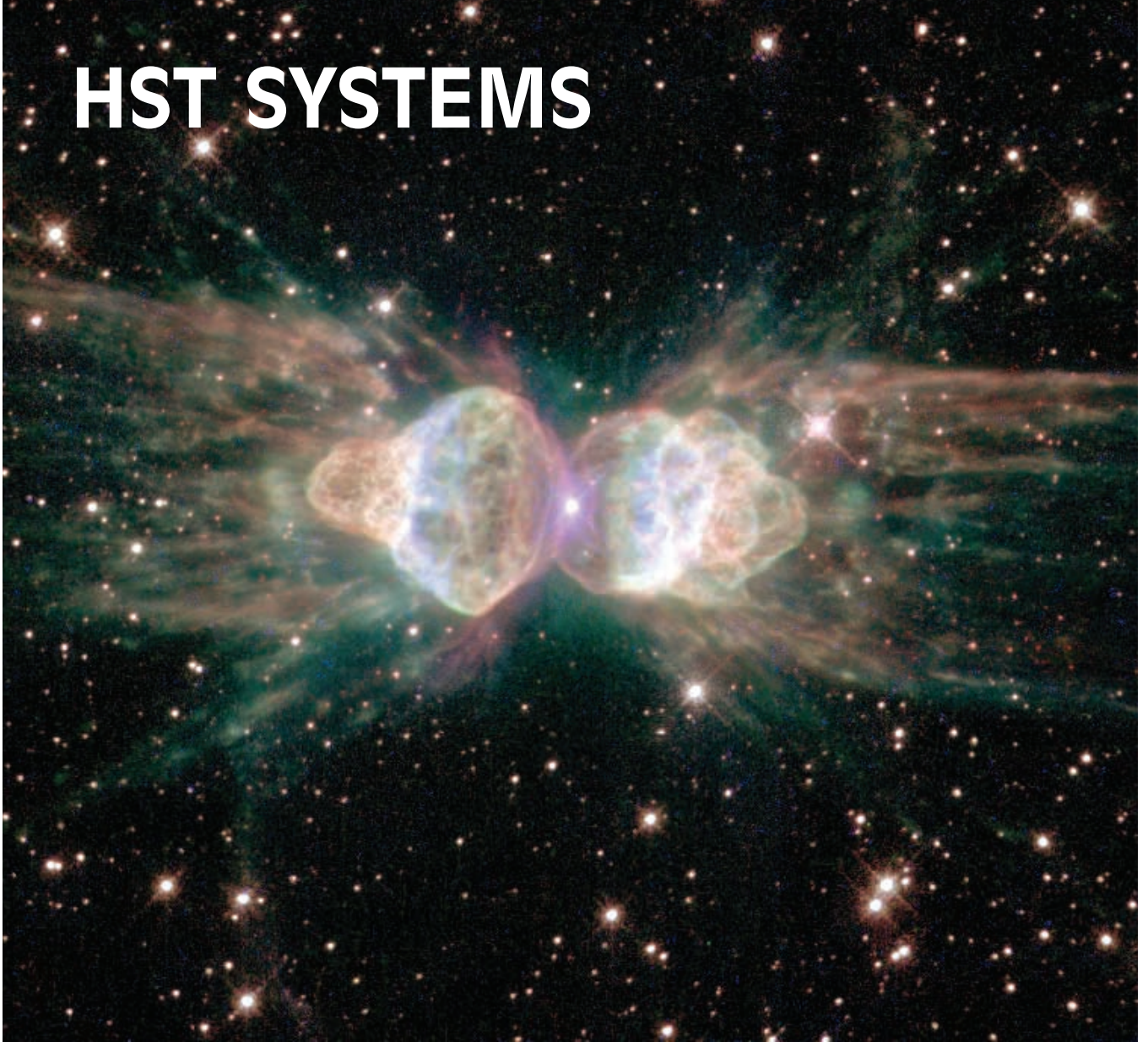


# HST SYSTEMS



**T**he Hubble Space Telescope (HST) performs much like a ground astronomical observatory. It has three interacting systems:

- Support Systems Module (SSM), an outer structure that houses the other systems and provides services such as electrical power, data communications, pointing control and maneuvering.
- Optical Telescope Assembly (OTA), which collects and concentrates 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. The Science Instrument

Control and Data Handling (SI C&DH) unit controls all the instruments except the Fine Guidance Sensors (FGS).

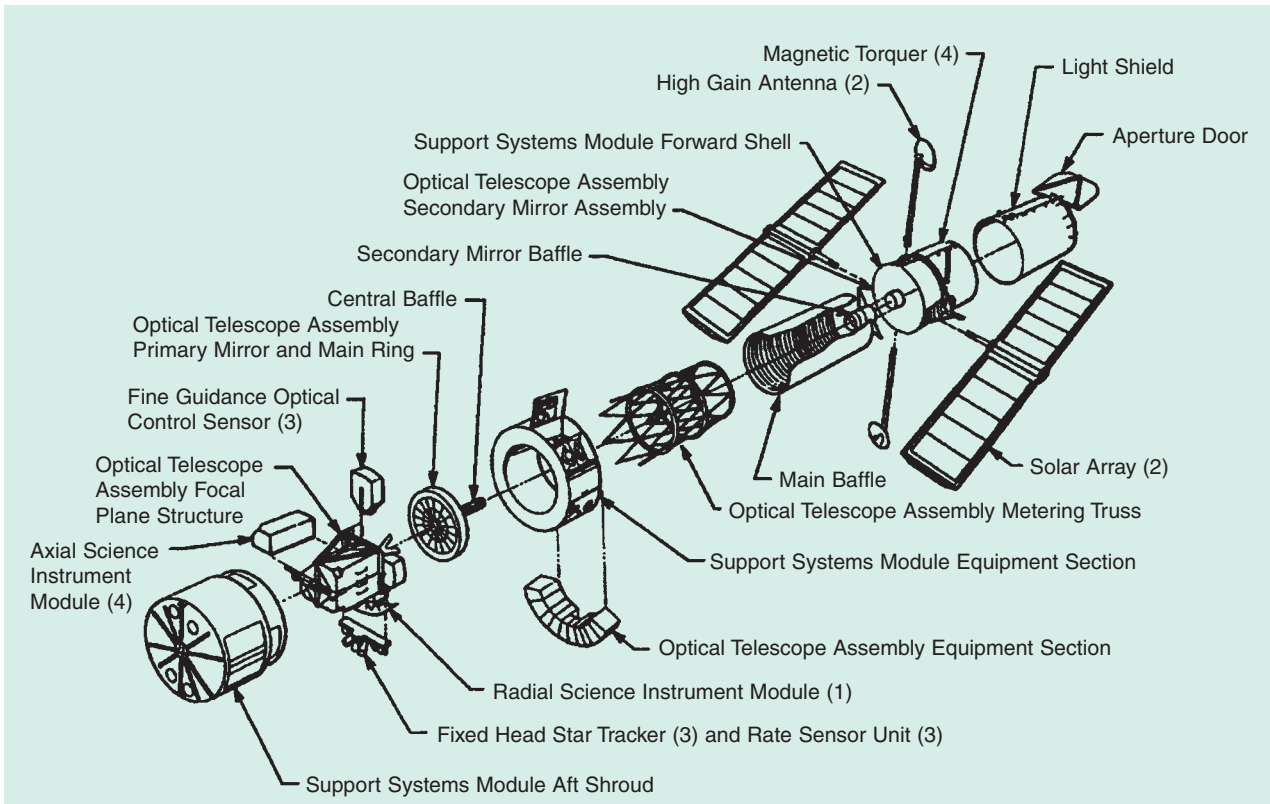
The SSM communicates with the OTA, SI C&DH unit and instruments to ready an observation. Light from an observed target passes through the Telescope and into one or more of the science instruments, where the light is recorded. This information goes to onboard computers for processing, then it is either temporarily stored or sent to Earth in real time, via the spacecraft communication system.

Two Solar Arrays (SA) also support HST operations. They generate electrical power and charge onboard batteries and

communications antennas to receive commands and send telemetry data from the HST.

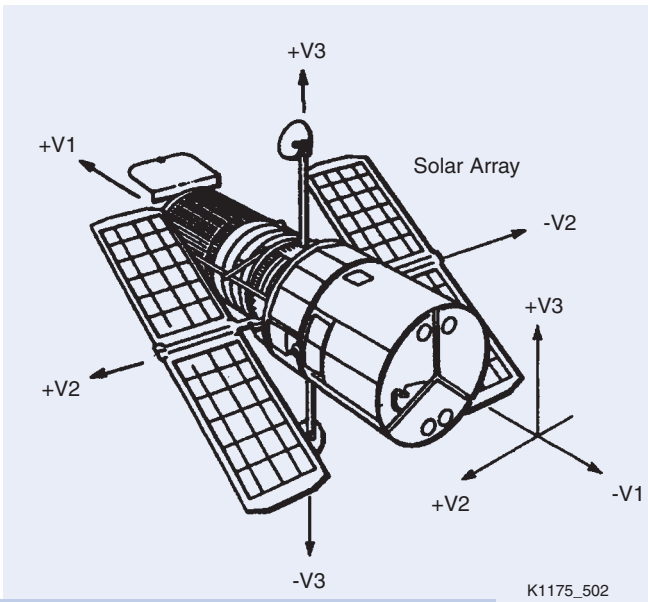
Figure 5-1 shows the HST configuration.

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



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**Fig. 5-1** Hubble Space Telescope – exploded view



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**Fig. 5-2** Hubble Space Telescope axes

**Support Systems Module**

Design features of the SSM include:

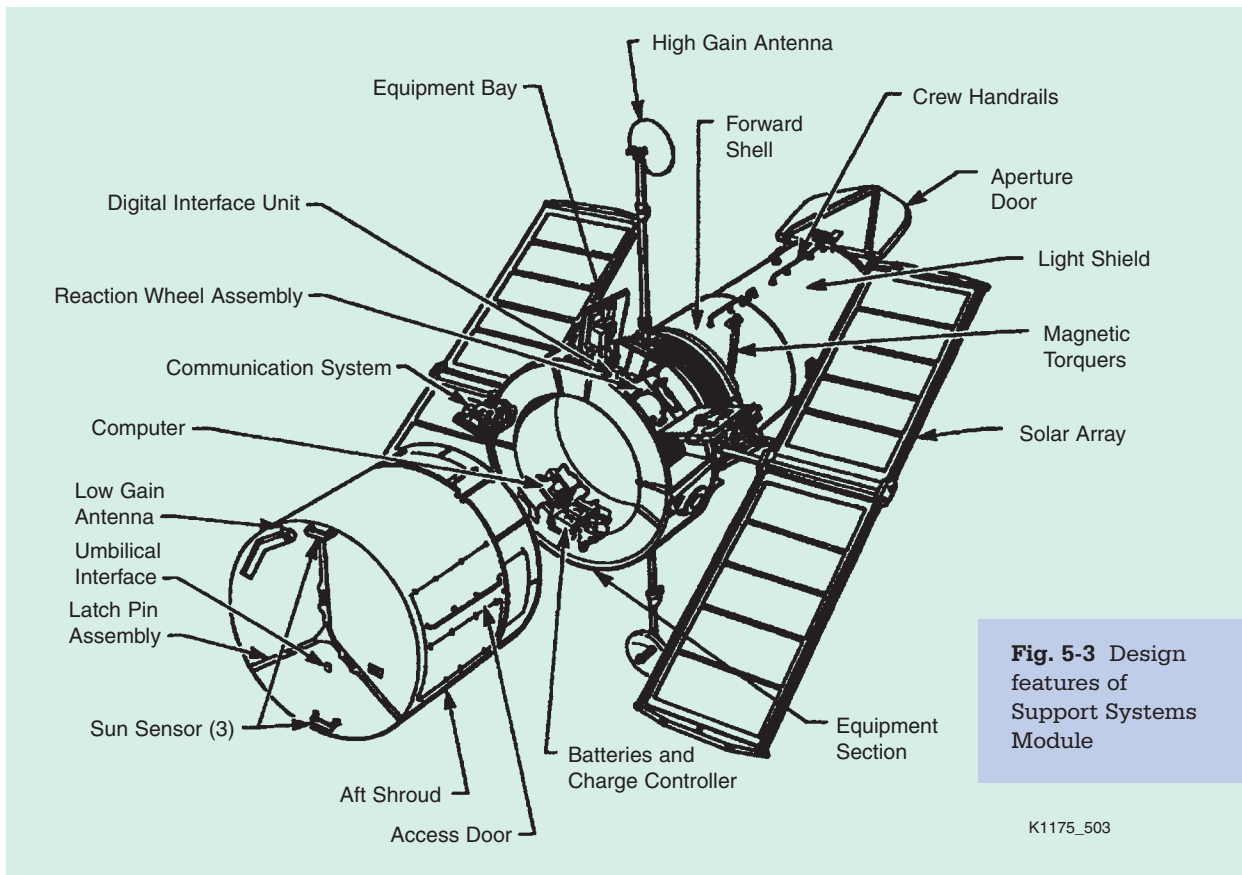
- An outer structure of interlocking shells
- Reaction wheels and magnetic torquers to maneuver, orient and attitude stabilize the Telescope

- 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 on page 5-19, OTA Equipment Section.)
- Computers to operate the spacecraft systems and handle data
- 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.



**Fig. 5-3** Design features of Support Systems Module

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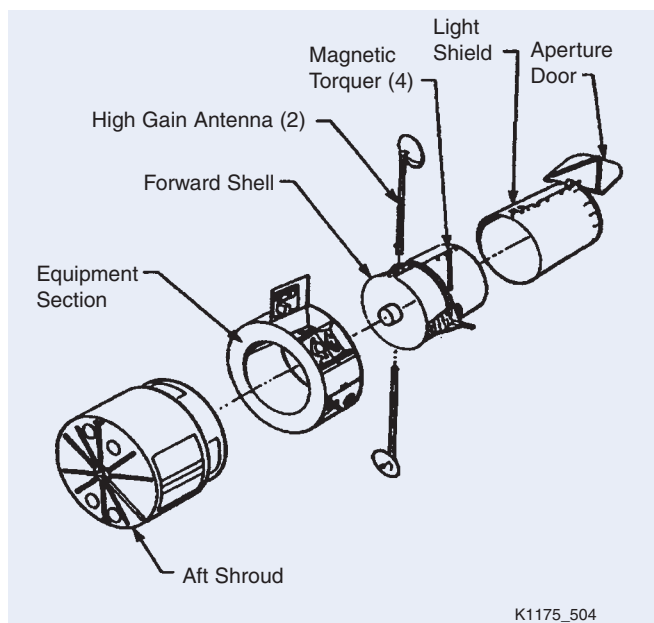
### Structures and Mechanisms Subsystem

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 Space Systems Company (see Fig. 5-4).

**Aperture Door.** A door approximately 10 feet (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 when the Sun is within  $\pm 35$  degrees of the +V1 axis and is closed by the time the sun reaches 20 degrees of +V1. This takes no longer than 60 seconds.

The Space Telescope Operations Control Center (STOCC) can override the protective door-closing mechanism for observations that fall within the 20-

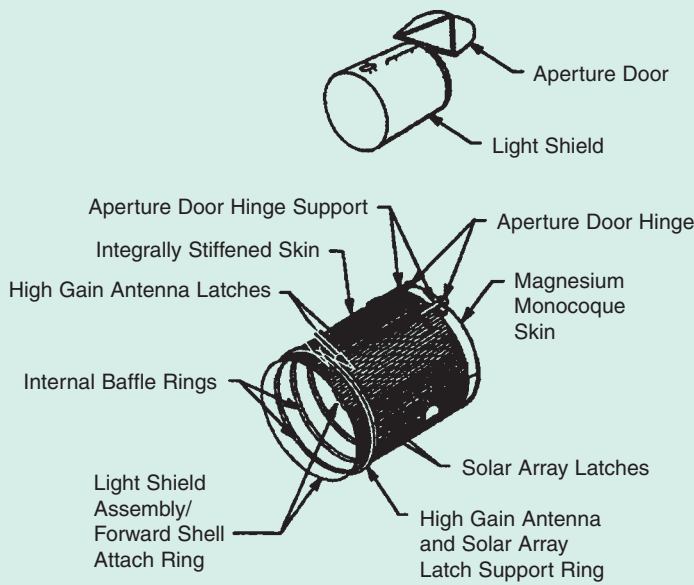


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**Fig. 5-4** Structural components of Support Systems Module

degree limit. An example is observing a bright object, using the dark limb (edge) of the Moon to partially block the light.

**Light Shield.** Used to block out stray light, the light shield (see Figs. 5-4 and 5-5) connects to both the aperture door and the forward shell. The outer skin of the Telescope has latches to secure the SAs and



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**Fig. 5-5** Aperture door and light shield

Machined from aluminum plating, the forward shell is 13 feet (4 m) long and 10 feet (3 m) in diameter. It has internal stiffened panels and external reinforcing rings. These 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. It contains 10 bays for equipment and two bays to support aft trunnion pins and scuff plates. As shown in Fig. 5-7, clockwise from the +V3 (top) position, the bays contain:

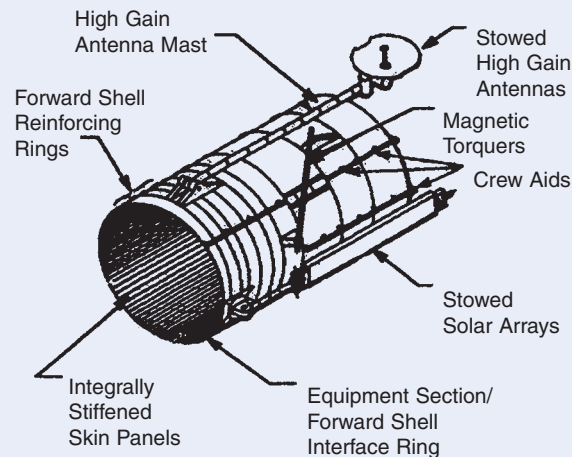
1. Bay 8 – pointing control hardware
2. Bay 9 – Reaction Wheel Assembly (RWA)
3. Bay 10 – SI C&DH unit
4. Unnumbered trunnion support bay
5. Bay 1 – data management hardware

HGAs when they are stowed. Near the SA latches are scuff plates—large protective metal plates on struts that extend approximately 30 inches 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.

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 shield measures 13 feet (4 m) long and 10 feet (3 m) in internal diameter. It is a stiffened, corrugated-skin barrel machined from magnesium and 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



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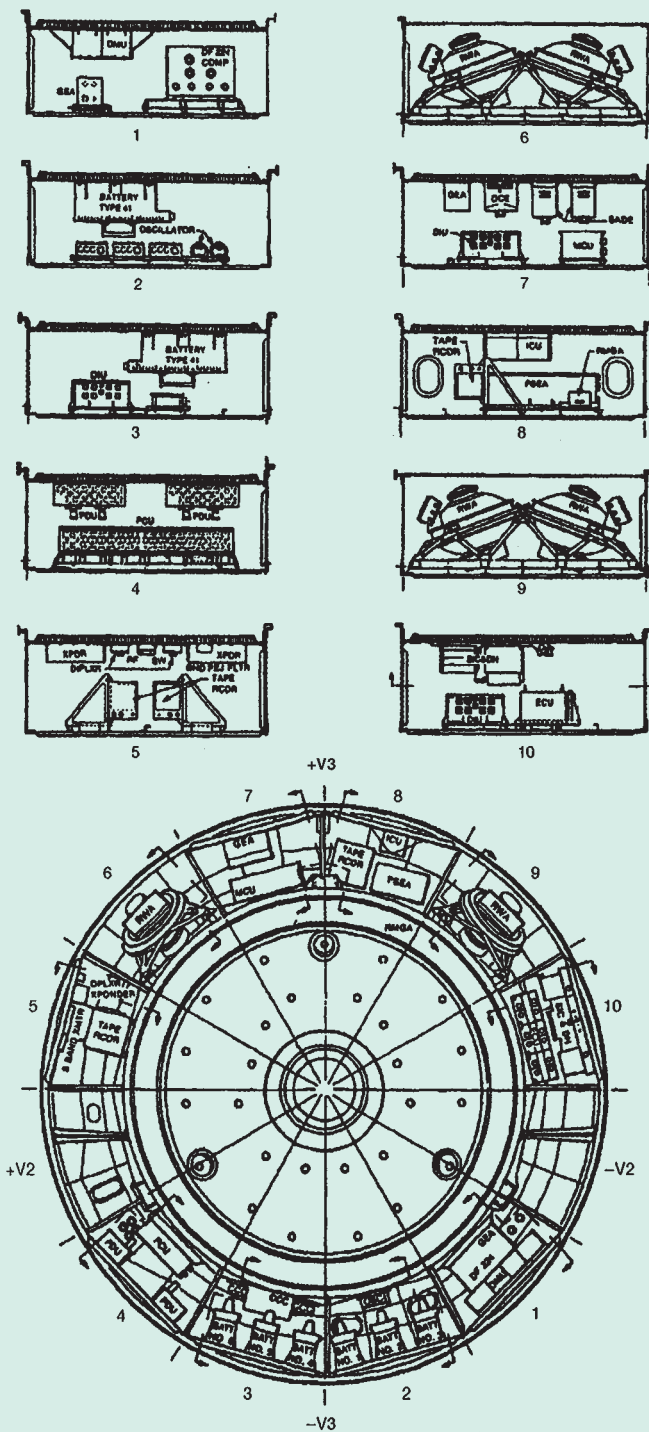
**Fig. 5-6** Support Systems Module forward shell

6. Bays 2, 3 and 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: the outer diameter (the door) is 3.6 feet (1 m) and the inner diameter is 2.6 feet (0.78 m). The bays are 4 feet (1.2 m) wide and 5 feet (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 astronauts to remove and change equipment and instruments easily. Handrails and foot restraints for the crew run along the length and circumference of the shroud. During maintenance or removal of an instrument,



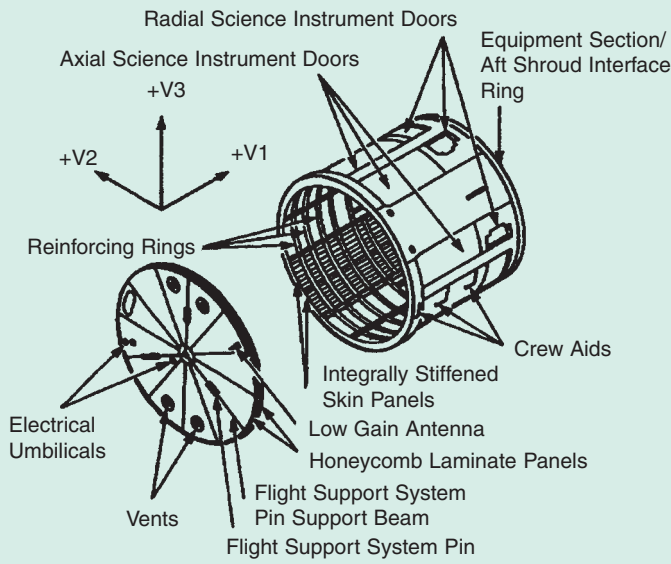
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**Fig. 5-7** Support Systems Module Equipment Section bays and contents

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 feet

(3.5 m) long and 14 feet (4.3 m) in diameter.

The aft bulkhead contains the umbilical connections between the Telescope and the Shuttle, used during on-orbit maintenance. The rear LGA attaches



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

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 to prevent stray light 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. Stepper motors called Rotary Drive Actuators (RDA) drive the latches.

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.

### 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 passes through the Data Management Subsystem (DMS).

#### S-Band Single Access

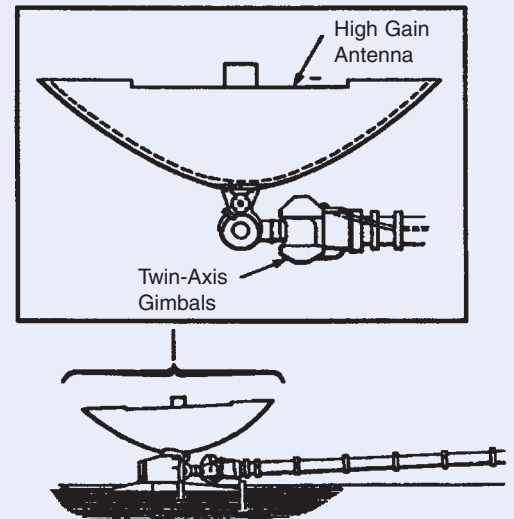
**Transmitter (SSAT).** HST is equipped with two SSATs.

“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 manufactured the antenna dishes using honeycomb aluminum and graphite-epoxy facesheets.

The HGAs achieve a much higher RF signal gain than the LGAs. The higher signal gain is required, for example, when transmitting high-data-rate scientific data. Because of their characteristically narrow beam widths, the HGAs must be pointed at the TDRSs. Each antenna can be aimed with a 1-degree pointing accuracy. This accuracy is consistent with the overall antenna beam width of over 4 degrees. The antennas



**Fig. 5-9** High Gain Antenna

transmit over two frequencies: 2255.5 MHz or 2287.5 MHz (plus or minus 10 MHz).

**Low Gain Antennas.** The LGAs are spiral cones, manufactured by Lockheed Martin, that provide spherical coverage (omnidirectional). They are set 180 degrees apart on the light shield and aft bulkhead of the spacecraft.

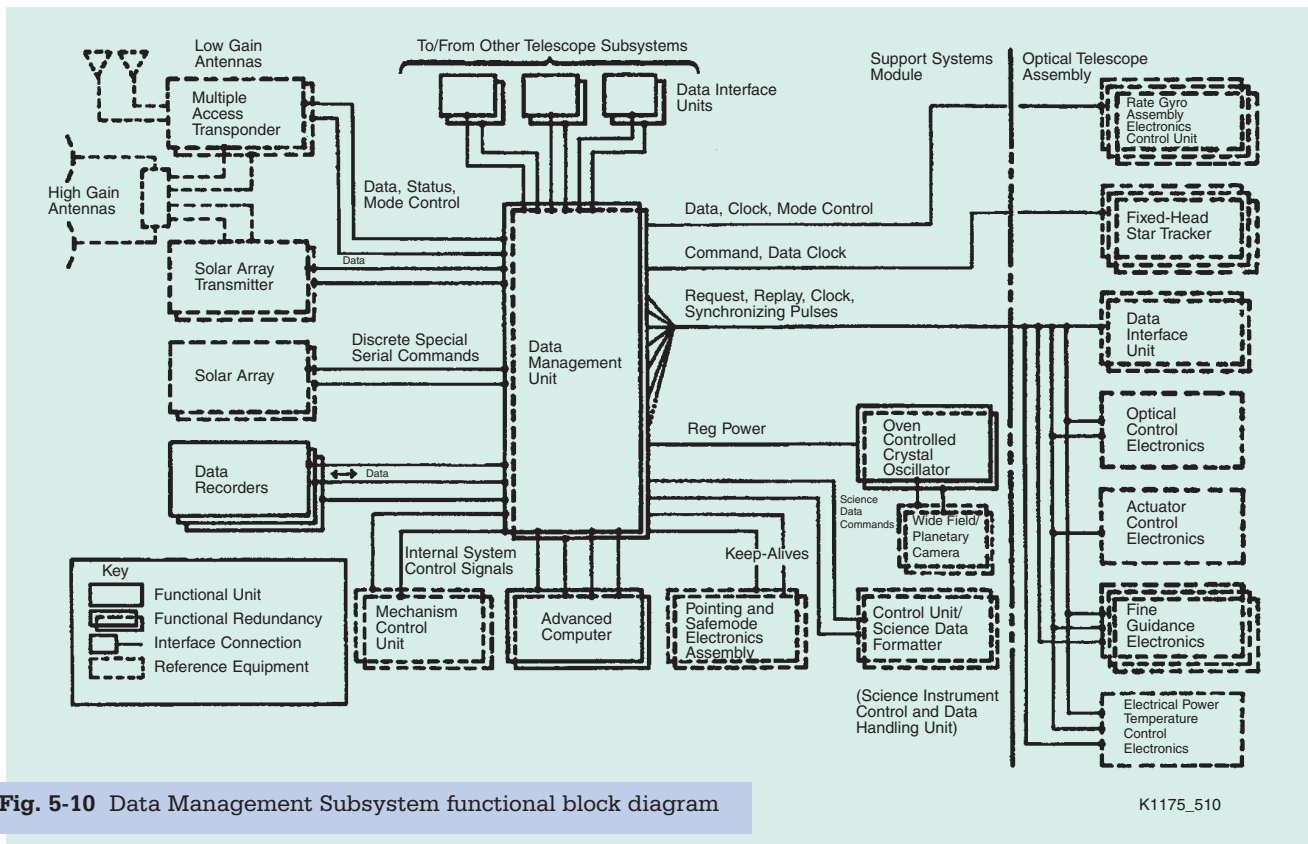


Fig. 5-10 Data Management Subsystem functional block diagram

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Operating over a frequency range from 2100 MHz to 2300 MHz, the LGAs receive ground commands and transmit engineering data. These antennas are used for all commanding of the Telescope and for low-data-rate telemetry, particularly during Telescope deployment or retrieval on orbit and during safemode operations.

### 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 (see Fig. 5-10).

Subsystem components are:

- 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.

**Advanced Computer.** The Advanced Computer is a general-purpose digital computer for onboard engineering computations. It executes stored commands, formats status data (telemetry), generates onboard commands to orient the SAs toward the Sun, evaluates the health status of the Telescope systems and commands the HGAs. It also performs all Pointing Control Subsystem (PCS) computations to maneuver, point and attitude stabilize the Telescope.

Based on the Intel 80486 microchip, the Advanced Computer operates 20 times faster and has six times as much memory as the DF-224 computer, which it replaced on SM3A. It is configured as three independent single-board computers (SBC). Each SBC has 2 megabytes of fast static random access memory and 1 megabyte of non-volatile memory.

The Advanced Computer communicates with the HST by using the direct memory access capability on each SBC through the DMU. Only one SBC controls 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 can diagnose any problems with the Advanced Computer and report them to the ground. The Advanced Computer uses fast static random access memory 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 pounds (32 kg). It is 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 serves as the central timing source. The DMU also receives and decodes all incoming commands, then transmits each processed command to be executed.

In addition, 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.

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

**Data Interface Unit.** Four DIUs provide a command and data link between the DMS and other 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 inches (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. These recorders, located in Equipment Section Bays 5 and 8, hold up to 12 billion bits of information. Two solid state recorders (SSR) are used in normal operations; the third, a backup, is a reel-to-reel tape recorder. Each recorder measures 12 x 9 x 7 inches (30 x 23 x 18 cm) and weighs 20 pounds (9 kg).

The SSRs have no reels or tape and no moving parts to wear out and limit lifetime (their expected on-orbit life is at least 8 years). Data is stored digitally in computer-like memory chips until HST 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 replaced.

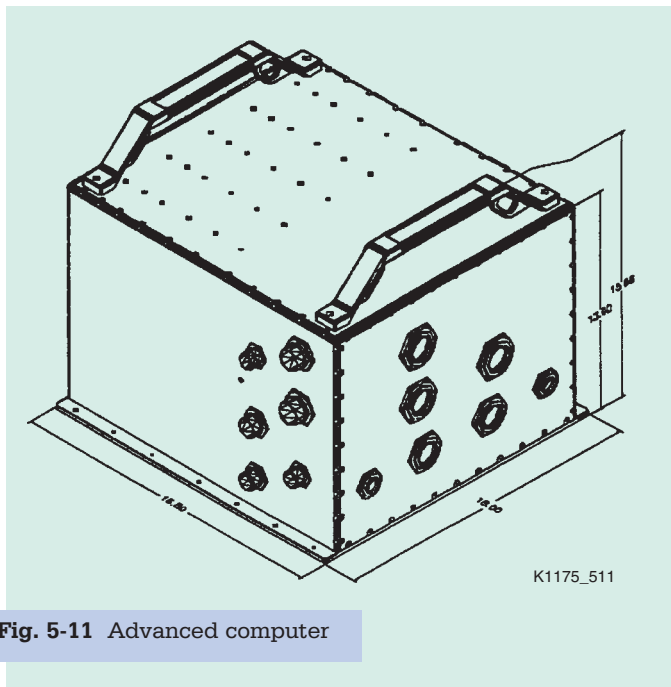


Fig. 5-11 Advanced computer

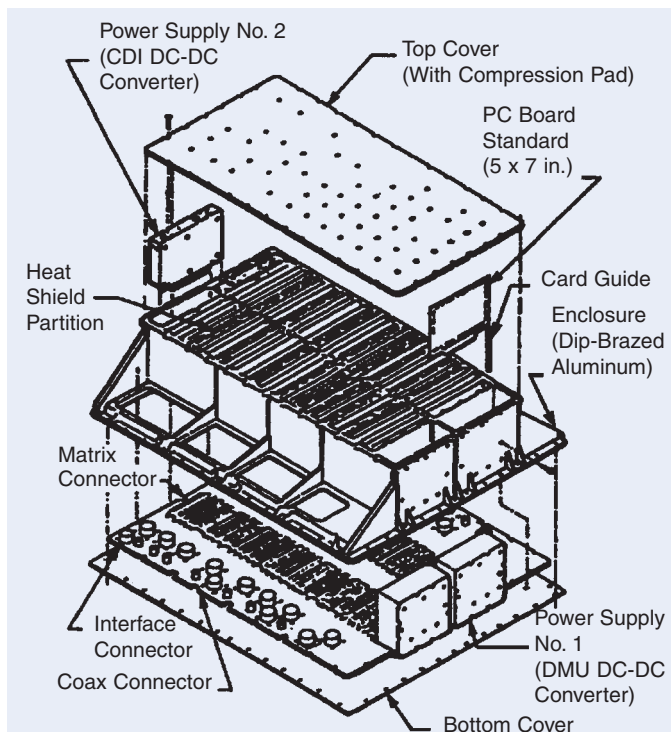


Fig. 5-12 Data Management Unit configuration



Each SSR 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.

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

### 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 within 0.01 arcsec and holding the Telescope in that orientation with 0.007-arcsec stability for up to 24 hours while HST orbits 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 in two FGSs and keeping the Telescope in the same position relative to these stars. When specific target requests require repositioning the spacecraft, the PCS 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), which are both used by the spacecraft safemode system. See page 5-13, Safing (Contingency) System, for details.

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

Five CSSs, located on the light shield and aft shroud, measure the Telescope's orientation to the Sun. They also 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. In addition, the CSSs 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. Two systems are located on the front end of the light shield. Each consists of magnetometers and dedicated electronic units that send data to the Advanced Computer and the Safemode Electronics Assembly.

HST has three RGAs, each consisting of a Rate Sensor Unit (RSU) and an Electronics Control Unit (ECU). An RSU contains two rate-sensing gyroscopes that measure attitude rate motion about their sensitive axes. Two sets of dedicated electronics in each ECU process this output. Three of the six gyroscopes are required to continue the Telescope science mission.

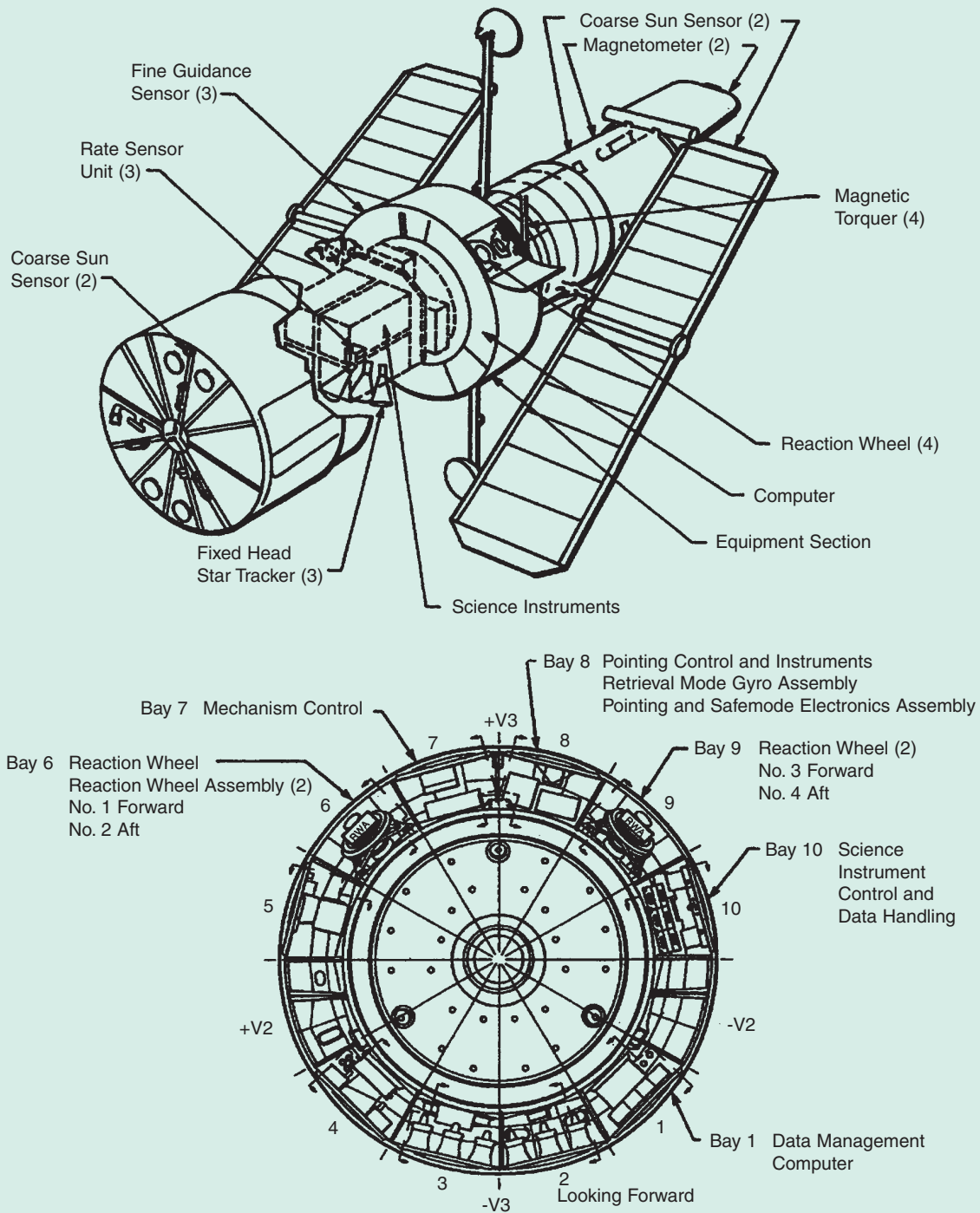
The RSUs are located behind the SSM Equipment Section, next to three FHSTs in the aft shroud. The ECUs are located inside Bay 10 of the SSM Equipment Section. The RGAs provide input to the PCS to control the orientation of the Telescope's line of sight and to give the attitude reference when maneuvering the Telescope.

An FHST is an electro-optical detector that locates and tracks a specific star within its FOV. STOCC uses FHSTs 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 provide angular position with respect to the stars (see page 5-20, Fine Guidance Sensor, for details). Their precise fine-pointing adjustments, accurate to within a fraction of an arcsecond, pinpoint the guide stars. Two of the FGSs perform guide-star pointing and 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 Hubble's main computer. This software translates ground targeting commands into reaction wheel torque profiles that reorient the spacecraft and smooth spacecraft motion 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 to minimize reaction wheel speeds. In addition, the software provides various telemetry formats.

Since the Telescope was launched, the PCS has been modified significantly. A digital filtering scheme,



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**Fig. 5-13** Location of Pointing Control Subsystem equipment

known as Solar Array Gain Augmentation (SAGA), now mitigates the effect of any SA vibration or jitter on pointing stability and an FGS Re-Centering Algorithm improves FGS performance when the Telescope is subjected to the same disturbances.

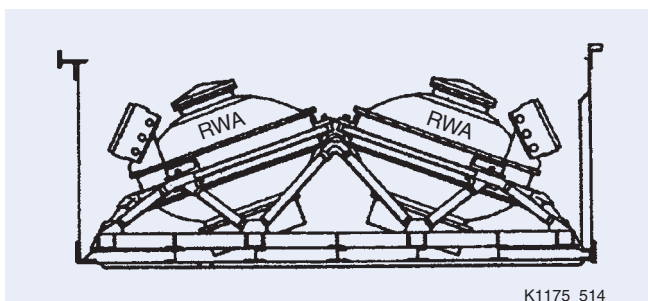
Software is used extensively to increase Telescope robustness during hardware failures. Two additional

software safemodes have been provided. The spin-stabilized mode enables 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. Data is maintained 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 control torques to stabilize the Telescope’s line of sight.

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



**Fig. 5-14** Reaction Wheel Assembly

Magnetic torquers 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.

Located externally on the forward shell of the SSM, the magnetic torquers also provide backup control to stabilize the Telescope’s orbital attitude during contingency modes (refer to page 5-6, Instrumentation and Communications Subsystem). Each torquer is 8.3 feet (2.5 m) long and 3 inches (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 latter 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 it possible to point the Telescope 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.

### 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 will begin converting solar radiation into electricity. Energy will be stored in nickel-hydrogen (NiH<sub>2</sub>) batteries and distributed by the PCUs and PDUs to all Telescope components as shown in Fig. 5-15. Hubble 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 solar panels that convert the Sun’s energy into electrical energy. Electricity produced by the panels charges the Telescope batteries.

Each array wing has associated electronics. These consist of (1) a Solar Array Drive Electronics (SADE) unit to transmit positioning commands to the wing assembly, (2) a Deployment Control Electronics Unit to control the drive motors extending and retracting the wings and (3) 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<sub>2</sub>



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 blankets 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.

During SM3A astronauts installed material to cover and restore some degraded MLI. The layer added to the SSM Equipment Section on SM3A 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. The additional materials have been life-tested to an equivalent of 10 years.

SM3B astronauts will complete the task of replacing thermal protection in degraded areas as time permits.

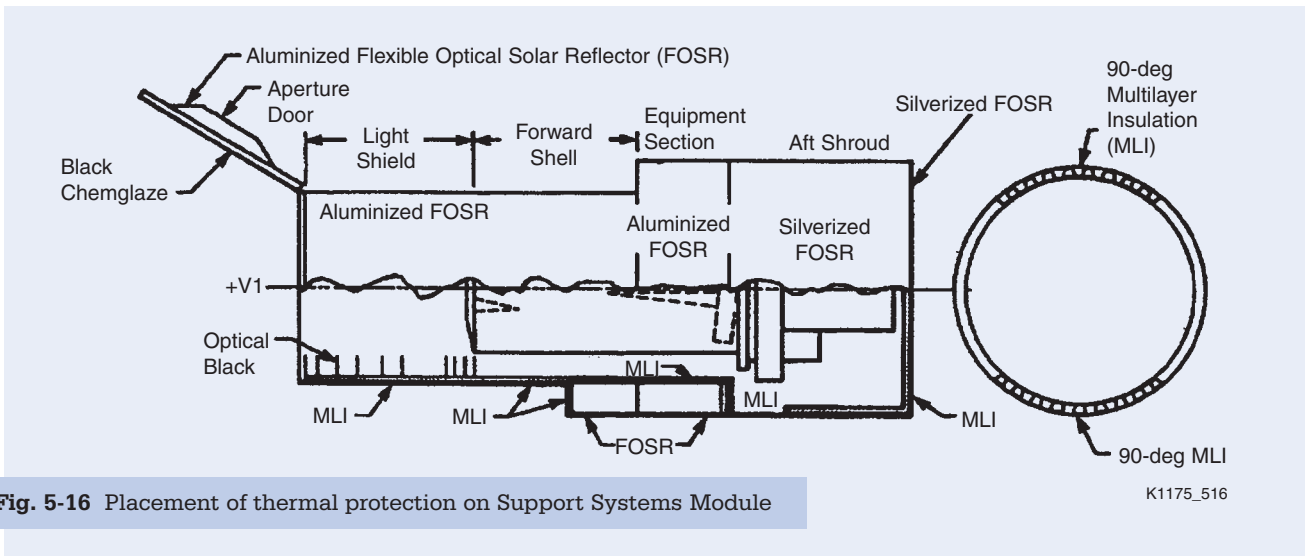
### Safing (Contingency) System

Overlapping or redundant equip-

ment safeguards the Telescope against any breakdown. In addition, a contingency or Safing System exists for emergency operations. Using dedicated PSEA hardware and many pointing control and data management components, 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 automatically monitors Telescope onboard functions. It sends Advanced Computer-generated “keep-alive” signals to the PSEA that indicate all Telescope systems are functioning. When a failure is detected, entry into the Safemode is autonomous.

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



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

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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 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 (refer to page 5-9, Pointing Control Subsystem).

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:

- 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 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 2 hours, the SI C&DH. Before this happens, 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 on 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 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.** These assemblies are installed in Bay 8. 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). A backup gyroscope package, the RMGA, is dedicated for the PSEA. The RMGA consists of three gyroscopes. These are lower quality rate sensors than the RGAs because they are not intended for use during observations.

## Optical Telescope Assembly

Perkin-Elmer Corporation (now Goodrich Corporation) designed and built the OTA. 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 feet (57.6 m) to be packaged into a small telescope length of 21 feet (6.4 m). (Several smaller mirrors in the science instruments are designed similarly to lengthen the light path within them.) This form of telescope is called a Cassegrain. 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.

Hubble’s OTA is a variant of the Cassegrain, called a Ritchey-Chretien, in which both mirrors are hyperboloidal in shape (having a deeper curvature than a parabolic mirror). This form is completely corrected for coma (an image observation with 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.

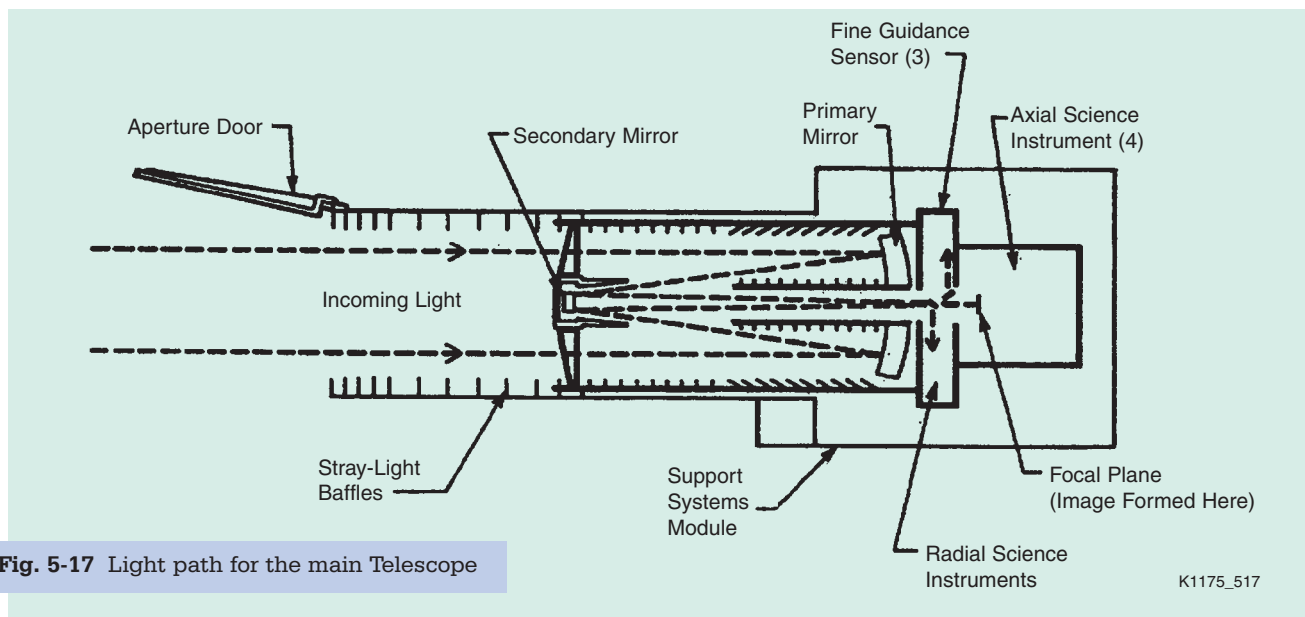
Both of these are zero exactly in the center of the field and increase toward the edge of the field. These aberrations are easily corrected within the instrument optics.

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

Corporation designed and built all the optical assemblies. Lockheed Martin built the OTA equipment section.

### Primary Mirror Assembly and Spherical Aberration

As the Telescope was first put through its paces on orbit in 1990, scientists discovered its primary mirror



**Fig. 5-17** Light path for the main Telescope

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attenuate reflected light from unwanted bright sources, to the 94.5-inch (2.4-m) primary mirror. Reflecting off the front surface of the concave mirror, the light bounces back up the tube to the 12-inch (0.3-m)-diameter convex secondary mirror. The light is now reflected and converged through a 23.5-inch (60-cm) hole in the primary mirror to the Telescope focus, 3.3 feet (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<sup>2</sup> of field in a 90-degree sector. Figure 5-18 shows instrument/sensor fields of view.

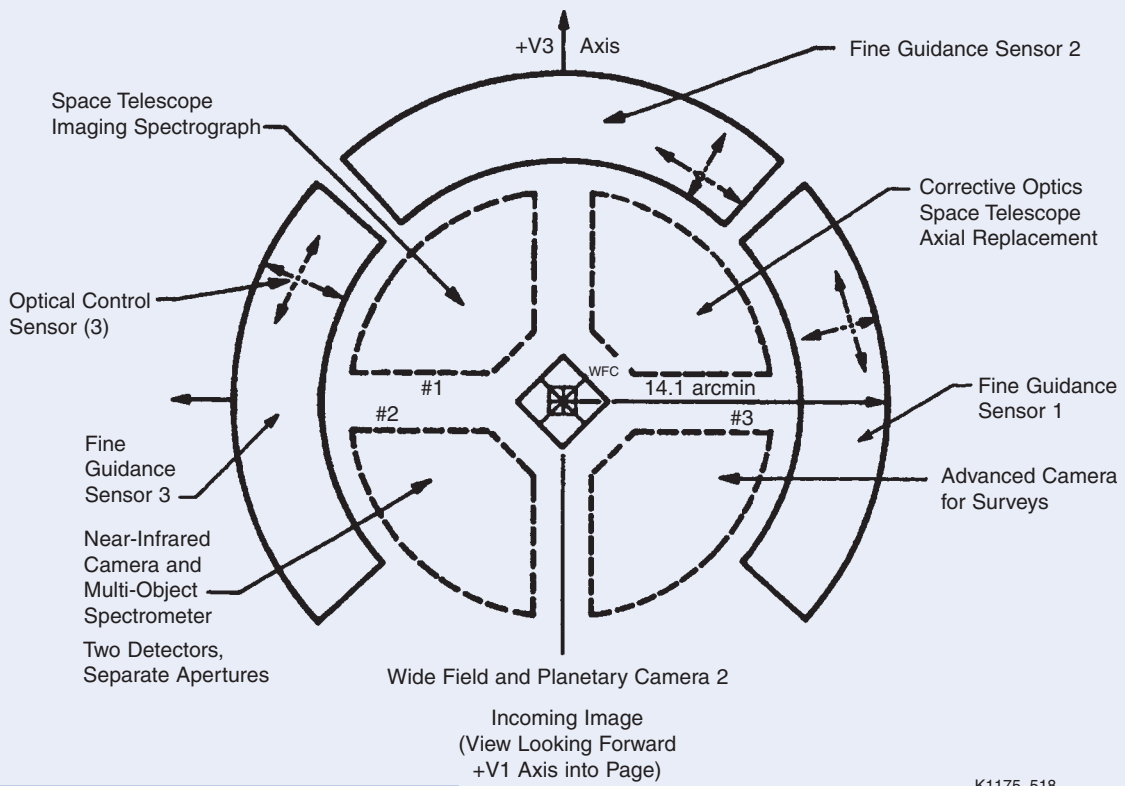
The OTA hosts the science instruments and FGSs in that it maintains the structural support and optical-image stability required for these instruments to fulfill their functions (see Fig. 5-19). Components of the OTA are the primary mirror, the secondary mirror, the FPS and the OTA Equipment Section.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

had a spherical aberration. The outer 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 the discovery, Ball Aerospace scientists and engineers built the Corrective Optics Space Telescope Axial Replacement (COSTAR). It 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 (see 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:

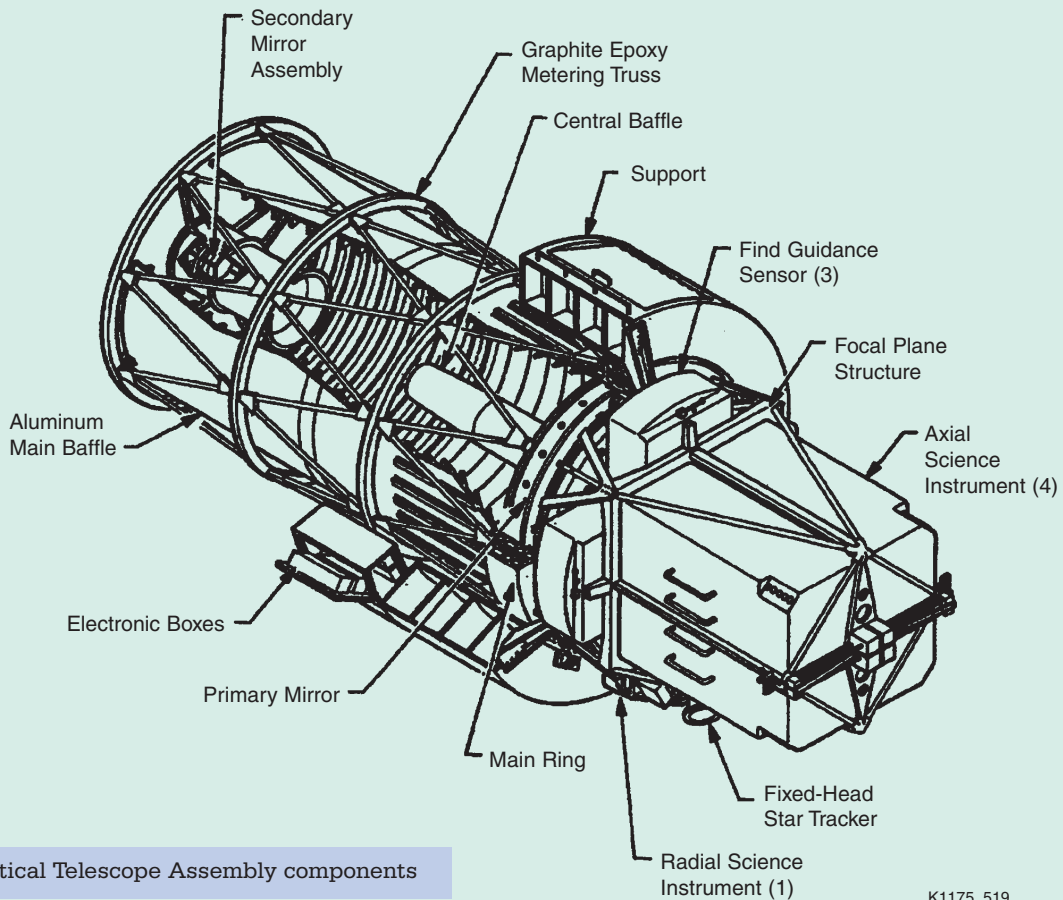
- Primary mirror
- Main ring structure
- Reaction plate and actuators
- Main and central baffles.

**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



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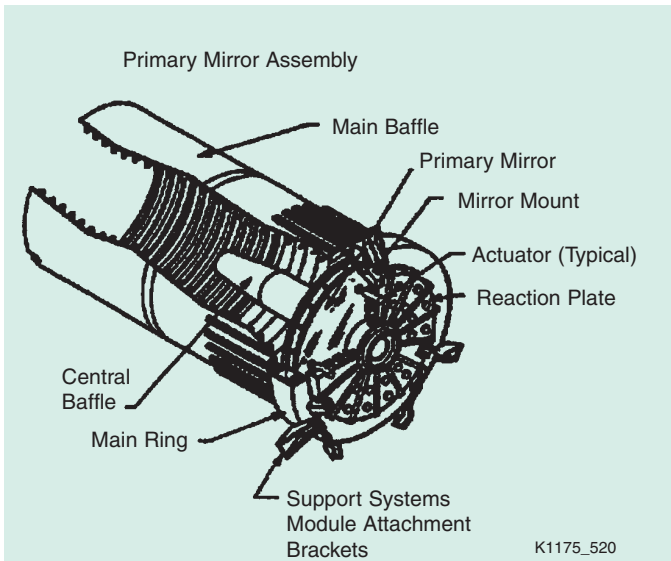
**Fig. 5-18** Instrument/sensor field of view after SM3B



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**Fig. 5-19** Optical Telescope Assembly components

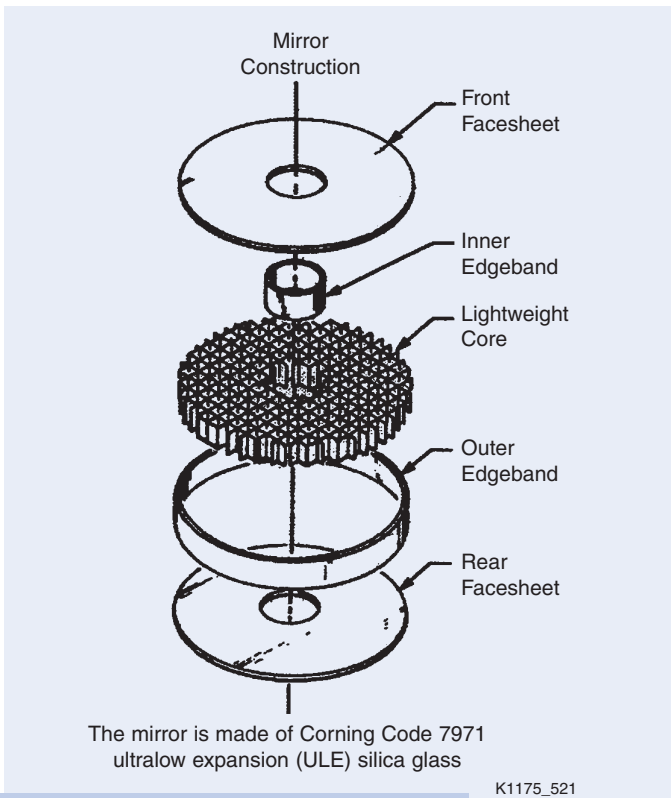




**Fig. 5-20** Primary mirror assembly

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

Perkin-Elmer ground the mirror blank, 8 feet (2.4 m)



**Fig. 5-21** Primary mirror construction

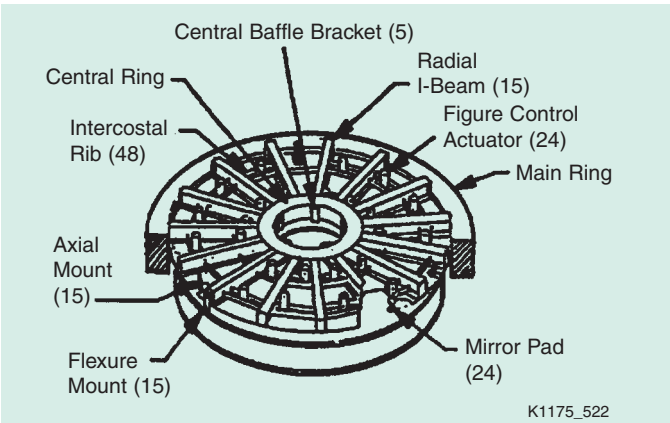
in diameter, to shape in its large optics fabrication facility. When it was close to its final hyperboloidal shape, the mirror was transferred to the company’s computer-controlled polishing facility.

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, 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 (see Fig. 5-22). This titanium ring, weighing 1200 pounds (545.5 kg), is a hollow box beam 15 inches (38 cm) thick with an outside diameter of 9.8 ft (2.9 m). 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 Fahrenheit. 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



**Fig. 5-22** Main ring and reaction plate

circles. These can be commanded from the ground, if necessary, to make small corrections to the shape of the mirror.

**Baffles.** The OTA's baffles 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 baffles. Attached to the front face of the main ring, the outer (main) baffle is an aluminum cylinder 9 feet (2.7 m) in diameter and 15.7 feet (4.8 m) long. Internal fins help it attenuate stray light. The central baffle is 10 feet (3 m) long, cone-shaped 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.

**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 inch 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.

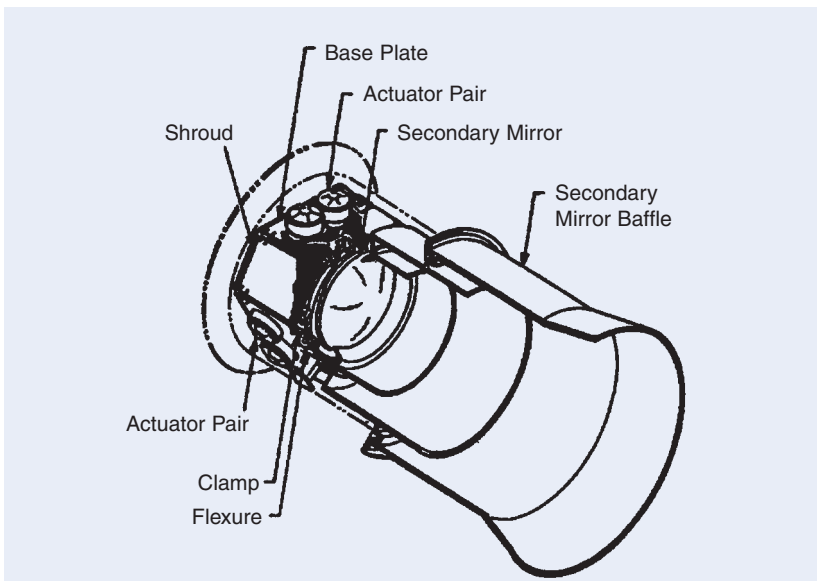
The secondary mirror has a magnification of 10.4X. It converts the primary-mirror converging rays from f/2.35 to a focal ratio system prime focus of f/24 and sends them back toward the center of the primary mirror, where they pass through the central baffle to the focal point. The mirror is a convex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

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 FGs.

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 feet (4.8 m) long and 9 feet (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 inch (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 stray bright-object light from sources outside the Telescope FOV.



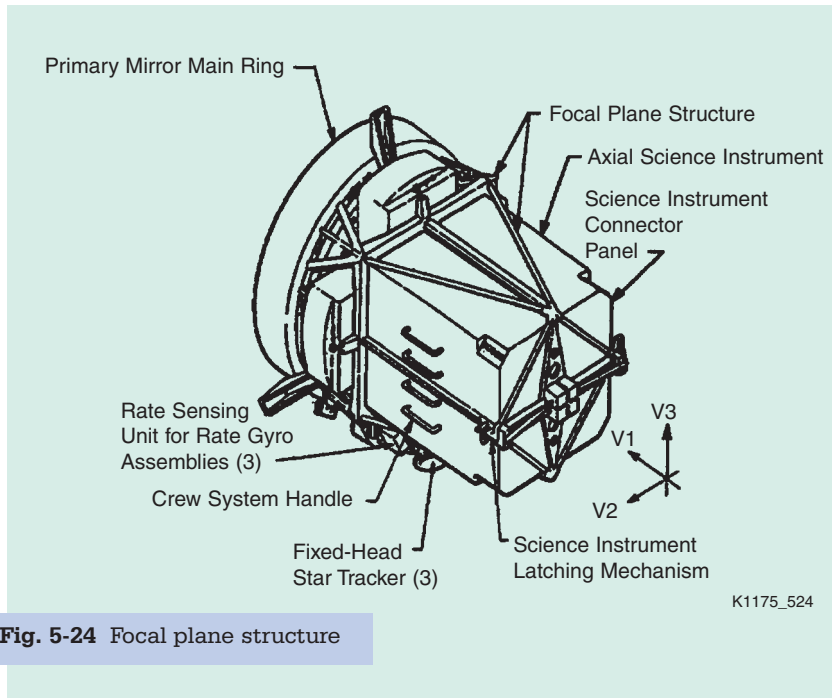
**Fig. 5-23** Secondary mirror assembly

### 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 feet (2.1 m) by 10 feet (3.04 m) long and weighs more than 1200 pounds (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

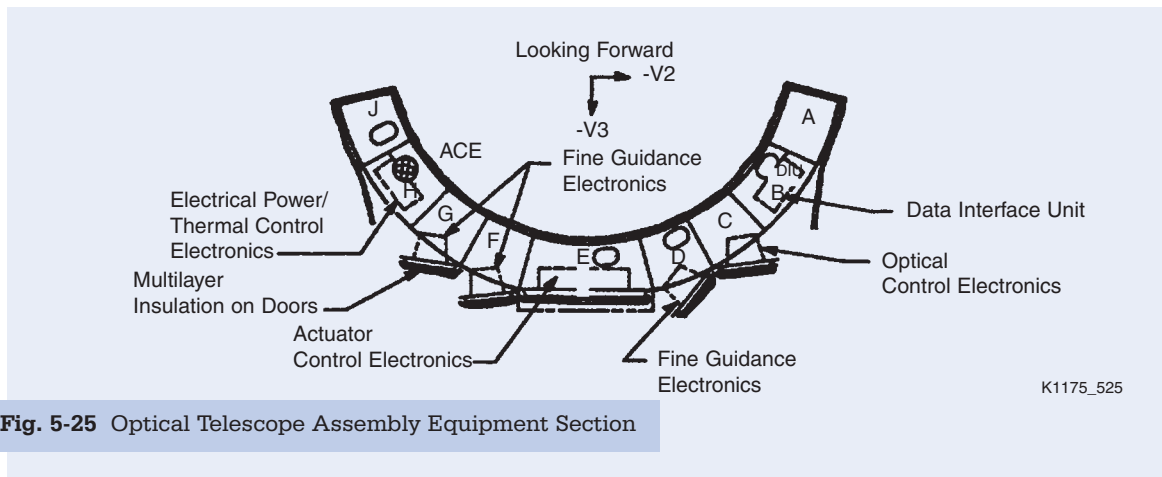
### OTA Equipment Section

The OTA Equipment Section 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.

Three FGE units provide power, commands and telemetry to the FGSs. The electronics perform computations for the sensors and interface with the spacecraft pointing system for effective Telescope line-of-sight pointing



**Fig. 5-25** Optical Telescope Assembly Equipment Section

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. 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.

## Fine Guidance Sensor

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 measures 5.4 feet (1.5 m) long and 3.3 feet (1 m) wide and weighs 485 pounds (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.

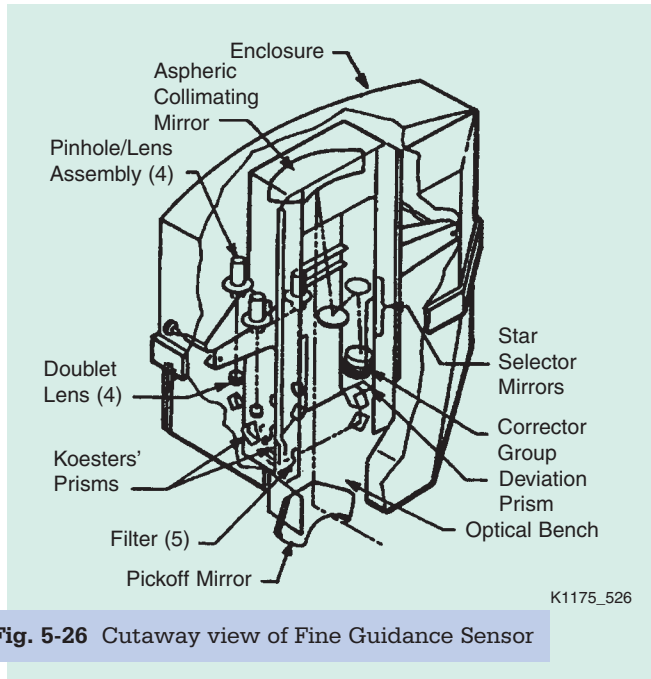
The Telescope's ability to remain pointing at a distant target to within 0.005 arcsec for long periods of time is due largely to the accuracy of the FGSs. They lock on a star and measure any apparent motion to an accuracy of 0.0028 arcsec. This is equivalent to seeing from New York City the motion of 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, Science Instruments. 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) was installed in the HST FGS Bay 2.

## FGS 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 (see 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<sup>2</sup>) FOV to search for and track stars, and a 5.0 arcsec<sup>2</sup> FOV used by the detector prisms to pinpoint the star.



**Fig. 5-26** Cutaway view of Fine Guidance Sensor

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 easier to find the target. 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. Once designated and located, the guide stars keep the image of the observation target in the aperture of the selected science instrument.

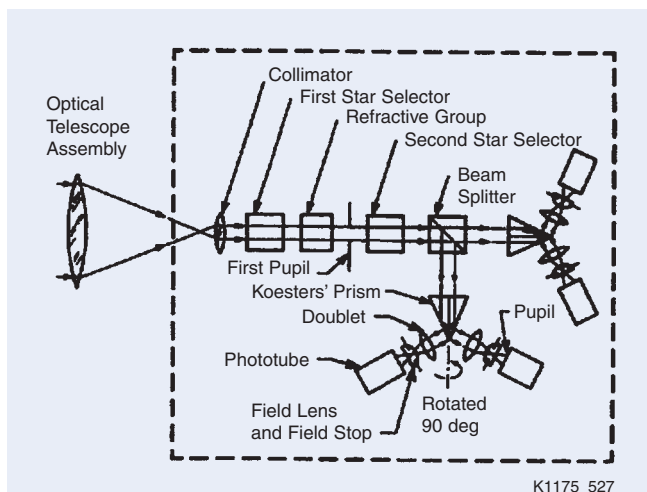
Each FGS uses a 90-degree sector of the Telescope's FOV outside the central "science" field. This region of the FOV has the greatest astigmatic and curvature distortions. The size of the FGS's FOV was chosen to heighten the probability of finding an appropriate guide star, even in the direction of the 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<sup>2</sup> available. The guide star of interest can be anywhere within this field. 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. Using a pair of star selector servos, the FGS can move its line of sight anywhere within its large FOV. Each

can be thought of as an optical gimbal: one servo moves north and south, the other east and west. They steer the small FOV ( $5 \text{ arcsec}^2$ ) 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 moving 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 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.



**Fig. 5-27** Optical path of Fine Guidance Sensor

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.

## 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 FGS performance with this innovative design improvement.

## Solar Arrays

New rigid solar arrays will be attached to the Telescope during SM3B. The original arrays fitted to Hubble—designed by the European Space Agency and built by British Aerospace, Space Systems—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.

Following deployment in 1990, engineers 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, caused the panels to distort twice during each orbit. As a temporary fix, software was written 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.

The two new solar array wings to be installed on SM3B are assembled from eight panels built at Lockheed Martin Space Systems Company in Sunnyvale, California, and designed originally for the commercial Iridium communications satellites. At Goddard Space Flight Center in Greenbelt, Maryland, four panels were mounted onto each aluminum-lithium support wing structure.

The new wing assemblies, which have higher efficiency Gallium Arsenide solar cells, will give Hubble approximately 20 percent more power than the current arrays. In addition, their smaller cross section and rigidity will reduce aerodynamic drag and produce significantly less vibration than the existing wings (see Fig. 5-28).

New Solar Array Drive Mechanisms (SADM) also will be installed during SM3B. These mechanisms will maneuver the new arrays to keep them constantly pointed at the Sun. The European Space Agency (ESA) designed, developed and tested the SADMs. ESA used its world-class test facility in The Netherlands to subject the new arrays and drive mechanisms to realistic simulations of the extreme temperature cycles encountered in Hubble’s orbit—including sunrise and sunset.

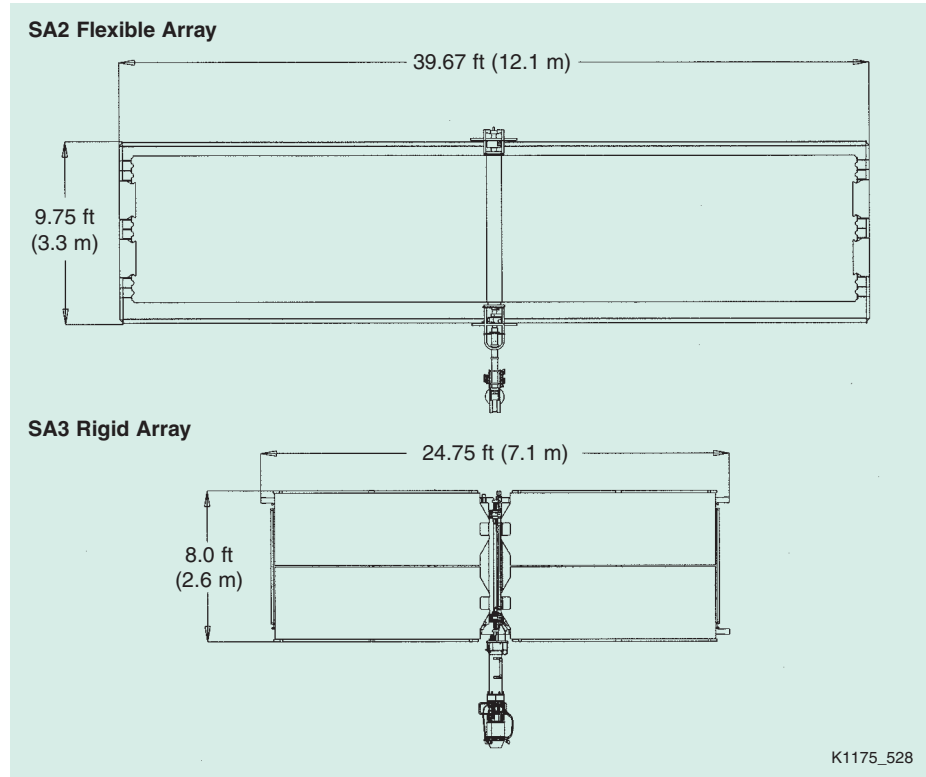
### Science Instrument Control and Data Handling Unit

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 science and engineering data to the ground.

### 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. 5-29). 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:



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Item	Power	Size	Weight	Comments
SA2 Flexible Array	4600 W at 6 years (actual)	39.67 ft x 9.75 ft (12.1 m x 3.3 m)	339 lb per wing	Actual on-orbit performance measured at Winter Solstice, December 2000
SA3 Rigid Array	5270 W at 6 years (predicted)	24.75 ft x 8.0 ft (7.1 m x 2.6 m)	640 lb per wing	Increased capability for planned science  Less shadowing and blockage

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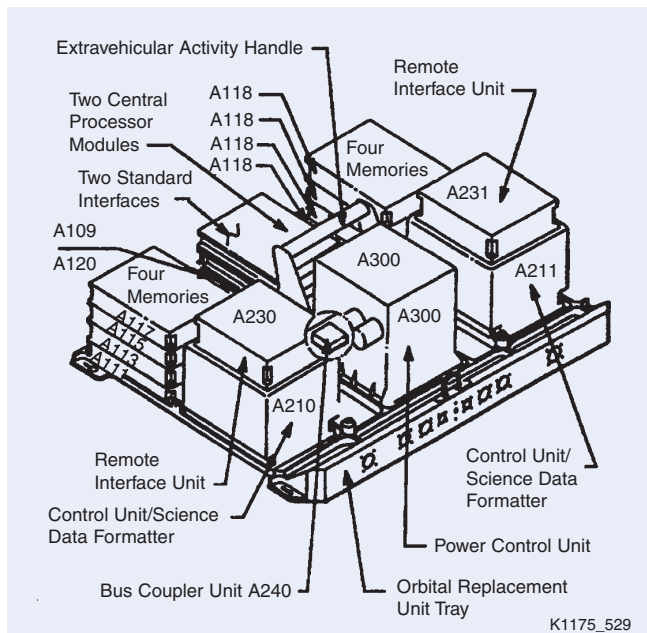
**Fig. 5-28** Solar Array wing detail comparison

- NASA Standard Spacecraft Computer (NSCC-I)
- Two standard interface circuit boards for the computer
- Two control units/science data formatter units (CU/SDF)
- Two CPU modules
- A PCU
- Two RIUs
- Various memory, data and command communications lines (buses) connected by couplers.

These components are redundant so the system can recover from any single failure.

**NASA Computer.** The NSCC-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.

The memory stores operational commands for execution when the Telescope is not in contact



**Fig. 5-29** Science Instrument Control and Data Handling unit

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 Board.** The circuit 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”—communica-

tions codes. The CU/SDF transmits commands and requests after formatting them so that the specific destination unit can read them. 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 while the CU/SDF requires +28 volts. The PCU ensures that all voltage requirements are met.

**Remote Interface Unit.** RIUs transmit commands, clock and other system signals, and engineering data between the science instruments and the SI C&DH unit. However, 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 fails. The SI C&DH coupler unit is on the ORU tray.

## 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 NSSC-I or SSM computer. The computers process or store the information. Any failure indicated by these constant tests could initiate a “safing hold” situation (refer to page 5-13, Safing (Contingency) System), and thus a suspension of science operations.

**Command Processing.** Figure 5-30 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 number of pointing control functions to make small Telescope maneuvers.

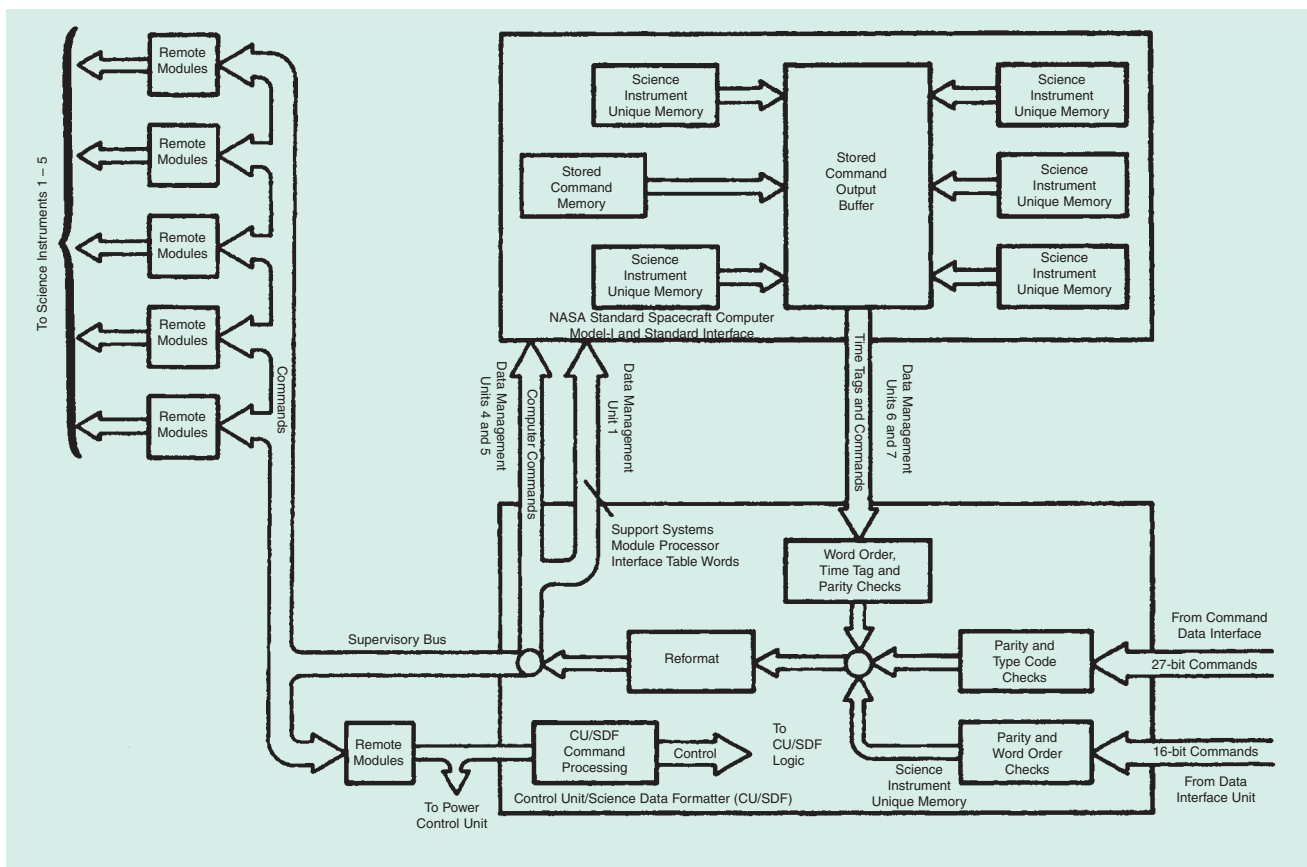
**Science Data Processing.** Science data can come from all science instruments at once. The CU/SDF transfers incoming data through computer memory locations called packet buffers. It fills each buffer in order, switching among them as the buffers fill and empty. Each data packet goes from the buffer 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 5-30 shows the flow of science data in the Telescope.

### Space Support Equipment

Hubble 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, then the crew will perform maintenance and replacement tasks. The Space Support Equipment (SSE) provides a maintenance platform to hold the Telescope, electrical support of the Telescope during servicing and storage for replacement components known as ORUs.

The major SSE items to be used for SM3B are the Flight Support System (FSS) and and ORU Carriers (ORUC), comprising the Rigid Array Carrier (RAC), the Second Axial Carrier (SAC) and the Multi-Use Lightweight Equipment (MULE) carrier. Crew aids and tools also will be used during servicing. Section 2 of this guide describes details specific to SM3B.



**Fig. 5-30** Command flow for Science Instrument Control and Data Handling unit

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### Orbital Replacement Unit Carrier

An ORUC is a pallet outfitted with shelves and/or enclosures that is used to carry replacements into orbit and to return replaced units to Earth. For SM3B the Columbia payload bay will contain three ORUCs. All ORUs and scientific instruments are carried within protective enclosures to provide them a benign environment throughout the mission. 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.

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.

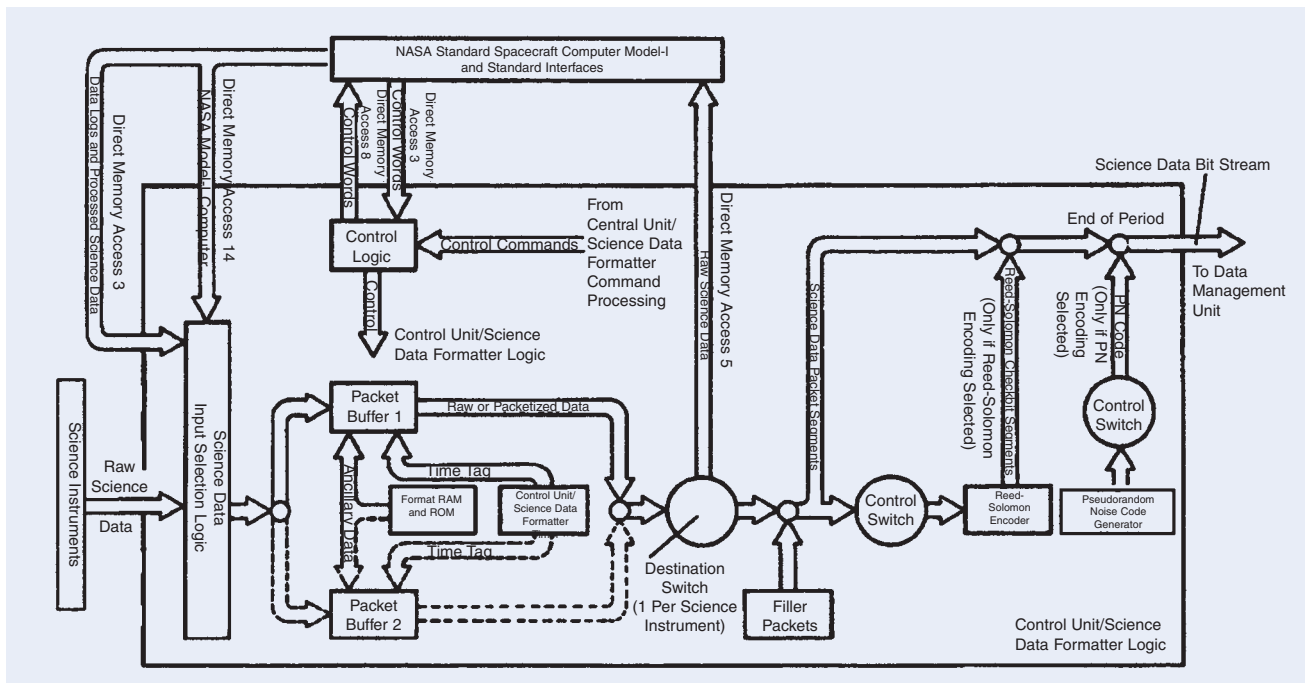
### Crew Aids

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 are 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 feet of handrails encircling the spacecraft. The rails are painted yellow for visibility. In addition, the crew can hold onto guiderails, trunnion bars and scuff plates fore and aft.

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).

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 the SA wings so the crew can push the equipment away from the Telescope.



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Fig. 5-31 Flow of science data in the Hubble Space Telescope