1211). The purpose of this test is to determine if the orbiter waste and supply water dumps can be successfully accomplished at 10.2 psia. This DTO will help validate the space station overboard water dump nozzle, which is similar in design to the orbiter water dump nozzle. The space station dump nozzle is designed to operate at an ambient pressure of 10.2 psia. The DTO requires the use of the RMS to view the serial waste and supply water dumps. DTO 1211 is a low-priority flight objective that will not be performed until the Hubble Space Telescope has been released.

DETAILED SUPPLEMENTARY OBJECTIVES

Window impact observations (target of opportunity) (DSO 326). This DSO is designed to link window damage found during orbiter turnaround processing to mission time, attitude, and altitude. This data will aid significantly in the effort to identify the sources of this damage. The crew will check the windows every morning and evening for new abrasions and will record their findings in a log. This DSO is a target of opportunity. It is called out as an EZ activity on flight days 1 and 11. The crew will make other observations if time is available.

In-flight radiation dose distribution (TEPC only) (DSO 469). This DSO will provide data to establish, evaluate, and verify analytical and measurement methods for assessing and managing health risks from exposure to space radiation. This DSO will measure the radiation environment inside the shuttle at a thinly shielded region: the dosimetry 2 location on the right middeck wall.

Back pain pattern in microgravity (DSO 483). This study will collect information about the back pain pattern and height changes experienced by 30 astronauts during flight on missions of at least eight days. All crew members are participating in this DSO, which requires each crew member to record height measurements and log back pain symptoms daily. This DSO will not be performed on EVA days.

Inter-Mars tissue equivalent proportional counter (ITEPC) (DSO 485). The purpose of this DSO is to demonstrate the ability of hardware to withstand the radiation environment of space flight in

preparation for the Mars '94 mission and to demonstrate the expanded capability of experiment software over the previously flown middeck TEPC. In addition, the experiment will gather key data on the radiation environment for future EVA and single-event upset data that affect the orbiter's hardware. This experiment will be flown on an adaptive payload carrier and is mounted on the starboard side of bay 2. It consists of a spectrometer, radiation detector, and support electronics. The equipment is activated by the crew after orbital insertion and deactivated during deorbit preparations.

Immunological assessment of crew members (DSO 487). This DSO will examine the mechanisms of space flight-induced alterations in human immune function. As shuttle mission durations increase, the potential for crew members to develop infectious illnesses during flight also increases. This investigation will assess immune system function using the immune cells from the standard flight medicine blood draw. There are no on-orbit crew activities associated with this DSO.

EVA dosimetry evaluation (DSO 489*). The current location of the crew passive dosimeter (CPD) in the EMU may be shielded by the upper torso of the liquid cooling garment and not give accurate exposure measurements. For this investigation, dosimeters will be placed in other areas of the body to determine the reliability of the CPD measurements. The placement of these dosimeters will be referenced from the EVA prep procedure in the EVA checklist. Verification of or improvements to the current EVA radiation exposure measurement system will improve the radiation cancer risk calcula-

*EDO buildup—medical evaluation DSO

tions for the shuttle and space station programs and, therefore, contribute to the increased safety of astronauts.

Visual-vestibular integration as a function of adaptation (DSO 604*). The objective of this DSO is to investigate visual-vestibular and perceptual adaptive responses as a function of mission duration. The operational impact of these responses on the crew members' ability to conduct entry, landing, and egress procedures will also be investigated. These data will be used to develop training and/or countermeasures to assure the safety and success of extended missions by promoting optimal neurosensory function needed for entry, landing, and emergency egress. The crew will perform investigation OI-3 before and after flight only.

Cardiovascular responses to submaximal exercise (DSO 624*). This DSO will help evaluate the changes in aerobic capacity using submaximal exercise testing to correlate preflight and in-flight crew activity with postflight aerobic performance. The DSO will assist in the development of optimal exercise prescriptions as countermeasures to prevent decrements in the nominal cardiorespiratory response. The crew will wear a heart watch during exercise. Crew members participating in this DSO will maintain an exercise log.

Cardiovascular and cerebrovascular responses to standing before and after space flight (DSO 626*). This DSO will characterize the integrated response of the arterial pressure control system to standing before and after space flight. There are no on-orbit crew activities associated with this DSO.

Documentary television (DSO 901). The purpose of DSO 901 is to provide live television transmission or VTR dumps of crew activities and spacecraft functions, such as payload bay views, STS and payload crew activities, in-flight crew press conference, orbiter operations, payload deployment/retrieval and operations, Earth views, rendezvous and proximity operations, and unscheduled activities. Telecasts are planned for communication periods with seven or more minutes of uninterrupted viewing time. The broadcast is accomplished using operational air-to-ground and/or operational intercom audio. VTR recording may be used when live television is not possible.

Documentary motion picture photography (DSO 902). This DSO requires documentary and public affairs motion picture photography of significant activities that best depict the basic capabilities of the space shuttle and key flight objectives. This DSO includes photography of payload bay activities, flight deck activities, mid-deck activities, and other unscheduled activities. This photography provides a historical record of the flight as well as material for release to the news media, independent publishers, and film producers.

Documentary still photography (DSO 903). This DSO requires still photography of crew activities in the orbiter and payload bay and mission-related scenes of general public and historical interest. Still photographs of exterior and interior scenes will be taken in 70mm and 35mm formats, respectively.