Hubble Space Telescope operations are of two types: science operations that plan and conduct the HST science program – observing celestial objects and gathering data – and mission operations that command and control HST to implement the observation schedule and maintain the Telescope's overall performance.

Science and mission operations often coincide and interact. For example, a science instrument may observe a star and calibrate incoming wavelengths against standards developed during scientific verification. Mission operations monitor observations to ensure that Telescope subsystems have functioned correctly.

Mission operations are carried out by the Telescope ground system, which consists of facilities at the Space Telescope Science Institute (STScI), and the Space Telescope Operations Control Center (STOCC), the Packet Processing Facility (PACOR), and other institutional facilities at the Goddard Space Flight Center (GSFC).

The STScI oversees science operations. It hosts astronomers, evaluates and chooses observation programs, schedules the selected observations, generates an overall mission timeline and command sequences, and stores and analyzes science data from the Telescope. Meanwhile, the flight operations team conducts mission operations from the STOCC. The team interacts with the STScI to receive daily mission schedules, to process engineering data and displays, and to manage the engineering data archive.

6.1 Space Telescope Science Institute

Located in Baltimore, Maryland, STScI is responsible to GSFC for the science programs on the HST. It is operated by the Association of Universities for Research in Astronomy (AURA), a consortium of 29 United States universities that operate several national facilities for astronomy.

STScI solicits and reviews observation proposals and selects observations to be carried out. It schedules observations and assists guest observers in their work; generates an integrated science and engineering timeline to support all spacecraft activities, including any special engineering tests; and provides the facilities and software to reduce, analyze, archive, and distribute Telescope data.

STScI also monitors the Telescope and science instruments for characteristics that could affect science data collection, such as instrument performance quality, pointing inaccuracies, and Telescope focus.

6.1.1 Scientific Goals

STScI helps conduct the science program to meet the overall scientific goals of the Telescope program, set by the Institute and NASA in consultation with AURA's Space Telescope Institute Council and committees representing the international astronomical community.

6.1.2 Institute Software

Computer hardware and software play an important role in STScI work. The STScI ground system consists of a planning and scheduling system and a science data processing system. The STScI also created the guide star catalog used to support the precise pointing requirements of the HST pointing control subsystem. In addition, Science Data Analysis Software (SDAS) provides analytical tools for astronomers studying observational data.

STScI handles mission planning and scheduling, observation support, software support, and routine data processing. Together, these functions perform computations needed to run the science operations on the Telescope.

As part of the Planning and Scheduling System, the STScI Guide Star Selection System (GSSS) provides reference stars and other bright objects so the Fine Guidance Sensors (FGS) can point the Telescope accurately. This system selects guide stars that can be located unambiguously in the sky when the sensors point the Telescope. The guide star catalog has information on 20 million celestial objects, created from 1,477 photographic survey plates covering the entire sky.

After the STScI Science Data Pipeline collects, edits, measures, and archives science data, observers can use SDAS to analyze and interpret the data.

6.1.3 Selecting Observation Proposals

Astronomers worldwide may use the Telescope. Any scientist may submit a proposal to the STScI outlining an observing program and describing the scientific objectives and instruments required. The STScI selects observations by evaluating these requests for technical feasibility, conducting peer reviews, and choosing the highest ranked proposals. Because individual astronomers and astronomy teams submit many more proposals than can possibly be accepted, a team approach is encouraged. The final decision rests with the STScI director, advised by a review committee of astronomers and scientists from many institutions.

6.1.4 Scheduling Selected Observations

The primary scheduling consideration is availability of a target, limited by environmental and stray-light constraints – for example, a faint object that must be observed when the Telescope is in Earth's shadow. The schedule takes into consideration system limits, observations that use more than one instrument, and required time for special observations.

6.1.5 Data Analysis and Storage

STScI archives calibrated science data. Computer resources include the Hubble Data Archive, SDAS and other selected computer facilities.

Science Data Pipeline processing receives science data from the PACOR at GSFC, then automatically formats it and verifies its quality. It calibrates data to remove the instrument's properties such as variation in the detector's sensitivity across the data field. Then the software places the data on digital archive media from which the data can be formatted and distributed to the observer or archival researcher. The STScI processes all data within 24 hours after receipt.

STScI is responsible for storing the massive amount of data collected by the Telescope. The Hubble Data Archive catalog records the location and status of data as it pours into the storage banks. Observers and visiting astronomers can easily retrieve the stored data for examination or use data manipulation procedures created by the STScI. The European Space Agency (ESA) provides approximately 15 staff members co-located with STScI staff and operates its own data analysis facility in Garching, Germany.

In addition to science data, the STScI stores engineering data. This is important for developing more efficient use of the Telescope systems and for adjusting Telescope operations based on engineering findings, for example, if an instrument provides unreliable data in certain temperature ranges.

6.2 Space Telescope Operations Control Center

The STOCC flight operation team runs day-to-day spacecraft operations. In addition, the STOCC team works with the NASA Communications Network (NASCOM) and the Tracking and Data Relay Satellite System (TDRSS) to facilitate HST data communications.

POCC uses mission-control facilities at GSFC built specifically for HST operations. The Vision 2000 Control Center System (CCS) has been developed to provide the next generation of operational capabilities in the STOCC. Built specifically to support the HST Third Servicing Missions (SM3A and SM3B), the CCS provides distributed capabilities with a completely new user interface that is on the forefront of spacecraft operations.

STOCC has three major operational responsibilities:

- Spacecraft operations, including sending commands to the spacecraft
- Telemetry processing
- Offline support.

Most specific spacecraft operations are executed based on time-tagged commands managed by the Telescope's onboard software. The STOCC flight operations team, using the CCS, uplinks the commands to the HST computers.

Engineering telemetry, received in the STOCC from the GSFC institutional communication system, provides information that reflects the HST spacecraft subsystem status. For example, telemetry can verify Pointing Control System operation and stability performance of the Telescope. In many cases, consultation between STOCC and STScI is necessary, particularly if the data affects an ongoing observation.

An important part of the ground system is PACOR processing. When data arrives from NASCOM for science handling, PACOR reformats the data, checks for noise or transmission problems, and passes each packet of data along to the STScI with a data quality report.

Another important STScI function is to support observers requiring a "quick-look" analysis of data. STScI alerts PACOR to that need, and the incoming data can be processed for the observer.

TDRSS has two communications relay satellites 130 degrees apart, with a ground terminal at White Sands, New Mexico. There is a small "zone of exclusion" where Earth blocks the Telescope signal to either of the satellites, but up to 91 percent of the Telescope's orbit is within communications coverage. Tracking and Data Relay Satellites (TDRS) receive and send both single-access (science data) and multiple-access (commands and engineering data) channels.

6.3 Operational Characteristics

Three major operational factors affect the success of the Telescope: orbital characteristics for the spacecraft, its maneuvering characteristics, and communications characteristics for sending and receiving data and commands.

6.3.1 Orbital Characteristics

The orbit of the Telescope is approximately 320 nmi (593 km). The orbit inclines at a 28.5-degree angle from the equator because the Shuttle launch was due east from Kennedy Space Center. The chosen orbit puts the Sun in the Telescope orbital plane so that sunlight falls more directly on the Solar Arrays. In addition, the orbit is high enough that aerodynamic drag from the faint atmosphere will not decay the Telescope's orbit to below the minimum operating altitude.

The Telescope completes one orbit every 97 minutes, passing into the shadow of the Earth during each orbit. The time in shadow varies from 28 to 36 minutes. The variation during a nominal 30-day period is between 34.5 and 36 minutes in shadow. If Earth blocks an object from the Telescope, the Telescope reacquires the object as the spacecraft comes out of Earth's occultation. Faint-object viewing is best while the Telescope is in Earth's shadow.

The Telescope orbit is tracked by the TDRSS, which plots the spacecraft's orbit at least eight times daily and sends the data to the Flight Dynamics Facility at GSFC. Although this helps predict future orbits, some inaccuracy in predicting orbital events, such as exit from Earth's shadow, is unavoidable. The environmental elements with greatest effect on the Telescope's orbit are solar storms and other solar activities. These thicken the upper atmosphere and increase the drag force on the Telescope, accelerating the orbit decay rate considerably.

6.3.2 Celestial Viewing

The Telescope is pointed toward celestial targets as a normal orientation to expose instrument detectors for up to 10 hours, if needed. A continuous-viewing zone exists, parallel to the orbit plane of the Telescope and up to 18 degrees on either side of the north and south poles of that orbital plane (see Fig. 6-1). Otherwise, celestial viewing depends on how long a target remains unblocked by Earth.

The amount of shadow time available for faint-object study also affects celestial observations. Shadow time for an observation varies with the time of year and the location of the target relative to the orbit plane. Astronomers use a geometric formula to decide when in a given period a target will be most visible while the Telescope is in shadow.

Other sources affecting celestial viewing are zodiacal light and integrated or background starlight.

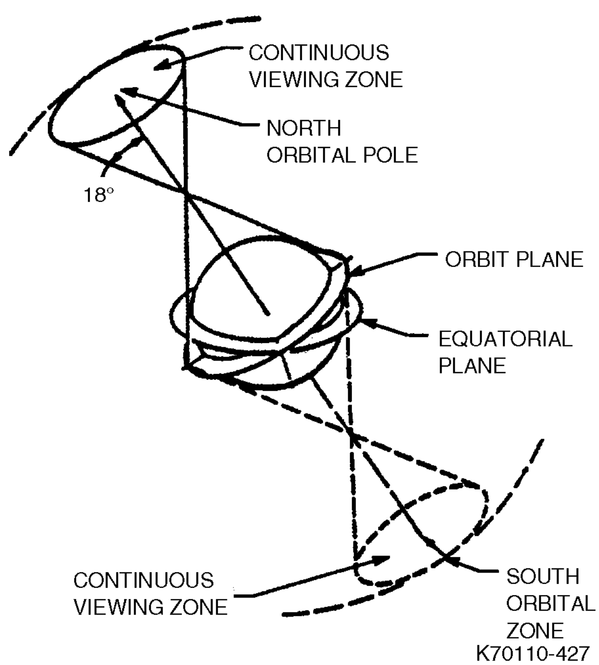

Fig. 6-1 "Continuous-zone" celestial viewing

6.3.3 Solar System Object Viewing

Solar system objects also are affected by the factors mentioned for celestial viewing. In addition, the Telescope works with imprecise orbit parameters for itself and objects such as the outer planets and comets. For example, Neptune's center may be off by 21 km when the sensors try to lock onto it because the Telescope is changing its position in orbit, which affects the pointing direction toward nearby objects. However, most solar system objects are so bright the Telescope needs only a quick snapshot of the object to fix its position. Tracking inaccuracies are more likely to cause a blurred image if they occur with long-exposure observations of dim targets.

The Telescope's roll attitude also may affect the view of the object and require a maneuver that rolls the spacecraft more than the 30-degree limit – for example, to place the image into a spectrographic slit aperture.

Tracking interior planets (Mercury and Venus) with the Telescope places the Sun within the Telescope opening's 50-degree Sun-exclusion zone. For this reason, HST never observes Mercury and has observed Venus only once, using Earth to block (occult) the Sun.

6.3.4 Natural Radiation

Energetic particles from different sources bombard the Telescope continuously as it travels around the Earth. Geomagnetic shielding blocks much of the solar and galactic particle radiation. When the Telescope passes through the South Atlantic Anomaly (SAA), a "hole" in Earth's magnetic field, charged particles can enter the Telescope and strike its detectors, emitting electrons and producing false data.

The Telescope passes through the SAA for segments of eight or nine consecutive orbits, then has no contact with it for six or seven orbits. Each encounter lasts up to 25 minutes. In addition, the SAA rotates with Earth, so it occasionally coincides with the Telescope as the spacecraft enters Earth-shadow observation periods. Careful scheduling minimizes the effects of the anomaly, but it has some regular impact.

Solar flares are strong pulses of solar radiation, accompanied by bursts of energetic particles. Earth's magnetic field shields the lower magnetic latitude regions, such as the Telescope's orbit inclination, from most of these charged particles. NASA regularly monitors the flares, and the Telescope can stop an observation until the flares subside.

6.3.5 Maneuver Characteristics

The Telescope changes its orientation in space by rotating its reaction wheels, then slowing them. The momentum change caused by the reaction moves the spacecraft at a baseline rate of 0.22 degree per second or 90 degrees in 14 minutes. Figure 6-2 shows a roll-and-pitch maneuver.

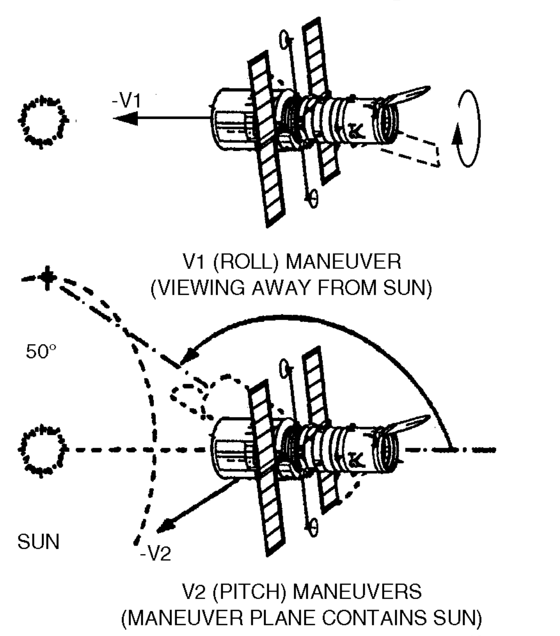

Fig. 6-2 HST single-axis maneuvers

When the Telescope maneuvers, it takes a few minutes to lock onto a new target and accumulate drift errors. This means that a larger region of the sky must be scanned for guide stars.

One consideration with maneuvering is the danger of moving the Solar Array wings out of the Sun's direct radiation for too long. Unprotected portions of the Support Systems Module aft shroud could be affected thermally. Therefore, maneuvers beyond a certain range in angle and time are limited.

When the Telescope performs a pitch to a target near the 50-degree Sun-avoidance zone, the Telescope curves away from the Sun. For example, if two targets are opposed at 180 degrees just outside the 50-degree zone, the Telescope follows an imaginary circle of 50 degrees around the Sun until it locates the second target (see Fig. 6-3).

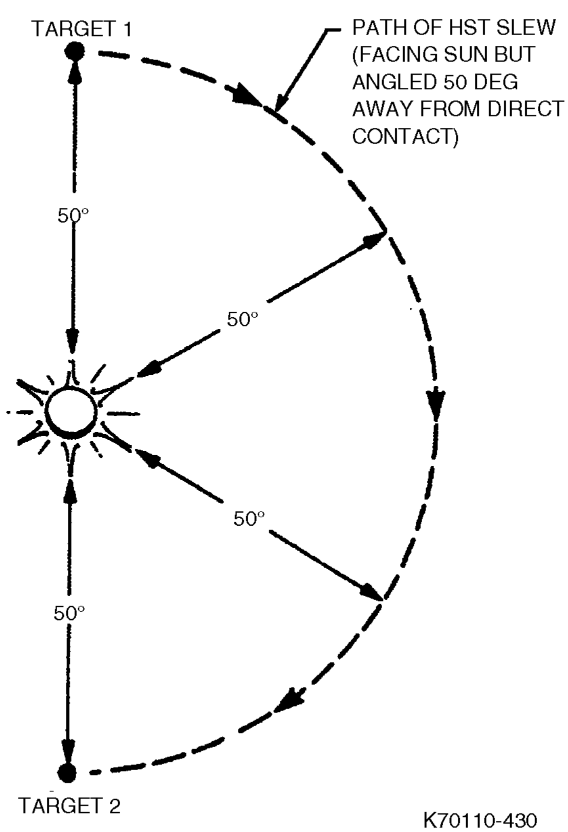

Fig. 6-3 Sun-avoidance maneuver

6.3.6 Communication Characteristics

The Telescope communicates with the ground via TDRSS. With two satellites 130 degrees apart in longitude, the maximum amount of contact time is 94.5 minutes of continuous communication, with only 2.5 to 7 minutes in a zone of exclusion out of reach of either TDRS (see Fig. 6-4). However, orbital variations by the Telescope and communications satellites affect this ideal situation to slightly widen the zone of exclusion.

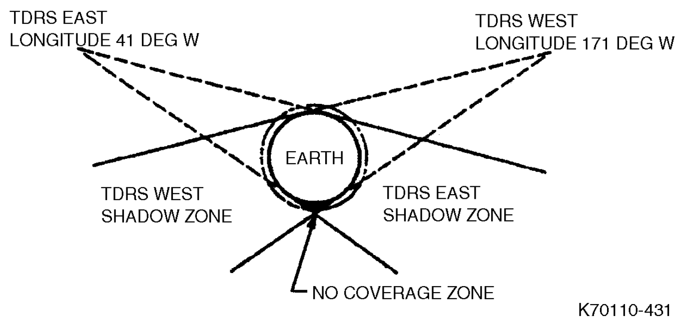

Fig. 6-4 TDRS-HST contact zones

The GSFC Network Control Center (NCC) schedules all TDRS communications. The Telescope has a general orbital communication schedule, supplemented by specific science requests. The NCC prepares schedules 14 days before the start of each mission week.

The backup communications link is the Ground Network, which receives engineering data or science data if the High Gain Antennas (HGA) cannot transmit to TDRSS. The longest single contact time is 8 minutes. The limiting factor of this backup system is the large gap in time between contacts with the Telescope. In practical terms, at least three contacts are required to read data from a filled science data recorder – with gaps of up to 11 hours between transmissions.

Each HGA maintains continuous contact with one TDRS to avoid unnecessary gaps in communication. Each antenna tracks the communication satellite, even during fine-pointing maneuvers.

Low Gain Antennas provide at least 95 percent orbital coverage via a TDRS for the minimum multiple-access command rate used.

6.4 Acquisition and Observation

The major steps in the observation process are target acquisition and observation, data collection and transmission, and data analysis.

Each science instrument has an entrance aperture, located in different portions of the Hubble's focal plane. The different aperture positions make precise pointing a sometimes-lengthy procedure for the FGSs, which must center the target in small apertures. Additional time is required to reposition the Telescope – an estimated 18 minutes to maneuver 90 degrees plus the time the sensors take to acquire the guide stars. If the Telescope overshoots its target, the Fixed Head Star Trackers may have to make coarse-pointing updates before the Telescope can use the FGSs again.

To increase the probability of a successful acquisition, Telescope flight software allows the use of multiple guide-star pairs to account for natural contingencies that might affect a guide-star acquisition – such as a guide star being a binary star and preventing the FGSs from getting a fine lock on the target. Therefore, an observer can submit a proposal that includes a multiple selection of guide-star pairs. If one pair proves too difficult to acquire, the sensors can switch to the alternate pair. However, each observation has a limited total time for acquiring and studying the target. If the acquisition process takes too long, the acquisition logic switches to coarse-track mode for that observation to acquire the guide stars.

Three basic modes are used to target a star.

- Mode 1 points the Telescope, then transmits a camera image, or spectrographic or photometric pseudo-image, to STOCC. Ground computers make corrections to precisely point the Telescope, and the coordinates pass up through the Advanced Computer.
- Mode 2 uses onboard facilities, processing information from the larger target apertures, then aiming the Telescope to place the light in the chosen apertures.
- Mode 3 uses the programmed target coordinates in the star catalog or updated acquisition information to reacquire a previous target. Called blind pointing, this is used mostly for generalized pointing and for the Wide Field and Planetary Camera 2, which does not require such precise pointing. Mode 3 relies increasingly on the updated guide-star information from previous acquisition attempts, stored in the computer system.