The Hubble Space Telescope (HST) has three interacting systems:

- The Support Systems Module (SSM), an outer structure that houses the other systems and provides services such as electrical power, data communications, and pointing control and maneuvering
- The Optical Telescope Assembly (OTA), which collects and concentrates the incoming light in the focal plane for use by the science instruments
- Eight major science instruments, four housed in an aft section focal plane structure (FPS) and four placed along the circumference of the spacecraft. With the exception of the Fine Guidance Sensors (FGS), the Science Instrument Control and Data Handling (SI C&DH) unit controls all.

Additional systems that also support HST operations include two Solar Arrays (SA). These generate electrical power and charge onboard batteries and communications antennas to receive commands and send telemetry data from the HST. Figure 5-1 shows the HST configuration.

The Telescope performs much like a ground observatory. The SSM is designed to support functions required by any ground astronomical observatory. It provides power, points the Telescope, and communicates with the OTA, SI C&DH unit, and instruments to ready an observation. Light from an observed target passes through the Telescope and into one or more of the science instruments, where the light is recorded. This information goes to onboard computers for processing, and then it is either temporarily stored or sent to Earth in real time, via the spacecraft communication system.

The Telescope completes one orbit every 97 minutes and maintains its orbital position along

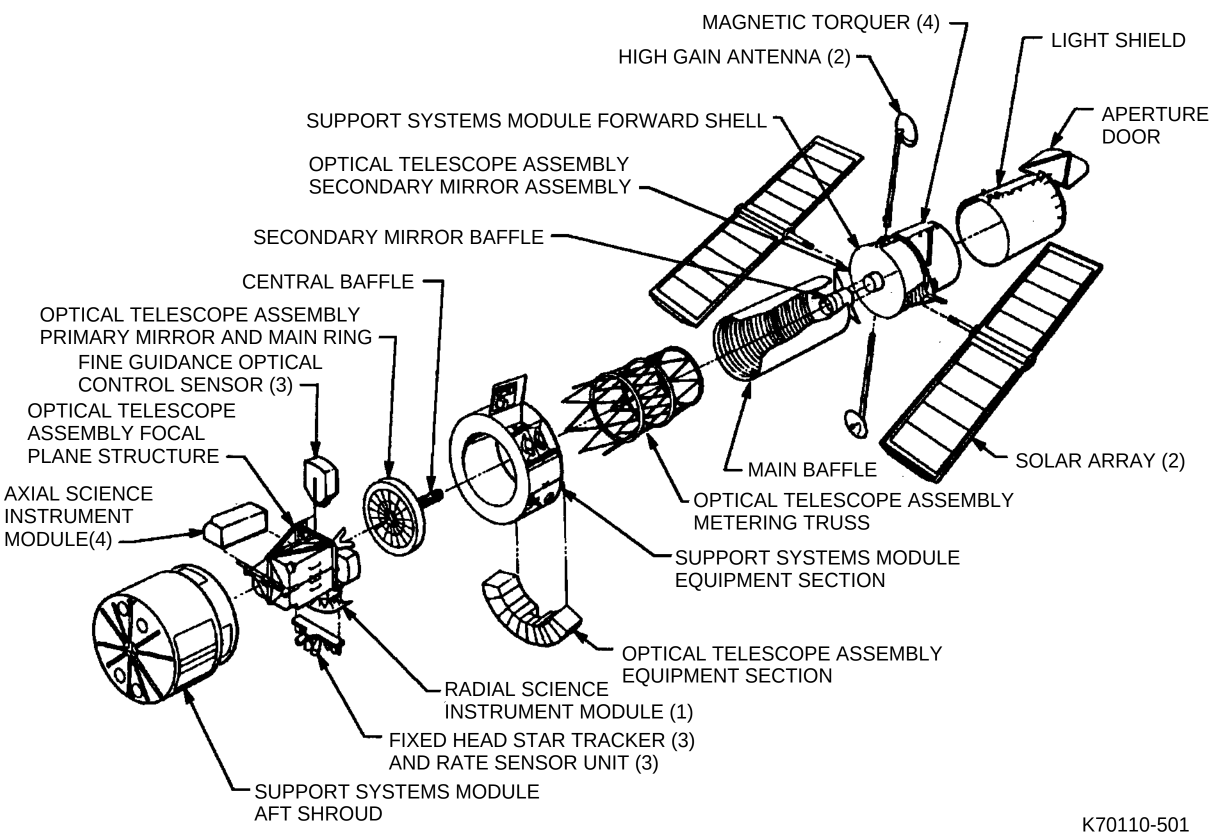

Fig. 5-1 Hubble Space Telescope – exploded view

three axial planes. The primary axis, V1, runs through the center of the Telescope. The other two axes parallel the SA masts (V2) and the High Gain Antenna (HGA) masts (V3) (see Fig. 5-2). The Telescope points and maneuvers to new targets by rotating about its body axes. Pointing instruments use references to these axes to aim at a target in space, position the SA, or change Telescope orientation in orbit.

5.1 Support Systems Module

The design features of the SSM include:

- An outer structure of interlocking shells
- Reaction wheels and magnetic torquers to maneuver, orient, and attitude stabilize the Telescope
- Two SAs to generate electrical power
- Communication antennas
- A ring of Equipment Section bays that contain electronic components, such as batteries, and communications equipment. (Additional bays are provided on the +V3 side of the spacecraft to house OTA electronics as described in para 5.2.4.)
- Computers to operate the spacecraft systems and handle data

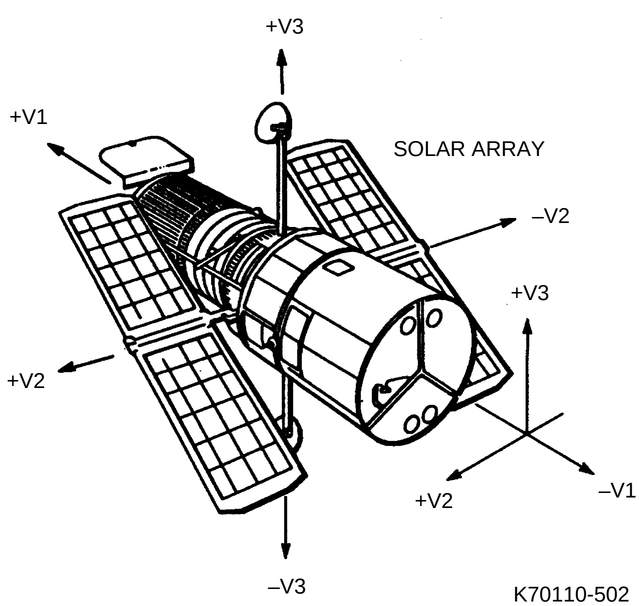

Fig. 5-2 Hubble Space Telescope axes

- Reflective surfaces and heaters for thermal protection
- Outer doors, latches, handrails, and footholds designed for astronaut use during on-orbit maintenance.

Figure 5-3 shows some of these features.

Major component subsystems of the SSM are:

- Structures and mechanisms
- Instrumentation and communications
- Data management
- Pointing control
- Electrical power
- Thermal control
- Safing (contingency) system.

5.1.1 Structures and Mechanisms Subsystem

The outer structure of the SSM consists of stacked cylinders, with the aperture door on top and the aft bulkhead at the bottom. Fitting together are the light shield, the forward shell, the SSM Equipment Section, and the aft shroud/bulkhead – all designed and built by Lockheed Martin Missiles & Space (see Fig. 5-4).

Aperture Door. The aperture door, approximately 10-ft (3 m) in diameter, covers the opening to the Telescope's light shield. The door is made from honeycombed aluminum sheets. The outside is covered with solar-reflecting material, and the inside is painted black to absorb stray light.

The door opens a maximum of 105 degrees from the closed position. The Telescope aperture allows for a 50-degree field of view (FOV) centered on the +V1 axis. Sun-avoidance sensors provide ample warning to automatically close the door before sunlight can damage the Telescope's optics. The door begins closing

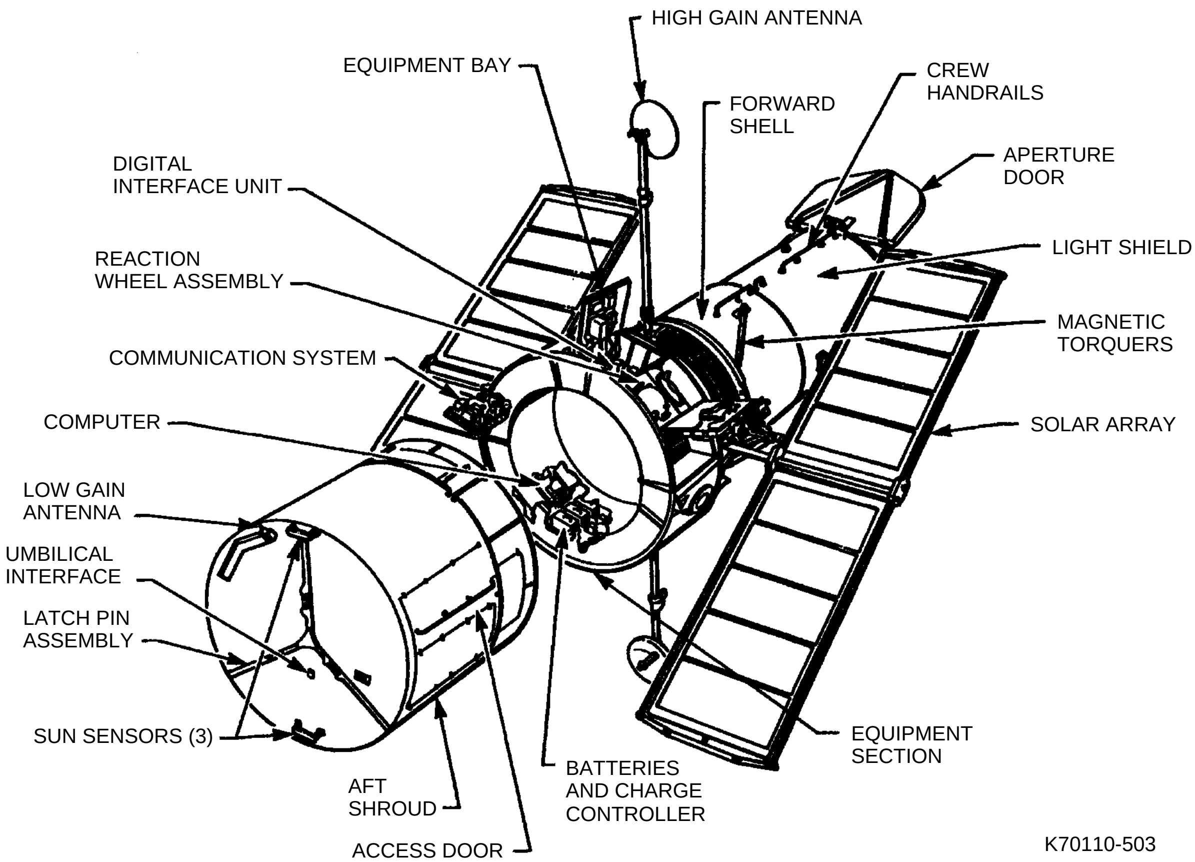

Fig. 5-3 Design features of Support Systems Module

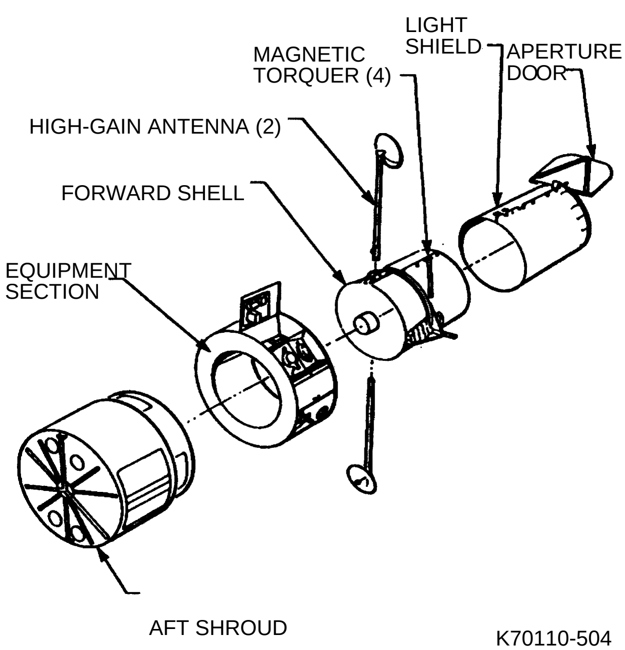

Fig. 5-4 Structural components of Support Systems Module

when the sun is within ±35 degrees of the +V1 axis and is closed by the time the sun reaches 20 degrees of +V1. This takes no more than 60 seconds.

The Space Telescope Operations Control Center (STOCC) can override the protective door-closing mechanism for observations that fall within the 20-degree limit. An example is observing a bright object, using the dark limb (edge) of the Moon to partially block the light.

Light Shield. The light shield (see Fig. 5-4) blocks out stray light. It connects to both the aperture door and the forward shell. On the outer skin of the Telescope on opposite sides are latches to secure the SAs and HGAs when they are stowed. Near the SA latches are scuff plates, large protective metal plates on struts that extend approximately 30 in. from the surface of the spacecraft. Trunnions lock the Telescope into the Shuttle cargo bay by hooking to latches in the bay. The light shield supports the forward Low Gain Antenna (LGA) and its communications waveguide, two magnetometers, and two sun sensors. Handrails encircle the light shield, and built-in foot restraints support the astronauts working on the Telescope.

Figure 5-5 shows the aperture door and light shield. The shield is 13-ft (4 m) long, with an internal diameter of 10-ft (3 m). It is machined from magnesium, with a stiffened, corrugated-skin barrel covered by a thermal blanket. Internally the shield has 10 light baffles, painted flat black to suppress stray light.

Forward Shell. The forward shell, or central section of the structure, houses the OTA main baffle and the secondary mirror (see Fig. 5-6). When stowed, the SAs and HGAs are latched flat against the forward shell and light shield. Four magnetic torquers are placed 90 degrees apart around the circumference of the forward shell. The outer skin has two grapple fixtures next to the HGA drives, where the Shuttle's Remote Manipulator System can attach to the Telescope. The forward shell also has handholds, footholds, and a trunnion, which is used to lock the Telescope into the Shuttle cargo bay.

The forward shell is 13-ft (4 m) long and 10-ft (3 m) in diameter. It is machined from aluminum plating, with external reinforcing rings and internal stiffened panels. The rings are on the outside to ensure clearance for the OTA inside. Thermal blankets cover the exterior.

Equipment Section. This section is a ring of storage bays encircling the SSM. It contains about 90 percent of the electronic components that run the spacecraft, including equipment serviced during extravehicular activities (EVA) by Space Shuttle astronauts.

The Equipment Section is a doughnut-shaped barrel that fits between the forward shell and aft shroud. This section contains 10 bays for equipment and two bays to support aft trunnion pins and scuff plates. As shown in Fig. 5-7,

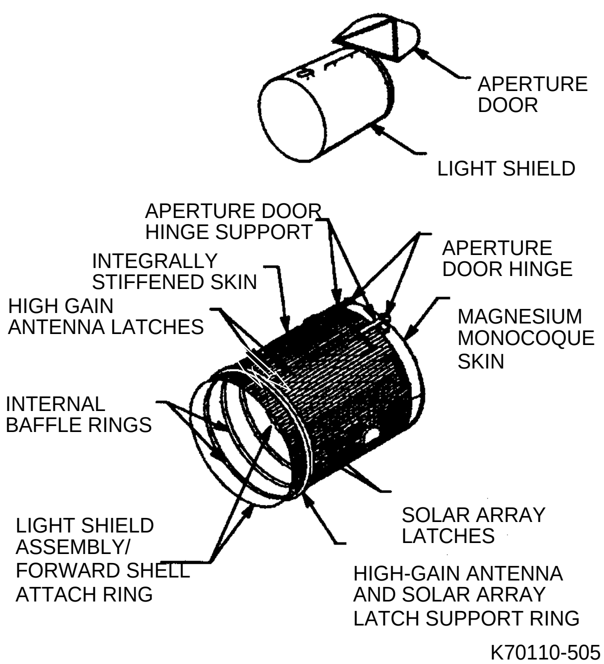

Fig. 5-5 Aperture door and light shield

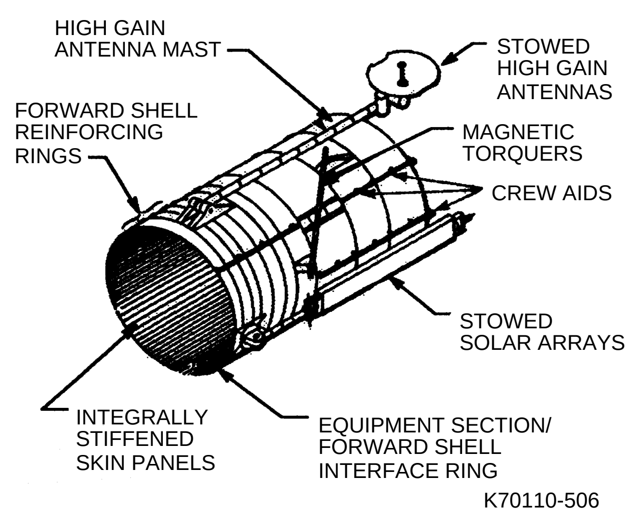

Fig. 5-6 Support Systems Module forward shell

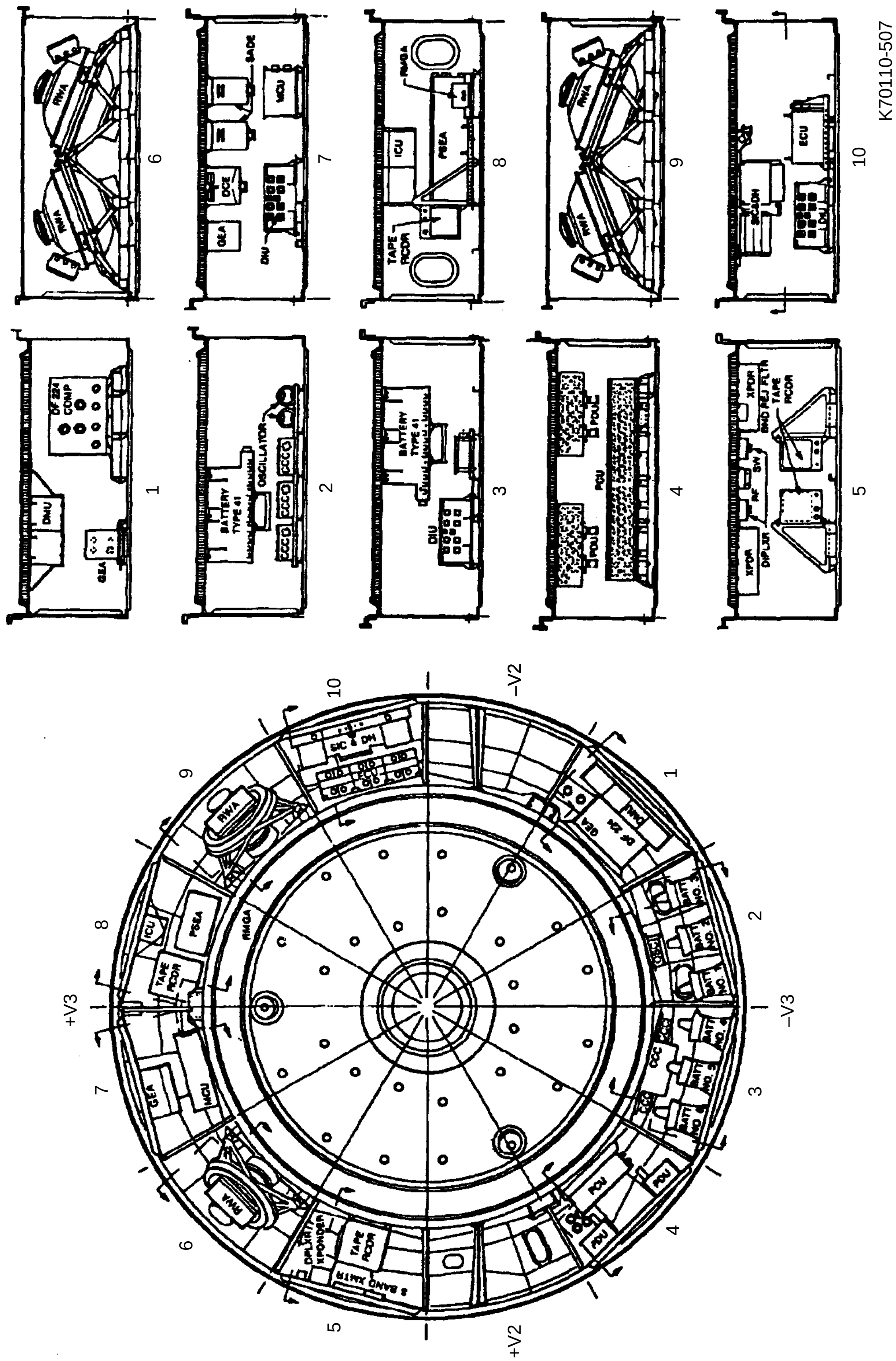

Fig. 5-7 Support Systems Module Equipment Section bays and contents

going clockwise from the +V3 (top) position, the bays contain:

1. Bay 8 – pointing control hardware
2. Bay 9 – Reaction Wheel Assembly (RWA)
3. Bay 10 – SI C&DH unit
4. Unnumbered trunnion support bay
5. Bay 1 – data management hardware
6. Bay 2 through Bay 4 – electrical power equipment
7. Unnumbered trunnion support bay
8. Bay 5 – communication hardware
9. Bay 6 – RWA
10. Bay 7 – mechanism control hardware.

The cross section of the bays is shaped like a trapezoid, with the outer diameter (the door) – 3.6-ft (1 m) – greater than the inner diameter – 2.6-ft (0.78 m). The bays are 4-ft (1.2 m) wide and 5-ft (1.5 m) deep. The Equipment Section is constructed of machined and stiffened aluminum frame panels attached to an inner aluminum barrel. Eight bays have flat honeycombed aluminum doors mounted with equipment. In Bays 6 and 9, thermal-stiffened panel doors cover the reaction wheels. A forward frame panel and aft bulkhead enclose the SSM Equipment Section. Six mounts on the inside of the bulkhead hold the OTA.

Aft Shroud and Bulkhead. The aft shroud (see Fig. 5-8) houses the FPS containing the axial science instruments. It is also the location of the Corrective Optics Space Telescope Axial Replacement (COSTAR) unit.

The three FGSs and the Wide Field and Planetary Camera 2 (WFPC2) are housed radially near the connecting point between the aft shroud and SSM Equipment Section. Doors on the outside of the shroud allow shuttle astronauts to remove and change equipment and instruments easily. Handrails and foot restraints for the crew run along the length and circumference of the

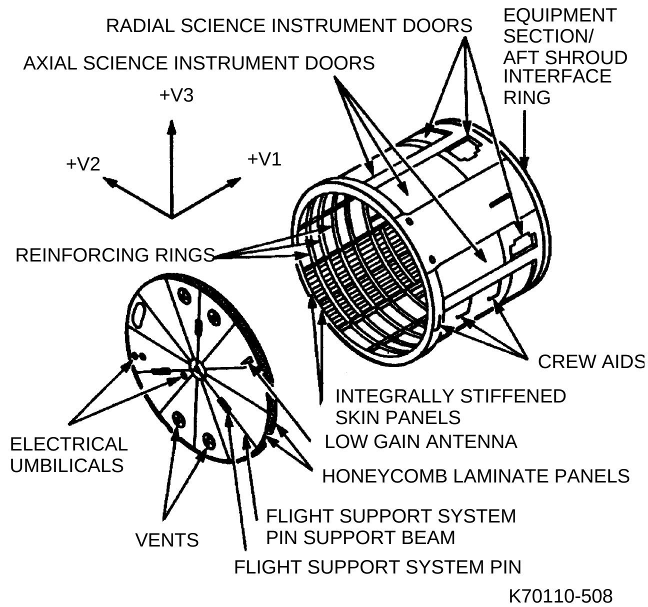

Fig. 5-8 Support Systems Module aft shroud and bulkhead

shroud. During maintenance or removal of an instrument, interior lights illuminate the compartments containing the science instruments. The shroud is made of aluminum, with a stiffened skin, internal panels and reinforcing rings, and 16 external and internal longeron bars for support. It is 11.5-ft (3.5 m) long and 14-ft (4.3 m) in diameter.

The aft bulkhead contains the umbilical connections between the Telescope and the shuttle, used during launch/deployment and on-orbit maintenance. The rear LGA attaches to the bulkhead, which is made of 2-in.-thick honeycombed aluminum panels and has three radial aluminum support beams.

The shroud and bulkhead support a gas purge system that was used to prevent contamination of the science instruments before launch. All vents used to expel gases are light tight. Thus, stray light is prevented from entering the OTA focal plane.

Mechanisms. Along the SSM structure are mechanisms that perform various functions, including:

• Latches to hold antennas and SAs
• Hinge drives to open the aperture door and erect arrays and antennas
• Gimbals to move the HGA dishes
• Motors to power the hinges and latches and to rotate arrays and antennas.

There are nine latches: four for antennas, four for arrays, and one for the aperture door. They latch and release using four-bar linkages and are driven by stepper motors called Rotary Drive Actuators (RDA).

There are three hinge drives, one for each HGA and one for the door. The hinges also use an RDA. Both hinges and latches have hex-wrench fittings so an astronaut can manually operate the mechanism to deploy the door, antenna, or array if a motor fails.

5.1.2 Instrumentation and Communications Subsystem

This subsystem provides the communications loop between the Telescope and the Tracking and Data Relay Satellites (TDRS), receiving commands and sending data through the HGAs and LGAs. All information is passed through the Data Management Subsystem (DMS).

The HGAs achieve a much higher RF signal gain, which is required, for example, when transmitting high-data-rate scientific data. These antennas require pointing at the TDRSs because of their characteristically narrow beam widths. On the other hand, the LGAs provide spherical coverage (omnidirectional) but have a much lower signal gain. The LGAs are used for low-rate-data transmission and all commanding of the Telescope.

S-Band Single Access Transmitter (SSAT). The Telescope is equipped with two SSATs. "S-Band" identifies the frequency at which the science data is transmitted, and "Single Access" specifies the type of antenna on the TDRS satellite to which the data is sent.

High Gain Antennas. Each HGA is a parabolic reflector (dish) mounted on a mast with a two-axis gimbal mechanism and electronics to rotate it 100 degrees in either direction (see Fig. 5-9). General Electric designed and made the antenna dishes. They are manufactured from honeycomb aluminum and graphite-epoxy facesheets.

Each antenna can be aimed with a one-degree pointing accuracy. This accuracy is consistent with the overall antenna beam width of over four degrees. The antennas transmit over two frequencies: 2255.5 MHz or 2287.5 MHz (plus or minus 10 MHz).

Low Gain Antennas. The LGAs receive ground commands and transmit engineering data. They are set 180 degrees apart on the light shield and aft bulkhead of the spacecraft. Each antenna is a spiral cone that can operate over a frequency range from 2100 MHz to 2300 MHz. Manufactured by Lockheed Martin, the LGAs

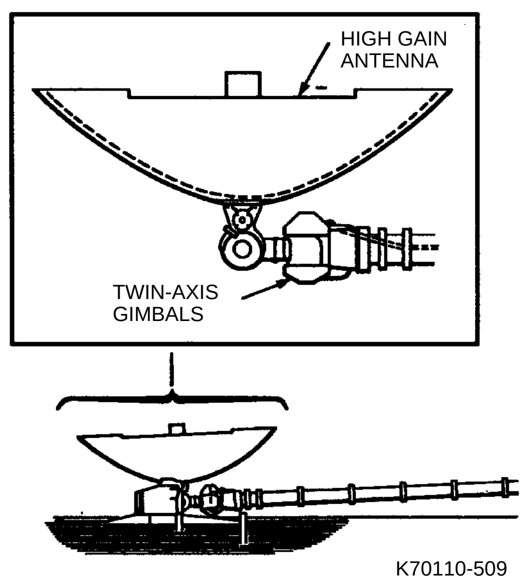

Fig. 5-9 High Gain Antenna

are used for all commanding of the Telescope and for low-data-rate telemetry, particularly during Telescope deployment or retrieval on orbit, or during safemode operations.

5.1.3 Data Management Subsystem

The DMS receives communications commands from the STOCC and data from the SSM systems, OTA, and science instruments. It processes, stores, and sends the information as requested. Subsystem components are:

- DF-224 computer (will be replaced on SM3A with the Advanced Computer)
- Data Management Unit (DMU)
- Four Data Interface Units (DIU)
- Three engineering/science data recorders
- Two oscillators (clocks).

The components are located in the SSM Equipment Section, except for one DIU stored in the OTA Equipment Section.

The DMS receives, processes, and transmits five types of signals:

1. Ground commands sent to the HST systems
2. Onboard computer-generated or computer-stored commands
3. Scientific data from the SI C&DH unit
4. Telescope engineering status data for telemetry
5. System outputs, such as clock signals and safemode signals.

Figure 5-10 is the subsystem functional diagram.

DF-224 Computer. The DF-224 computer is a general-purpose digital computer for onboard

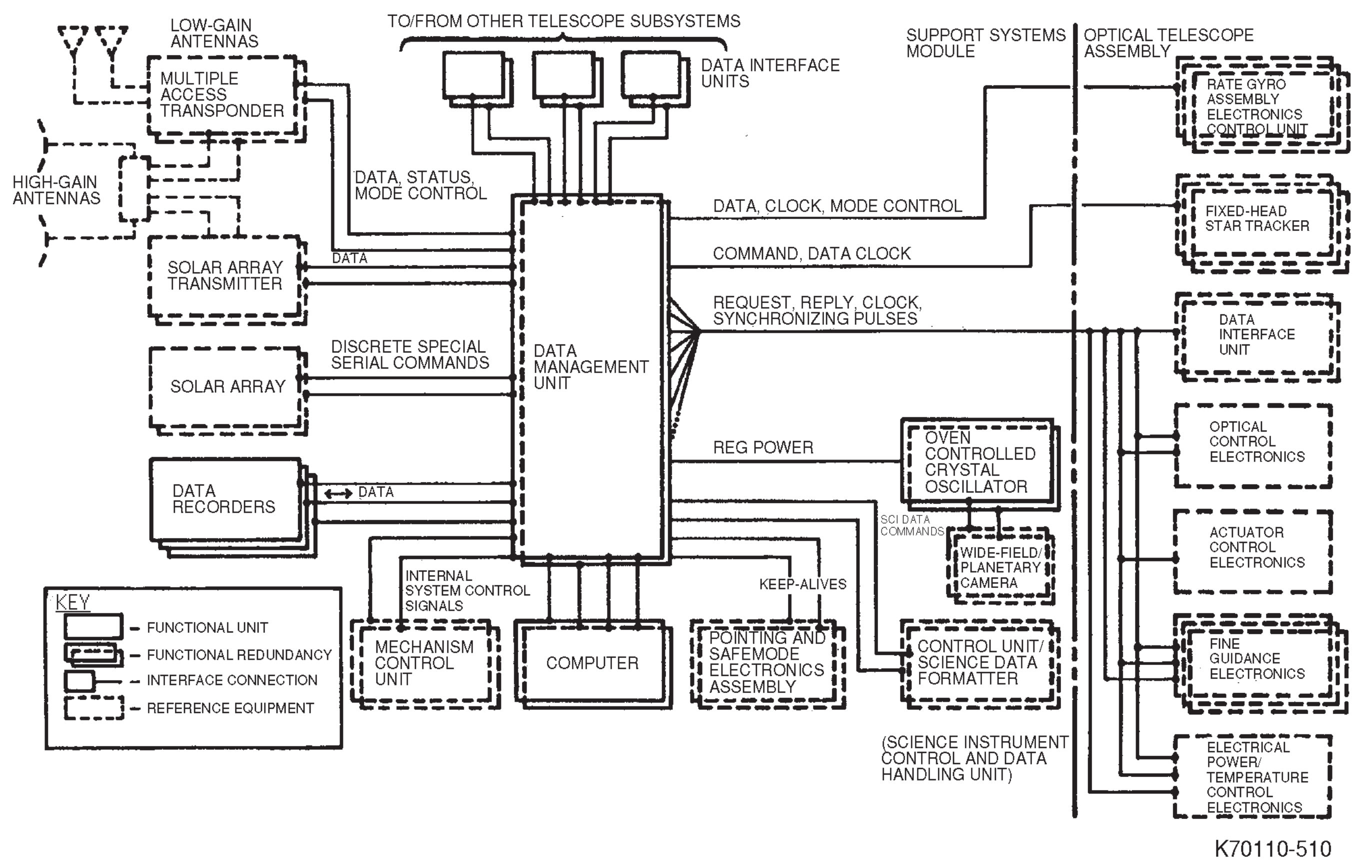

Fig. 5-10 Data Management Subsystem functional block diagram

engineering computations. It executes stored commands; formats status data (telemetry); performs all Pointing Control Subsystem (PCS) computations to maneuver, point, and attitude stabilize the Telescope; generates onboard commands to orient the SAs toward the Sun; evaluates the health status of the Telescope systems; and commands the HGAs. The Advanced Computer will replace the DF-224 on SM3A and will assume its functions.

Advanced Computer. The Advanced Computer is based on the Intel 80486 microchip. It operates 20 times faster and has six times as much memory as the DF-224.

The Advanced Computer was designed using commercially developed components. A battery of mechanical, electrical, radiation and thermal tests were performed at GSFC to assure its survival in the space environment. A successful flight test of the hardware was carried out aboard the space shuttle *Discovery* on STS-95 in October 1998.

The Advanced Computer is configured as three independent single-board computers. Each single-board computer (SBC) has two megabytes of fast static random access memory and one megabyte of non-volatile memory.

The Advanced Computer communicates with the HST by using the direct memory access capability on each SBC through the Data Management Unit (DMU). Only one SBC may control the Telescope at a time. The other SBCs can be off, in an idle state, or performing internal tasks.

Upon power on, each SBC runs a built-in self-test and then copies the operating software from slower non-volatile memory to faster random access memory. The self-test is capable of diagnosing any problems with the Advanced Computer and reporting them to the ground. Fast static random access memory is used in the Advanced Computer to eliminate wait states and allow it to run at its full-rated speed.

The Advanced Computer measures 18.8 x 18 x 13 inches (0.48 x 0.46 x 0.33 m) and weighs 70.5 lb (32 kg). It will be located in Bay 1 of the SSM Equipment Section (see Fig. 5-11).

Data Management Unit. The DMU links with the computer. It encodes data and sends messages to selected Telescope units and all DMS units, powers the oscillators, and is the central timing source. The DMU also receives and decodes all incoming commands, then transmits each processed command to be executed.

The DMU receives science data from the SI C&DH unit. Engineering data, consisting of sensor and hardware status readings (such as temperature or voltages), comes from each Telescope subsystem. The data can be stored in the onboard data recorders if direct telemetry via a TDRS is unavailable.

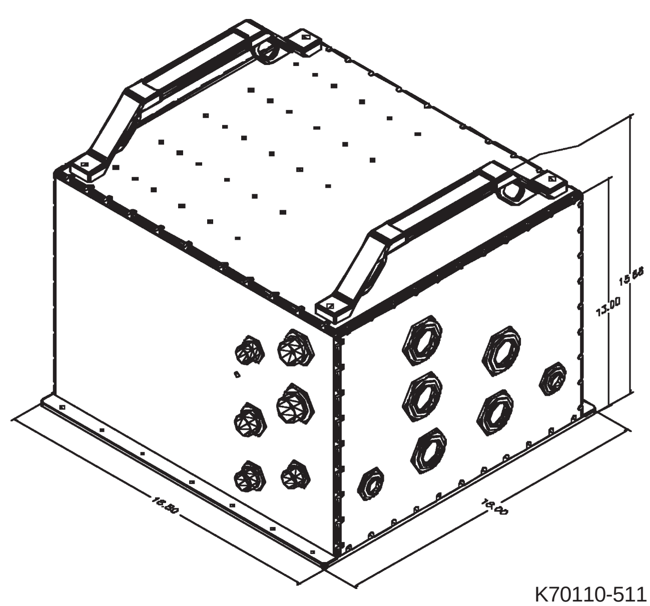

Fig. 5-11 Advanced computer

The DMU is an assembly of printed-circuit boards, interconnected through a backplate and external connectors. The unit weighs 83 lb (37.7 kg), measures 26 x 30 x 7 in. (60 x 70 x 17 cm), and is attached to the door of Equipment Section Bay 1 (see Fig. 5-12).

Data Interface Unit. The four DIUs provide a command and data link between DMS and other Telescope electronic boxes. The DIUs receive commands and data requests from the DMU and pass data or status information back to the DMU. The OTA DIU is located in the OTA Equipment Section; the other units are in Bays 3, 7, and 10 of the SSM Equipment Section. As a safeguard, each DIU is two complete units in one; either part can handle the unit's functions. Each DIU measures 15 x 16 x 7 in. (38 x 41 x 18 cm) and weighs 35 lb (16 kg).

Engineering/Science Data Recorders. The DMS includes three data recorders that store engineering or science data that cannot be transmitted to the ground in real time. The recorders, which are located in Equipment Section Bays 5 and 8, hold up to 12 billion bits of information. Two recorders are used in normal operations; the third is a backup. Each recorder measures 12 x 9 x 7 in. (30 x 23 x 18 cm) and weighs 20 lb (9 kg).

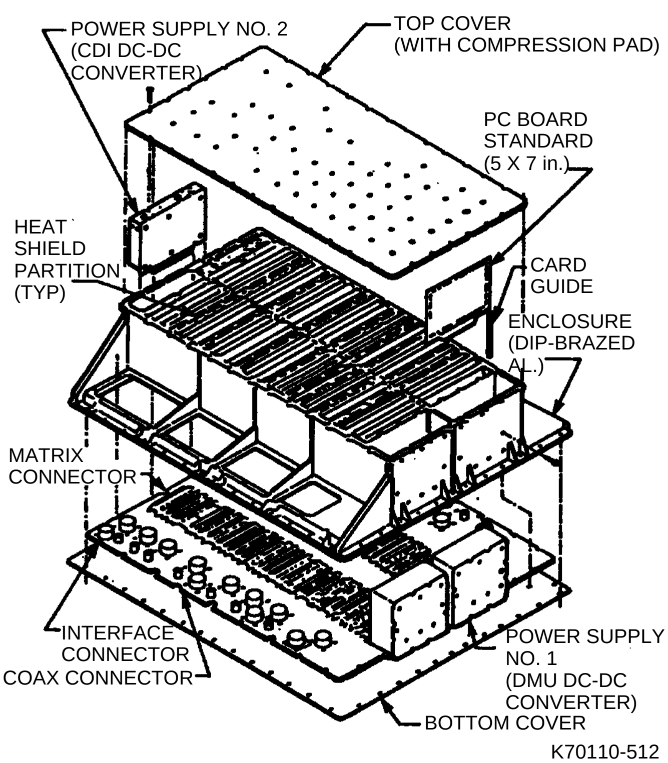

Fig. 5-12 Data Management Unit configuration

Solid State Recorder. During SM2 a Solid State Recorder (SSR) was installed, replacing a reel-to-reel tape recorder. A second state-of-the-art SSR will be installed during SM3A. This digital recorder will replace one of the two remaining reel-to-reel recorders on HST. The Solid State Recorders have an expected on-orbit life of at least eight years. They can record two data streams simultaneously, allowing both science and engineering data to be captured on a single recorder. In addition, data can be recorded and played back at the same time.

The SSR has no reels or tape, and no moving parts to wear out and limit lifetime. Data is stored digitally in computer-like memory chips until HST's operators at GSFC command the SSR to play it back. Although they are the same size as the reel-to-reel recorders, the SSRs can store over 10 times more data — 12 gigabits versus only 1.2 gigabits for the tape recorders they replace.

Oscillator. The oscillator provides a highly stable central timing pulse required by the Telescope. It has a cylindrical housing 4 in. (10 cm) in diameter and 9 in. (23 cm) long and weighs 3 lb (1.4 kg). The oscillator and a backup are mounted in Bay 2 of the SSM Equipment Section.

5.1.4 Pointing Control Subsystem

A unique PCS maintains Telescope pointing stability and aligns the spacecraft to point to and remain locked on any target. The PCS is designed for pointing to within 0.01 arcsec and holding the Telescope in that orientation with 0.007-arcsec stability for up to 24 hours while the Telescope continues to orbit the Earth at 17,500 mph. If the Telescope were in Los Angeles, it could hold a beam of light on a dime in San Francisco without the beam straying from the coin's diameter.

Nominally, the PCS maintains the Telescope's precision attitude by locating guide stars into two FGSs and controlling the Telescope to keep it in the same position relative to these stars. When specific target requests require repositioning the spacecraft, the pointing system selects different reference guide stars and moves the Telescope into a new attitude.

The PCS encompasses the Advanced Computer, various attitude sensors, and two types of devices, called actuators, to move the spacecraft (see Fig. 5-13). It also includes the Pointing/ Safemode Electronics Assembly (PSEA) and the Retrieval Mode Gyro Assembly (RMGA); both used by the spacecraft safemode system. See para 5.1.7 for details.

Sensors. The five types of sensors used by the PCS are the Coarse Sun Sensors (CSS), the Magnetic Sensing System (MSS), the Rate Gyro Assemblies (RGA), the Fixed Head Star Trackers (FHST), and the FGSs.

The CSSs measure the Telescope's orientation to the Sun. They are used to calculate the initial deployment orientation of the Telescope, determine when to begin closing the aperture door, and point the Telescope in special sun-orientation modes during contingency operations. Five CSSs are located on the light shield and aft shroud. CSSs also provide signals to the PSEA, located in Bay 8 of the SSM Equipment Section.

The MSS measures the Telescope's orientation relative to Earth's magnetic field. The system consists of magnetometers and dedicated electronic units that send data to the Advanced Computer and the Safemode Electronic Assembly. Two systems are provided. Both are located on the front end of the light shield.

Three RGAs are provided on the Telescope. Each assembly consists of a Rate Sensor Unit (RSU) and an Electronics Control Unit (ECU). An RSU contains two rate-sensing gyroscopes, each measuring attitude rate motion about its sensitive axis. This output is processed by its dedicated electronics, which are contained in the ECU. Each unit has two sets of electronics. The RSUs are located behind the SSM Equipment Section, next to the FHSTs in the aft shroud. The ECUs are located inside Bay 10 of the SSM Equipment Section. The RGAs provide input to the PCS to control the orientation of the Telescope's line of sight and to provide the attitude reference when maneuvering the Telescope.

Four of the original six rate gyros were replaced during the First Servicing Mission. All six rate gyros are planned for replacement during SM3A. Three of six gyroscopes are required to continue the Telescope science mission.

An FHST is an electro-optical detector that locates and tracks a specific star within its FOV. Three FHSTs are located in the aft shroud behind the FPS, next to the RSUs. STOCC uses star trackers as an attitude calibration device when the Telescope maneuvers into its initial orientation. The trackers also calculate attitude information before and after maneuvers to help the FGS lock onto guide stars.

Three FGSs, discussed in more detail in para 5.3, provide angular position with respect to the stars. Their precise fine-pointing adjustments, accurate to within a fraction of an arcsecond,

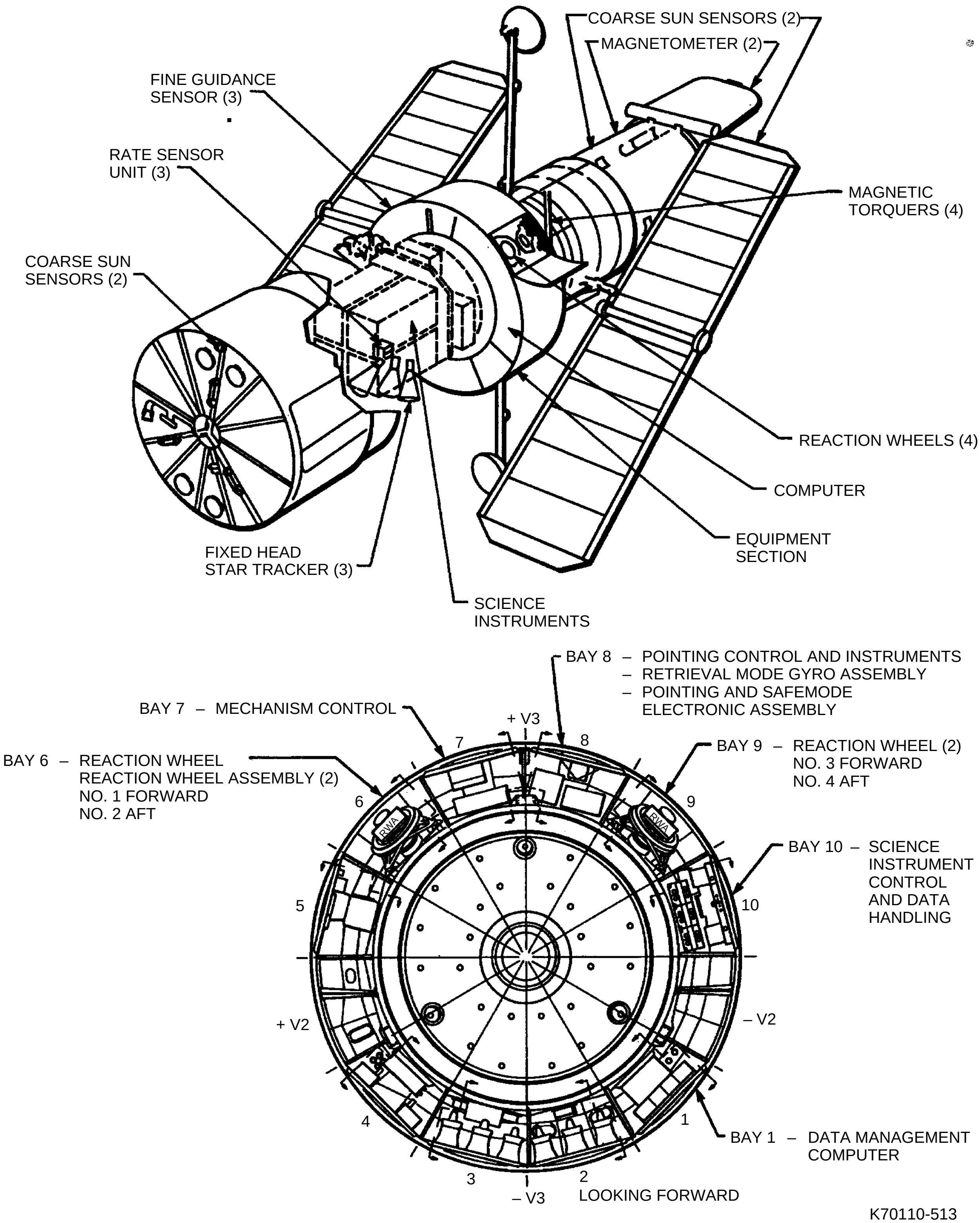

Fig. 5-13 Location of Pointing Control Subsystem equipment

pinpoint the guide stars. Two of the FGSs perform guide-star pointing, while the third is available for astrometry, the positional measurement of specific stars.

Pointing Control Subsystem Software. PCS software accounts for a large percentage of the flight code executed by the Hubble's main computer. This software translates ground targeting commands into reaction wheel torque profiles that reorient the spacecraft. All motion of the spacecraft is smoothed to minimize jitter during data collection. The software also determines Telescope orientation, or attitude, from FHST or FGS data and commands the magnetic torquer bars so that reaction wheel speeds are always minimized. In addition, the software provides various telemetry formats.

Since the Telescope was launched, major modifications have been made to the PCS. A digital filtering scheme, known as Solar Array Gain Augmentation (SAGA) was incorporated to mitigate the effect of any SA vibration or jitter on pointing stability. Software also was used to improve FGS performance when the Telescope is subjected to the same disturbances. This algorithm is referred to as the FGS Re-Centering Algorithm.

Software is used extensively to increase Telescope robustness when hardware failures are experienced. Two additional software safemodes have been provided. The spin-stabilized mode provides pointing of the Telescope -V1 axis to the Sun with only two of the four RWAs operating. The other mode allows Sun pointing of the Telescope without any input from the RGA; magnetometer and CSS data is used to derive all reference information needed to maintain Sun pointing (+V3 and -V1 are options).

A further software change "refreshes" the FGS configuration. This is achieved by maintaining data in the Advanced Computer memory so it can be sent periodically to the FGS electronics, which are subject to single-event upsets (logic state change) when transitioning through the South Atlantic Anomaly.

Actuators. The PCS has two types of actuators: RWAs and magnetic torquers. Actuators move the spacecraft into commanded attitudes and provide required control torques to stabilize the Telescope's line of sight.

The reaction wheels work by rotating a large flywheel up to 3000 rpm or braking it to exchange momentum with the spacecraft. The wheel axes are oriented so that the Telescope can provide science with only three wheels operating. Wheel assemblies are paired, two each in Bays 6 and 9 of the SSM Equipment Section. Each wheel is 23 in. (59 cm) in diameter and weighs about 100 lb (45 kg). Figure 5-14 shows the RWA configuration.

Magnetic torquers create torque on the spacecraft and are primarily used to manage reaction wheel speed. The torquers react against Earth's magnetic field. The torque reaction occurs in the direction that reduces the reaction wheel speed, managing the angular momentum.

The magnetic torquers also provide backup control to stabilize the Telescope's orbital attitude during the contingency modes, as described in para 5.1.2. Each torquer, located externally on the forward shell of the SSM, is 8.3

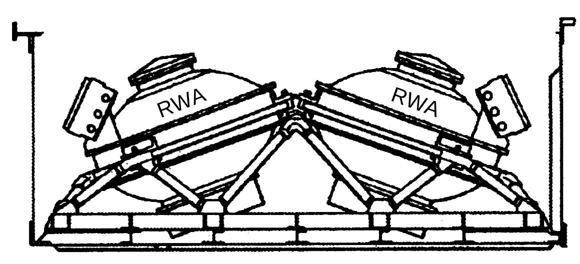

Fig. 5-14 Reaction Wheel Assembly

ft (2.5 m) long and 3 in. (8 cm) in circumference and weighs 100 lb (45 kg).

Pointing Control Operation. To point precisely, the PCS uses the gyroscopes, reaction wheels, magnetic torquers, star trackers, and FGSs. The FGSs provide the precision reference point from which the Telescope can begin repositioning. Flight software commands the reaction wheels to spin, accelerating or decelerating as required to rotate the Telescope toward a new target. Rate gyroscopes sense the Telescope's angular motion and provide a short-term attitude reference to assist fine pointing and spacecraft maneuvers. The magnetic torquers reduce reaction wheel speed.

As the Telescope nears the target area, star trackers locate preselected reference stars that stand out brightly in that region of the sky. Once the star trackers reduce the attitude error below 60 arcsec, the two FGSs take over the pointing duties. Working with the gyroscopes, the FGSs make possible pointing the Telescope to within 0.01 arcsec of the target. The PCS can maintain this position, wavering no more than 0.005 arcsec, for up to 24 hours to guarantee faint-object observation.

5.1.5 Electrical Power Subsystem

Power for the Telescope and science instruments comes from the Electrical Power Subsystem (EPS). The major components are two SA wings and their electronics, six batteries, six Charge Current Controllers (CCC), one Power Control Unit (PCU), and four Power Distribution Units (PDU). All except the SAs are located in the bays around the SSM Equipment Section.

During the servicing mission, the Shuttle will provide the electrical power. After deployment, the SAs again begin converting solar radiation into electricity. Energy will be stored in nickel-hydrogen (NiH_2) batteries and distributed by the PCUs and PDUs to all Telescope components as shown in Fig. 5-15. The Telescope will not be released until the batteries are fully charged.

Solar Arrays. The SA panels, discussed later in this section, are the primary source of electrical power. Each array wing has a solar cell blanket that converts solar energy into electrical energy. Electricity produced by the solar cells charges the Telescope batteries.

Each array wing has associated electronics. These consist of a Solar Array Drive Electronics (SADE) unit, which transmits positioning commands to the wing assembly; a Deployment Control Electronics Unit, which controls the drive motors extending and retracting the wings; and diode networks to direct the electrical current flow.

Batteries and Charge Current Controllers. Developed for the 1990 deployment mission, the Telescope's batteries were NASA's first flight NiH_2 batteries. They provide the observatory with a robust, long-life electrical energy storage system.

Six NiH_2 batteries support the Telescope's electrical power needs during three periods: when demand exceeds SA capability, when the Telescope is in Earth's shadow, and during safemode entry. The batteries reside in SSM Equipment Section Bays 2 and 3. These units have extensive safety and handling provisions to protect the Shuttle and its astronauts. The design and operation of these batteries, along with special nondestructive inspection of each cell, have allowed these units to be "astronaut-rated" for replacement during a servicing mission. To compensate for the effects of battery aging, SM3A astronauts will install a Voltage/Temperature Improvement Kit (VIK) on each of

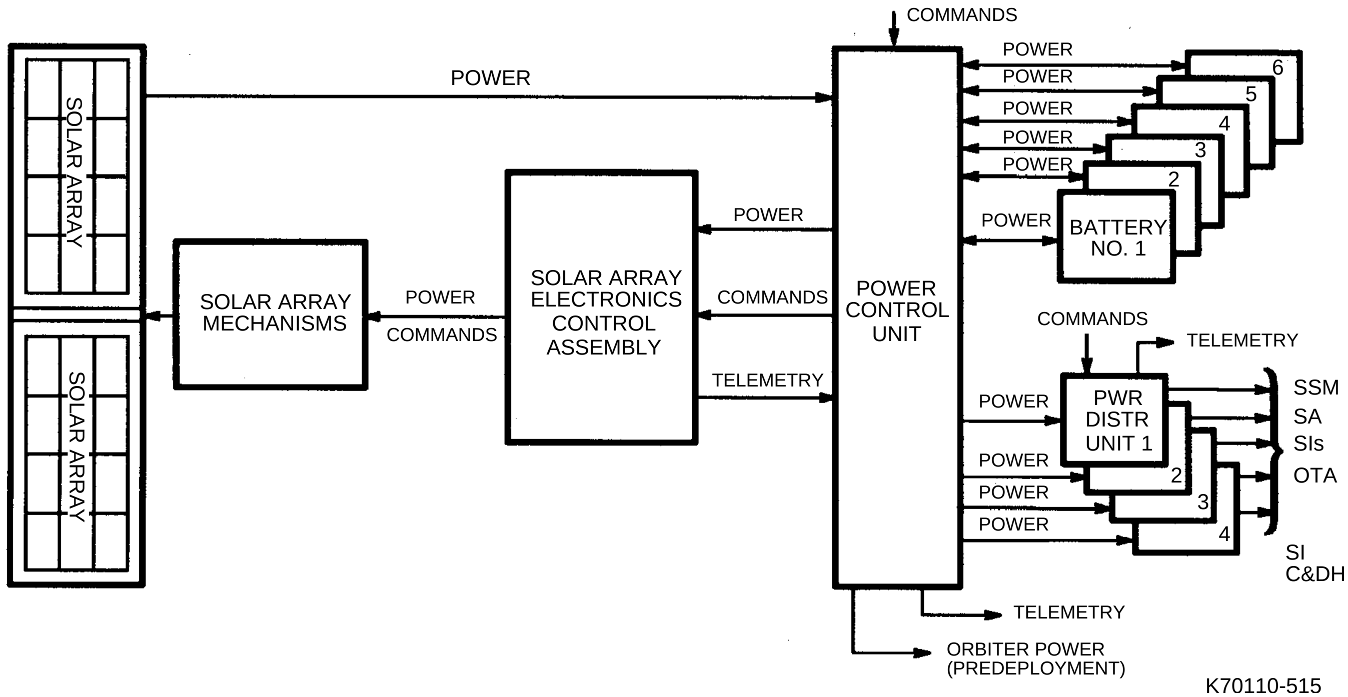

Fig. 5-15 Electrical Power Subsystem functional block diagram

Hubble's six batteries. The VIK provides battery thermal stability by precluding battery overcharge when the HST enters safemode, effectively lowering the Charge Current Controller (CCC) recharge current.

Each battery consists of 22 cells in series along with heaters, heater controllers, pressure measurement transducers and electronics, and temperature-measuring devices and their associated electronics. Three batteries are packaged into a module measuring roughly 36 by 36 by 10 in. (90 x 90 x 25 cm) and weighing about 475 lb (214 kg). Each module is equipped with two large yellow handles that astronauts use to maneuver the module in and out of the Telescope in space.

The SAs recharge the batteries every orbit following eclipse (the time in the Earth's shadow). The recharge current is controlled by the CCCs. Each battery has its own CCC that uses voltage-temperature measurements to control battery recharge.

Fully charged, each battery contains more than 75 amp-hours. This is sufficient energy to sustain the Telescope in normal science operations mode for 7.5 hours or five orbits. The batteries provide an adequate energy reserve for all possible safemode contingencies and all enhancements programmed into the Telescope since launch.

Power Control and Distribution Units. The PCU interconnects and switches current flowing among the SAs, batteries, and CCCs. Located in Bay 4 of the Equipment Section, the PCU provides the main power bus to the four PDUs. The PCU weighs 120 lb (55 kg) and measures 43 x 12 x 8 in. (109 x 30 x 20 cm).

Four PDUs, located on the inside of the door to Bay 4, contain the power buses, switches, fuses, and monitoring devices for electrical power distribution to the rest of the Telescope. Two buses are dedicated to the OTA, science instruments, and SI C&DH; two supply the SSM. Each PDU measures 10 x 5 x 18 in. (25 x 12.5 x 45 cm) and weighs 25 lb (11 kg).

5.1.6 Thermal Control

Multilayer insulation (MLI) covers 80 percent of the Telescope's exterior, and supplemental electric heaters maintain its temperatures within safe limits. The insulation blankets are 15 layers of aluminized Kapton, with an outer layer of aluminized Teflon flexible optical solar reflector (FOSR). Aluminized or silvered flexible reflector tape covers most of the remaining exterior. These coverings protect against the cold of space and reflect solar heat. In addition, reflective or absorptive paints are used.

The SSM Thermal Control Subsystem (TCS) maintains temperatures within set limits for the components mounted in the Equipment Section and structures interfacing with the OTA and science instruments. The TCS maintains safe component temperatures even for worst-case conditions such as environmental fluctuations, passage from "cold" Earth shadow to "hot" solar exposure during each orbit, and heat generated from equipment operation.

Specific thermal-protection features of the SSM include:

- MLI thermal blankets for the light shield and forward shell
- Aluminum FOSR tape on the aperture door surface facing the sun
- Specific patterns of FOSR and MLI blankets on the exteriors of the Equipment Section bay doors, with internal MLI blankets on the bulkheads to maintain thermal balance between bays
- Efficient placement of equipment and use of equipment bay space to match temperature requirements, such as placing heat-dissipating equipment on the side of the Equipment Section mostly exposed to orbit shadow
- Silvered FOSR tape on the aft shroud and aft bulkhead exteriors
- Radiation shields inside the aft shroud doors and MLI blankets on the aft bulkhead and shroud interiors to protect the science instruments
- More than 200 temperature sensors and thermistors placed throughout the SSM, externally and internally, to monitor individual components and control heater operations.

Figure 5-16 shows the location and type of thermal protection used on the SSM. SM2 observations identified degradations of all of the MLI. Additional material will be installed during SM3A to cover some of the degraded material and restore the external layer surface properties. The additional material has been life-tested to an equivalent of 10 years.

The layer being added to the SSM Equipment Section is a composite-coated (silicone dioxide) stainless steel layer, known as the New Outer Blanket Layer (NOBL). The light shield/forward shell material is Teflon with a scrim backing for durability.

5.1.7 Safing (Contingency) System

Overlapping or redundant Telescope equipment safeguards against any breakdown. Nonetheless, a contingency or Safing System exists for emergency operations. It uses many pointing control and data management components as well as dedicated PSEA hardware. This system maintains stable Telescope attitude, moves the SAs for maximum Sun exposure, and conserves electrical power by minimizing power drain. The Safing System can operate the spacecraft indefinitely with no communications link to ground control.

During scientific observations (normal mode), the Safing System is relegated to monitor automatically Telescope onboard functions. The system sends Advanced-Computer-generated

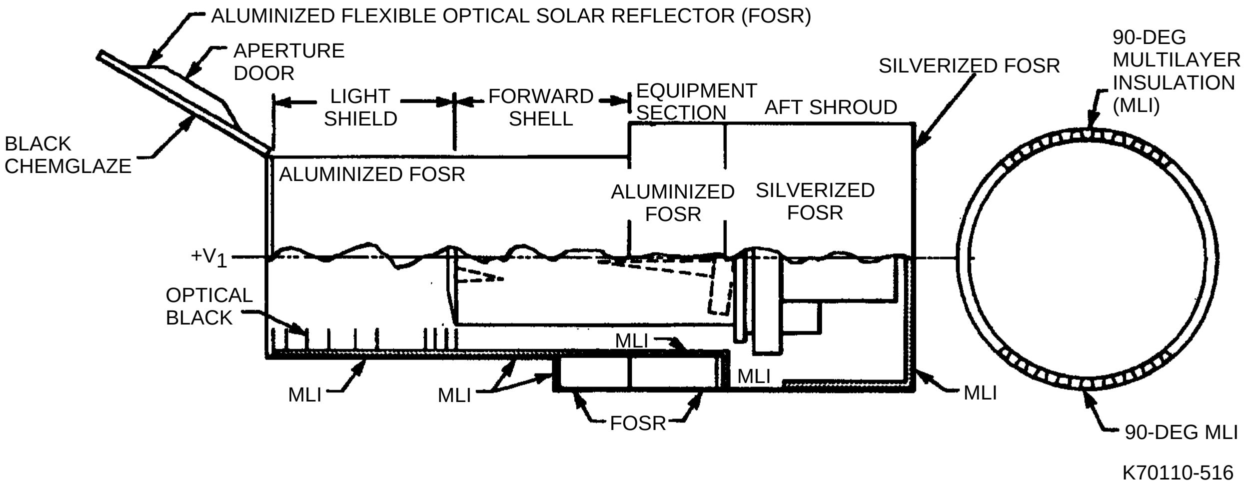

Fig. 5-16 Placement of thermal protection on Support Systems Module

"keep-alive" signals to the PSEA that indicate all Telescope systems are functioning. Entry into the Safemode is autonomous once a failure is detected.

The Safing System is designed to follow a progression of contingency operating modes, depending on the situation aboard the Telescope. If a malfunction occurs and does not threaten the Telescope's survival, the Safing System moves into a Software Inertial Hold Mode. This mode holds the Telescope in the last position commanded. If a maneuver is in progress, the Safing System completes the maneuver, then holds the Telescope in that position, suspending all science operations. Only ground control can return to science operations from Safemode.

If the system detects a marginal electrical power problem, or if an internal PCS safety check fails, the Telescope enters the Software Sun Point Mode. The Safing System maneuvers the Telescope so the SAs point toward the Sun to continuously generate solar power. Telescope equipment is maintained within operating temperatures and above survival temperatures, anticipating a return to normal operations. The STOCC must intercede to correct the malfunction before any science operations or normal functions can be resumed.

Since deployment of the Telescope in 1990, the Safing System has seen additional improvements to increase its robustness to survive hardware failures and still protect the Telescope. Paragraph 5.1.4 describes these features.

For the modes described above, the Safing System operates through computer software. If conditions worsen, the system turns over control to the PSEA in Hardware Sun Point Mode. Problems that could provoke this action include any of the following:

- Computer malfunction
- Batteries losing more than 50 percent of their charge
- Two of the three RGAs failing
- DMS failing.

If these conditions occur, the Advanced Computer stops sending keep-alive signals. This is the "handshake" mechanism between the flight software and the PSEA.

In the Hardware Sun Point Mode, the PSEA computer commands the Telescope and turns off selected equipment to conserve power. Components shut down include the Advanced Computer and, within two hours, the SI C&DH. Before this, a payload (instruments) safing sequence begins and, if it has not already done so, the Telescope turns the SAs toward the Sun, guided by the CSSs. The PSEA removes operating power from equipment not required for Telescope survival.

Once ground control is alerted to a problem, NASA management of the STOCC convenes a failure analysis team to evaluate the problem and seek the best and safest corrective action while the Safing System maintains control of the Telescope.

The failure analysis team is led by a senior management representative from NASA/GSFC with the authority not only to call upon the expertise of engineers and scientists employed by NASA or its support contractors, but also to draft support from any organization previously affiliated with the Telescope Project. The failure analysis team is chartered to identify the nature of the anomaly and to recommend corrective action. This recommendation is reviewed at a higher management level of NASA/GSFC. All changes to the Telescope's hardware and all software configurations require NASA Level I concurrence as specified in the HST Level I Operations Requirements Document.

Pointing/Safemode Electronics and Retrieval Mode Gyro Assemblies. The PSEA consists of 40 electronic printed-board circuits with redundant functions to run the Telescope, even in the case of internal circuit failure. It weighs 86 lb (39 kg) and is installed in the Equipment Section Bay 8. A backup gyroscope package, the RMGA, is dedicated for the PSEA and is also located in Bay 8. The RMGA consists of three gyroscopes. These are lower quality rate sensors than the RGAs because they are not intended for use during observations.

5.2 Optical Telescope Assembly

The OTA was designed and built by the Perkin-Elmer Corporation (Raytheon Optical Systems, Inc.). Although the OTA is modest in size by ground-based observatory standards and has a straightforward optical design, its accuracy – coupled with its place above the Earth's atmosphere – renders its performance superior.

The OTA uses a "folded" design, common to large telescopes, which enables a long focal length of 189 ft (57.6 m) to be packaged into a small telescope length of 21 ft (6.4 m). (Several smaller mirrors in the science instruments are designed similarly to lengthen the light path within the particular science instrument.) This form of telescope is called a Cassegrain, and its compactness is an essential component of an observatory designed to fit inside the Shuttle cargo bay.

Conventional in design, the OTA is unconventional in other aspects. Large telescopes at ground-based sites are limited in their performance by the resolution attainable while operating under the Earth's atmosphere, but the HST orbits high above the atmosphere and provides an unobstructed view of the universe. For this reason the OTA was designed and built with exacting tolerances to provide near-perfect image quality over the broadest possible region of the spectrum.

The OTA is a variant of the Cassegrain, called a Ritchey-Chretien, in which both the mirrors are hyperboloidal in shape (having a deeper curvature than a parabolic mirror). This form is completely corrected for coma (an image observation having a "tail") and spherical aberrations to provide an aplanatic system in which aberrations are correct everywhere in the FOV. The only residual aberrations are field curvature and astigmatism. Both of these are zero exactly in the center of the field and increase toward the edge of the field. These aberrations are easily corrected within the instrument optics. For example, in the Faint Object Camera (FOC) there is a small telescope designed to remove image astigmatism.

Figure 5-17 shows the path of a light ray from a distant star as it travels through the Telescope to the focus. Light travels down the tube, past baffles that attenuate reflected light from unwanted bright sources, to the 94.5-in. (2.4-m) primary mirror. Reflecting off the front surface of the concave mirror, the light bounces back up the tube to the 12-in. (0.3-m)-diameter convex secondary mirror. The light is now reflected and converged through a 23.5-in. (60-cm) hole in the primary mirror to the Telescope focus, 3.3 ft (1.5 m) behind the primary mirror.

Four science instruments and three FGSs share the focal plane by a system of mirrors. A small "folding" mirror in the center of the FOV directs light into the WFPC2. The remaining "science" field is divided among three axial science instruments, each receiving a quadrant of the circular FOV. Around the outside of the science field, a "guidance" field is divided among the three FGSs by their own folding mirrors. Each FGS receives 60 arcmin^2 of field in a 90-degree sector. Figure 5-18 shows instrument/sensor fields of view.

The OTA hosts the science instruments and FGSs in that it maintains the structural support and optical-image stability required for these instruments to fulfill their functions (see Fig. 5-19). Components of the OTA are the primary mirror, the secondary mirror, the FPS, and the OTA Equipment Section. Perkin-Elmer Corporation designed and built all the optical assemblies; Lockheed Martin built the OTA equipment section.

5.2.1 Primary Mirror Assembly and Spherical Aberration

As the Telescope was put through its paces on orbit in 1990, scientists discovered its primary mirror had a spherical aberration. The outer

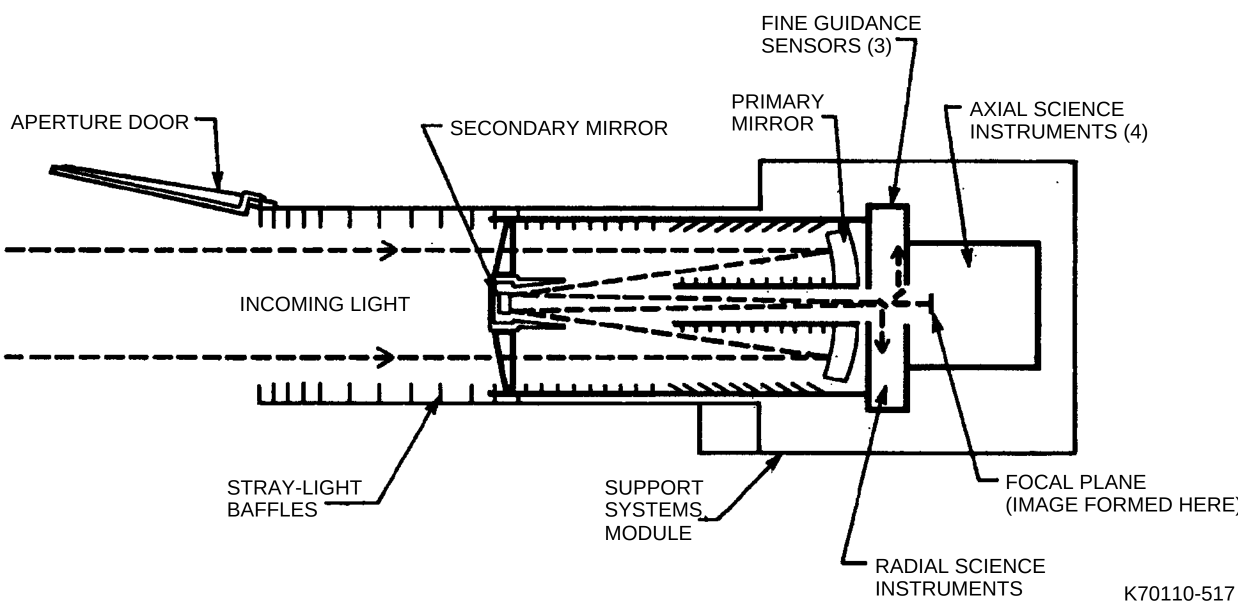

Fig. 5-17 Light path for the main Telescope

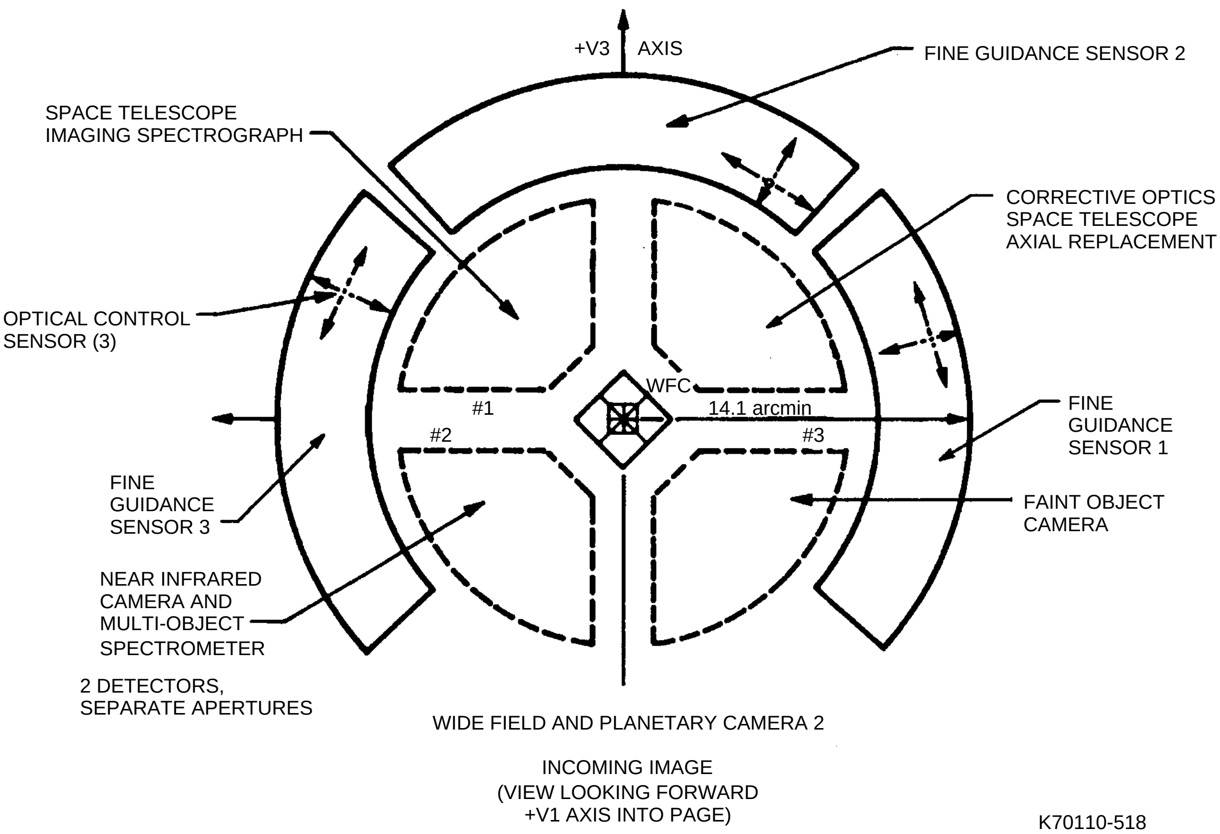

Fig. 5-18 Instrument/sensor field of view

edge of the 8-foot (2.4-m) primary mirror was ground too flat by a width equal to 1/50 the thickness of a sheet of paper (about 2 microns). After intensive investigation, the problem was traced to faulty test equipment used to define and measure mirror curvature. The optical component of this test equipment was slightly out of focus and, as a result, had shown the mirror to be ground correctly. After the discovery, Ball Aerospace scientists and engineers built the Corrective Optics Space Telescope Axial Replacement (COSTAR). The COSTAR was installed during the First Servicing Mission in December 1993 and brought the Telescope back to its original specifications.

The primary mirror assembly consists of the mirror supported inside the main ring, which is the structural backbone of the Telescope, and the main and central baffles shown in Fig. 5-20. This assembly provides the structural coupling to the rest of the spacecraft through a set of kinematic brackets linking the main ring to the SSM. The assembly also supports the OTA baffles. Its major parts are:

- Primary mirror
- Main ring structure
- Reaction plate and actuators
- Main and central baffles.

Primary Mirror. The primary mirror blank, a product of Corning Glass Works, is known as ultralow-expansion (ULE) glass. It was chosen for its very low-expansion coefficient, which ensures the Telescope minimum sensitivity to temperature changes. The mirror is of a "sandwich" construction: two lightweight facesheets separated by a core, or filling, of glass honeycomb ribs in a rectangular grid (see Fig. 5-21). This construction results in an 1800-lb

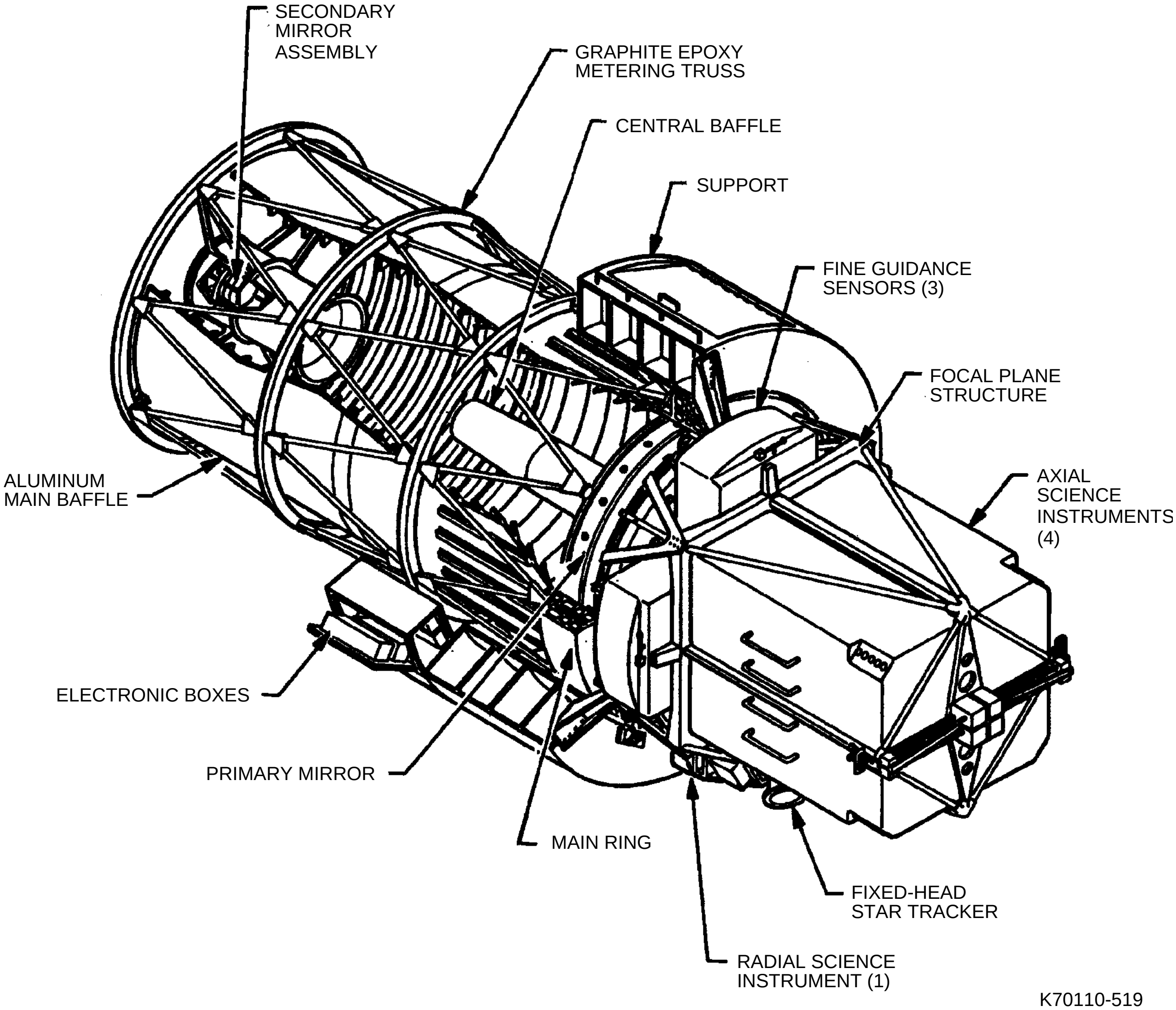

Fig. 5-19 Optical Telescope Assembly components

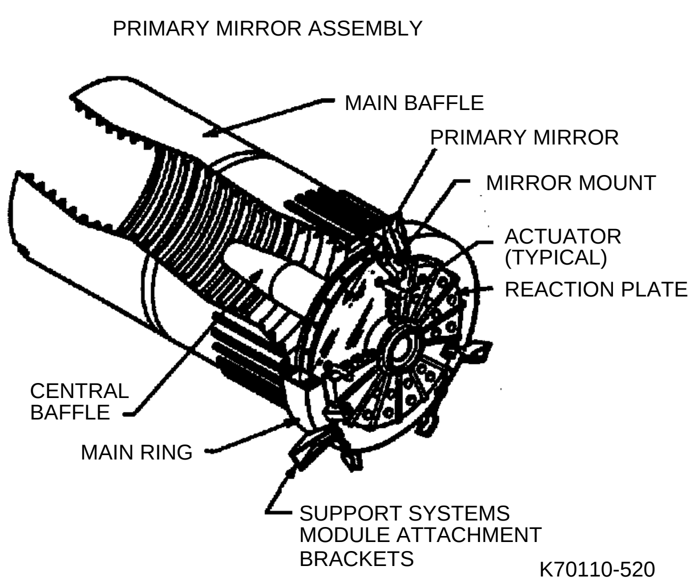

Fig. 5-20 Primary mirror assembly

(818-kg) mirror instead of an 8000-lb solid-glass mirror.

Perkin-Elmer (now Raytheon Optical Systems, Inc.) ground the mirror blank, 8 ft (2.4 m) in diameter, to shape in its large optics fabrication facility. When it was close to its final hyperboloidal shape, the mirror was transferred to Perkin-Elmer's computer-controlled polishing facility.

After being ground and polished, the mirror was coated with a reflective layer of aluminum and a protective layer of magnesium fluoride only 0.1 and 0.025 micrometer thick,

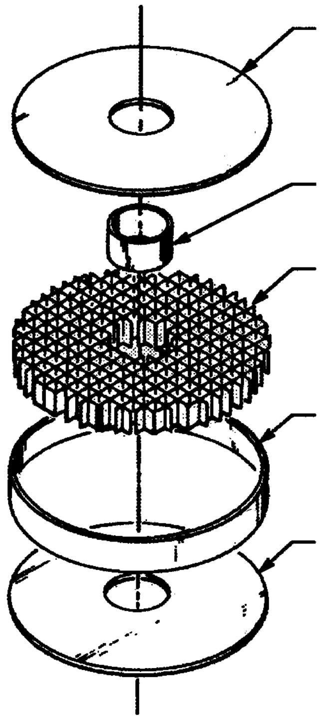

Fig. 5-21 Primary mirror construction

respectively. The fluoride layer protects the aluminum from oxidation and enhances reflectance at the important hydrogen emission line known as Lyman-Alpha. The reflective quality of the mirror is better than 70 percent at 1216 angstroms (Lyman-Alpha) in the ultraviolet spectral range and better than 85 percent for visible light.

The primary mirror is mounted to the main ring through a set of kinematic linkages. The linkages attach to the mirror by three rods that penetrate the glass for axial constraint and by three pads bonded to the back of the glass for lateral support.

Main Ring. The main ring encircles the primary mirror; supports the mirror, the main baffle and central baffle, and the metering truss; and integrates the elements of the Telescope to the spacecraft. The titanium ring is a hollow box beam 15 in. (38 cm) thick, weighing 1200 lb (545.5 kg), with an outside diameter of 9.8 ft (2.9 m) (see Fig. 5-22). It is suspended inside the SSM by a kinematic support.

Reaction Plate. The reaction plate is a wheel of I-beams forming a bulkhead behind the main ring, spanning its diameter. It radiates from a central ring that supports the central baffle. Its primary function is to carry an array of heaters that warm the back of the primary mirror, maintaining its temperature at 70 degrees. Made of lightweight, stiff beryllium, the plate also supports 24 figure-control actuators attached to the primary mirror and arranged around the reaction plate in two concentric circles. These can be commanded from the ground, if necessary, to make small corrections to the shape of the mirror.

Baffles. The baffles of the OTA prevent stray light from bright objects, such as the Sun, Moon, and Earth, from reflecting down the Telescope tube to the focal plane. The primary mirror assembly includes two of the three assembly baffles.

Attached to the front face of the main ring, the outer, main baffle is an aluminum cylinder 9 ft (2.7 m) in diameter and 15.7 ft (4.8 m) long. Internal fins help it attenuate stray light. The central baffle is 10 ft (3 m) long, conical in shape,

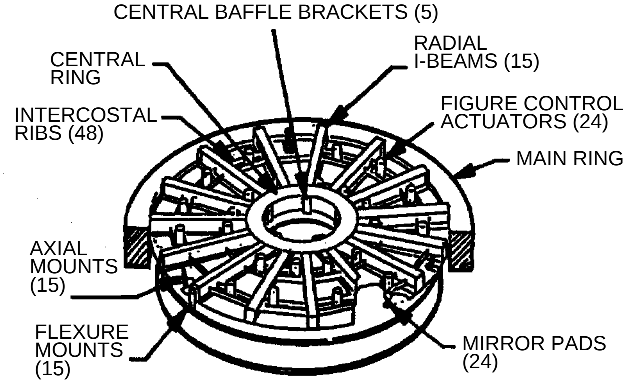

Fig. 5-22 Main ring and reaction plate

and attached to the reaction plate through a hole in the center of the primary mirror. It extends down the centerline of the Telescope tube. The baffle interiors are painted flat black to minimize light reflection.

5.2.2 Secondary Mirror Assembly

The Secondary Mirror Assembly cantilevers off the front face of the main ring and supports the secondary mirror at exactly the correct position in front of the primary mirror. This position must be accurate within 1/10,000 in. whenever the Telescope is operating. The assembly consists of the mirror subassembly, a light baffle, and an outer graphite-epoxy metering truss support structure (see Fig. 5-23).

The Secondary Mirror Assembly contains the mirror, mounted on three pairs of alignment actuators that control its position and orientation. All are enclosed within the central hub at the forward end of the truss support.

The secondary mirror has a magnification of 10.4X, converting the primary-mirror converging rays from f/2.35 to a focal ratio system prime focus of f/24 and sending them back toward the center of the primary mirror, where they pass through the central baffle to the focal point. The mirror is a convex hyperboloid 12 in. (0.3 m) in diameter and made of Zerodur glass coated with aluminum and magnesium fluoride. Steeply convex, its surface accuracy is even greater than that of the primary mirror.

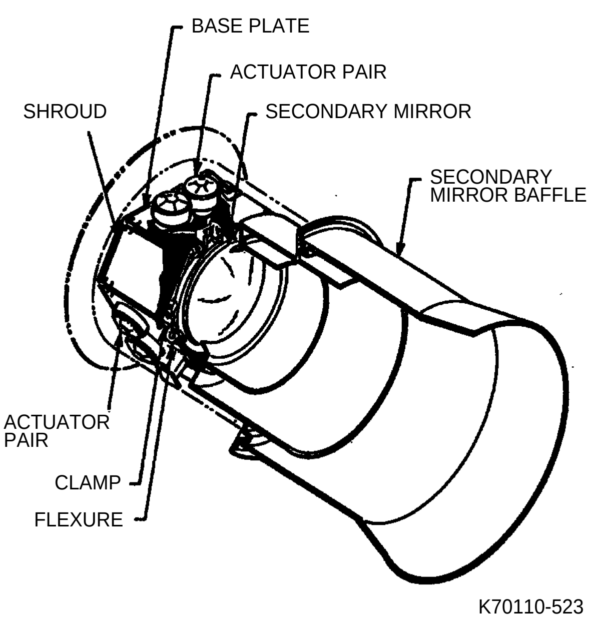

Fig. 5-23 Secondary mirror assembly

Ground command adjusts the actuators to align the secondary mirror to provide perfect image quality. The adjustments are calculated from data picked up by tiny optical control system sensors located in the FGSs.

The principal structural element of the Secondary Mirror Assembly is the metering truss, a cage with 48 latticed struts attached to three rings and a central support structure for the secondary mirror. The truss, 16 ft (4.8 m) long and 9 ft (2.7 m) in diameter, is a graphite, fiber-reinforced epoxy structure. Graphite was chosen for its high stiffness, light weight, and ability to reduce the structure's expansiveness to nearly zero. This is vital because the secondary mirror must stay perfectly placed relative to the primary mirror, accurate to within 0.0001 in. (2.5 micrometers) when the Telescope operates.

The truss attaches at one end to the front face of the main ring of the Primary Mirror Assembly. The other end has a central hub that houses the secondary mirror and baffle along the optical axis. Aluminized mylar MLI in the truss compensates for temperature variations of up to 30 degrees Fahrenheit when the Telescope is in Earth's shadow so the primary and secondary mirrors remain aligned.

The conical secondary mirror subassembly light baffle extends almost to the primary mirror. It reduces the stray bright-object light from sources outside the Telescope FOV.

5.2.3 Focal Plane Structure Assembly

The FPS is a large optical bench that physically supports the science instruments and FGSs and aligns them with the image focal plane of the Telescope. The -V3 side of the structure, away from the Sun in space, supports the FHSTs and RSUs (see Fig. 5-24). It also provides facilities for on-orbit replacement of any instruments and thermal isolation between instruments.

The structure is 7 ft (2.1 m) by 10 ft (3.04 m) long and weighs more than 1200 lb (545.5 kg). Because it must have extreme thermal stability and be stiff, lightweight, and strong, the FPS is constructed of graphite-epoxy, augmented with mechanical fasteners and metallic joints at strength-critical locations. It is equipped with metallic mounts and supports for Orbital Replacement Units (ORU) used during maintenance.

The FPS cantilevers off the rear face of the main ring, attached at eight flexible points that adjust to eliminate thermal distortions. The structure provides a fixed alignment for the FGSs. It has guiderails and latches at each instrument mounting location so Shuttle crews can easily exchange science instruments and other equipment in orbit.

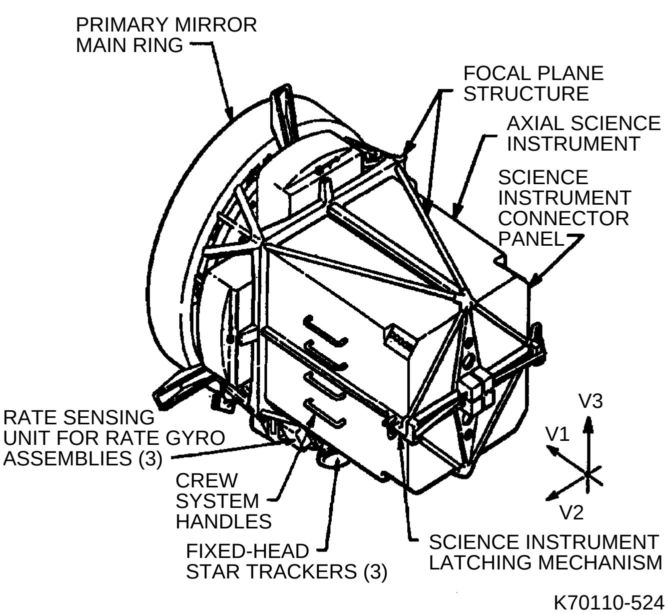

Fig. 5-24 Focal plane structure

5.2.4 OTA Equipment Section

The Equipment Section for the OTA is a large semicircular set of compartments mounted outside the spacecraft on the forward shell of the SSM (see Fig. 5-25). It contains the OTA Electrical Power and Thermal Control Electronics (EP/TCE) System, Fine Guidance Electronics (FGE), Actuator Control Electronics (ACE), Optical Control Electronics (OCE), and the fourth DMS DIU. The OTA Equipment Section has nine bays: seven for equipment storage and two for support. All bays have outward-opening doors for easy astronaut access, cabling and connectors for the electronics, and heaters and insulation for thermal control.

The EP/TCE System distributes power from the SSM EPS and the OTA system. Thermostats regulate mirror temperatures and prevent mirror distortion from the cold of space. The electrical and thermal electronics also collect thermal sensor data for transmission to the ground.

The three FGE units provide power, commands, and telemetry to each FGS. The electronics perform computations for the sensor and interface with the spacecraft pointing system for effective Telescope line-of-sight pointing and stabilization. There is a guidance electronics assembly for each guidance sensor.

The ACE unit provides the command and telemetry interface to the 24 actuators attached to the primary mirror and to the six actuators attached to the secondary mirror. These electronics select which actuator to move and monitor its response to the command.

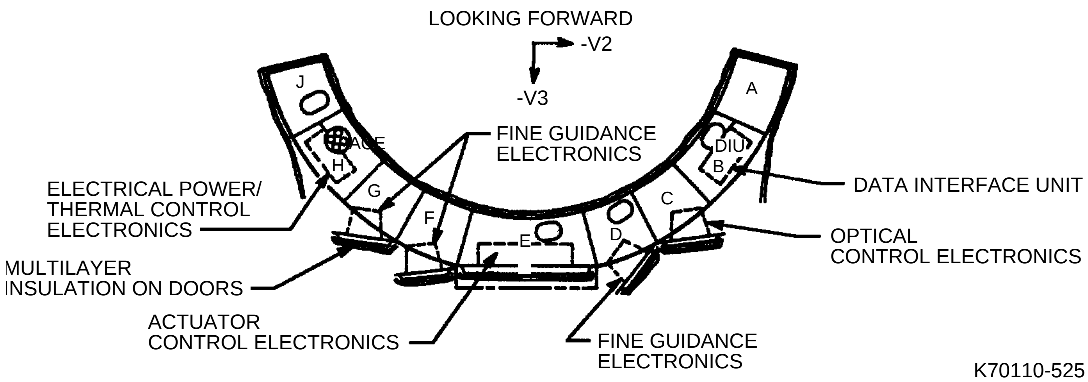

Fig. 5-25 Optical Telescope Assembly Equipment Section

Positioning commands go from the ground to the electronics through the DIU.

The OCE unit controls the optical control sensors. These white-light interferometers measure the optical quality of the OTA and send the data to the ground for analysis. There is one optical control sensor for each FGS, but the OCE unit runs all control sensors. The DIU is an electronic interface between the other OTA electronics units and the Telescope command and telemetry system.

5.3 Fine Guidance Sensor

The three FGSs are located at 90-degree intervals around the circumference of the focal plane structure, between the structure frame and the main ring. Each sensor is 5.4 ft (1.5 m) long and 3.3 ft (1 m) wide and weighs 485 lb (220 kg).

Each FGS enclosure houses a guidance sensor and a wavefront sensor. The wavefront sensors are elements of the optical control sensor used to align and optimize the optical system of the Telescope.

The Telescope's ability to remain pointing at a distant target to within 0.005 arcsec for long periods of time is due largely to the accuracy of the FGSs. They lock on a star and measure any apparent motion to an accuracy of 0.0028 arcsec. This is equivalent to seeing from New York City the motion of a landing light on an aircraft flying over San Francisco.

When two sensors lock on a target, the third measures the angular position of a star, a process called astrometry. Sensor astrometric functions are discussed in Section 4. During SM2 a re-certified FGS (S/N 2001) was installed as a replacement in the HST FGS Bay 1. During SM3A a re-certified FGS (S/N 2002) will be installed in the HST FGS Bay 2.

5.3.1 Fine Guidance Sensor Composition and Function

Each FGS consists of a large structure housing a collection of mirrors, lenses, servos to locate an image, prisms to fine-track the image, beam splitters, and four photomultiplier tubes, as shown in Fig. 5-26. The entire mechanism adjusts to move the Telescope into precise alignment with a target star. Each FGS has a large (60 $arcmin^2$) FOV to search for and track stars, and a 5.0 $arcsec^2$ FOV used by the detector prisms to pinpoint the star.

The sensors work in pairs to aim the Telescope. The Guide Star Selection System, developed by the Science Institute, catalogs and charts guide stars near each observation target to make it

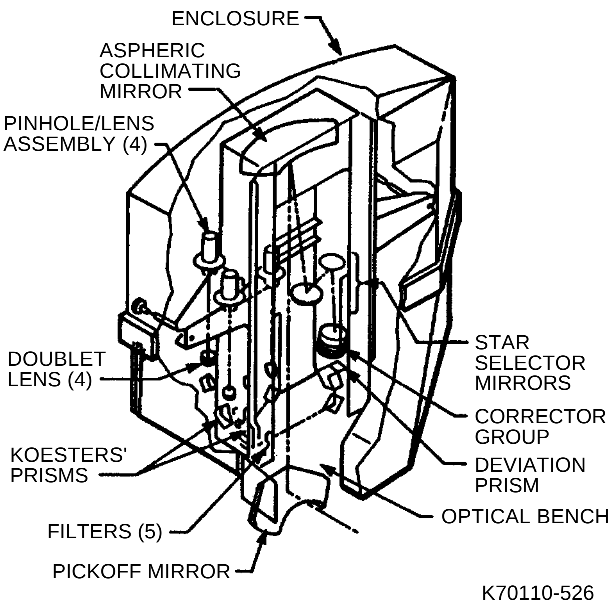

Fig. 5-26 Cutaway view of Fine Guidance Sensor

easier to find the target. First, one sensor searches for a target guide star. After the first sensor locks onto a guide star, the second sensor locates and locks onto another target guide star. The guide stars, once designated and located, keep the image of the observation target in the aperture of the selected science instrument.

Each FGS uses a 90-degree sector of the Telescope's FOV outside the central "science" field. This region of the FOV has the greatest astigmatic and curvature distortions. The size of the FGS's FOV was chosen to heighten the probability of finding an appropriate guide star, even in the direction of the lowest star population near the galactic poles.

An FGS "pickoff" mirror intercepts the incoming stellar image and projects it into the sensor's large FOV. Each FGS FOV has 60 arcmin^2 available. The guide star of interest can be anywhere within this field, so the FGS will look anywhere in that field to find it. After finding the star, the sensor locks onto it and sends error signals to the Telescope, telling it how to move to keep the star image perfectly still.

The FGS can move its line of sight anywhere within its large FOV using a pair of star selector servos. Each can be thought of as an optical gimbal: One servo moves in a north-south direction, the other east and west. They steer the small FOV (5 arcsec^2) of the FGS detectors to any position in the sensor field. Encoders within each servo system send back the exact coordinates of the detector field centers at any point.

Because the exact location of a guide star may be uncertain, the star selector servos also can cause the detector to search the region around the most probable guide star position. It searches in a spiral pattern, starting at the center and spiraling out until it finds the guide star it seeks. Then the detectors are commanded to go into fine-track mode and hold the star image exactly centered in the FOV, while the star selector servo encoders send information about the position of the star to the spacecraft PCS.

The detectors are a pair of interferometers, called Koester's prisms, coupled to photomultiplier tubes (see Fig. 5-27). Each detector operates in one axis, so two detectors are needed. Operating on the incoming wavefront from the distant guide star, the interferometers compare the wave phase at one edge of the Telescope's entrance aperture with

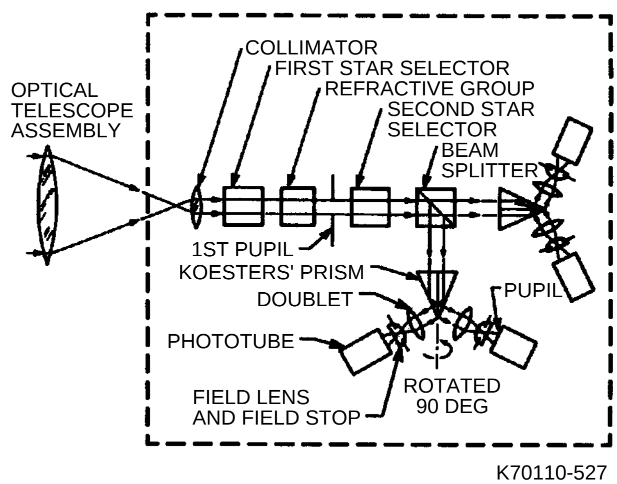

Fig. 5-27 Optical path of Fine Guidance Sensor

the phase at the opposite edge. When the phases are equal, the star is exactly centered. Any phase difference shows a pointing error that must be corrected.

Along the optical path from Telescope to detector are additional optical elements that turn or fold the beam to fit everything inside the FGS enclosure, and to correct the Telescope's astigmatism and field curvature. All optical elements are mounted on a temperature-controlled, graphite-epoxy composite optical bench.

5.3.2 Articulated Mirror System

Analysis of the FGS on-orbit data revealed that minor misalignments of the optical pupil centering on Koester's prism interferometer in the presence of spherical aberration prevented the FGS from achieving its optimum performance. During the recertification of FGS (S/N 2001), fold flat #3 in the radial bay module optical train was mechanized to allow on-orbit alignment of the pupil.

Implementation of this system utilized existing signals and commands by rerouting them with a unique interface harness enhancement kit (OCE-EK) interfacing the OCE, the DIU, and the Fine Guidance System/Radial Bay Module (FGS/RBM). The OCE-EK was augmented with the Actuator Mechanism Electronics (AME) and the fold flat #3 Actuator Mechanism Assembly (AMA) located internal to the FGS/RBM. Ground tests indicate a substantial increase in performance of the FGS with this innovative design improvement.

5.4 Solar Array and Jitter Problems

From the beginning, in the late 1970s, the SAs – designed by the European Space Agency and built by British Aerospace, Space Systems – have been scheduled for replacement because of their power loss from radiation exposure in space. However, as engineers put the Telescope through its paces in April 1990, they discovered two problems: a loss of focus and images that jittered briefly when the Telescope flew into and out of Earth's shadow. The jitter problem was traced to the two large SAs. Abrupt temperature changes, from -150 to 200 degrees Fahrenheit during orbit, cause the panels to distort twice during each orbit. As a temporary fix, engineers created software that commanded the PCS to compensate for the jitter automatically. The problem was mitigated during SM1 by the replacement of the old arrays with new ones that had been modified to reduce thermal swings of the bi-stems.

5.4.1 Configuration

The SAs are two large rectangular wings of retractable solar cell blankets fixed on a two-stem frame. The blanket unfurls from a cassette in the middle of the wing. A spreader bar at each end of the wing stretches the blanket and maintains tension. For the replacement SAs delivered to the Telescope during the First Servicing Mission, the spring-loaded roller assembly was replaced by a series of springs connecting the spreader bar to the blanket. This change eliminated the jitter induced into the Telescope as it passed from eclipse (night) into sunlight (day) each orbit.

The wings are on arms that connect to a drive assembly on the SSM forward shell at one end and to the secondary deployment mechanism (blankets and bistems) on the other end. The total length of the cassette, arm, and drive is 15.7 ft (4.8 m) (see Fig. 5-28).

Each wing has 10 panels that roll out from the cassette. The panels are made of 2438 solar cells

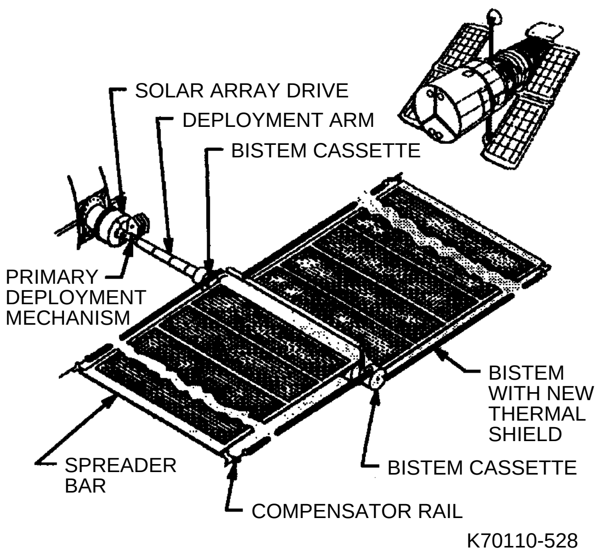

Fig. 5-28 Solar Array wing detail

attached to a glass-fiber/Kapton surface, with silver mesh wiring underneath, covered by another layer of Kapton. The blankets are less than 500 micrometers thick, so they roll up tightly when the wings are stowed. Each wing weighs 17 lb (7.7 kg) and, at full extension, is 40 ft (12.1 m) long and 8.2 ft (2.5 m) wide.

5.4.2 Solar Array Subsystems

The SA subsystems include the primary and secondary deployment mechanisms, their drives, and associated electronics.

The primary deployment mechanism raises the SA mast from the side of the SSM to a standing position perpendicular to the Telescope. There are two mechanisms, one for each wing. Each mechanism has motors to raise the mast and supports to hold it in place when erect.

An astronaut can raise the array mast manually if the drive power fails. Using a wrench fitting on the deployment drive, the astronaut hand-cranks the mast after releasing the latches.

Once the SA is raised, the secondary deployment mechanism unfurls the wing blankets. Each wing has a secondary mechanism assembly: a cassette drum to hold solar panels, a cushion to protect the blanket, and motors and subassemblies. The assembly rolls out the blanket, applies tension evenly so the blankets stretch, and transfers data and power along the wing assembly. The blanket can roll out completely or part way. The secondary deployment mechanism also has a manual override (see Fig. 5-29).

A SA drive at the base of each mast rotates the deployed array toward the Sun, turning in either direction. Each drive has a motor that rotates the mast on command and a brake to keep the array in a fixed position with respect to the Telescope. The drive can move and lock the SA into any position.

Each drive has a clamp ring that acts as a release mechanism if opened. This allows a crew member to jettison the entire SA if necessary.

Two electronics assemblies (boxes) – the Solar Array Deployment Electronics and the Solar Array Drive Electronics – control and monitor all functions of each SA. They provide the electronic interface to the other Telescope systems and generate the commands for the primary and secondary deployment mechanisms and the SA drive.

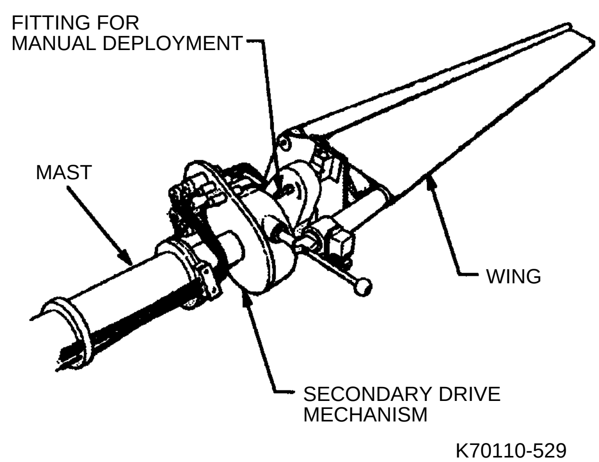

Fig. 5-29 Fitting for Solar Array manual deployment

5.4.3 Solar Array Configuration for Servicing Mission 3A

The Solar Array wings will remain deployed during servicing. This will allow the Telescope's batteries to remain fully charged during the mission and will not impact servicing activities.

5.5 Science Instrument Control and Data Handling Unit

The SI C&DH unit keeps all science instrument systems synchronized. It works with the DMU to process, format, temporarily store on the data recorders, or transmit all science and engineering data created by the instruments to the ground. Fairchild Camera and Instrument Corporation and IBM built this unit.

5.5.1 Components

The SI C&DH unit is a collection of electronic components attached to an ORU tray mounted on the door of Bay 10 in the SSM Equipment Section (see Fig. 5-30). Small Remote Interface Units (RIU), also part of the system, provide the interface to individual science instruments. Components of the SI C&DH unit are the NASA Standard Spacecraft Computer (NSCC-I), two standard interface circuit boards for the computer, two control units/science data formatter units, two CPU modules, a PCU, two RIUs, and various memory, data, and command communications lines (buses) connected by couplers. The SI C&DH components are redundant so the system can recover from any single failure.

NASA Computer. The NSSC-I has a CPU and eight memory modules, each holding 8,192 eighteen-bit words. One embedded software program (the "executive") runs the computer. It moves data, commands, and operation programs (called applications) for individual science instruments in and out of the processing unit. The application programs monitor and control specific instruments and analyze and manipulate the collected data.

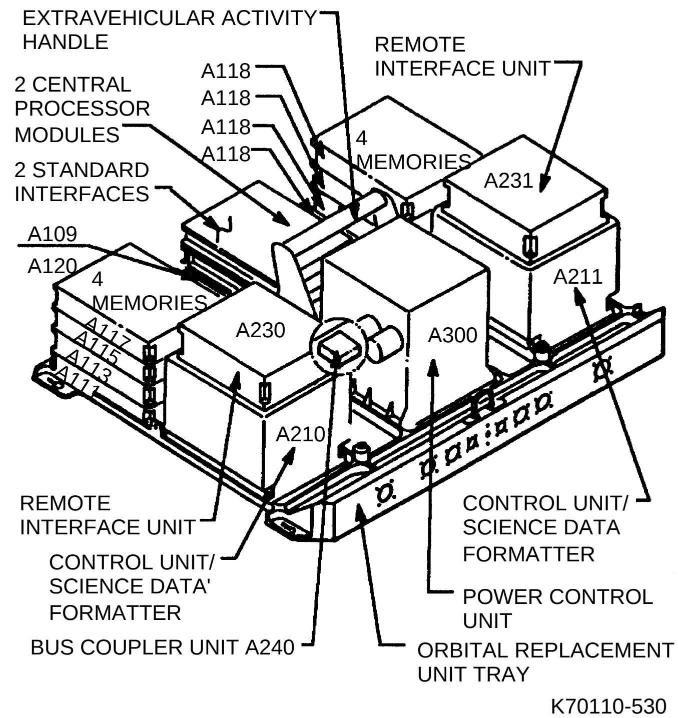

Fig. 5-30 Science Instrument Control and Data Handling unit

The memory stores operational commands for execution when the Telescope is not in contact with the ground. Each memory unit has five areas reserved for commands and programs unique to each science instrument. The computer can be reprogrammed from the ground for future requests or for working around failed equipment.

Standard Interface Unit. The standard interface board is the communications bridge between the computer and the CU/SDF.

Control Unit/Science Data Formatter. The heart of the SI C&DH unit is the CU/SDF. It formats and sends all commands and data to designated destinations such as the DMU of the SSM, the NASA computer, and the science instruments. The unit has a microprocessor for control and formatting functions.

The CU/SDF receives ground commands, data requests, science and engineering data, and system signals. Two examples of system signals are "time tags," clock signals that synchronize the entire spacecraft, and "processor interface tables," or communications codes. The CU/SDF transmits commands and requests after formatting them so that the specific destination unit can read. For example, ground commands and SSM commands are transmitted with different formats. Ground commands use 27-bit words, and SSM commands use 16-bit words. The formatter translates each command signal into a common format. The CU/SDF also reformats and sends engineering and science data. Onboard analysis of the data is an NSSC-I function.

Power Control Unit. The PCU distributes and switches power among components of the SI C&DH unit. It conditions the power required by each unit. For example: The computer memory boards typically need +5 volts, -5 volts, and +12 volts; the CU/SDF, on the other hand, requires +28 volts. The PCU ensures that all voltage requirements are met.

Remote Interface Units. RIUs transmit commands, clock and other system signals, and engineering data between the science instruments and the SI C&DH unit. The RIUs do not send science data. There are six RIUs in the Telescope: five attached to the science instruments and one dedicated to the CU/SDF and PCUs in the SI C&DH unit. Each RIU can be coupled with up to two expander units.

Communications Buses. The SI C&DH unit contains data bus lines that pass signals and data between the unit and the science instruments. Each bus is multiplexed: one line sends system messages, commands, and engineering data requests to the module units, and a reply line transmits requested information and science data back to the SI C&DH unit. A coupler attaches the bus to each remote unit. This isolates the module if the RIU should fail. The SI C&DH coupler unit is on the ORU tray.

5.5.2 Operation

The SI C&DH unit handles science instrument system monitoring (such as timing and system checks), command processing, and data processing.

System Monitoring. Engineering data tells the monitoring computer whether instrument systems are functioning. At regular intervals, varying from every 500 milliseconds to every 40 seconds, the SI C&DH unit scans all monitoring devices for engineering data and passes data to the NSCC-I or SSM computer. The computers process or store the information. Any failure indicated by these constant tests could initiate a "safing hold" situation (see para 5.1.7), and thus a suspension of science operations.

Command Processing. Figure 5-31 shows the flow of commands within the SI C&DH unit. Commands enter the CU/SDF (bottom right in the drawing) through the SSM Command DIU (ground commands) or the DIU (SSM commands). The CU/SDF checks and reformats the commands, which then go either to the RIUs or to the NSCC-I for storage. "Time-tagged" commands, stored in the computer's memory (top right of drawing), also follow this process.

Each command is interpreted as "real time," as if the SI C&DH just received it. Many commands actually are onboard stored commands activated by certain situations. For example, when the Telescope is positioned for a programmed observation using the Space Telescope Imaging Spectrograph, that program is activated. The SI C&DH can issue certain requests to the SSM, such as to execute a limited

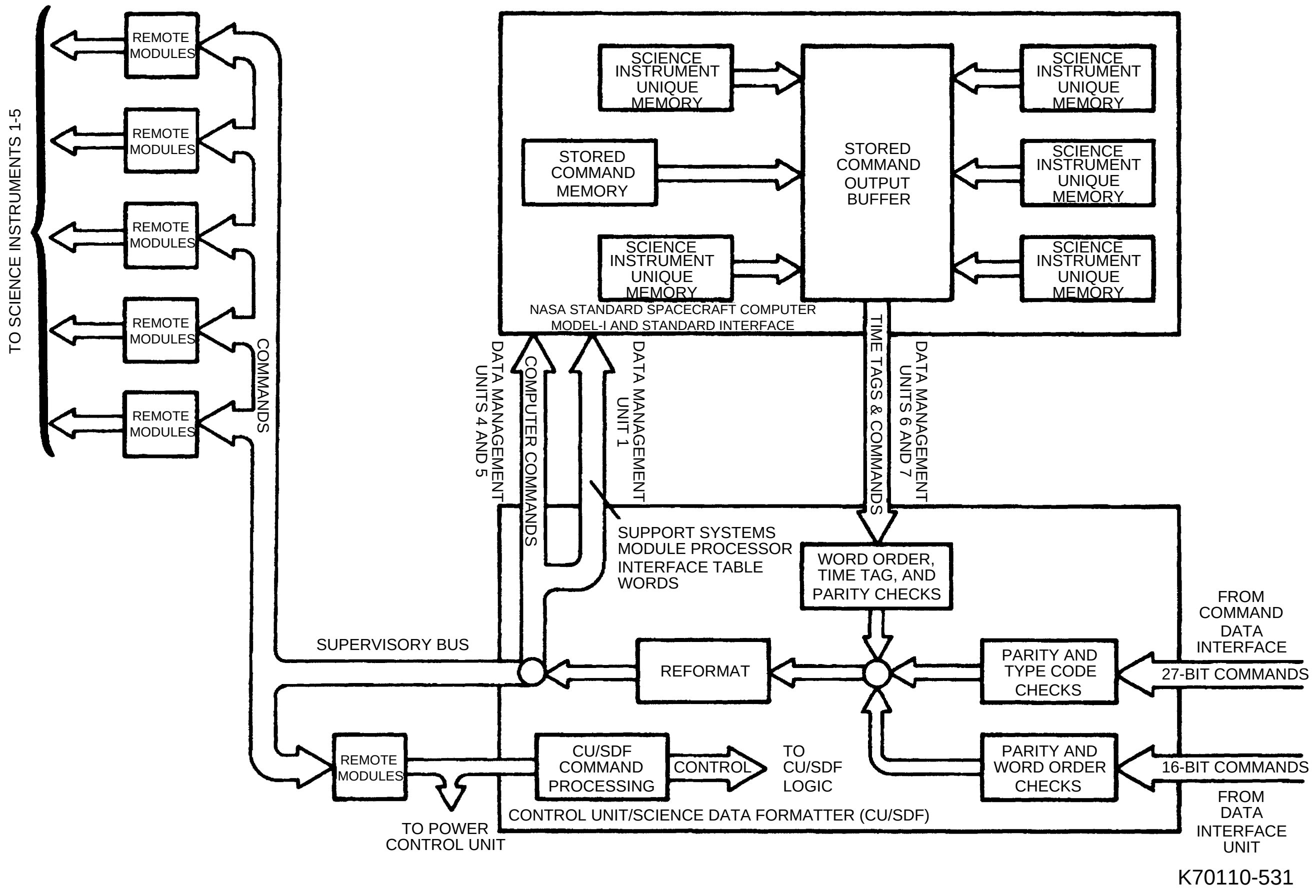

Fig. 5-31 Command flow for Science Instrument Control and Data Handling unit

number of pointing control functions to make small Telescope maneuvers.

Science Data Processing. Science data can come from all science instruments at once. The CU/ SDF transfers incoming data through computer memory locations called packet buffers. It fills each buffer in order, switching among them as the buffers fill and empty. Each data packet goes from the buffer to the NSCC-I for further processing, or directly to the SSM for storage in the data recorders or transmission to the ground. Data returns to the CU/SDF after computer processing. When transmitting, the CU/ SDF must send a continuous stream of data, either full packet buffers or empty buffers called filler packets, to maintain a synchronized link with the SSM. Special checking codes (Reed-Solomon and pseudo-random noise) can be added to the data as options. Figure 5-32 shows the flow of science data in the Telescope.

5.6 Space Support Equipment

The Hubble Space Telescope was designed to be maintained, repaired, and enhanced while in orbit, extending its life and usefulness. For servicing, the Space Shuttle will capture and position the Telescope vertically in the aft end of the cargo bay, and the crew will perform maintenance and replacement tasks. The Space Support Equipment (SSE) to be used during the mission provides a maintenance platform to hold the Telescope, provides electrical support of the Telescope during servicing, and provides storage for replacement components known as ORUs.

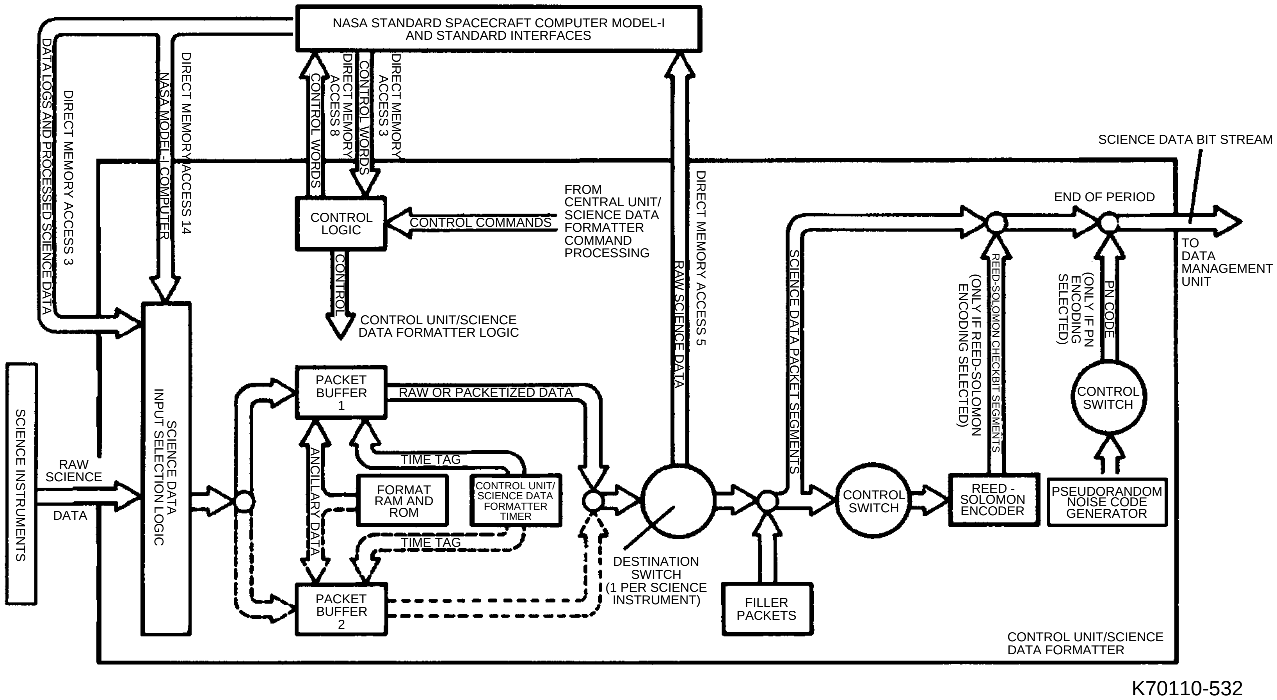

Fig. 5-32 Flow of science data in the Hubble Space Telescope

The major SSE items used for the Servicing Mission 3A are the Flight Support System (FSS) and the ORU Carrier (ORUC). Additionally, crew aids and tools will be used during servicing.

5.6.1 Flight Support System

The FSS provides the platform that holds the Telescope during servicing (see Fig. 5-33). The FSS has been used in different configurations for the HST First and Second Servicing Missions, the Solar Maximum Repair Mission, and the Upper Atmospheric Research Satellite Deploy Mission. The FSS consists of two major components: a horseshoe-shaped cradle and a supporting latch beam providing a structural and electrical interface with the Shuttle. A circular ring called the Berthing and Positioning System (BAPS) interfaces with the Telescope, allowing it to pivot or rotate during the mission.

The BAPS ring is pivoted down and locked for liftoff. During the mission, the ring is pivoted up to a horizontal position. A closed-circuit television camera mounted to the FSS helps astronauts guide the Telescope onto the ring. Three remote-controlled latches on the ring grab and hold three towel-rack-like pins on the rear of the Telescope. A remote-controlled electrical umbilical connector on the FSS engages the Telescope, providing it with orbiter power through the FSS. This power helps relieve the drain on the Telescope's batteries during the mission. Radio communications provide telescope telemetry data and control.

Once the Telescope is berthed to the ring (see Fig. 5-34), the FSS can pivot (tilt) or rotate the Telescope. This positions the appropriate region of the Telescope for access during extravehicular activity. Additionally, the ring can pivot the Telescope to an appropriate attitude for orbiter reboost.

During the first EVA, crew members will install the BAPS Support Post (BSP). The BSP provides an additional linkage to support and isolate the

FSS – AFT VIEW

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

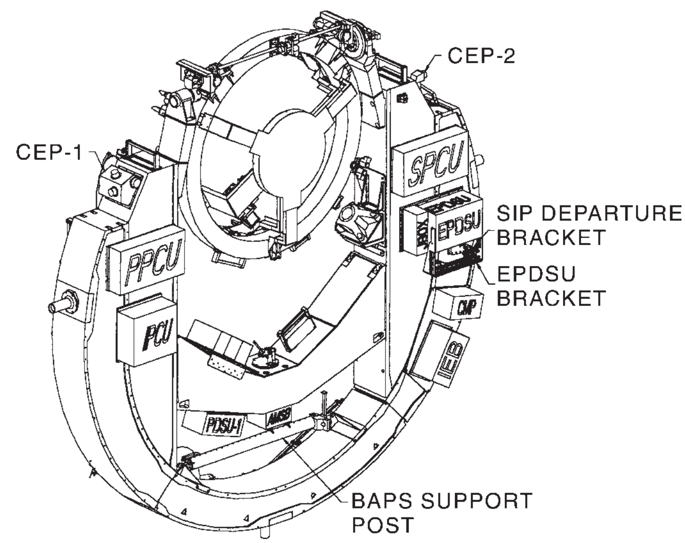

Fig. 5-33 Flight Support System configuration

Telescope during EVAs and for any orbital reboosts. The BSP will remain in position for landing.

Astronauts remotely control all FSS mechanisms – berthing latches, umbilical connector, pivoter, BSP lock, rotator, and ring down-lock – from the orbiter's aft flight deck, providing the crew maximum flexibility. Besides being fully electrically redundant, each mechanism contains manual overrides and backups to ensure mission success and astronaut safety.

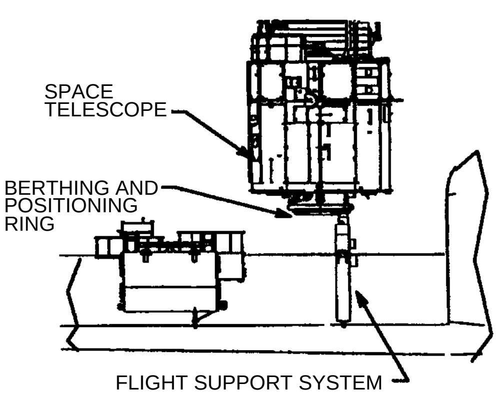

Fig. 5-34 Flight Support System Berthing and Positioning System ring pivoted up with Telescope berthed

5.6.2 Orbital Replacement Unit Carrier

An ORUC is used to carry replacements into orbit and to return replaced units to Earth. The carrier consists of a Spacelab pallet outfitted with shelves and protective enclosures to hold the replacement units (see Fig. 5-35). Items on the ORUC for SM3A include (1) the Advanced Computer and two spare VIKs in the LOPE and (2) a Solid State Recorder, an S-Band Single Access Transmitter, the Rate Sensor Units, and associated flight harnesses in the COPE.

The FGS will be transported in the FGS Scientific Instrument Protective Enclosure (FSIPE). A spare Advanced Computer, a spare Rate Sensor Unit, and Multi-Layer Insulation patches will be carried in the Axial Scientific Instrument Protective Enclosure (ASIPE). The NOBL will be carried in a NOBL Protective Enclosure (NPE).

All ORUs and scientific instruments are carried within protective enclosures to provide them a benign environment throughout the mission.

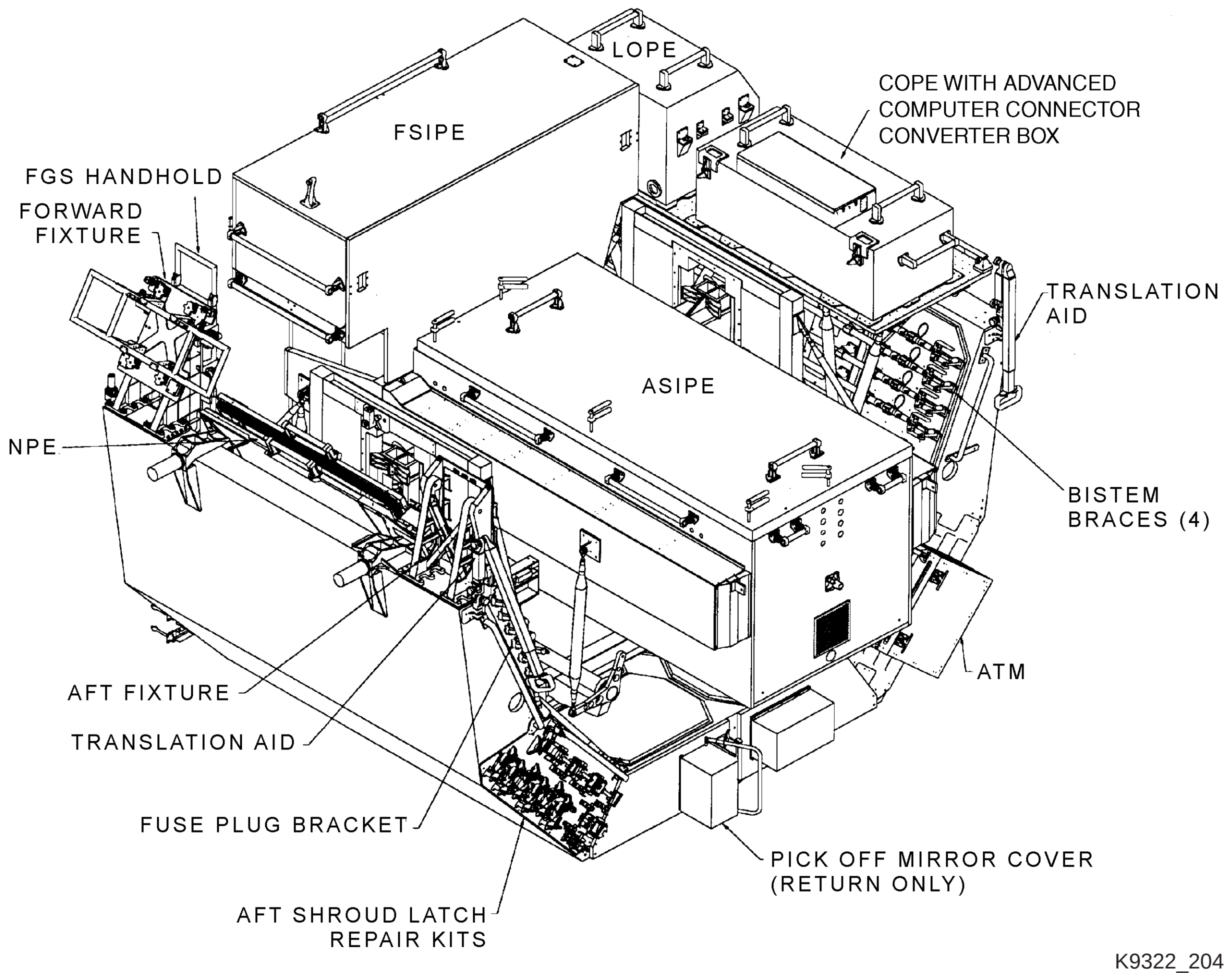

Fig. 5-35 Orbital Replacement Unit Carrier

The enclosures protect the instruments from contamination and maintain the temperature of the instruments or ORUs within tight limits.

Instruments are mounted in the enclosures using the same manually driven latch system that holds instruments in the Telescope. The ASIPE and FSIPE are mounted to the pallet on a spring system that reduces the level of vibration the instruments receive, especially during liftoff and landing.

The other ORUs are carried in an additional enclosure called the Large ORU Protective Enclosure (LOPE). The enclosure also provides contamination and thermal control, though not to such stringent requirements as the SIPE. The LOPE contains Transport Modules that are designed to custom fit each ORU. The transport modules have foam or Visco-Elastic Material that surrounds the ORU and isolates it from launch and landing vibration environments.

During the change-out process, replaced science instruments are stored temporarily in the ORUC. A typical change-out begins with an astronaut removing the old instrument from the Telescope and attaching it to a bracket on the ORUC. The astronaut then removes the new instrument from its protective enclosure and installs it in the Telescope. Finally, the astronaut places the old instrument in the appropriate protective enclosure for return to Earth.

The ORUC receives power for its TCS from the FSS. The carrier also provides temperature telemetry data through the FSS for readout in the Shuttle and on the ground during the mission.

5.6.3 Crew Aids

Astronauts perform extravehicular activities using many tools to replace instruments and equipment, to move around the Telescope and the cargo bay, and to operate manual override drives. Tools and equipment, bolts, connectors, and other hardware were standardized not only for the Telescope but also between the Telescope and the Shuttle. For example, grappling receptacles share common features.

To move around the Telescope, the crew uses 225 ft of handrails encircling the spacecraft. For visibility, the rails are painted yellow. In addition, the crew can hold onto guiderails, trunnion bars, and scuff plates fore and aft.

The astronauts can install portable handhold plates where there are no permanent holds, such as on the FGS. Another tool is the Portable Foot Restraint (PFR), shown in Fig. 5-36.

While the astronauts work, they use tethers to hook tools to their suits and tie replacement units to the Telescope. Each crew member has a ratchet wrench to manually crank the antenna and array masts if power for the mast drives fails. A power wrench also is available if hand-cranking is too time consuming. Other hand tools include portable lights and a jettison handle, which attach to sockets on the aperture door and to SA wings so the crew can push the equipment away from the Telescope.

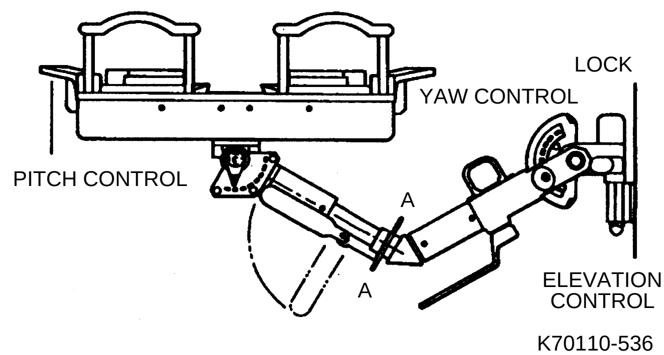

Fig. 5-36 Portable Foot Restraint