

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Memorandum No. 33-264*

*Surveyor Mission Operations System*

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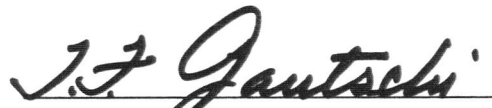
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*Technical Memorandum No. 33-264*

*Surveyor Mission Operations System*

A handwritten signature in dark ink, reading "T. F. Gautschi". The signature is written in a cursive style with a horizontal line underneath the name.

T. F. Gautschi, Manager  
*Surveyor Mission Operations System*

JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

April 4, 1966

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## PREFACE

It is the purpose of this Technical Memorandum to provide the reader with a basic understanding of the Mission Operations System (MOS). In recognition of the wide variation in reader interest and familiarity with this system, treatment of the subject, though purposely broad, contains sufficient detail to convey an accurate knowledge of the workings of the entire system. Technical data and explicit information about all elements of the MOS are found in the official MOS planning, design, and operational documents which this Memorandum summarizes.

This publication is comprised of five sections. The description of the MOS is progressively developed in the first four.

*Section I* gives a functional description of the major systems of the Project, thereby introducing the reader to the basic purpose of the MOS.

*Section II* identifies the principal elements of the MOS and describes how they are combined to form the MOS.

*Section III* explains one of the more advanced technical concepts introduced to space flight operations by *Surveyor*. This is the Command System—the heart of the MOS control of the spacecraft.

*Section IV* describes the three basic types of pre-mission tests conducted to verify that the MOS is ready for a mission. It shows how, in the final phase of testing, all the elements of the *Surveyor* Project directly involved in the space flight are brought together and exercised under conditions simulating the actual mission.

*Section V* presents to the reader, in flight-relationship, the activities of the MOS during Mission A (the initial flight of the *Surveyor* Project). This presentation consists of an overall view of the communications that take place during the mission, and then, in chronological order, the space flight activities controlled by these communications. These events, taken collectively, constitute the entire mission as it proceeds from launch through the conclusion of lunar surface activities.

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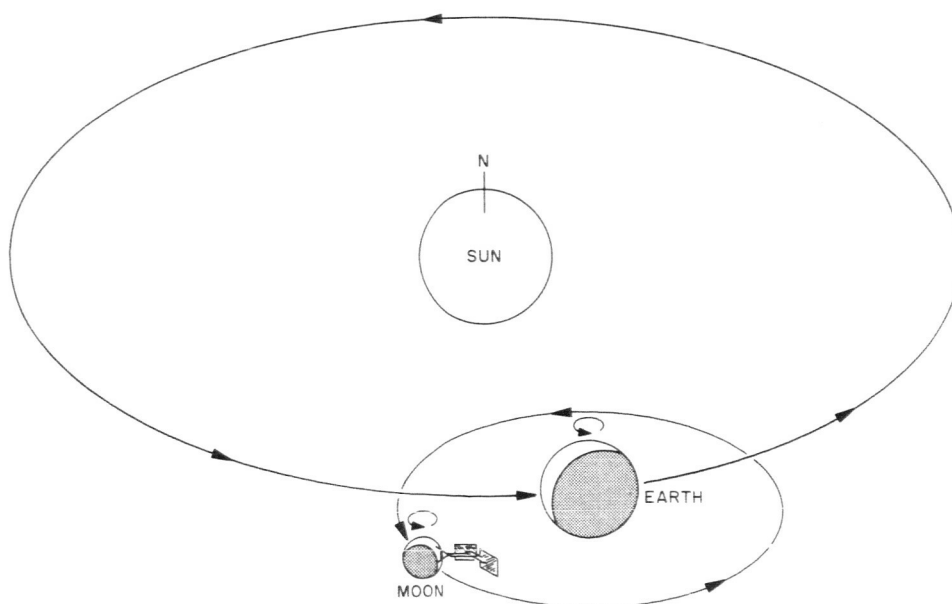
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### **About the Frontispiece**

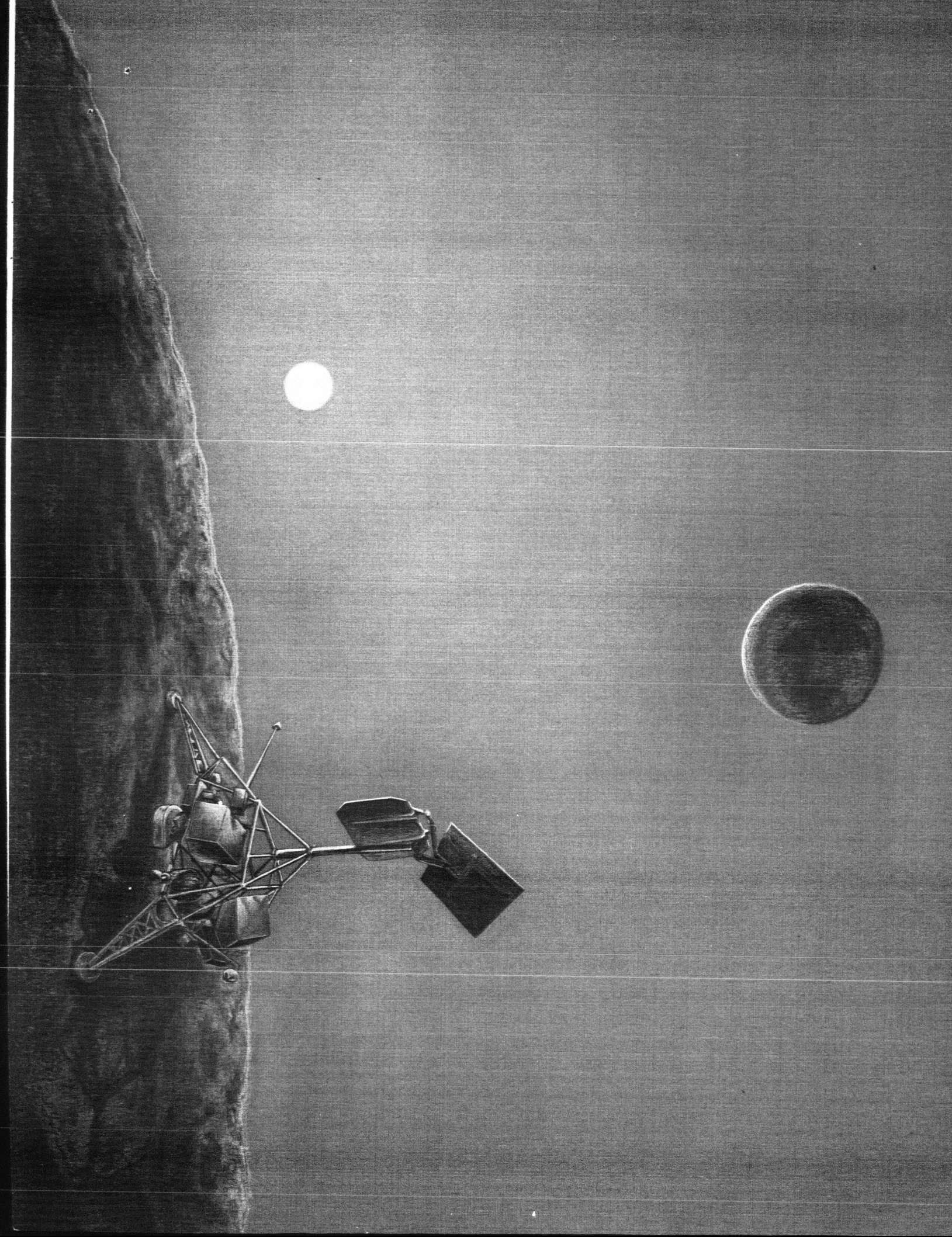
*Surveyor* has landed on the Moon. Commands received from the Deep Space Station at Goldstone have caused the spacecraft to point its high-gain antenna toward Earth and align its solar panel on the Sun in preparation for the transmission of television pictures and other information to Earth.

The orientation of the spacecraft, its posture on the Moon, and its relationship to the Sun and Earth are explained in this diagram. The orbits of the Earth and the Moon lie in nearly the same plane, the ecliptic. Both bodies rotate counterclockwise on their axes while revolving together around the Sun in a counterclockwise direction, as viewed from Earth.

In this frontispiece, North is pictured at the top of the page. *Surveyor* (near the Equator) is on the lunar surface, held in this position by the Moon's gravity.







## I. THE SURVEYOR PROJECT

A basic knowledge of the *Surveyor* Project is the vital key to a clear understanding of the Mission Operations System (MOS). This section provides such a key—a complete, though brief, picture of the Project.

The *Surveyor* Project was established to develop and demonstrate a technology for (1) transporting engineering and scientific instrumentation to the Moon, (2) accomplishing a lunar soft landing, and (3) conducting post-landing spacecraft operations to extend man's knowledge of the nature of the Moon.

The overall objectives<sup>1</sup> of the *Surveyor* Project are to:

- (1) Accomplish successful soft landings on the Moon as demonstrated by operations of the spacecraft subsequent to landing.
- (2) Provide basic data in support of *Apollo*.
- (3) Perform operations on the lunar surface which will contribute new scientific knowledge about the Moon and provide further information in support of *Apollo*.

<sup>1</sup>"*Surveyor* A-G Project Development Plan," Project Document No. 13 (latest revision), Jet Propulsion Laboratory, Pasadena, California.

Seven missions, designated A (the initial flight) through G (the final flight), are currently planned for *Surveyor*.

### A. Project Organization

The *Surveyor* Project may be viewed as being administratively and functionally divided into four major systems: Launch Vehicle, Spacecraft, Tracking and Data Acquisition, and Mission Operations. The major elements of the four systems are illustrated in Fig. 1.

During the design phase of the project, these major systems (discussed below) were developed in parallel. Then interrelationships were analyzed, defined, and resolved in such a manner that, during the operational phases, the *Surveyor* Project becomes a single operating unit—an integrated functional whole.

#### 1. Launch Vehicle System

The Launch Vehicle System, managed by the NASA Lewis Research Center, has its greatest interface with the Spacecraft System, since its function is to physically transport the spacecraft from Earth and place it in the desired Moon-intercept orbit.

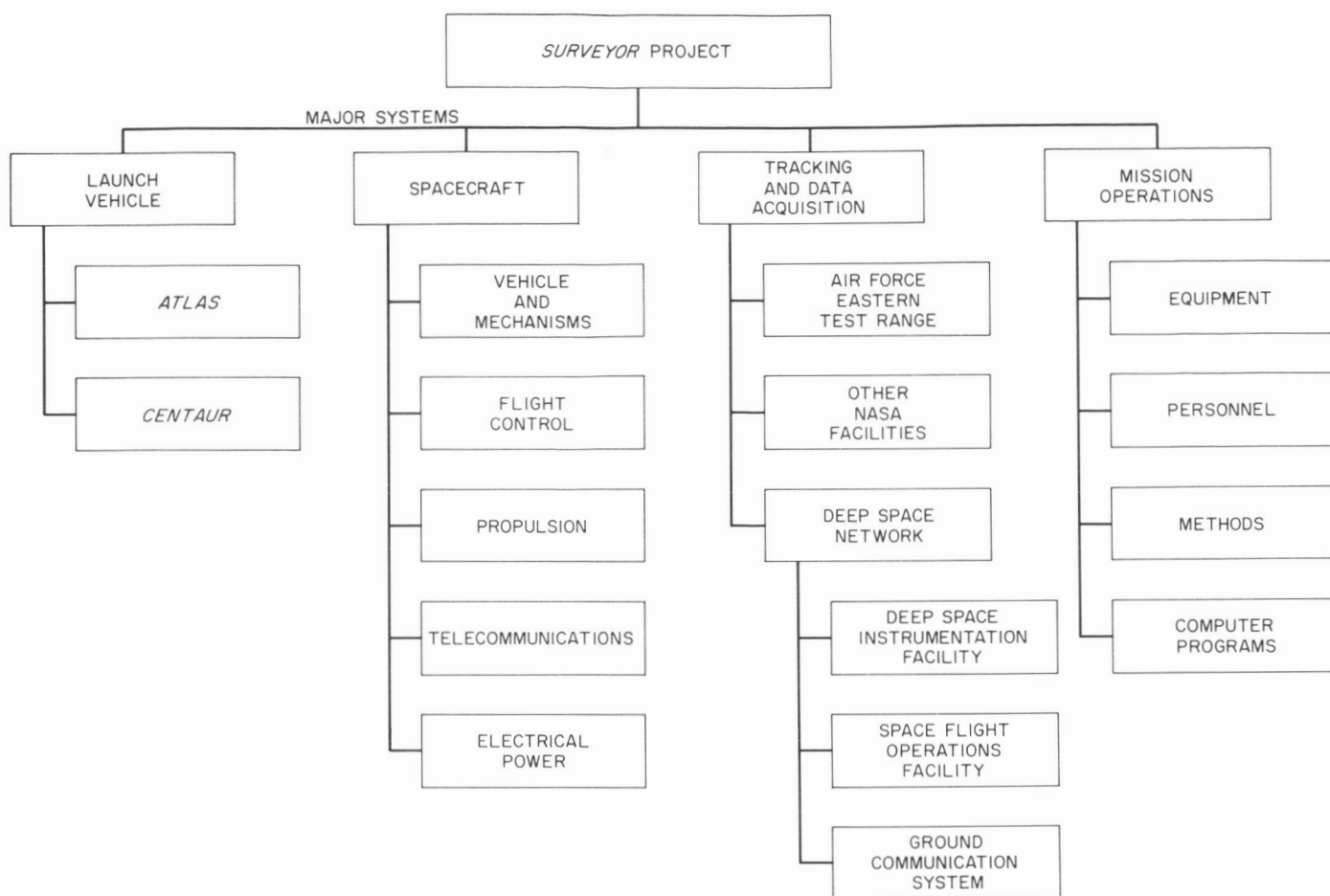


Fig. 1. Surveyor Project organization

The launch vehicle is a two-stage vehicle, consisting of a United States Air Force *Atlas* ICBM Series D first stage and a *Centaur* second stage.

The *Atlas* propulsion subsystem consists of twin booster engines, a single sustainer engine, and two vernier engines for attitude and velocity corrections. All engines are gimbal-mounted. The flight control system steering signals are received from the *Centaur* inertial guidance system.

The *Atlas/Centaur* separation subsystem utilizes a linear shaped charge. Separation is initiated by a signal from the first-stage flight control programmer and is coincident with *Atlas* sustainer and vernier engine cutoff.

The *Centaur* propulsion subsystem consists of two gimbal-mounted liquid-hydrogen/liquid-oxygen engines rated at 15,000-lb thrust each at 200,000-ft altitude. The guidance system provides attitude information for the au-

topilot system and controls injection errors so that the midcourse correction will be within the specified limits.

The first-stage telemetry subsystem transmits functional and environmental data on a very-high-frequency (VHF) carrier. The second-stage telemetry system transmits both *Centaur* and spacecraft data on a VHF carrier. The *Centaur* carries a C-band beacon to facilitate ground tracking by radar transponder.

## 2. Spacecraft System

The *Surveyor* ready for flight weighs 2250 lb and is mounted within an aerodynamic nose fairing atop the *Atlas/Centaur* launch vehicle (Fig. 2); Fig. 3 is a photograph of *Surveyor*. *Surveyor's* Spacecraft System is expressly designed to transport a payload to the surface of the Moon, provide the communication link for controlling the spacecraft and the elements of the payload from Earth, and telemeter their information back to

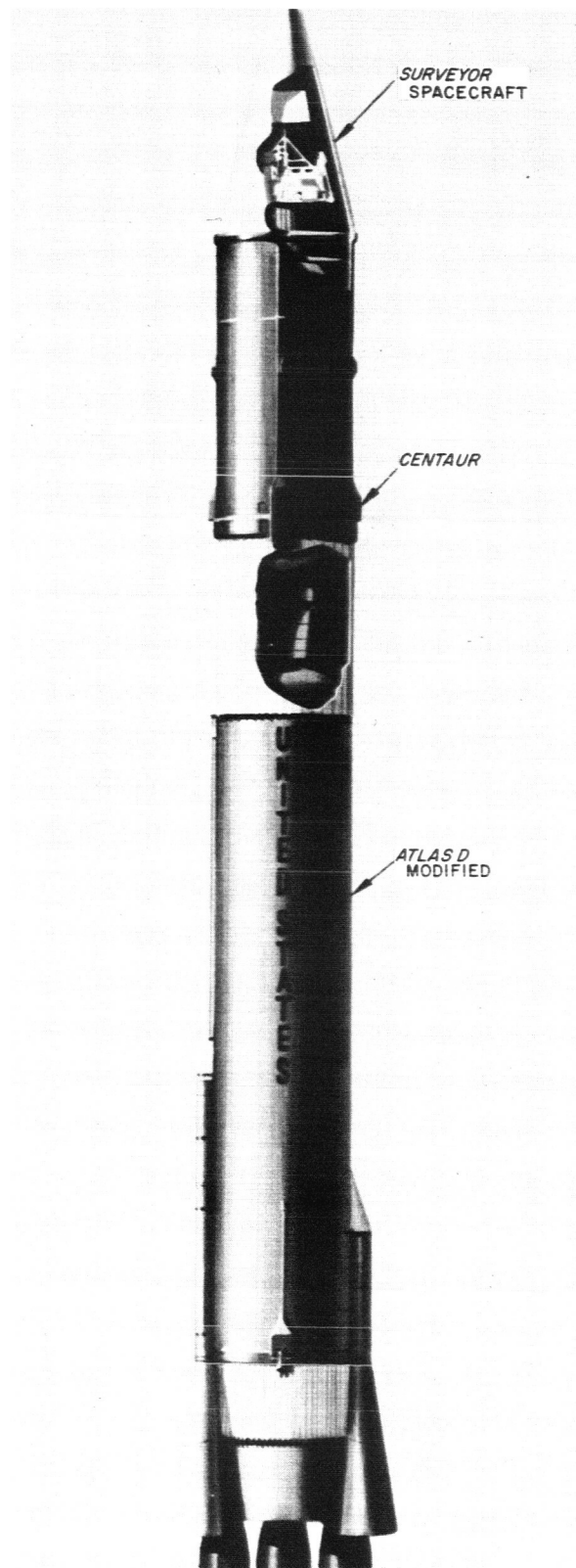


Fig. 2. *Atlas/Centaur* launch vehicle



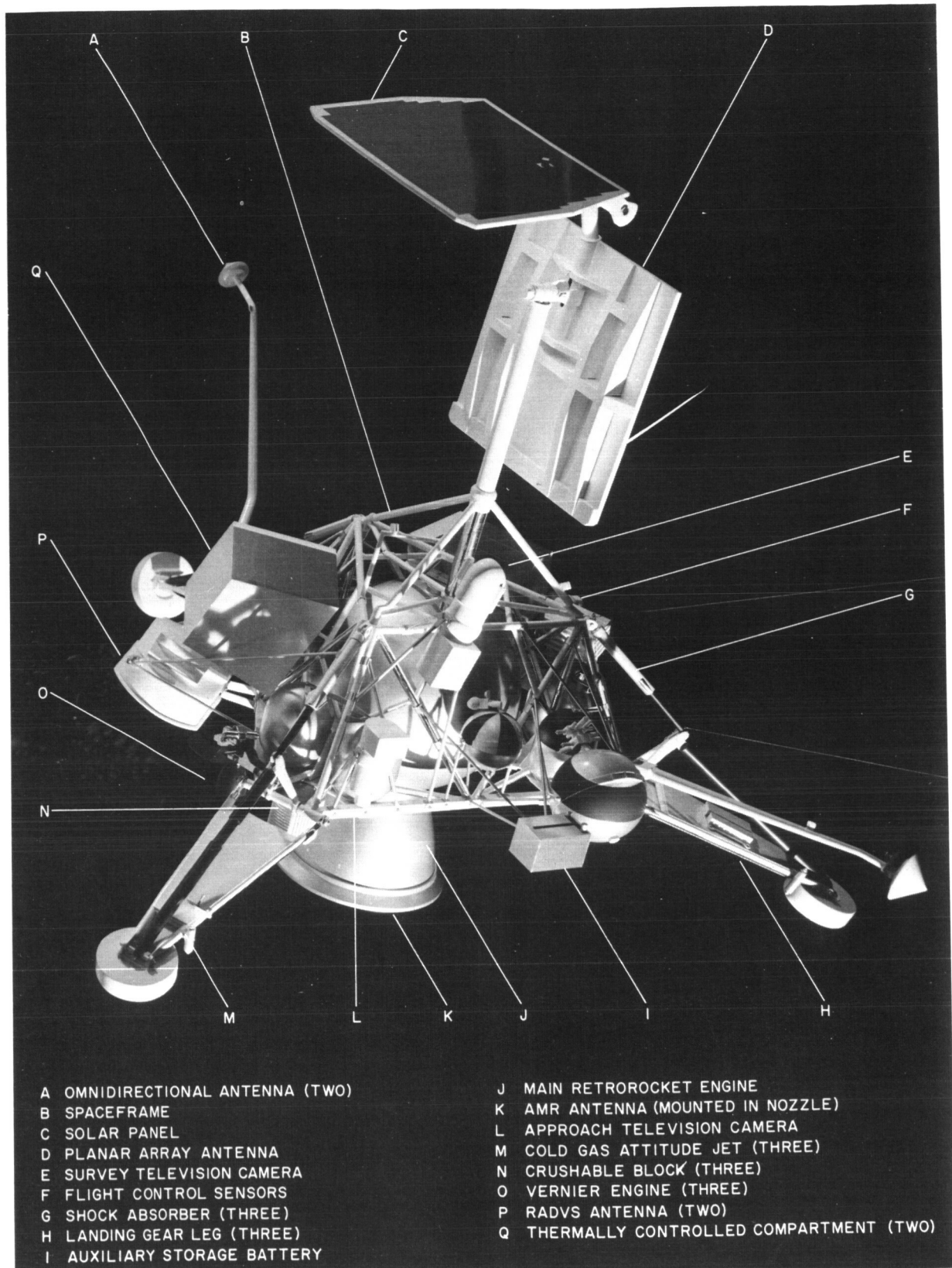


Fig. 3. Surveyor spacecraft

Earth. The essential spacecraft subsystems remain basically the same from flight to flight. This grouping of essential spacecraft elements, known as the bus, is designed to provide transportation, power, and communication to the payloads. The bus is composed of the following major subsystems: vehicle and mechanisms, flight control, propulsion, telecommunications, and electrical power; the basic payload includes a survey television subsystem.

**a. Vehicle and mechanisms subsystem.** The remaining mechanisms and other subsystems are mounted on the structural framework of the vehicle, called the spaceframe; this spaceframe is included within the *vehicle and mechanisms subsystem*. A tripod landing gear is folded to fit inside the shroud during launching. Shock absorbers in the legs absorb the calculated landing shock; in case the Moon's surface or the final rate of descent do not conform to the design model, each leg has beneath it a crushable block of aluminum foil honeycomb to absorb the energy of impact. Two thermally controlled compartments protect temperature-sensitive components of the electrical power and telecommunications subsystems and of the payload.

**b. Flight control subsystem.** The *flight control subsystem* maintains the spacecraft in a chosen orientation and directs it through midcourse, cruise, and terminal maneuvers when commanded from Earth. Two stabilization modes afford attitude reference during the flight. One is the optically stabilized mode, in which the spacecraft uses the Sun and the star Canopus as reference objects. The other is the inertially stabilized mode utilizing three gyroscopes for roll, pitch, and yaw attitude reference. A flight control programmer converts attitude signals into signals that control cold gas attitude jets, to maintain the spacecraft in a stable attitude. The programmer also directs certain automatic sequences during the flight.

**c. Propulsion subsystem.** Two distinct reaction elements are included in the *propulsion subsystem*. A set of three liquid-fueled vernier engines supplies thrust for the midcourse maneuver as well as for modulated braking and attitude control during the terminal descent. This subsystem uses a self-igniting mixture of fuel and oxidizer, which is fed into the three thrust chambers by helium under pressure. A solid-propellant main retro-rocket engine provides the principal deceleration for landing. An altitude marking radar (AMR) initiates the firing of the main retro when it senses the fact that the spacecraft is at a preset distance from the Moon.

In the final descent, the vernier engines are controlled by signals from a radar altimeter and doppler velocity sensor (RADVS) which continuously measures slant range, velocity, and attitude of the spacecraft with respect to the Moon.

**d. Telecommunications subsystem.** The spacecraft has a two-way *telecommunications subsystem* (Fig. 4) that provides (1) a method of telemetering information to the Earth, (2) the capability of receiving and processing commands to the spacecraft, and (3) angle tracking and one- or two-way doppler for orbit determination.

Two independent, identical receivers and two central command decoders are used for enhanced reliability. Commands pass through one of the receivers to a central command decoder, and then to the subsystem decoder that controls a particular subsystem of the spacecraft, such as electrical or flight control. The system provides for continuous operation of the command link in the event that either of the spacecraft receivers or either of the two central command decoders should fail.

Each of two identical transmitters can be selected by Earth commands. The transmitters have two power levels, 10 w and 0.10 w, and provide for both frequency and phase modulation. A signal processing system transforms television frame identification and engineering data signals into a composite telemetry subcarrier form suitable for modulating the transmitter. Signals indicating conditions within the spacecraft subsystems are sampled in sequence by commutators in one of seven modes. The commutated analog signals are digitized at any of five bit rates (17.2, 137.5, 550, 1100, or 4400 bits/sec) in analog-to-digital converters. The resulting digital signal used to modulate a subcarrier is generated in one of 17 subcarrier oscillators. Other analog data signals are frequency- or phase-modulated (PM) onto others of the subcarriers. Then the FM, PCM-FM, or PM carriers are multiplexed together in summing amplifiers to produce the baseband signal. In six of the seven modes, the signal is comprised of one to seven subcarrier channels at a time and carries telemetry data from as many as 120 points within the spacecraft subsystems. The seventh mode permits direct frequency modulation of the carrier by the time-multiplexed television signal, which consists of the video and frame identification data. The baseband signal is frequency- or phase-modulated onto the carrier wave generated in the transmitter. The transmitter output goes to the antenna

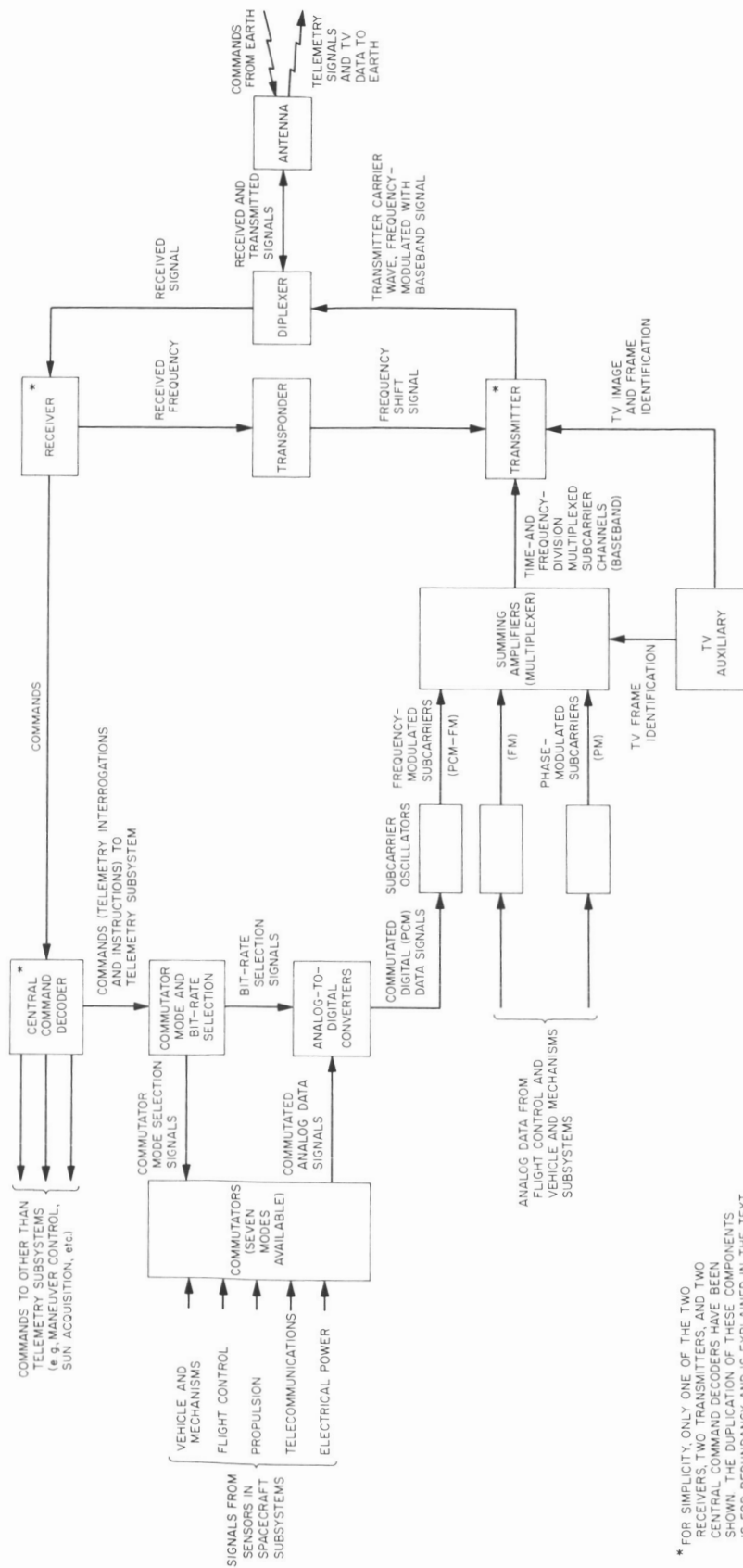


Fig. 4. Spacecraft telecommunications subsystem

\* FOR SIMPLICITY, ONLY ONE OF THE TWO RECEIVERS, TWO TRANSMITTERS, AND TWO CENTRAL COMMAND DECODERS HAVE BEEN SHOWN. THE DUPLICATION OF THESE COMPONENTS IS FOR REDUNDANCY AND IS EXPLAINED IN THE TEXT

through a diplexer, which permits simultaneous transmission and reception over the same antenna.

Highly accurate tracking of the spacecraft requires transponders that permit two-way coherent doppler shift measurements. In this mode, a transmitter is phase-locked to a receiver through transponder interconnection circuitry; the signal transmitted back to Earth is phase-coherent with the received signal. On a command from Earth, the spacecraft receiver operates in a phase-lock mode and tracks the frequency of the signal it receives from the DSIF Station.

There are three telecommunications antennas aboard the spacecraft: a high-gain directional antenna; a planar array, used only for transmission; and two conical omnidirectional antennas (also called *omni-antennas*) used for both transmission and reception. The planar array orientation with respect to the vehicle is controlled by Earth commands. Each of the omnidirectional antennas is permanently connected through a diplexer to one of the spacecraft receivers. The omnidirectional antennas are moved after launch to such a position that the effects of spacecraft attitude upon the capability of receiving commands is minimized. Since the antenna pattern of each individual omnidirectional antenna actually has areas of low sensitivity (nulls), the simultaneous operation of both antennas in the receive mode is required to give truly omnidirectional coverage. This requirement is critical if the spacecraft is to have complete freedom of attitude during maneuvers.

**e. Electrical power subsystem.** The spacecraft derives energy for its *electrical power subsystem* from a solar panel and storage battery. (Spacecraft for Missions A through D also carry an auxiliary battery for transit operations.) The solar panel furnishes power for functional use and for battery charging during transit and during the lunar day after touchdown.

**f. Survey television subsystem.** The spacecraft carries a survey television camera for post-touchdown operation. This camera is equipped with a variable focal length lens for wide-angle or narrow-angle viewing, and a movable mirror to provide scanning of the lunar surface. The mirror is adjusted by Earth command in both azimuth and elevation angles. The camera can be operated in either a 600-line TV or a 200-line TV mode. The 600-line TV mode provides better picture quality at the expense of greater power requirements and necessitates the use of both the high-power transmitter and the high-gain antenna, whereas the 200-line TV mode can be transmitted using the high-power transmitter and an omni-antenna.

### 3. Tracking and Data Acquisition System

The Tracking and Data Acquisition (T&DA) System, consisting of all facilities used for tracking and for acquiring telemetry data, is the communications link between the spacecraft and the MOS. The T&DA System includes many NASA facilities. For the *Surveyor* missions the T&DA System uses the facilities of the Air Force Eastern Test Range (AFETR), the Deep Space Network (DSN), and the NASA/Goddard Space Flight Center (NASA/GSFC).

**a. Air Force Eastern Test Range.** The AFETR provides the facilities used for prelaunch tests and for launching the space vehicle; it also provides tracking of the launch vehicle, telemetry from both the launch vehicle and the spacecraft, and data handling support. Its tracking stations include island-based as well as ship-based stations that track the space vehicle from launch through the time the spacecraft is separated from the *Centaur* second stage. At this point, AFETR tracking support of the mission is concluded and is assumed by the DSN.

**b. Deep Space Network.** The DSN is a precision system designed to communicate with, and permit control of, spacecraft launched on lunar and planetary missions; it provides equipment for data processing, reducing, computing, and plotting as well as the technical areas in which this work is conducted.

The main elements of the DSN are the Deep Space Instrumentation Facility (DSIF), space communication and tracking stations established around the world; the Space Flight Operations Facility (SFOF) at JPL in Pasadena, California, the command and control center; and the Ground Communication System (GCS), which connects all parts of the DSN by voice, teletype (TTY) lines, and high-speed data lines (HSDL). These elements of the DSN are shown, in simplified form, in Fig. 5.

**Deep Space Instrumentation Facility.** The DSIF uses 85-ft parabolic antennas, low-noise receiving systems, and high-power transmitters located at stations around the Earth to track, command, and receive data continuously from the spacecraft.

Currently the functions of deep space tracking, command transmission, and reception of spacecraft transmissions are handled by three Deep Space Stations (DSS) of the DSIF. These are the Pioneer Station at Goldstone, California (DSS 11); the Johannesburg Station at



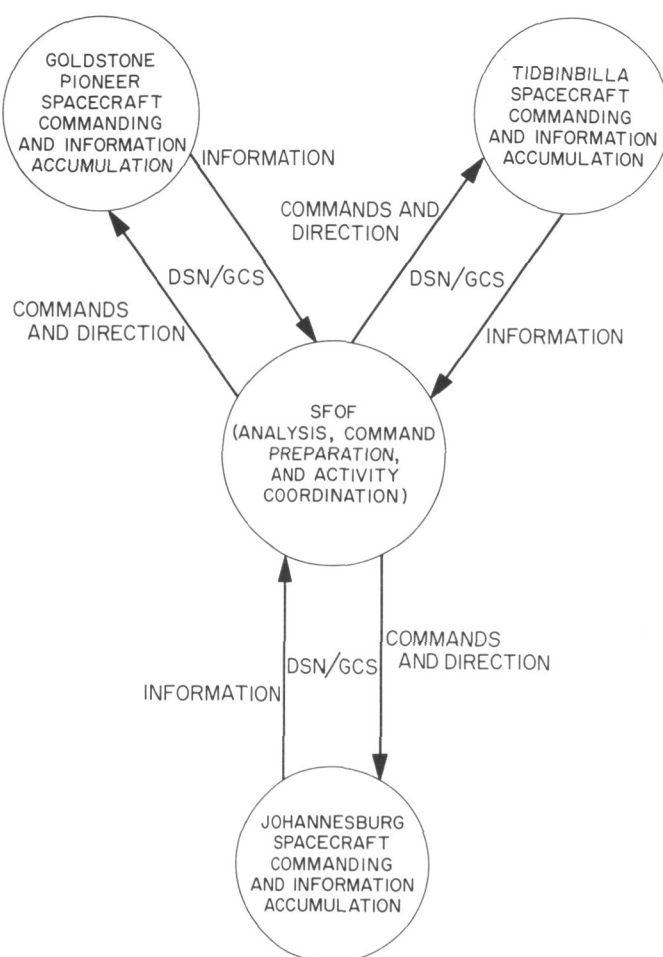


Fig. 5. Functional relationship of DSN elements

Johannesburg, South Africa (DSS 51)<sup>2</sup>; and the Tidbinbilla Station, near Canberra, Australia (DSS 42). These stations are situated approximately 120 deg apart in longitude, so that during space operations the spacecraft is always within the field of view of at least one station. The geographic location of the three prime Deep Space Stations for *Surveyor* is shown in Fig. 6; photographic views are shown in Figs. 7 through 9.

**Space Flight Operations Facility.** The Space Flight Operations Facility is located at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. The SFOF is a three-story building in which are housed the following space flight operations functions:

- (1) DSN control of DSIF Stations.

<sup>2</sup>It is anticipated that, starting January 1967, the station near Madrid, Spain (DSS 62) will be used after the initial acquisition pass by DSS 51.

- (2) DSN ground communications operation control of the DSN/GCS and of the internal voice, teletype, and high-speed data circuits and equipment.
- (3) Data processing, monitoring, display, distribution, and storage (library).
- (4) Space operations direction.
- (5) Space operations evaluation and spacecraft command analyses in real and near-real time.

**Deep Space Network/Ground Communication System.** The DSN/GCS consists of voice, teletype, and high-rate data circuits provided by the NASA World-Wide Communications Network (NASCOM) and is managed by NASA/GSFC. The circuits between the DSN/SFOF and each of the overseas stations and AFETR are controlled by GSFC. The management of the communications circuits between Goldstone and the SFOF has been delegated to the DSN.

**c. NASA/Goddard Space Flight Center.** This facility supplies the Earth-based communication system in support of the *Surveyor* Project. This communication system is a world-wide communications network under the management and operation of the GSFC. The system is known as NASCOM.

#### 4. Mission Operations System

The Space Flight Operations System (SFOS) is composed of hardware, software, and highly trained personnel; when using the appropriate Tracking and Data Acquisition facilities, this combination operates the spacecraft from liftoff until the end of the mission to accomplish the objective of the *Surveyor* Project. During preflight tests and space flight operations, the DSN portion of the T&DA System is under operational control of the *Surveyor* Space Flight Operations Director (SFOD); for convenience, the term MOS will generally be used to indicate both the *Surveyor* SFOS and the appropriate portions of the DSN.

The MOS hardware includes those systems and equipments built and used exclusively for *Surveyor* mission operations. Such items are known as mission-dependent equipment. Included in this category are the Command and Data Handling Consoles (CDC) installed at the DSIF Stations, the Spacecraft Television Ground Data Handling System (SCTV-GDHS) and other special display equipment.

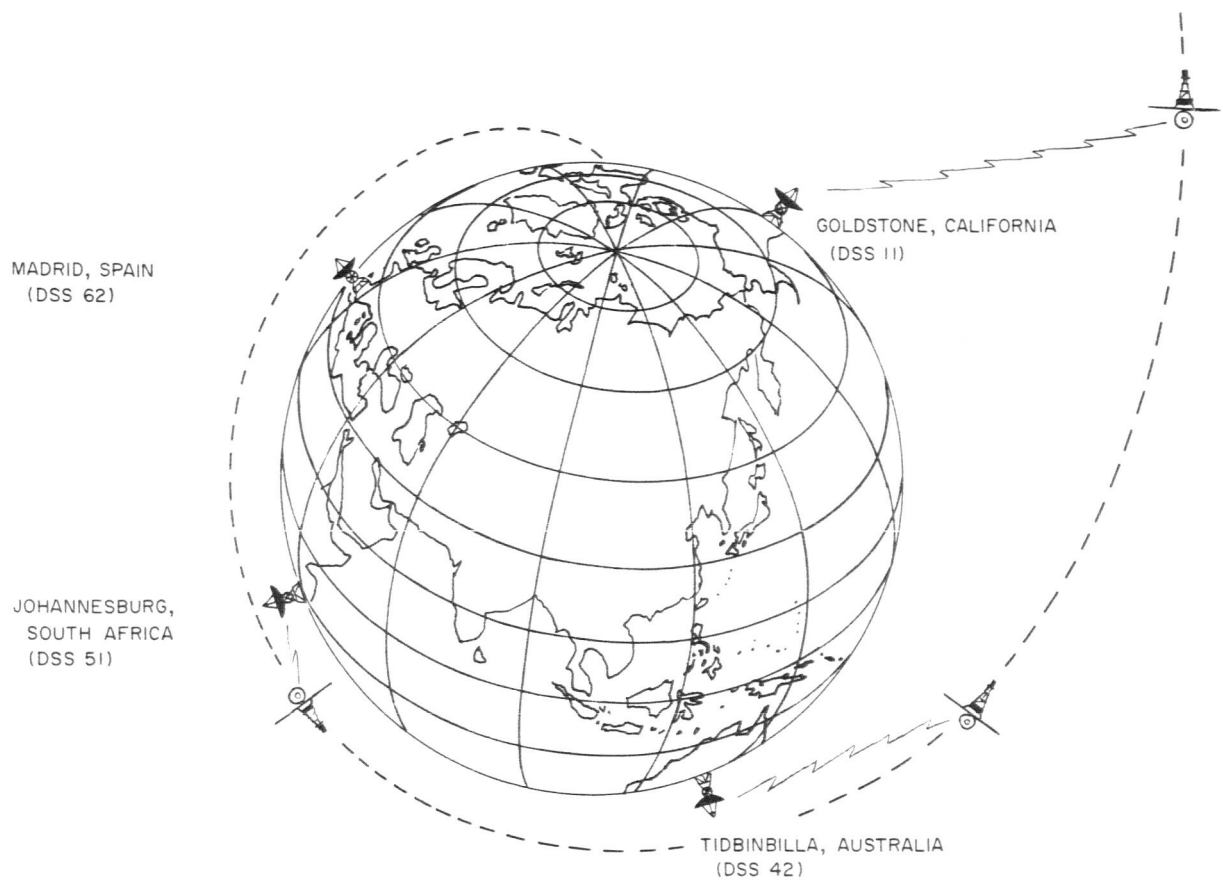


Fig. 6. Placement of DSIF Stations

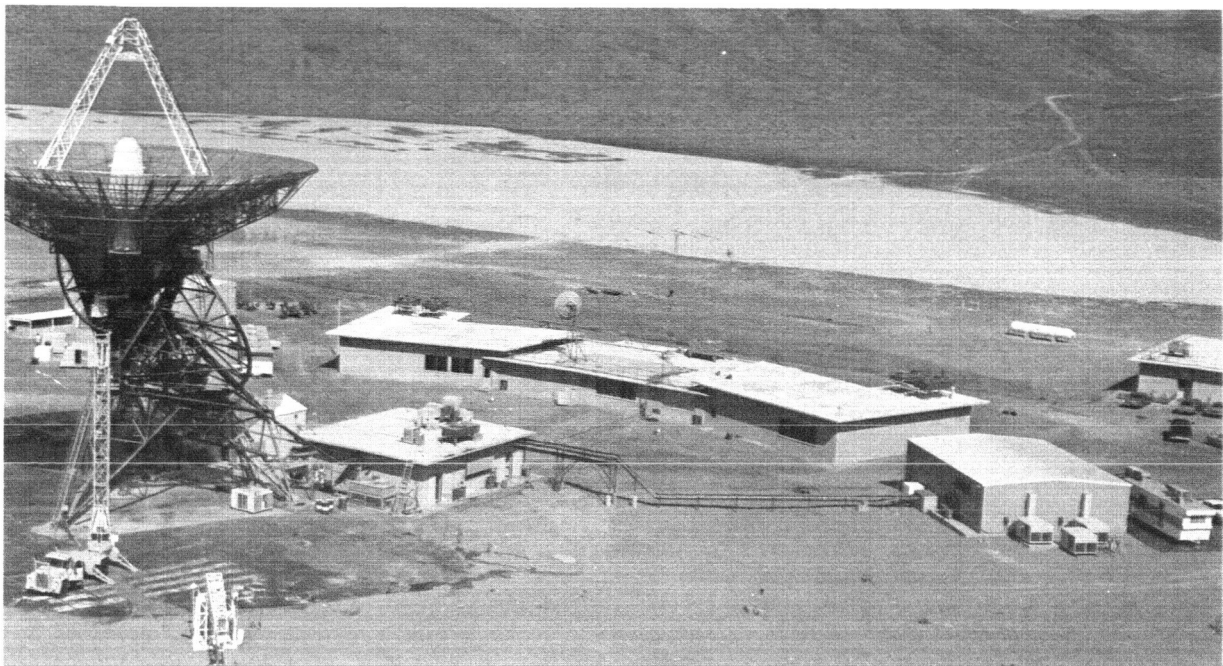
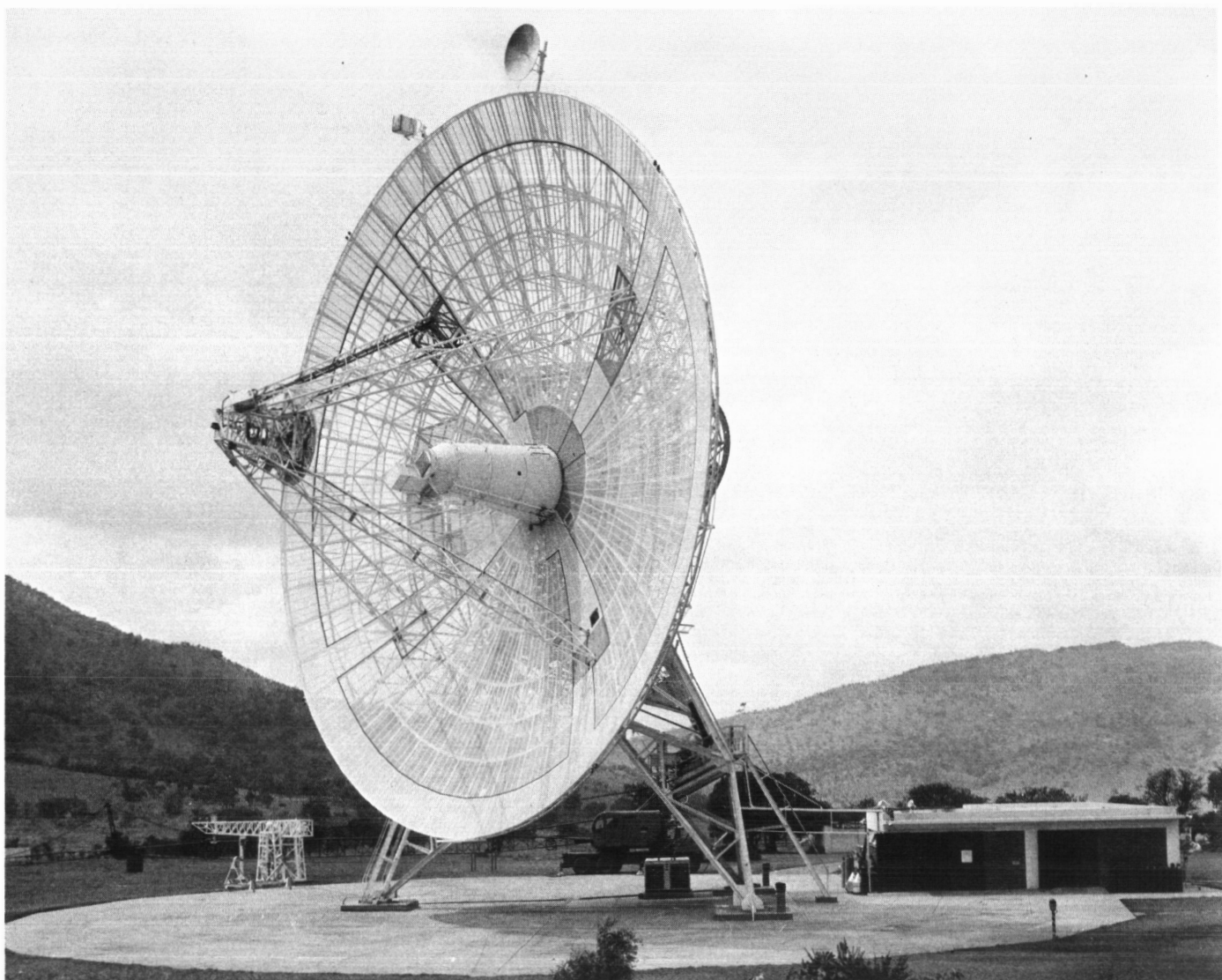


Fig. 7. DSS 11: master station of the network



**Fig. 8. DSS 51: makes initial acquisition after launch**

The MOS software includes the necessary computer programs and the accumulation of all the methods used in operating the mission. In addition to generalized specifications and plans, detailed operating procedures have been prepared for the SFOF and for the individual DSIF Stations. These procedures take extensive advantage of the capability of rapid computation offered by digital data processing equipment, and many computer programs have been prepared to aid in rapid display and analysis of data and generation of commands to the spacecraft.

One of the unique features of the *Surveyor* Project is the extensive and versatile system of commands that the MOS uses to control the spacecraft during transit and

after touchdown. The Command System is explained in Section III of this Technical Memorandum.

A most important phase of the *Surveyor* Project is a thorough testing program for the entire operational configuration of the MOS and of its various subsystems. These tests ensure that the equipment, both mission-dependent and mission-independent, can function correctly as a total system; that the MOS software is entirely adequate in concept, scope, and execution; and that the MOS working members know their individual functions and perform as a team. (See Section IV.)

Operating under the supervision of the Mission Director, the SFOD assumes overall control of all space flight

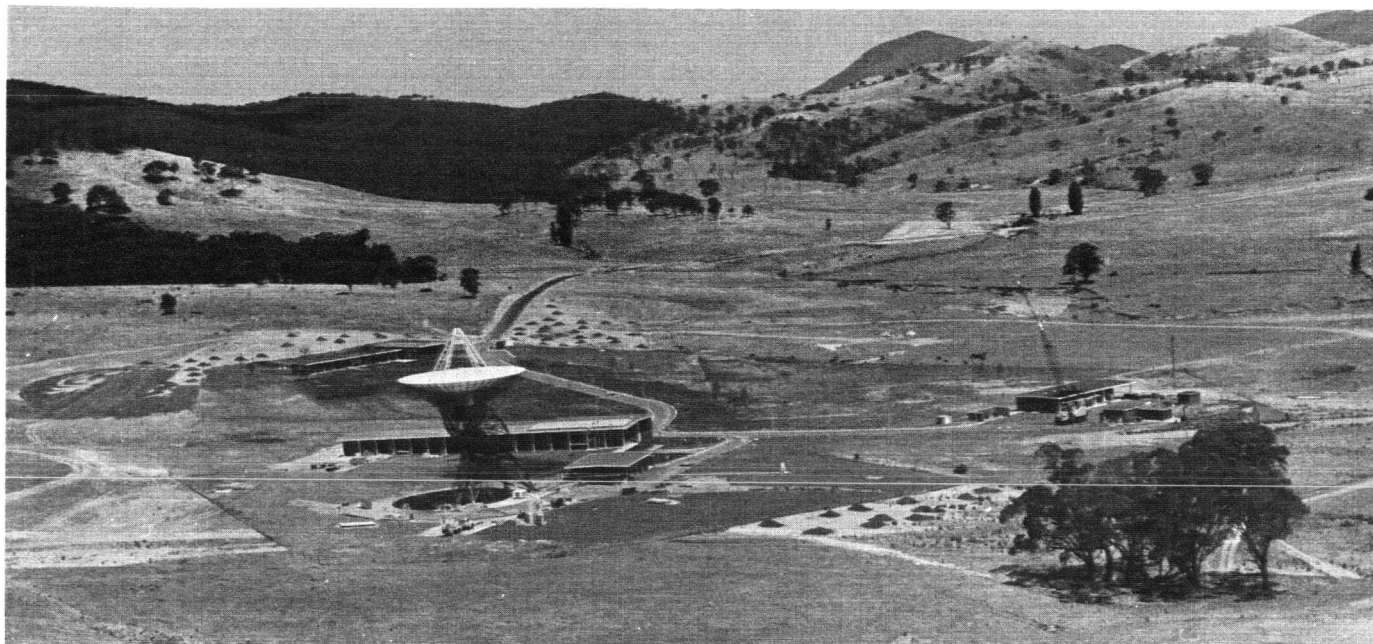


Fig. 9. DSS 42: completes DSN coverage for *Surveyor*

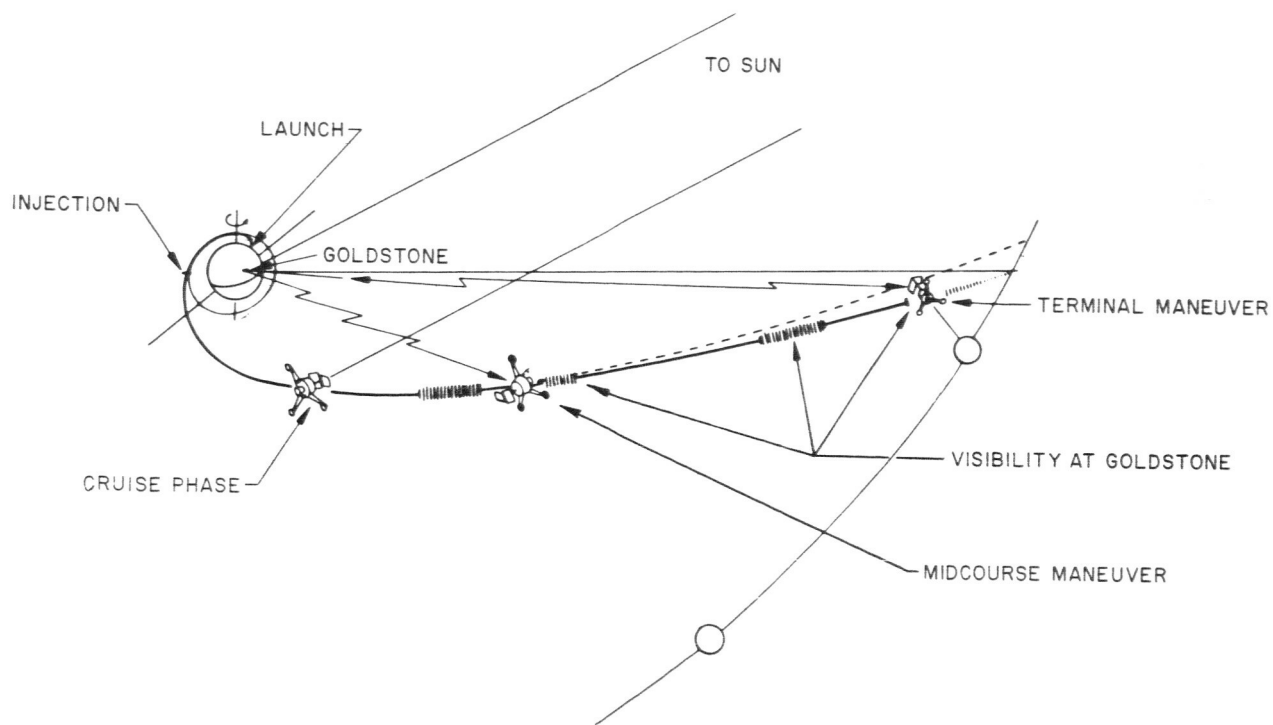


Fig. 10. *Surveyor* mission profile

and lunar surface operations and is supported by groups of experts in spacecraft performance analysis, flight path determination, and space sciences in the SFOF, and by the DSIF Station Managers and their operations teams. Included in each DSIF team is a *Surveyor* Operations Chief (SOC) who controls the operation of the CDC.

### **B. Summary of Surveyor Mission**

An abbreviated version of a typical *Surveyor* mission (described in Section V) is shown in Fig. 10. This illustration identifies only the major events of the mission: launch, injection, cruise mode, midcourse maneuver, and the terminal maneuver. It also illustrates the fact that the Goldstone DSS will be the prime DSIF Station in communication with the spacecraft during the midcourse and terminal maneuvers.

For attitude stabilization, the spacecraft's flight control subsystem is locked onto the Sun and Canopus as the spacecraft enters the initial cruise phase. Some 15 to 20 hr after injection, the spacecraft performs a midcourse trajectory correction maneuver, in response to commands sent from the Earth, in order to refine the trajectory and optimize the time and place of landing on the Moon. Then follows the second cruise phase, which ends when the spacecraft is commanded to turn and align its main retrorocket with the flight path. At a signal from the AMR, the main retrorocket ignites and dissipates most of the spacecraft's velocity. The main retro is ejected after it has burned out and the vernier engines, under control of the RADVS, bring the spacecraft to a soft landing on the lunar surface. Once there, a television survey will be performed, as directed and controlled by the MOS team.



## II. MISSION OPERATIONS SYSTEM

Because of the complex nature of the space flight operations it is assigned to direct and control, the MOS is both extensively and intricately organized. Its basic function is to control the spacecraft through its defined mission activities. This, in turn, involves:

- (1) Coordination and direction of the activities of the DSIF, SFOF, and MOS personnel conducting the mission; evaluation of the spacecraft's progress, and issuance of the requisite commands to the spacecraft.
- (2) Evaluation of the performance of the spacecraft as well as of the MOS during the flight in real time<sup>3</sup> to identify and determine the nature of any nonstandard performance that would require a deviation from the nominal mission plan.
- (3) Determination in real time of corrective actions which would maximize the mission capabilities of the systems under nonstandard performance conditions.
- (4) Coordination and direction of corrective actions in real time.
- (5) Recording and dissemination of data for post-mission analysis.

With the basic functions defined, a description of the hardware, personnel, and software and the means by which they perform the work completes the explanation of the MOS. A description of these physical elements of the system: hardware (equipment); personnel (engineers, scientists, and technicians); and software (methods and computer programs) is given in the following paragraphs.

### A. Equipment

The MOS equipment falls into two categories: mission-independent and mission-dependent. The former is composed chiefly of the *Surveyor* T&DA System equipment, called mission-independent because it is general purpose equipment which can be utilized by more than one NASA project. Selected parts of this equipment have been assigned to perform the functions necessary to the *Surveyor* Project. Certain *Surveyor* Project equipment

has been installed at DSN facilities for specific functions peculiar to the Project; such equipment is designated mission-dependent.

DSN equipment is described in the following text under the DSIF and SFOF mission-independent and mission-dependent categories. The third element of the DSN, the GCS, contains only mission-independent equipment. Equipment typical to each *Surveyor* DSIF Station is shown in Fig. 11.

### 1. Deep Space Instrumentation Facility

*a. Mission-independent.* The Pioneer, Johannesburg, and Tidbinbilla Stations use essentially identical equipment. Each is equipped with a steerable, 85-ft parabolic antenna capable of precision tracking of the spacecraft. Precision radio equipment at each station, operating in the S-band (approximately 2300 Mc), locks electronically with the spacecraft's transponder equipment to provide measurements of direction and velocity between the DSIF station and the spacecraft. The Deep Space Stations transmit commands to the spacecraft, receive telemetry signals, and relay this telemetry data to the control center in the SFOF.

The 85-ft parabolic antenna focuses the incoming telemetry signals from the spacecraft and sends them to the DSS receiving equipment. Outgoing signals from the DSS transmitter are directed to the spacecraft through the same antenna. Incoming and outgoing signals pass through a diplexer, which allows the antenna simultaneously to transmit outgoing commands and to receive telemetry or television signals from the spacecraft.

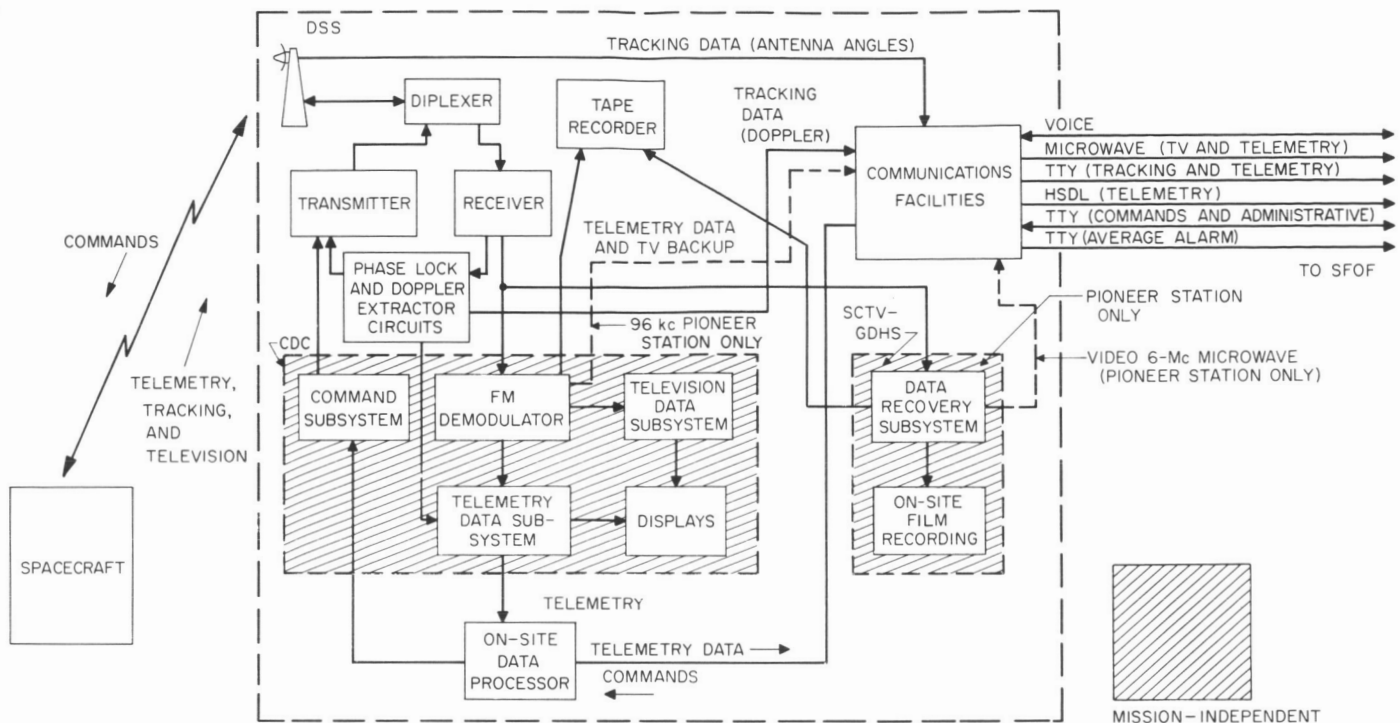
A DSIF Station normally tracks *Surveyor* from horizon to horizon, while maintaining two-way frequency lock between ground and spacecraft transmitters and receivers. As the antenna automatically follows the spacecraft across the sky, readouts of the antenna hour angle<sup>4</sup> and declination<sup>5</sup> give spacecraft angular direction accurate to 0.14 deg. The spacecraft velocity, obtained from the two-way doppler signals, is accurate to 0.03 m/sec. All incoming telemetry and TV signals are recorded at

<sup>3</sup>Real time is used to express the idea of timeliness—the need for factual information about an event being made available as close in time to the actual occurrence of the event as possible.

<sup>4</sup>Angle between the antenna and the spacecraft, measured westward from the DSIF antenna in the 24 hr of one rotation of Earth.

<sup>5</sup>Angle in degrees north (+) or south (–) between the celestial equator and the spacecraft.





**Fig. 11. Typical equipment for DSS**

the DSIF Stations on magnetic tape for later delivery to the SFOF. The real-time spacecraft telemetry data is converted by the On-Site Data Processor (OSDP) to a suitable format and is transmitted to the SFOF.

The DSIF Station in view of the spacecraft is in continuous contact with the SFOF by voice, teletype, and high-speed data lines. A microwave link also exists between Goldstone and the SFOF.

*b. Mission-dependent.* In addition to the standard DSS equipment previously mentioned, each station has been equipped with a *Surveyor* mission-dependent CDC, which modulates the DSS transmitter during transmission of commands; demodulates, processes, and displays incoming telemetry signals before sending them on to the OSDP; and processes, displays, and records incoming spacecraft TV signals. A *Surveyor* SCTV-GDHS at the Goldstone Station recovers and records the incoming TV signals on 70-mm film.

The CDC (Figs. 12 and 13) consists of four major sub-systems:

- (1) The *command subsystem* generates FM digital command signals from punched tape or manual inputs for the DSS transmitter, and prints a permanent record of the commands sent. The

major units of the command subsystem, which can accommodate 1024 different commands, are the command generator, the command subcarrier oscillator, the punched tape reader, and the command printer. Outgoing commands are relayed to the SFOF and logged on magnetic tape by the DSS.

- (2) The *FM demodulator subsystem* accepts the FM intermediate-frequency signal of the DSS receiver and derives from it a baseband signal. The baseband signal consists of either video data or a composite of engineering subcarrier signals. Depending upon the type of data constituting the baseband signal, the CDC processes the data in either the TV data subsystem or the telemetry data subsystem.
- (3) The *TV data subsystem* receives video data from the FM demodulator and processes it for real-time display at the CDC and for 35-mm photographic recording. In addition, telemetered frame-identification data is displayed and photo-recorded. A long-persistence-screen TV monitor is mounted in the CDC. The operator, when requested, can thus evaluate the picture and, upon the SFOD's direction, initiate corrective commands during lunar television surveys.

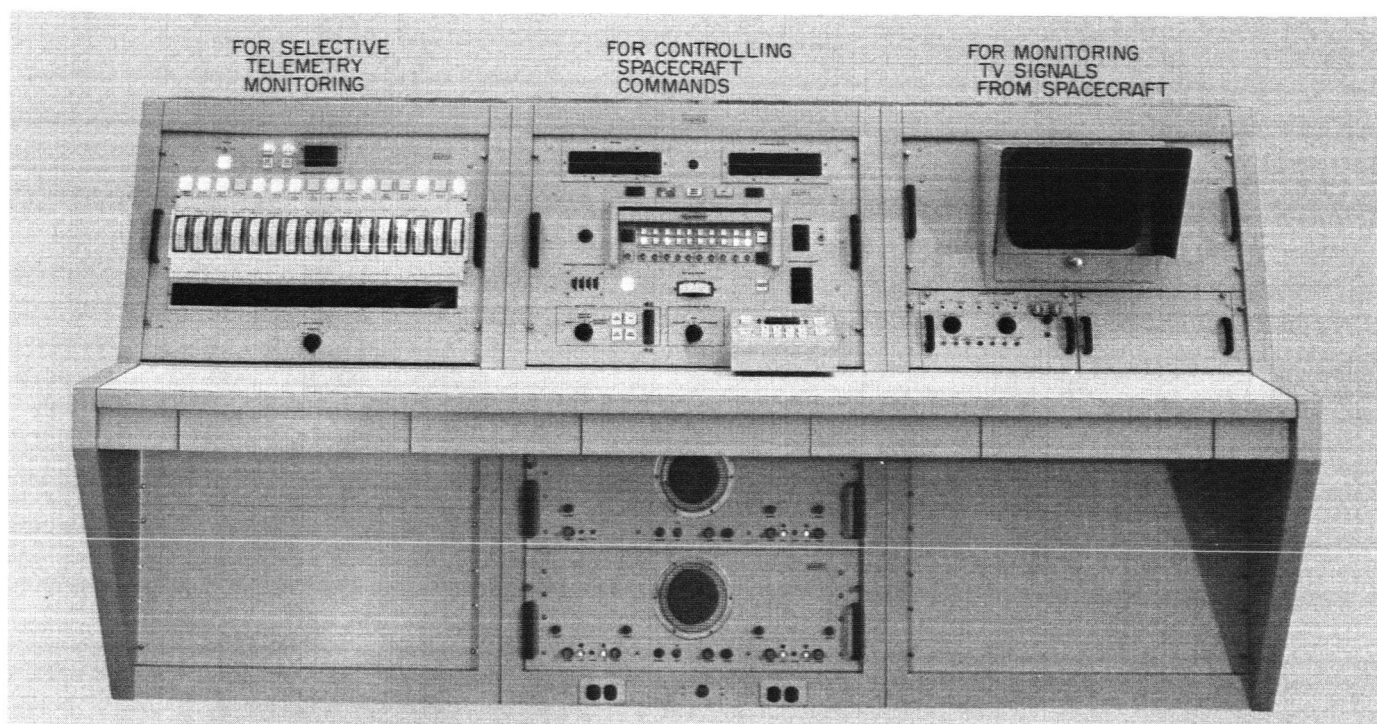


Fig. 12. CDC operator's console

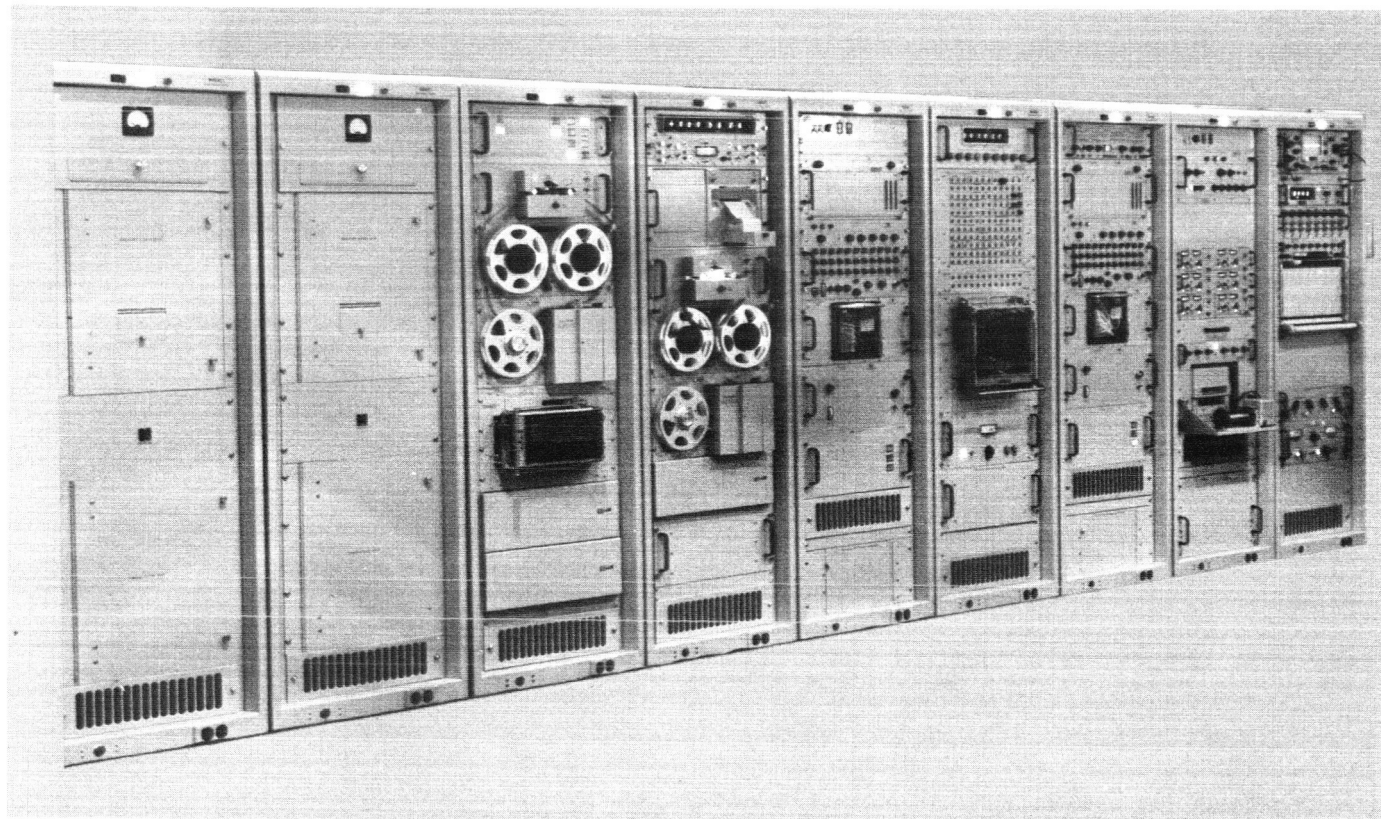


Fig. 13. CDC equipment racks

The photographic recording unit provides a 35-mm film frame-by-frame record of the video data. It consists of a short-persistence-screen cathode-ray tube and associated electronics, a 35-mm film transport, and an optical system for focusing the image onto the film. The photographic recording unit equals the TV monitor in linearity. It exceeds the monitor, however, in image and gray scale resolution.

- (4) The *telemetry data subsystem* of the CDC separates the various data channels from the baseband signal coming from either the FM demodulator or the DSS receiver phase-detected output and displays the desired data to the operators. Discriminators are provided for each subcarrier channel contained in the baseband signal. The output of each discriminator is relayed to the

OSDP for transmission to the SFOF, and is also applied at the DSS, as required, to a meter or oscillograph channel, or, in the case of time-multiplexed data, to the PCM decommutator.

The CDC contains built-in test equipment to ensure normal operation of its subsystems. A CDC tester, consisting of a spacecraft transponder with the necessary modulation and demodulation equipment, ensures day-to-day compatibility of the CDC and DSIF Stations.

At DSS 11, the prime TV recording capability is the SCTV-GDHS, which produces precision recordings of TV images together with the associated frame identification data. The output of the DSS receiver goes to a data recovery subsystem (DRS), which performs the functions of intermediate-frequency translation, demodulation, and recovery of synchronization and ID data.

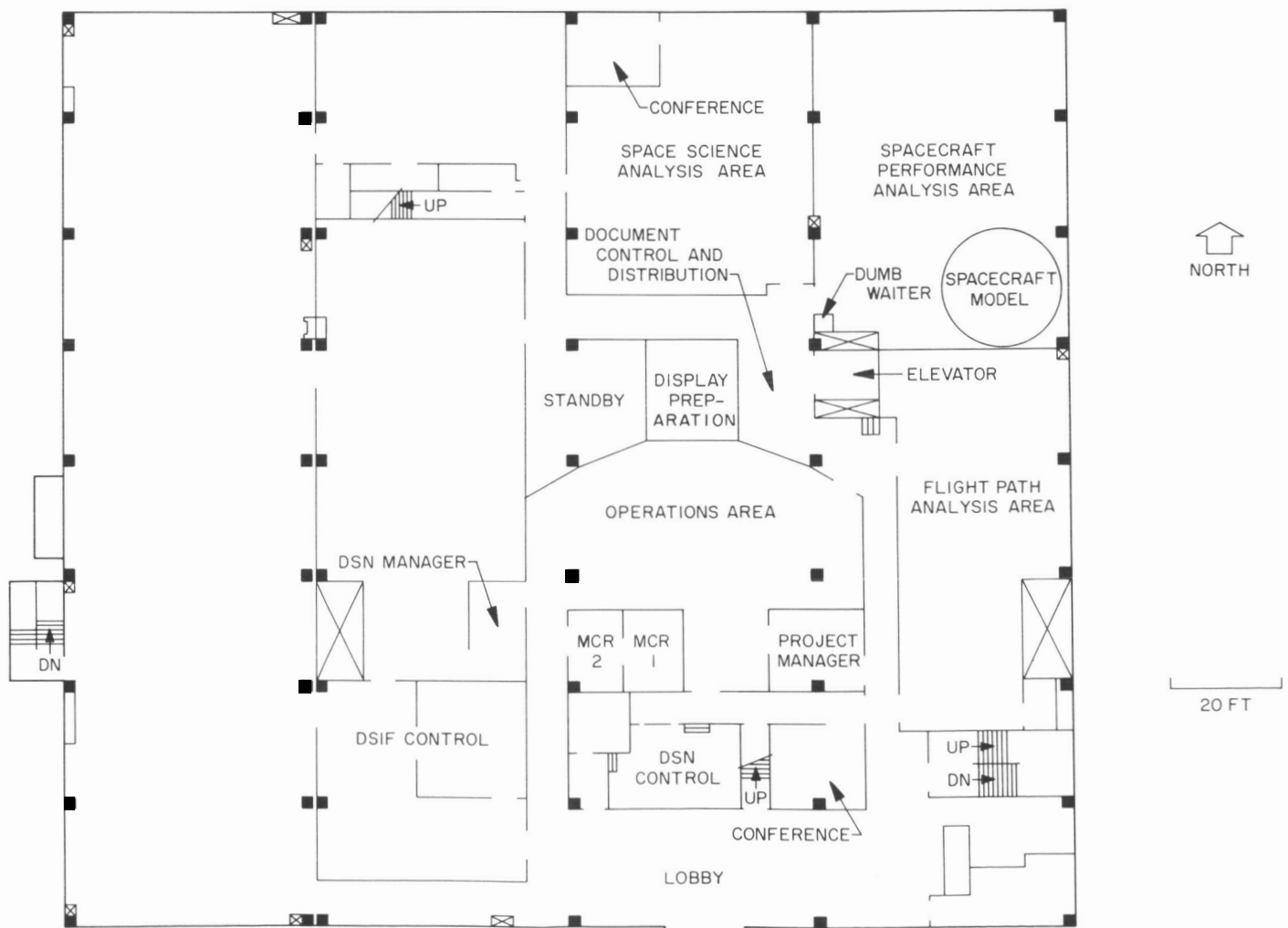


Fig. 14. First-floor plan of SFOF

The signals from the DRS pass to the on-site film recording (OSFR) subsystem. Here they are converted from electrical signals to a latent image on 70-mm film, which is then taken to the SFOF for developing. In addition to the TV picture, the image on the film contains a calibrating gray scale, the raw ID bit-stream, and certain DSS-derived data to uniquely identify the record. The output of the DRS is also transmitted from Goldstone by microwave to Pasadena for recording and display in the SFOF.

## 2. Space Flight Operations Facility

*a. Mission-independent.* All *Surveyor* space flight and lunar post-landing operations are controlled from the

SFOF by the SFOD and his staff. Here are centered the facilities and the abilities needed for controlling an entire mission from injection to end of the mission. To this end, the *Surveyor* Project has been assigned Mission Control Rooms (MCR); the use of the main Operations Area, as needed for mission operations; the Flight Path Analysis Area (FPAA); the Spacecraft Performance Analysis Area (SPAA); and the Space Science Analysis Area (SSAA). These areas are adjacent to each other and are located on the main floor of the SFOF building (Fig. 14). The communication center of the SFOF, where the lines to the DSIF Stations around the world terminate, is in the basement. The SFOF Telemetry Processing Station (TPS) and the computer complex are on the second floor (Fig. 15). In addition,

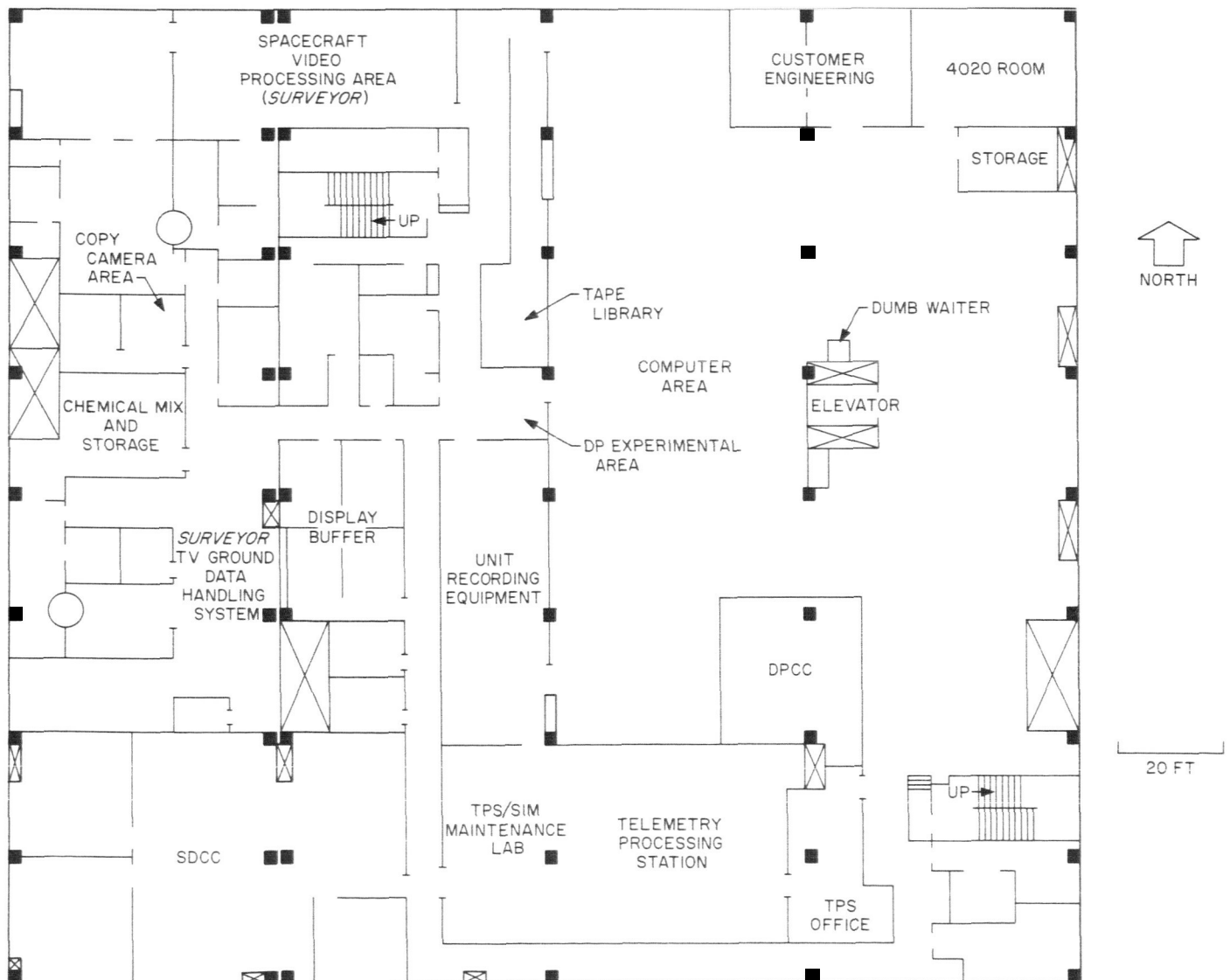


Fig. 15. Second-floor plan of SFOF

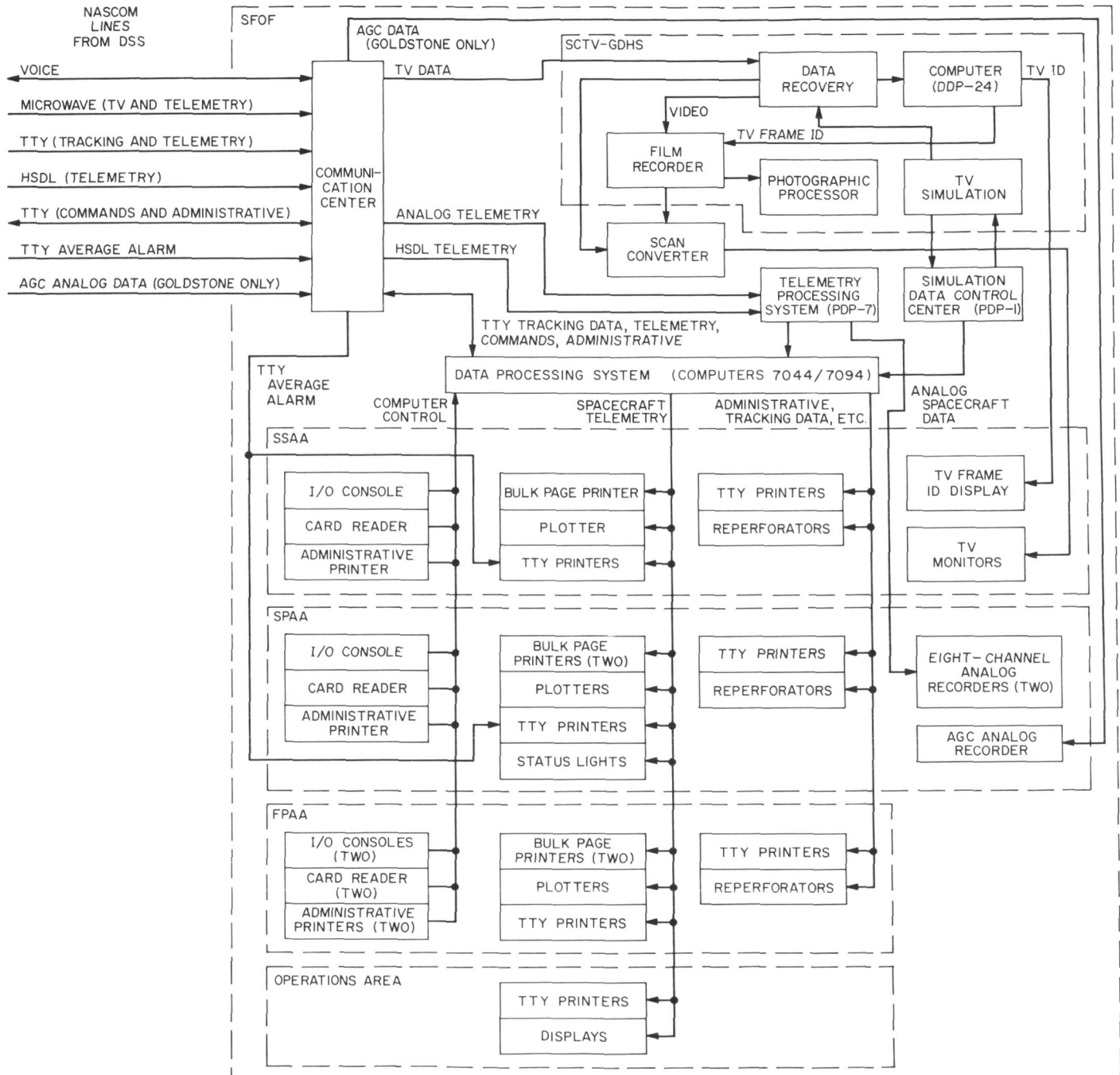


Fig. 16. SFOF configuration for Surveyor







The FPAA is across a hall from the Operations Area. A communication and control console gives access to the necessary communication nets. Two computer input/output (I/O) consoles, together with such peripheral equipment as page printers [Fig. 18(a) and (b)], card punch and reader, and plotters, give access to the computer complex. Figure 19(a) shows the 11- by 17-in. model, which plots selected telemetry data channels as required by the phase of the mission; the 30- by 30-in. plotter is shown in Fig. 19(b). Six TTY printers (Fig. 20) provide tracking data and other telemetered information. Multiple banks of CCTV monitors afford views of over 30 different SFOF areas and data sources, such as the mission master digital clock and closeups of TTY printers.

The equipment in the SPAA is much the same as that in the FPAA, with certain notable exceptions. Again, a communication and control console gives access to appropriate communication networks, and an I/O console and associated peripheral equipment make the computer available for analysis and command uses. Teletype machines bring important telemetry information into the area.

Five *Surveyor* mission-dependent, computer-driven status light displays show the condition of up to 24 different spacecraft subsystems in real time. Two 8-channel analog recorders, driven by the computers in the TPS, are also a part of the *Surveyor* equipment.

A unique feature of the SPAA is the Spacecraft Functional Model. A hemispherical dome of translucent plastic, 18 ft in diameter, with two observation ports, is permanently installed in the SPAA. A door provides access to the interior. A star map is painted on the inside of the dome, and the model of the *Surveyor* spacecraft rests on a gimballed mount in the middle of the floor. A small control panel enables an operator to position the model to correspond to the attitude of the spacecraft. Lights projected from the model to the dome help the operators to visualize the orientation of the spacecraft and the effects of proposed maneuvers.

The SSAA includes, as the other areas, communication network access, a computer I/O console, CCTV monitors, and printers. It also includes two special spacecraft TV monitors that show the TV image and frame ID data after conversion to the closed-circuit scan rates,

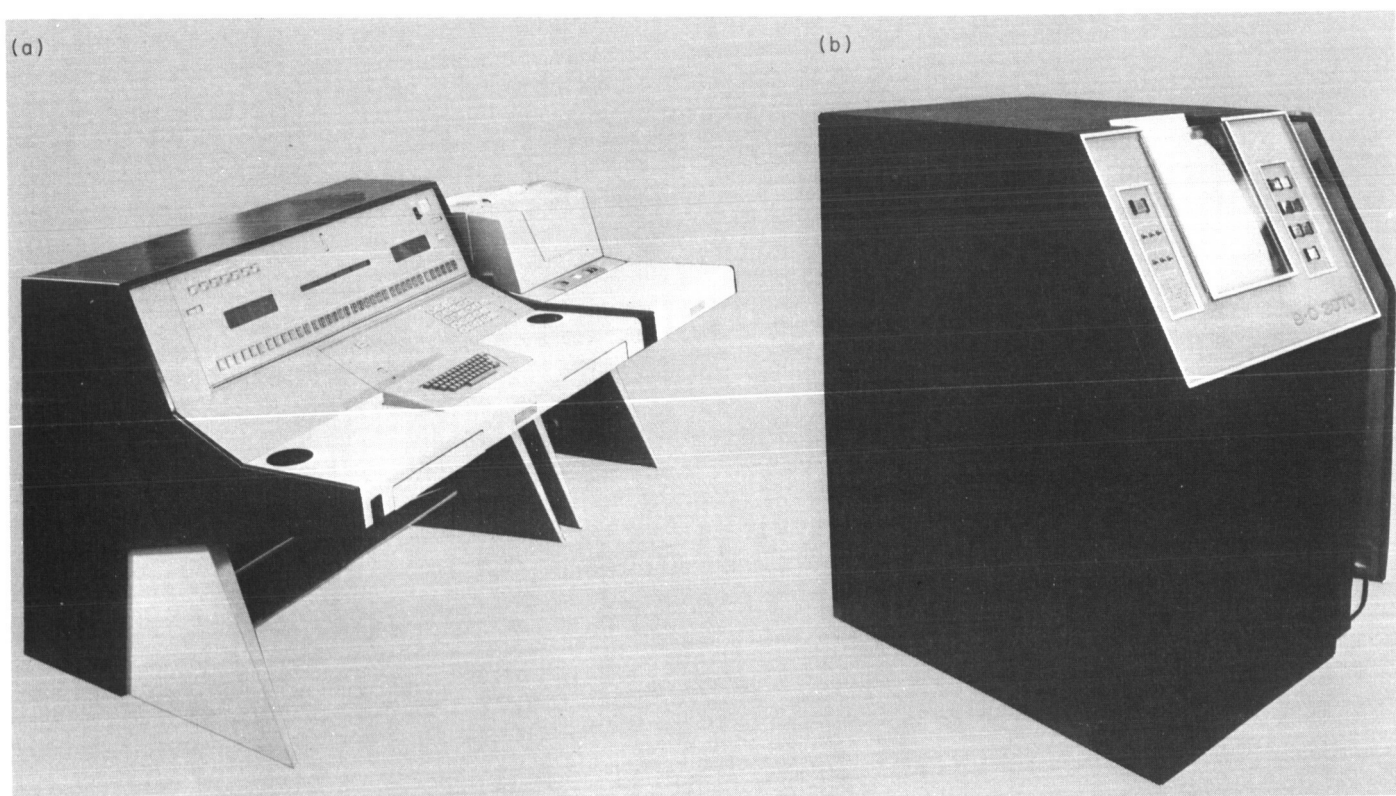


Fig. 18. Input/output console and printers

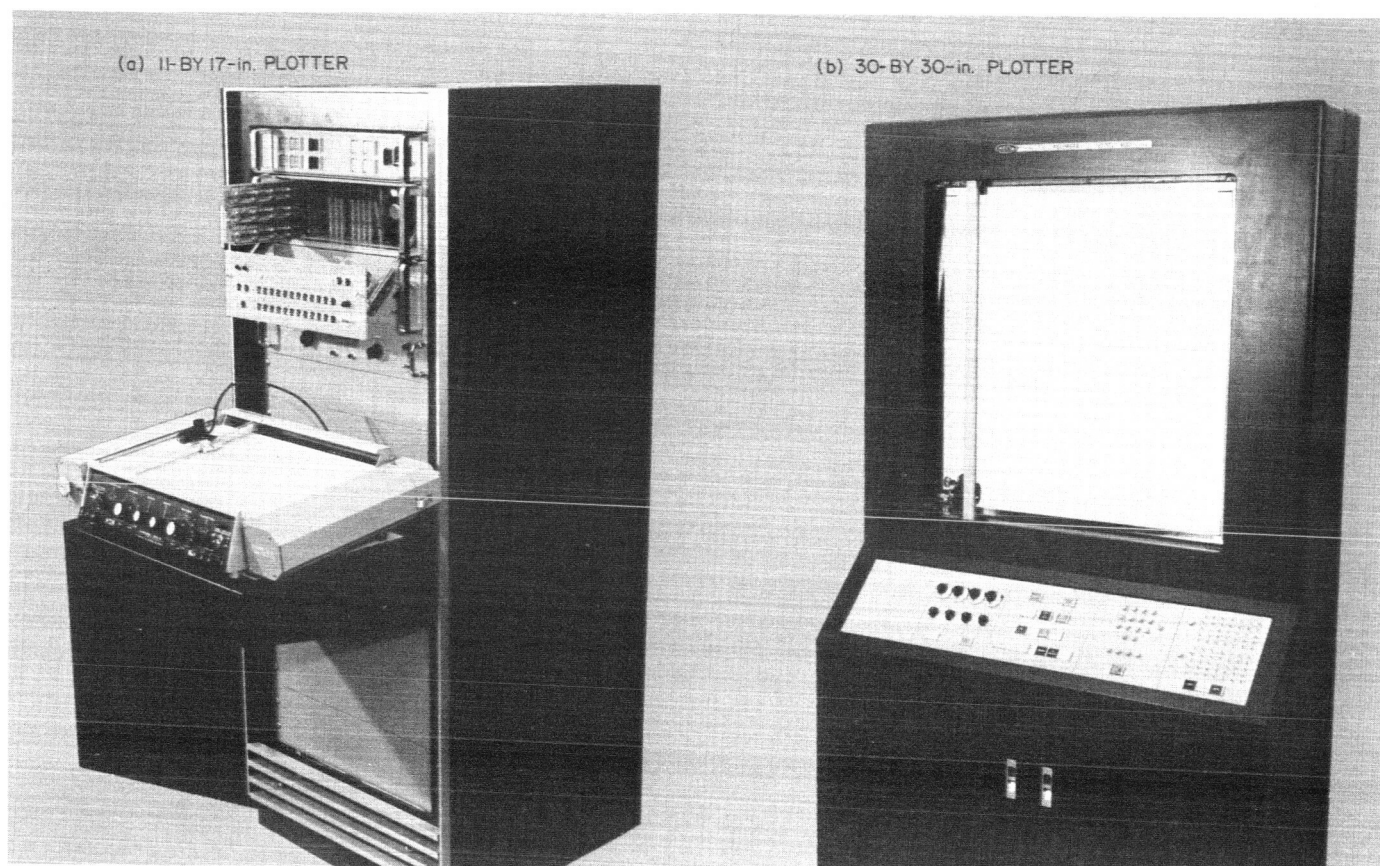


Fig. 19. Plotters



Fig. 20. Display teleprinter

as well as one monitor showing the TV image at the spacecraft TV camera scan rate. Quick-response paper-tape cameras permit the preparation of quick-look mosaics.

On the second floor of the SFOF, the TPS handles the incoming high-speed data stream from the DSIF Stations. Any of three PDP-7 computers receives the near-raw data, identifies it by time, and formats it for input to the Data Processing System (DPS) and eventual distribution to the various teletype printers throughout the operational areas of the SFOF.

Certain parts of the DPS are used by *Surveyor*. This includes the basic SFOF IBM 7044 and 7094 data processors interfacing through banks of disk storage. The entire DPS is operated from the Data Processing Control Area (DPCA), where I/O consoles and switching consoles provide for the control of the DPS, while a communication and control console puts the operator on the appropriate communication nets within the SFOF during space operations.

The PDP-1 computer of the Simulation Data Control Center has been adapted for *Surveyor* Project test and training use. The addition of a shift register allows the PDP-1 to simulate spacecraft telemetry data and input it directly into the TPS in the same manner in which data comes over the HSDL from the DSIF Stations during an actual mission.

**b. Mission-dependent.** The SFOF sections of the SCTV-GDHS are divided between the SSAA and the second floor of the SFOF. Here the media conversion subsystem (MCSS) receives, in real time, all video signals transmitted from Goldstone over the microwave link. The MCSS performs functions similar to those of the DRS and the OSFR at the DSIF Stations and equivalent to that of the SCTV-GDHS section at Goldstone, in that it affords magnetic tape recording of the incoming signal and converts the spacecraft TV signal into a latent image on 70-mm film. To accomplish this, a data recovery package demodulates the incoming FM signal, and recovers synchronization and ID information. The signal then

goes to a DDP-24 general purpose computer and to a film recorder, where the latent image is exposed onto the film. This photographic record (Fig. 21) includes the image from the spacecraft TV subsystem and the associated ID information in a form readable by the users. The frame identification information is also displayed on the ID and Status Display Board in the SSAA (Fig. 22). The computer also generates an index file identification related to all film records at the SFOF. Simultaneously the scan converter in the MCSS provides storage to permit display of the image at the standard rate used in the CCTV system in the SFOF. The MCSS can perform these same conversions on signals played back from tapes recorded at the DSIF.

Exposed films, from the DSIF (70 mm from Goldstone and 35 mm from all stations) and from the MCSS at the SFOF, are developed in the storage/retrieval and photographic processing subsystem. This subsystem provides facilities for developing and printing TV pictures, producing duplicate negatives, storing originals as archival

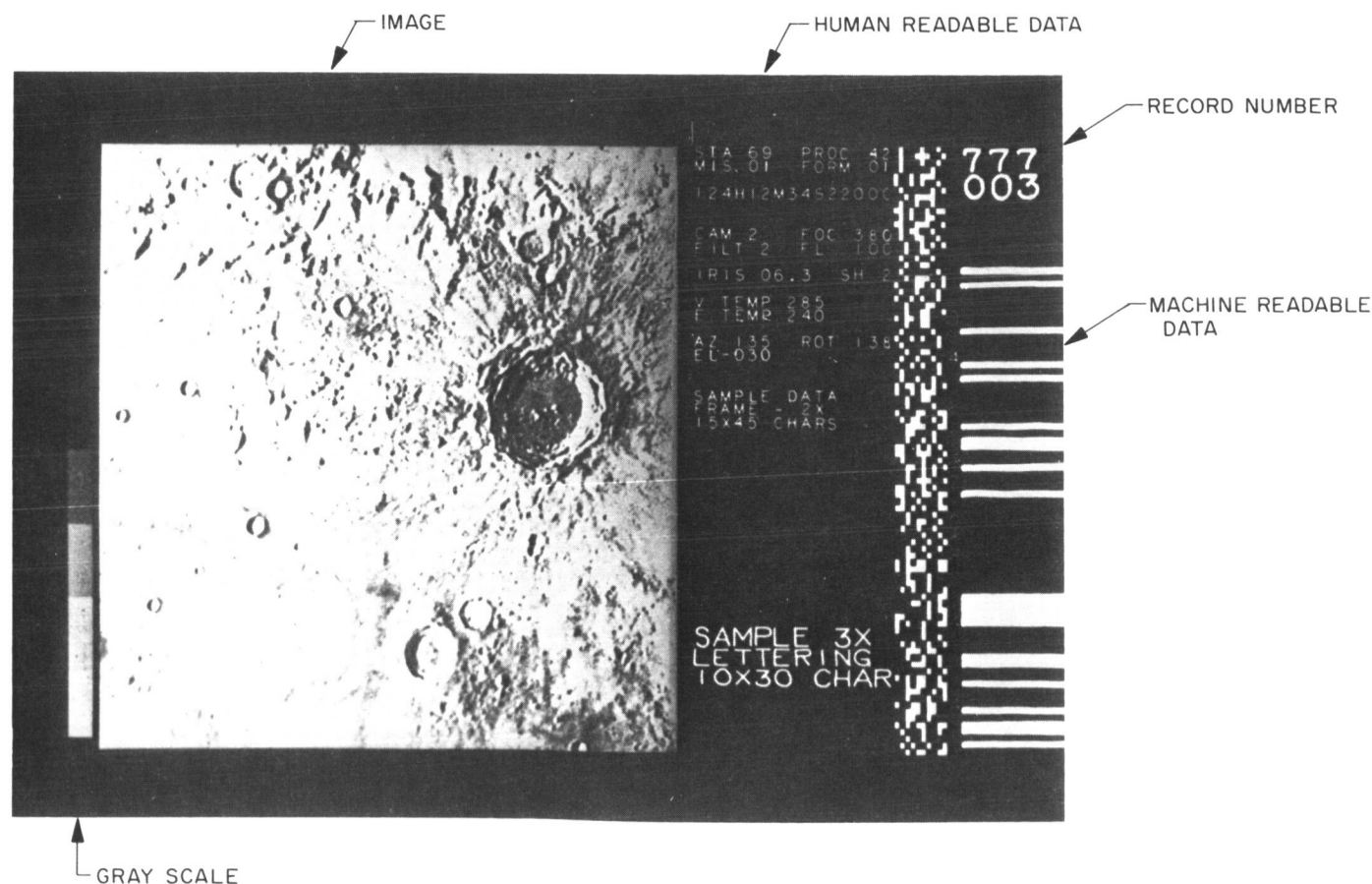


Fig. 21. Sample film chip of SCTV-GDHS



|                        |        |                        |                |
|------------------------|--------|------------------------|----------------|
| 01 AZIMUTH .....       | 000°   | 21-22 GMT .....        | 000 00 00 00   |
| 02 ELEVATION .....     | 00°    | 23 FILE NO. ....       | 00000          |
| 03 FOCUS .....         | 000m   | 24 FRAME NO. ....      | 0000           |
| 04 IRIS .....          | f/ 000 | 25 TOTAL IMAGES .....  | 00000          |
| 05 FOCAL LENGTH .....  | 000mm  | 26                     |                |
| 06 SHUTTER .....       | 0000   | 27                     | STATUS RESTORE |
| 07 FILTER .....        | 000 0  | 28 DSIF .....          | ↑ 00           |
| 08 IRIS SERVO .....    | 000    | 29 DATA LINK .....     | ↑ 00 00        |
| 09 M/STEP FOCUS .....  | 000    | 30 MC DATA REC. ....   | ↓ 00 00        |
| 10 VIDICON .....       | 000°C  | 31 SCAN CONV. ....     | ↑ 00 00        |
| 11 CAMERA ELECT. ....  | 000°C  | 32 SFOF FILM REC. .... | ↑ 00 00        |
| 12 CALIB. VOLT .....   | 000V   | 33 ON LINE P/P .....   | ↓ 00 00        |
| 13 CAMERA NO. ....     | 0      | 34 OFF LINE P/P .....  | ↓ 00 00        |
| 14 PICT. ROT. ....     | 000°   | 35                     |                |
| 15                     |        | 36 SCAN MODE .....     | 0000           |
| TELEM. QUALITY         |        | 37                     |                |
| 17 BITS REC'D .....    | 0000   | 38                     |                |
| 18 BITS USED .....     | 000    | 39                     |                |
| 19 PARITY ERRORS ..... | 00     | 40                     |                |
| 20 USABLE WORDS .....  | 00     |                        |                |

SCTV Ground Data Handling System

Fig. 22. SCTV-GDHS Status Board

records, retrieving stored records on request, and producing prints on demand. The display and analysis subsystem includes facilities for creating mosaics. Two console-type work stations are included in this subsystem: (1) the engineering console, supports the engineering analysis of television experiments; (2) the control console, supports scientific analysis of spacecraft television data.

One element of the SCTV-GDHS, the television simulation subsystem, provides a unique testing and TV experiment simulation capability. A TV camera, similar to the actual flight model of the TV camera, is mounted in the center of a large drum, the interior wall of which is a continuous black and white photo mosaic of a desert scene. The simulation subsystem, interfaced with the PDP-1 computer, enables the actual taking of video pictures during pre-mission tests of post-landing operations.

### 3. Ground Communication System

The voice, teletype, and high-speed data lines connecting each DSIF Station to the SFOF are part of the NASCOM world-wide network assigned to support the *Surveyor* missions. Both cables and radio links are used to cover various spans across the oceans and continents.

The voice circuits linking the stations are two-way telephone links that permit simultaneous communication in both directions between the DSIF Stations and the Communications Center in the SFOF. Similarly, the TTY lines are two-way lines. The HSDL's, however, are special high-data-rate lines capable of carrying significant portions of the spacecraft telemetry signals to the SFOF in real time. Of the two microwave links between the Goldstone Station and the SFOF, one link, operating with a 6-Mc bandwidth, carries live TV pictures for real-time viewing and recording; the other provides a 96-kc, wideband, high-speed data link. Table 1 shows the rate capabilities of the GCS.

Table 1. DSIF GCS rate capabilities

| Station      | HSDL rates,<br>bits/sec |      |     | TTY rate<br>(characters/sec) |
|--------------|-------------------------|------|-----|------------------------------|
|              | 4400                    | 1100 | 550 | 6.1                          |
| Goldstone    | x                       | x    | x   | x                            |
| Johannesburg |                         |      | x   | x                            |
| Tidbinbilla  |                         | x    | x   | x                            |
| AFETR        |                         | x    | x   | x                            |

## B. Personnel

Many of the personnel who designed the MOS participate directly in the mission operations. The mission is controlled by *Surveyor* personnel, while other members of the team are DSN and AFETR personnel performing a service for the *Surveyor* Project. During the mission, the MOS organization is as shown in Fig. 23.

### 1. Mission Direction

The *Surveyor* Project Manager, in his capacity as Mission Director, is in full charge of all mission operations. Aiding him in a staff capacity and acting for him during absences or on specific request is the Assistant Mission Director.

Mission operations are under the immediate, primary control of the SFOD, who makes certain that the MOS is ready before the mission begins. During space operations, the SFOD maintains overall control of all operations, and participates directly in all major decisions by presenting the alternatives to the Mission Director.

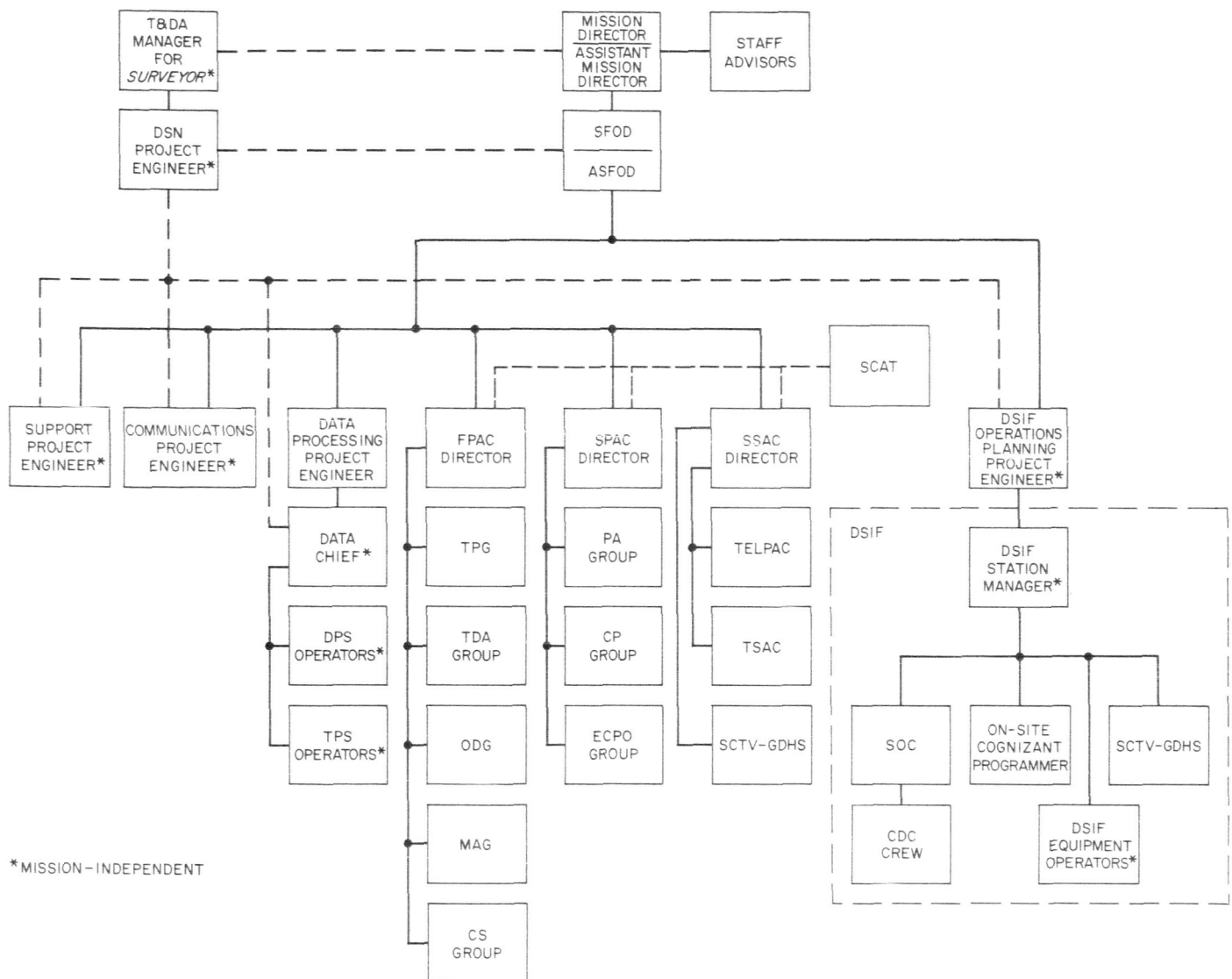
The Assistant Space Flight Operations Directors (ASFOD) aid the SFOD in the conduct and control of the mission and afford backup and relief to the SFOD.

### 2. Technical Support Groups

During space flight and lunar surface operations, all orders emanate from the SFOD or by his specifically delegated authority. Three groups of specialists provide technical support to the SFOD. These groups are specialists in the flight path, spacecraft performance, and scientific experiments, respectively.

*a. Flight Path Analysis and Command Group.* The Flight Path Analysis and Command (FPAC) Group handles those space flight functions that relate to the location of the spacecraft. The FPAC Director maintains control of the activities of the group and makes specific recommendations for maneuvers to the SFOD in accordance with the flight plan. In making these recommendations, the FPAC Director relies on sub-groups of specialists within the FPAC Group.

Within the FPAC Group, the *trajectory prediction group* (TPG) forms a sub-group. The TPG determines the nominal conditions of spacecraft injection and generates lunar encounter conditions based on injection conditions as reported by AFETR and computed from tracking data by the orbit determination group. The actual trajectory determinations are made by computer.



**Fig. 23. Organization of MOS**

Another sub-group of FPAC, the *tracking data analysis (TDA) group*, makes a quantitative and descriptive evaluation of tracking data received from the DSIF Stations. The TDA group provides 24-hr/day monitoring of incoming tracking data. To perform these functions, the TDA group takes advantage of the DPS and of computer programs generated for their use. The TDA acts as direct liaison between the data users (the orbit determination group) and the DSIF and provides predictions to the DSS.

The *orbit determination group* (ODG) of FPAC, during mission operations, determines the actual orbit of the spacecraft by processing the tracking data received from

the DSN tracking stations by way of the TDA group. Also, statistics on various parameters are generated so that maneuver situations can be evaluated. The ODG generates tracking predictions for the DSIF Stations and recomputes the orbit of the spacecraft after maneuvers to determine the success of the maneuver.

The *maneuver analysis group* (MAG) is the sub-group of FPAC responsible for describing possible midcourse and terminal maneuvers for both standard and non-standard missions in real time during the actual flight. In addition, once the decision has been made as to what maneuver should be performed, the MAG generates the proper spacecraft commands to effect these maneuvers.



These commands are then relayed to the Spacecraft Performance Analysis and Command Group to be included with other spacecraft commands. Once the command message has been generated, the MAG must verify that the calculated commands are correct.

The FPAC *computing support group* acts in a service capacity to the other FPAC sub-groups, and is responsible for ensuring that all computer programs used in space operations are fully checked out before mission operations begin. They also see that optimum use is made of the DPS facilities.

**b. Spacecraft Performance Analysis and Command Group.** The Spacecraft Performance Analysis and Command (SPAC) Group, operating under the SPAC Director, is basically responsible for the operation of the spacecraft itself. The SPAC Group is divided into three sub-groups:

- (1) The *performance analysis (PA) group* monitors incoming engineering data telemetered from the spacecraft, determines the status of the spacecraft, and maintains spacecraft status displays throughout the mission. The PA group also determines the results of all commands sent to the spacecraft. In the event of a failure aboard the spacecraft, as indicated by telemetry data, the PA group analyzes the cause and recommends appropriate non-standard procedures.
- (2) The *command preparation (CP) group* is basically responsible for preparing command sequences to be sent to the spacecraft. In so doing they provide inputs for computer programs used in generating the sequences, verify that the commands for the spacecraft have been correctly received at the DSS, and then ascertain that the commands have been correctly transmitted to the spacecraft. If nonstandard operations become necessary, the CP group also generates the required command sequences.
- (3) The *engineering computer program operations (ECPO) group* includes the operators for the DPS I/O console and related card punch, card reader, page printers, and plotters in the SPAA. The ECPO group handles all computing functions for the rest of the SPAC Group, including the maintenance of an up-to-date list of parameters for each program.

In order to take maximum advantage during the mission of the knowledge and experience of the various

personnel who are not a part of the "hard-core" operations teams (FPAC, SPAC, and SSAC) but have been engaged in detail design, analysis, or testing of the spacecraft, a spacecraft analysis team (SCAT) has been established. The SCAT group, located in a building adjacent to the SFOF, will have appropriate data displays to keep them abreast of the current status of the mission. The SCAT will be available upon request for immediate consultation and detailed analysis in support of the SPAC.

**c. Space Science Analysis and Command Group.** The Space Science Analysis and Command (SSAC) Group performs those space flight functions related to the operation of the survey TV camera. SSAC is divided into two operating sub-groups:

- (1) The *television performance analysis and command (TelPAC) group* analyzes the performance of the TV equipment and is responsible for generating standard and nonstandard command sequences for the survey TV cameras.
- (2) The *television science analysis and command (TSAC) group* analyzes and interprets the TV pictures for the purpose of ensuring that the mission objectives are being met. The TSAC group is under the direction of the project scientist and performs the scientific analysis and evaluation of the TV pictures.

The portion of the SCTV-GDHS in the SFOF provides direct support to the SSAC Group in the form of processed electrical video signals and finished photographic prints. The SCTV-GDHS operates as a service organization within the MOS structure. Documentation, system checkout, and quality control within the system are the responsibility of the SCTV-GDHS Operations Manager. During operations support, the SCTV-GDHS Operations Manager reports to the SSAC Director.

**d. Operations Personnel.** The term operations personnel refers to those individuals in the SFOF and in the DSIF Stations who operate the equipment and who actually track, control, and communicate with the spacecraft. Many of these are the mission-independent personnel of the DSN, assigned to perform necessary services for the *Surveyor* Project during mission operations; others are *Surveyor* personnel, whose functions are directly and exclusively related to the *Surveyor* Project.

*e. SFOF Personnel.* The personnel working in the SFOF provide data processing, communication control, and facility support to the *Surveyor* MOS.

The use of the DPS by *Surveyor* is under the direction of the ASFOD for Computer Programming. His job is to direct the use of the DPS from the viewpoint of the MOS. He communicates directly with the Data Chief, who is in direct charge of DPS personnel and equipment. Included among these personnel are the I/O console operators throughout the SFOF, as well as the equipment operators in the DPS and TPS areas.

The Communications Project Engineer (PE) controls the operational communications personnel and equipment within the SFOF, as well as the DSN/GCS lines to the DSIF Stations throughout the world.

The Support PE is responsible for ensuring the availability of all SFOF support functions, including air conditioning and electric power; for monitoring the display of *Surveyor* information on the MSB and throughout the facility; for directing the handling, distribution, and storage of data being derived from the mission; and ensuring that only those personnel necessary for mission operations are allowed to enter the operational areas.

*f. DSIF Personnel.* The DSIF Operations Planning PE is in overall control of the DSIF Stations at Goldstone, Johannesburg, and Tidbinbilla; his post of duty is in the SFOF in Pasadena. At each station, there is a local DSIF Station Manager, who is in charge of all aspects of his DSIF Station and its operation during a mission. The *Surveyor* personnel located at each station report to the Station Manager.

### C. Methods

This third element of the MOS is the means of combining its other elements (equipment, personnel, and computer programs) into a system that will perform in a consistent predictable manner. This third element is, in essence, the overall plan of the MOS, which includes the design criteria and mission requirements of the system, creation of the mission-dependent equipment, use of the mission-independent equipment, and the procedures needed to operate the system. Since this Technical Memorandum is intended primarily to show how the MOS functions, design and equipment fabrication aspects are not discussed further.

### 1. Plans and Procedures

The development of plans and procedures is conducted in parallel by the various groups (within the MOS and T&DA) that have been assigned technical cognizance and responsibility for specific areas of the space flight operations. Essentially, these groups design their operations to meet the technical requirements imposed on their areas by the overall MOS plan, and then submit these self-developed instructions to their appropriate authority for approval. When approved, the instructions are published and become in essence the official textbooks for the mission; all personnel involved in the mission perform in accordance with these books.

The evolution of these operational instructions can be seen in Fig. 24, which shows the basic planning documents from which the operational documents are genetically developed. A summary of the content, purpose, and scope of the controlling documents is discussed in the following paragraphs.

#### a. Project control documents.

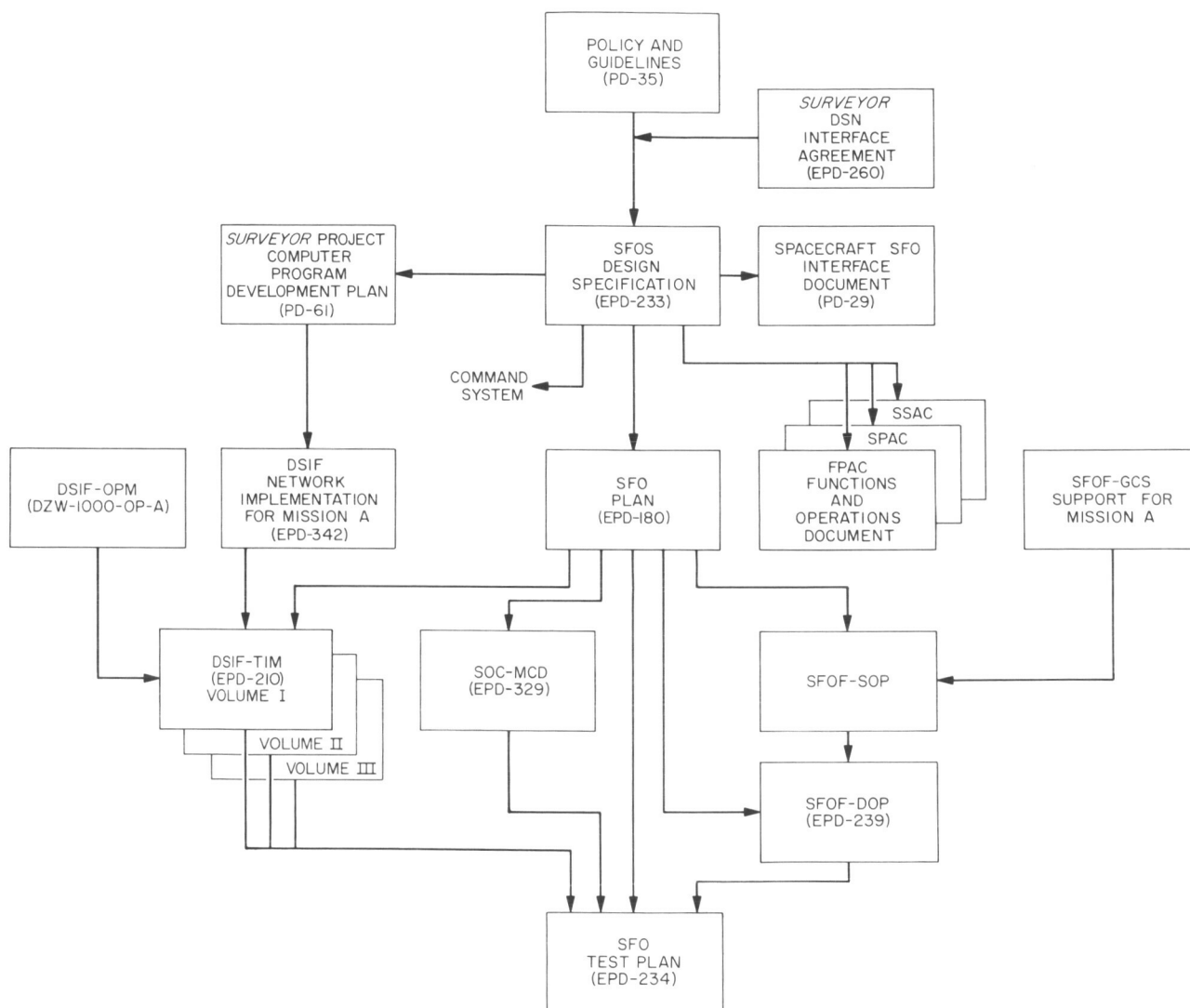
*Surveyor Documentation Plan*, PD-41, is a guide to all major project documents, which are shown graphically in a series of eight document trees indicating the relationships and dependencies among the various publications. All *Surveyor* major systems are covered in PD-41.

The publication identification numbers given below are correct for Mission A. Updated editions of PD-41 will reflect the current documents applicable for subsequent missions.

While *Surveyor Spacecraft/Launch Vehicle Guidance and Trajectory Interface Schedule*, PD-14, is limited in scope to the subjects of guidance and trajectory, it is more detailed in that area than PD-41, thus extending the coverage provided by that document.

A periodically issued document of particular interest to persons working in the MOS is the *Surveyor: Mission A and B Operations System Schedule*. Issued every 4 wk, it gives the current status of all *Surveyor* Mission Operations hardware, testing, documents, and computer programs.

The document most basic to an understanding of the MOS is the *Surveyor Project Control Document* entitled *Surveyor Project Policy and Guidelines for Space Operations*, PD-35 (formerly EPD-160). The purpose of this document is to establish basic policies for *Surveyor* space



**Fig. 24. Basic MOS documents**

operations. It establishes the broad outlines of MOS pre-flight planning and design, operations, documentation, scheduling, and computer program control. All other *Surveyor* Mission Operations System documents described below are subordinate to PD-35.

**b. Developmental documents.** Proceeding, from PD-35 in a sequence of direct dependency and increasing depth of analysis is a group of several basic and quite detailed documents.

The *Surveyor DSN Interface Agreement*, EPD-260, describes all hardware, computer program, and man/machine interfaces existing between project elements and elements under DSN cognizance which are used in support of the *Surveyor* Project. These interfaces include those formed between the spacecraft and the DSS data handling equipment; between the latter and the CDC at the DSS; between the CDC and DSS on-site data processing system; etc. Two documents spring directly from EPD-260: (1) *DSIF Network Configuration for Mission A*, EPD-342, and (2) *SFOF-GCS Support for Mission A*. These EPD's document the configuration of the DSIF and SFOF for *Surveyor* Mission Support.

*Space Flight Operations System Design Specification*, EPD-233, defines design characteristics and constraints. A series of specifications then sets forth the requirements for the organization and functions of the MOS personnel. Another series of specifications on equipment gives the requirements for the design of the CDC and for other equipment at the DSIF. Ground communication requirements are also given. The computer programs used for mission operations are described in EPD-233; these programs are explained later in this section. The *Command System* specification sets forth the basic philosophy and requirements for the establishment and handling of the spacecraft commands. Since the Command System is one of the most important characteristics of the *Surveyor* Project, it is described in detail in Section III of this Technical Memorandum.

A developmental document springing directly from EPD-233 is *Surveyor Spacecraft/Space Flight Operations Interface Document*, PD-29. It defines the interfaces between the spacecraft and the MOS and describes and sets forth procedures intended to ensure continuing compatibility at the interfaces. The body of the document is a series of tabular presentations of all major events in the mission profile, presenting from the viewpoint of the spacecraft and from that of the MOS the initial conditions, listings of related mission events and descriptive

data, references to germane information, and constraints or other remarks for each.

Expanding from the functional specifications of computer programs contained in EPD-233, the *Surveyor Project Computer Program Development Plan*, PD-61, defines the manner in which the design, development, and documentation of the computer programs will be controlled. Additionally, PD-61 contains the basic instructions by which the individual computer programs are operated.

Also a direct outgrowth of EPD-233 is a set of three documents, describing in considerable detail the functions and operations of the FPAC, SPAC, and SSAC Groups. Each group has analyzed and described its own area of special interest in terms ranging from flow diagrams to detailed definitions of operational steps. From the viewpoint of actual mission operations, these are source documents of considerable interest.

**c. Operational documents.** There is an interrelated set of documents that present a detailed plan for conducting mission operations from the time of prelaunch preparations until the end of a mission. Most basic of this group of documents is *Space Flight Operations Plan* (SFOP), EPD-180. Its function is to define the method by which space flight operations are conducted, both in the standard case and in any departures from the standard case. Space flight operations are defined as the operations necessary for obtaining and processing spacecraft information and for determining and executing spacecraft commands from launch to the accomplishment of the mission. The operational facilities used by the MOS are summarized, and the flow of data among the various facilities of the DSN is described. Then a section on spacecraft commands, after reviewing the requirements set forth in EPD-233, tabulates for each command the octal command number, the short command title, and the response of the spacecraft to the command. (See Section III for further explanation of the Command System.)

The heart of EPD-180 is the Standard Sequence of Events (SSE). This table specifies a series of activities/actions for normal operations from the start of the pre-launch countdown to the end of the mission. The sequence of mission events is based on a representative trajectory. The DSIF Station view periods shown in the SSE are based on that trajectory. This section of EPD-180 also gives a complete tabulation of all major command sequences and their constituent minor sequences.

Of equal importance with the SSE is the final section of EPD-180 on nonstandard operations. Since it is predictable that some deviations from standard procedures will occur during a mission, the MOS has prepared for such an eventuality by defining various failure modes and developing a preplanned attack on such problems.

The number of combinations of failures which could occur is virtually limitless. For this reason, nonstandard procedures were developed on the assumptions that only a single fault would occur at one time and that the telemetry equipment would be operating normally. After a preliminary analysis of anticipated failure modes, a limited number was studied further. Fault isolation trees have been developed to meet these situations. The trees, identified by the numbers 1 through 31, are called *Non-standard Procedures (NSP)*. The NSP's are bound separately; a set of them is mounted in a multi-leaf wall display in the SPAA.

The *SFOF Standard Operating Procedures (SFOF-SOP)* and the *SFOF-GCS Support for Mission A* are prepared by the DSN. They set forth the mission equipment configuration of the SFOF and the mission-independent procedures, and they include mission-dependent procedures derived from the *Surveyor SFOP*, EPD-180; therefore, they interface between the *Surveyor MOS* and the SFOF operations. Both documents are of specific interest to those who operate the mission-independent equipment during *Surveyor* missions, because they cover the particular usage of SFOF equipment for the *Surveyor* Project. Included in the SFOF-SOP are operator's instructions for the DPS and TPS, CCTV, communications equipment, and support systems.

The *Surveyor-SFOF Detailed Operating Procedures (SFOF-DOP)*, EPD-239, is an expansion of the material in the SFOP, along with directly related material, from the viewpoint of those who work in the SFOF. Broken down into Mission Control, FPAC, SPAC, and SSAC groupings, the individual specifications, which comprise the SFOF-DOP, cover the work of each group thoroughly. The Mission Control group of specifications covers general procedures which are not covered in detail in the SFOP, EPD-180. Each of the other groupings includes a mission sequence of events, parallel to the one given in EPD-180 but from the viewpoint of the FPAC, SPAC, or SSAC Groups, respectively. In addition, the individual specifications give detailed information on organizational structure; personnel assignment schedules to cover operations on a 24-hr basis; breakdowns of the mission into specific tasks that certain sub-groups and

individuals must accomplish; formats for teletype, page printer, and plotter outputs, and much similar information.

Another DSN document of interest to the *Surveyor MOS* is the *DSIF Operating Procedures Manual (OPM)*, DZW-1000-OP-A. This is a document similar in scope to the SFOF-SOP, covering operation of mission-independent DSIF equipment. While not of direct interest to MOS people, the DSIF-OPM is important in that it is a source for other *Surveyor* documents concerning the DSIF.

The *DSIF Tracking Instruction Manual (TIM)*, EPD-210 and the *DSIF Network Configuration for Surveyor Mission A*, EPD-342, represent an interface between the *Surveyor MOS* and the mission-independent aspects of the DSIF Stations. Derived from the DSIF-OPM and the *Surveyor SFOP*, they give general information on the application of the DSIF to the *Surveyor* missions. The TIM is in three volumes. Volume I describes the mission-independent operational procedures to be employed by the DSIF during a mission, such as tracking, telemetry, and recording. Volume II covers the *Surveyor* mission-dependent aspects of operations at the DSIF Stations. In standard situations, operations are controlled from the SFOF according to the SSE; however, the station can effect limited autonomous operation in the event of communication failure between the SFOF and the DSIF. Under such nonstandard conditions, the station will operate according to the nonstandard procedures and the NSP's contained in the TIM. Much collateral information of importance to DSIF operations during *Surveyor* missions is included. Volume III contains information such as preflight nominal look-angle data and signal-level predictions for the individual DSIF Stations.

EPD-342, as indicated by its title, defines the network configuration of the DSIF for Mission A. The network configurations for subsequent missions will be defined by similar documents.

*Surveyor Operations Chief Mission Control Directive (SOC-MCD)*, EPD-329, is another operational document used at the DSIF Stations. This document contains all of the detailed operating procedures that relate directly to the SOC and the operation of the CDC.

*d. Pre-operational document.* The *Surveyor Space Flight Operations Test Plan*, EPD-234, may be considered a pre-operational document because it is used only before an actual launch. It is based on the SFOP, SFOF-DOP, and DSIF-TIM and comprises a series of tests of equipment, personnel, and methods. The test plan set



forth in EPD-234 is described in considerable detail in Section IV of this Technical Memorandum.

#### D. Computer Programs

The computer programs are the means of selecting and combining the extensive data processing capabilities of electronic computers. By means of electronic data processing, the vast quantities of mission-produced data are assembled, identified, categorized, processed, and displayed in the various areas of the SFOF where the data is used. Their most significant service to the MOS is providing knowledge in real time of the current state of the spacecraft throughout the entire mission. This service is particularly important to engineers and scientists of the technical support groups since, by use of the computer programs, they can select, organize, compare, and process current-status data urgently needed to form their time-critical recommendations to the SFOD.

The MOS family of computer programs interfaces and blends with each of the other elements of the MOS.

First, the MOS computer programs may be considered to be a part of the equipment, since in effect they convert a general purpose computer to a temporary special purpose computer. Second, the computational ability of the computer is an extension of the mental abilities of the MOS personnel, performing their routine arithmetic computations according to the algorithms devised by *Surveyor* personnel. However, the computer programs are an operational element since they are used repeatedly, almost continuously, during the SSE and also during non-standard operations. They are described and listed in their operational context in Tables 2 through 5. An understanding of the MOS computer programs is therefore necessary to an understanding of the total MOS.

The MOS computer programs consist of four sets: FPAC, SPAC, SSAC, and mission support programs. Each program is assigned a name and a mnemonic designator. The mnemonic appears in a display on the I/O console when a program is called (selected). An I/O console, typical of those located throughout the SFOF, is shown in Fig. 25.



Fig. 25. Typical I/O console in Operations Area of SFOF

## 1. FPAC Programs

The FPAC Group uses many computer programs during the course of a mission. The analyses of the spacecraft's flight path that are a major function of the FPAC Group are made by selecting appropriate programs, feeding the necessary data, and using the DPS computers to run the program and print out the results. During the course of a normal mission from injection to post-landing, the FPAC Group runs computer programs through the DPS approximately 70 times. The computer

runs can consume from 1 to 170 min each. The computer programs used by the FPAC Group during the course of a mission are summarized in Table 3.

## 2. SPAC Programs

The SPAC Group normally generates all commands to the spacecraft, even when the command is on behalf of the FPAC or SSAC Group. In addition to this continuous function of command generation and verification, the SPAC Group also maintains a constant vigil

Table 2. SSAC computer programs

| Program name and mnemonic      | Input                                                                                           | Function                                                                                                                                                                    | Output                                                                                    |
|--------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| TV Command Generation<br>TVCS  | Mnemonic abbreviations of English language commands to TV camera                                | Interprets input commands and definitions of camera settings for each exposure. Formats camera parameters in a manner acceptable to TV camera sequences; subroutine of SCPS | Commands in form acceptable to SCPS in camera incremental units written on disk file      |
| TV ID Response Monitor<br>TIRS | TV commands as sent to spacecraft; same as returned from spacecraft; TV ID frames; all via disk | Compares commands as sent and as received; detects and corrects errors in returned commands. Matches ID frames to corresponding commands                                    | Printout of discrepancies and of complete mission history of TV commands and TV ID frames |

Table 3. FPAC computer programs

| Program name and mnemonic                 | Input                                     | Function                                                                                                 | Output                                                                                         |
|-------------------------------------------|-------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Booster Model<br>DPES (DAPFS)             | Launch time                               | Looks up stored launch conditions; then operates on stored equations for <i>Atlas/Centaur</i> trajectory | Injection conditions                                                                           |
| Tracking Data Processor<br>TDPX (TDP)     | Tracking data: raw TTY or tape            | Tests raw data for validity; rejects bad and converts good to engineering units                          | Good tracking data stored on Master Data Tape                                                  |
| Orbit Data Generator<br>ODGX (ODG)        | Master Data Tape from TDPX                | Sorts data by time, removes possible errors, performs simple calculations and conversions                | Clean data for ODPX                                                                            |
| Utility Orbit Determination<br>ODPX (ODP) | Tracking data from ODPX                   | Refines figures for injection conditions, then computes actual Sun orbit of spacecraft                   | Flight path of spacecraft                                                                      |
| Trajectory<br>TRJX                        | Flight path data from DPES or ODPX        | Converts predicted Sun orbit to Earth-referenced data                                                    | Spacecraft ephemeris, view periods, present position and speed, impact point predictions, etc. |
| Trajectory Processor<br>(Surveyor) HPPS   | Flight path data from DPES, ODPX, or TRJX | Computes positions of Earth, Sun, Moon, and Canopus relative to spacecraft                               | Spacecraft position, tracking predicts, miss parameters                                        |
| Midcourse Maneuver Analysis<br>MTGS (MAG) | Injection conditions from ODPX            | Computes lunar encounter parameters, then computes required midcourse or terminal maneuver               | Required midcourse and terminal maneuvers                                                      |

over such spacecraft performance factors as temperature, electrical power, telecommunications, and other factors involving the basic spacecraft bus. Furthermore, the SPAC Group is charged with the responsibility for preparing command messages during lunar surface operations, when the SSAC Group is conducting experiments. The scope of the work of the SPAC Group is reflected in the computer programs used during mission operations. Table 4 gives a summary of each of these.

### 3. SSAC Programs

The SSAC Group uses two computer programs in operating the TV cameras: (1) TV command generation, which must be active during all periods when SSAC is

called upon to prepare commands for the TV camera; (2) TV-ID response monitor, which is used whenever the TV subsystem is returning pictures from space, as well as during off-line TV analysis. (See Table 2).

### 4. Mission Support Programs

These consist of a group of programs which are not the sole concern of any one technical group, but rather are used for the benefit of mission operations as a whole. These are basic programs used on the several computers of the MOS equipment, located both in the SFOF and the DSIF Stations. The mission support programs are explained in Table 5.

Table 4. SPAC computer programs

| Program name and mnemonic                | Input                                                                                                      | Function                                                                                                                                                            | Output                                                                                                      |
|------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| Power Management PWR                     | Telemetry data from spacecraft affecting power usage                                                       | Integrates all power drains against time, and calculates effect on batteries and solar panel                                                                        | On-line printer and magnetic tape for off-line printout of significant parameters                           |
| Thermal Management THM                   | Telemetry data on spacecraft thermal compartment temperatures                                              | Predicts various spacecraft component temperatures to aid in planning nonstandard operations                                                                        | Plot or tabulated printout comparing predicted and reported temperatures                                    |
| Tape Read/Write TRW                      | Tape and disk selection instructions from operator                                                         | Transfers PWR or THM data from disk file to magnetic tape or vice versa                                                                                             | Save tape containing initiation and updated predictions for PWR and THM                                     |
| Engineering Programs Submonitor EPMS     | Initialization data, order of running, and correction and control data for engineering management programs | Controls the exchange of data among PWR, THM, and TRW                                                                                                               | Binary image of card input read onto disk file for use of applicable programs                               |
| Post-Landing Attitude Determination PLAS | Spacecraft location and attitude at time of retrofire                                                      | Computes lunar attitude of spacecraft; predicts directions of Sun and Earth, then pointing angles for solar panel and planar array                                  | Spacecraft position on Moon, spacecraft attitude, Selenographic coordinates of Earth and Sun, etc.          |
| Telecommunications CPPM                  | Trajectory, spacecraft and DSIF design parameters                                                          | Computes signal-to-noise ratio margins in the DSIF receiver as a function of trajectory and spacecraft component parameters for all Surveyor data and command modes | Printout and plot of telecommunications performance margins                                                 |
| AGC Calibration AGCM                     | Calibration data for automatic gain control (AGC) in DSIF receiver                                         | Generates curves of spacecraft signal strength against signal voltage and against frequency                                                                         | Calibration curves in plot and tabular forms; and as cards suitable for transmitting curves to DSIF Station |
| Engineering Data Reduction EDRS          | Raw telemetry data and command data                                                                        | Interprets raw spacecraft telemetry data, calibrates, processes and prints out data in a readily interpretable format                                               | Edited data on disk; error data printed out on bulk printer                                                 |

Table 5. Mission support computer programs

| Program name and mnemonic                                     | Input                                                                                                                            | Function                                                                                                                                                                                                                                                                                                                         | Output                                                                                                                                                                                                                         |
|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyor Command Preparation SCPS                             | Pre-stored command dictionary, user data, disk-stored outputs from other programs                                                | Checks inputs for format errors, assembles command message from pre-stored dictionary, and prepares printed output in English language and octal numbers                                                                                                                                                                         | Command messages, onto disk accessible to CVT; English and octal printout; edited command message, command dictionary, or SFOP SSE; assembled command message                                                                  |
| Command Verify/Transmit CVT                                   | Same as SCPS; TTY codes                                                                                                          | Verifies that command message fulfills spacecraft constraints; compares commands from SCPS with dictionary, transforms command sequences or SSE to TTY code; stores commands on disk for transmission; checks out commands returned from DSIF for verification                                                                   | Command message ready for transmission; notification to SPAC that message is ready; printout of message; verification of message retransmitted from DSIF; confirmation that commands as executed by DSIF agree with pre-stored |
| 7044 SFO System                                               | Raw spacecraft data from HSDL or TTY or via PDP-7; 7094 output via disk. Inputs accepted from two DSIF Stations at once          | Monitors data continuously to see if it falls within preset bounds; prints out alarms in user area, or lights status light displays in SPAA. Calibrates temperature, flight control, power, and TV ID frame signals and scales to engineering units. Converts data from TTY or HSDL format to that required for magnetic storage | Printouts, plots, etc., of spacecraft data, alarm printouts, and light displays. All processed data recorded on disk and tape                                                                                                  |
| 7094 SFO System Monitor                                       | Interrogation by 7044                                                                                                            | Executes user programs; establishes link with 7044 computer and controls data transfer between the two computers and disk file                                                                                                                                                                                                   | Commands to disk file and 7044; interrupted programs stored on disk (and retrieved)                                                                                                                                            |
| Telemetry Processing Station TPS (PDP-7 program)              | Raw spacecraft data over HSDL or 96-kc microwave link from Goldstone                                                             | Identifies start of digital data frame and locks in synchronism, then formats and assigns parameter identification to all PCM telemetry data words                                                                                                                                                                               | Digital data to IBM 7044; also 16 channels of spacecraft data converted to analog and plotted on analog recorders in SPAA                                                                                                      |
| Surveyor On-Site Computer Program SOCP (Used on OSDP at DSIF) | Spacecraft engineering and TV ID data from CDC; command messages from SFOP or tape, or executed commands from spacecraft via CDC | Edits spacecraft engineering data and labels editing mode, averages certain data and signals out-of-limits condition; edits and formats TV ID data for HSDL or TTY. Converts command messages between TTY 5-level and CDC 7-level tapes, reformatting both ways; can also control TTY command transmission                       | Engineering and TV ID data to SFOP via TTY or HSDL; command data; program error printouts                                                                                                                                      |
| Telemetry Data Simulation (PDP-1 program)                     | Tables of spacecraft telemetry data from digital magnetic tape                                                                   | Reads tape, time-correlates the data. Optional digital-to-analog conversion of data. Provides telemetry portion of TV simulation in response to spacecraft commands                                                                                                                                                              | Simulated real-time spacecraft telemetry signals to PDP-7. Analog tape containing telemetry data of a simulated spacecraft mission; optional                                                                                   |

### III. COMMAND SYSTEM

The *Surveyor* Command System philosophy introduces a major change in the concept of unmanned spacecraft control: virtually all inflight and lunar actions of the spacecraft must be initiated from Earth. In previous deep-space missions, the spacecraft were directed by a minimum of Earth-based commands. Most inflight actions of those spacecraft were automatically controlled by an on-board sequencer which stored pre-programmed instructions; these instructions were initiated by either an on-board timer or by single direct commands from Earth. For example, during the 67 hr of the *Ranger VIII* mission, only 11 commands were sent to the spacecraft; whereas for a standard *Surveyor* mission, approximately 280 commands must be sent to the spacecraft during the transit phase, out of a command vocabulary of 256 different direct commands.

Throughout the space flight operations of each *Surveyor* mission, the command link between Earth and the spacecraft is in continuous use, transmitting either fill-in or real commands every 0.5 sec. The *Surveyor* commands are initiated from the SFOF, and are transmitted to the spacecraft by a DSIF Station. The mission control design philosophy provides two schemes that simplify the handling of commands by personnel and by the Earth-based equipment used by the Command System. One scheme shortens the lengthy, 24-digit-long binary number (representing the 24 RF pulses which are sent to the spacecraft for each command) to a more manageable 4-digit number expressed in octal form. The second scheme provides for grouping individual commands into specific sequences needed to effect the desired spacecraft reaction. These sequences are identified as major and minor sequences and make possible the most expeditious handling of large quantities of individual commands through the Earth-based elements of the system. A major command sequence is composed of one or more minor command sequences; a minor command sequence is composed of one or more individual commands.

The routing of commands and how they flow from the SFOF to the DSS and hence to the spacecraft is illustrated in Fig. 26.

#### A. Spectrum of Control

During a nominal mission, the MOS Command System directs the spacecraft to accomplish approximately 1100 SSE items. This series of activities comprises about

110 major and 250 minor command sequences, which in turn are made up from a listing of 256 direct commands and 1024 quantitative commands. The only portions of the entire flight sequence that normally do not require direct Earth control are those concerned with certain phases of attitude stabilization, terminal descent, and solar panel deployment (and these have backup Earth commands). The *Surveyor* flight is essentially a "fly-by-wire" operation.

The Command Sequence Glossary, with its detailed descriptions of each major and minor sequence, is too lengthy for inclusion here; it may be found in *Space Flight Operations Plan*, EPD-180. The SSE is described in Section V of this Technical Memorandum. Command octal numbering systems, explanations of types of commands, and a brief description of command flow through the spacecraft command subsystem are described below. The Command System must have the ability to execute the proper command at the proper time.

#### 1. Command Vocabulary

Those commands that turn certain equipment on or off or select telemetry modes are called the direct commands; those that determine the duration of thrust to be exerted by the attitude control jets or the vernier engines are referred to as quantitative or magnitude commands. A summary of the 256 direct commands that can be sent to the spacecraft is given in Table 6. These direct commands, combined with quantitative commands, permit a fine degree of control over the operation of the various subsystems of the spacecraft. For example, the planar array and solar panel can be locked and unlocked and are adjustable in all three axes in increments of 0.125 deg. Omni-antennas and other telecommunications subsystem components (housed in thermally controlled compartments) are turned on or off; various telemetry modes and combinations can be selected. The RADVS, TV camera, and flight control subsystem (including inertial reference unit, Sun sensor, Canopus sensor, and electronics) are also controlled and selected by Earth-based commands (Fig. 27; also see Fig. 3).

Each individual command and each command sequence is represented by four octal digits of a command "word." There are two types of command tapes:

- (1) The type that is prepared and verified before the mission; it contains major and minor sequences



ECS MMA



**Fig. 26. Basic relationships within Command System**

Table 6. Summary of the 256 direct commands

|             |                                                                                                                                                                                                                                                       |             |                                                                                                                                                                                                                                                                    |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 01xx series | Data link and TV approach camera subsystem (32 commands)<br>Transmitters on-off, select antennas, transponders, etc.;<br>Approach TV on-off-start and temperature controls                                                                            | 05xx series | Engineering payload subsystem (32 commands)<br>Augments 02xx series: cruise mode (low data rate) subcarrier oscillators, low bit rates (550 or less bits/sec), cruise and thrust phase commutators, touchdown strain gages propulsion strain gages, accelerometers |
| 02xx series | Signal processing subsystem (32 commands)<br>Controls for subcarrier oscillators, analog-to-digital converters and 1100 and 4400-bit/sec bit rates, FM and PM multiplexing, engineering commutator mode, basic bus accelerometers, gyro speed signals | 06xx series | Engineering mechanisms auxiliary subsystem (32 commands)<br>Attitude control, vernier engine, AMR, RADVS, solar panel, landing gear, omni-antenna controls                                                                                                         |
| 03xx series | Electrical power subsystem (32 commands)<br>Select solar panels, main battery, or auxiliary battery; power controls                                                                                                                                   | 07xx series | Flight control subsystem (32 commands)<br>Control of spacecraft stabilization mode, midcourse and terminal firings, emergency backup commands for automatic sequences, etc.                                                                                        |
| 04xx series | Mechanisms and vehicle subsystem (32 commands)<br>Controls solar panel position, spacecraft attitude, and thermal compartment temperature                                                                                                             | 11xx series | Television survey camera subsystem (32 commands)<br>Power, temperature, shutter, lens, mirror, and filter controls for lunar surface TV camera                                                                                                                     |

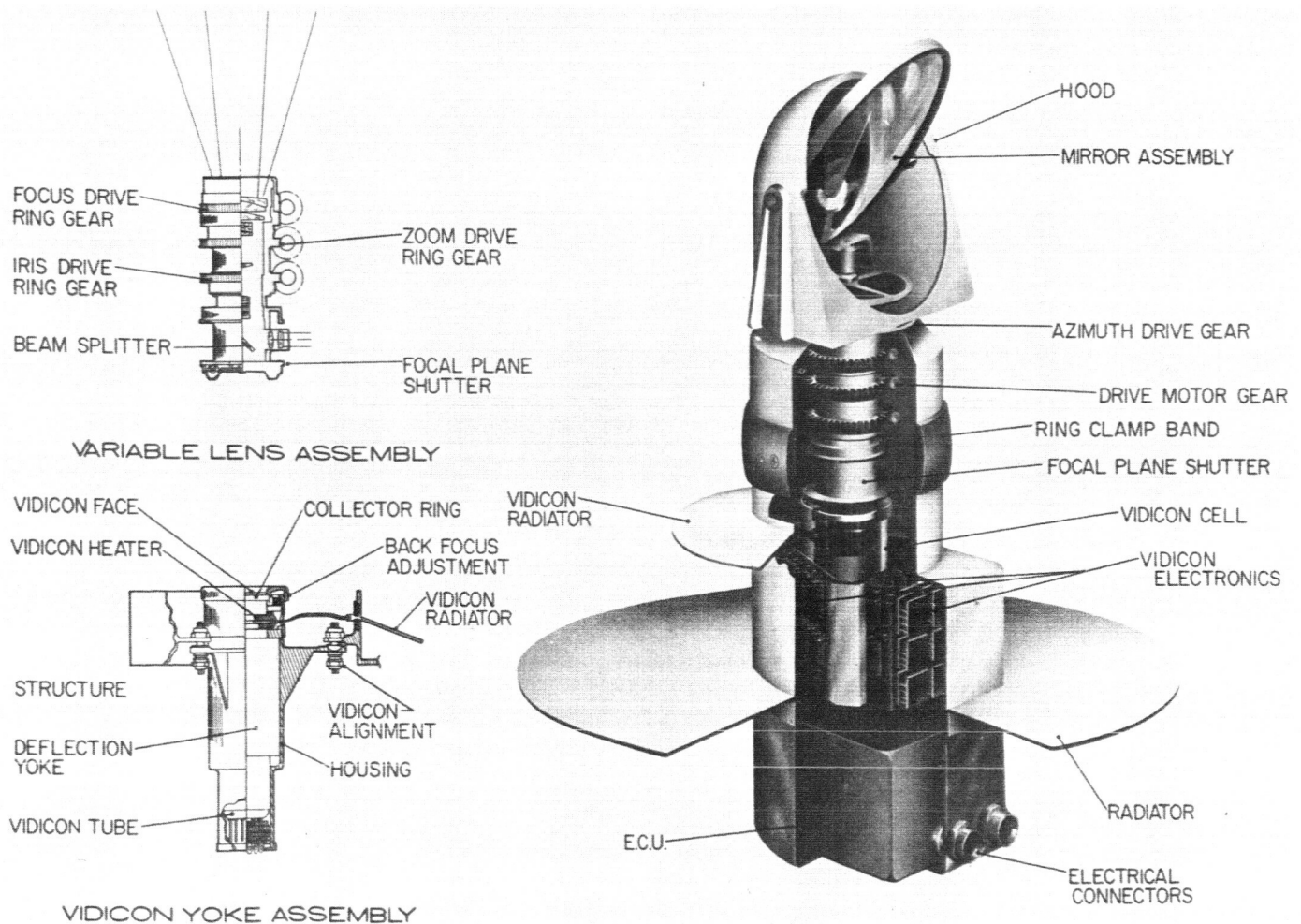


Fig. 27. Survey TV camera showing adjustments controllable by command

and direct commands only. Quantitative commands can be inserted at the appropriate times in the sequence of direct commands. Verified copies of these tapes are stored prior to the mission at the SFOF and at the DSIF Stations.

- (2) The type that is prepared during the mission; it can contain major and minor sequences comprising direct, and quantitative commands. (This type is prepared by special computer programs, described elsewhere in this section.)

**Table 7. Typical command sequence representing a pre-mission-prepared command tape**

|                           |           |                |
|---------------------------|-----------|----------------|
| Major Sequence Identifier | 0 1 4 2   | Major Sequence |
| Minor Sequence Identifier | 0 1 4 3   | Major Sequence |
| Direct Command Identifier | (0 0 5 1) | Minor Sequence |
|                           | 0 1 0 5   |                |
|                           | 0 5 1 0   |                |
|                           | 0 2 2 6   |                |
|                           | 0 1 2 7   |                |
|                           | 0 1 3 6   |                |
|                           | (0 2 5 7) |                |
|                           | 0 2 2 0   |                |
|                           | (0 3 5 0) |                |
|                           | 0 5 0 2   |                |
|                           | (0 4 5 2) |                |
|                           | 0 2 1 6   |                |
|                           | 0 1 4 4   | Major Sequence |
|                           | (0 2 5 7) | Minor Sequence |
|                           | 0 2 2 0   |                |
|                           | 0 1 4 5   | Major Sequence |
|                           | (0 1 5 5) | Minor Sequence |
|                           | 0 2 2 3   |                |
|                           | 0 1 4 6   |                |

Note: Third digit has a value of 0, 1, 2, or 3 in a direct command; 4 in a major sequence number; and 5 in a minor sequence number.

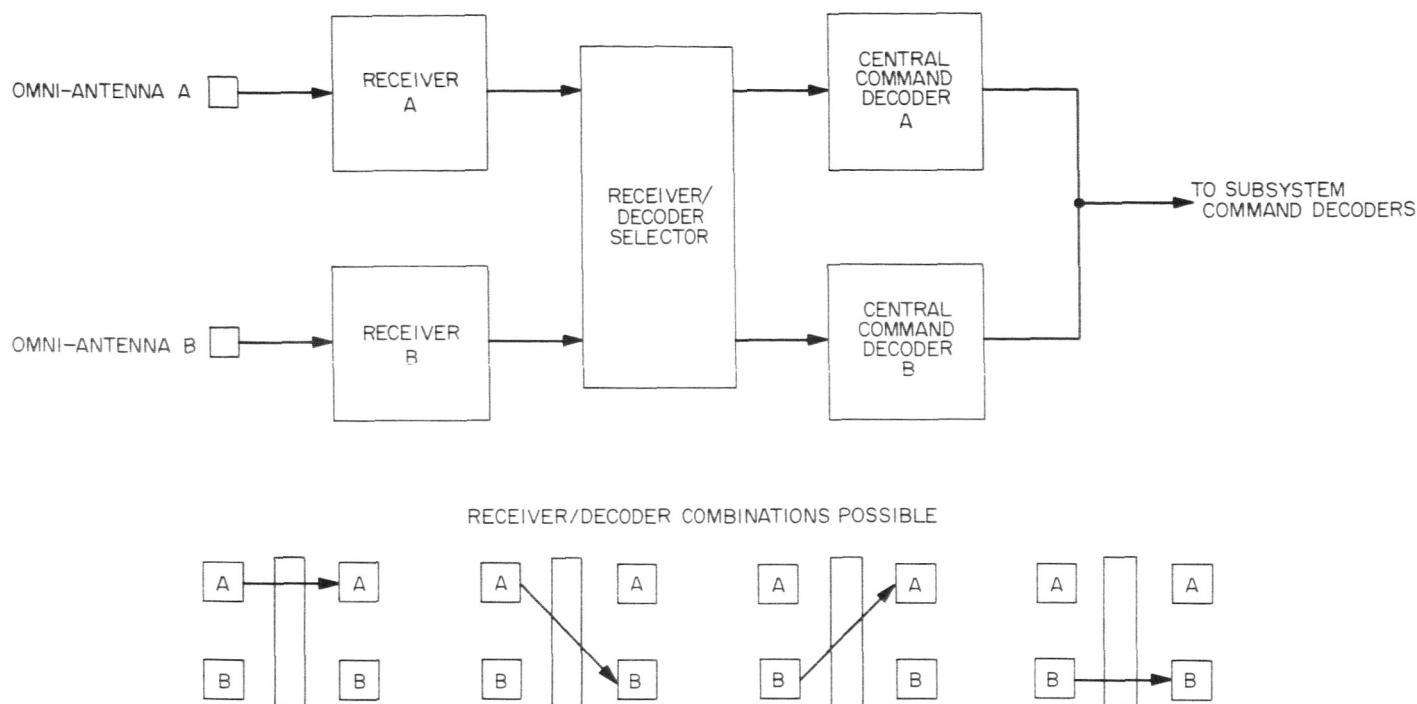
A typical sequence on a pre-mission-prepared command tape is presented in Table 7. The major sequence number is the main identifier for the minor sequences and individual commands constituting that particular major sequence. This command tape format was developed to allow the MOS personnel maximum control of the mission sequence without compromising mission accomplishment through the many time delays that would result if every minor sequence and individual command number had to be verified separately by the SFOD. The standard octal command format is shown in Table 8.

## 2. Spacecraft Command Subsystem

The spacecraft command subsystem consists of the two identical receivers, one receiver/decoder selector, two redundant central command decoders, and up to 32 subsystem command decoders. Only one of the two receivers and one of the central command decoders are used at one time. Selecting the combination of receiver and

**Table 8. Standard octal command format**

| Description                                                                                                                                                                           | First digit | Second digit | Third digit | Fourth digit |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------|-------------|--------------|
| Major Sequence<br>Composed of one or more minor sequences<br><br>Represented by unique 4-digit octal number                                                                           | 0 to 3      | 0 to 7       | 4           | 0 to 7       |
| Minor Sequence<br>Composed of one or more commands<br><br>Represented by unique 4-digit octal number                                                                                  | 0 to 3      | 0 to 7       | 5           | 0 to 7       |
| Direct Command<br>Transmitted to spacecraft; produces immediate response<br><br>Represented by unique 4-digit octal number                                                            | 0 to 3      | 0 to 7       | 0 to 3      | 0 to 7       |
| Quantitative Command<br>Transmitted to spacecraft; stored (time quantity) for determining duration of subsequent direct command<br><br>Represented by non-unique 4-digit octal number | 0 to 3      | 0 to 7       | 0 to 3      | 0 to 7       |



**Fig. 28. Receiver/decoder selector function**

decoder is the function of the receiver/decoder selector. The four possible receiver/decoder combinations are shown in Fig. 28. Whenever the command modulation is interrupted for at least 0.5 sec (i.e., no command word or a fill-in word is received by the spacecraft), the receiver/decoder selector cycles to the next combination. This multiple redundancy would enable the mission to be carried to a successful conclusion despite the failure of one of the receivers, or central command decoders, or one of each.

The receiver recovers the 24-pulse command wavetrain arriving from Earth and routes it to the receiver/decoder selector. This unit routes the command to either of the two central command decoders for processing; this, sends the command to the addressed subsystem command decoder for execution.

Figure 29 shows how the 4-digit octal number that forms the command word is translated into the 24-bit binary form that represents the 24-pulse wavetrain sent to the spacecraft. When the spacecraft is receiving a di-

rect command, the central decoder performs a complement check<sup>a</sup> on the address and command bits as a condition for entry into the correct system decoder. If the complement fails to check, a command reject signal is generated and telemetered back to Earth. If the command is correctly transmitted and received, a command enable signal goes to Earth while the central decoder routes the command to the spacecraft's subsystem decoder, signified by the address portion of the command (See Fig. 29.) The subsystem decoder then initiates the spacecraft response called out by the command portion of the 24-pulse wavetrain.

If the central decoder receives a quantitative command it performs a complement check on the address only, generating a command enable or reject signal to the Earth. Since the magnitude bits are not complement checked, they are telemetered to Earth for verification.

<sup>a</sup>In a binary digital system, the complement of a *one* is a *zero* and vice versa. The complement check is the spacecraft's method of verifying that the command as received is complete and in the correct form.

| ASSIGNED<br>SIGNIFICANCES<br>OF PULSES | GROUP<br>DESIGNATIONS      | WORD<br>SYNCHRONIZA-<br>TION SIGNAL | ADDRESS PORTION |                |                |                |  |  |  |  |  |  |  |  | COMMAND PORTION |  |  |  |  |  |  |  |  |  |  |  |
|----------------------------------------|----------------------------|-------------------------------------|-----------------|----------------|----------------|----------------|--|--|--|--|--|--|--|--|-----------------|--|--|--|--|--|--|--|--|--|--|--|
|                                        | "BIT" POSITION Nos.        | 1 2 3 4                             | 5 6 7 8 9       | 10 11 12 13 14 | 15 16 17 18 19 | 20 21 22 23 24 |  |  |  |  |  |  |  |  |                 |  |  |  |  |  |  |  |  |  |  |  |
|                                        | ARITHMETICAL<br>EQUIVALENT | NONE                                | 2 1 4 2 1       | 2 1 4 2 1      | 2 1 4 2 1      | 2 1 4 2 1      |  |  |  |  |  |  |  |  |                 |  |  |  |  |  |  |  |  |  |  |  |

|                                  |                                      |                 |                                                 |  |           |  |  |  |           |  |  |  |           |  |  |  |           |  |  |  |  |  |  |  |  |  |
|----------------------------------|--------------------------------------|-----------------|-------------------------------------------------|--|-----------|--|--|--|-----------|--|--|--|-----------|--|--|--|-----------|--|--|--|--|--|--|--|--|--|
| EXAMPLE:<br>COMMAND<br>WORD 0531 | 24-PULSE<br>WAVETRAIN                |                 |                                                 |  |           |  |  |  |           |  |  |  |           |  |  |  |           |  |  |  |  |  |  |  |  |  |
|                                  | BINARY EQUIVALENT<br>OF PULSES SHOWN |                 | 0 - - 1 1 1 0 1 0 0 0 1 0 1 0 0 1 1 0 1 1 0 0 1 |  |           |  |  |  |           |  |  |  |           |  |  |  |           |  |  |  |  |  |  |  |  |  |
|                                  | OCTAL<br>EQUIVALENTS                 | PULSES<br>SHOWN | NONE                                            |  | 2 1 0 2 0 |  |  |  | 0 0 4 0 1 |  |  |  | 0 0 4 2 0 |  |  |  | 2 1 0 0 1 |  |  |  |  |  |  |  |  |  |
|                                  |                                      | WORD<br>PARTS   | NONE                                            |  | 3 2       |  |  |  | 0 5       |  |  |  | 0 6       |  |  |  | 3 1       |  |  |  |  |  |  |  |  |  |
|                                  |                                      | COMMAND<br>WORD | —                                               |  | —         |  |  |  | 0 5       |  |  |  | —         |  |  |  | 3 1       |  |  |  |  |  |  |  |  |  |

Fig. 29. Bit structure of a direct command word

The central decoder routes a correctly checked quantitative command to the flight control subsystem decoder for decoding and storage and generates confirmation of correct storage to Earth.

The interlock command is a special command used in conjunction with certain direct commands related to critical functions and all quantitative commands. The purpose of the interlock command is (1) to prevent unintentional execution of critical direct commands including such irrevocable actions as firing of squibs, midcourse motor burn, etc. and (2) to ensure that improper magnitudes are not stored. The transmission of critical direct commands must be preceded by the interlock command before the spacecraft will accept the command.

Fill-in words have a format similar to that of direct commands; however, they violate the complement check, and therefore do not enter the subsystem decoders.

## B. Command System Functions and Procedures

The *Surveyor* Command System is the means whereby the SFOD and the supporting technical teams, located in the SFOF, maintain continuous control of the spacecraft throughout space operations. After the SFOD has approved the sending of a command and when he has been advised that the DSS has sent the desired command and that the spacecraft has responded correctly, this confirmation closes the Command System loop.

The three alternatives used to carry out the Command System functions after a command decision has been made are graphically described in Fig. 30.

Alternative 1 is the usual procedure, used whenever the required command sequence exists on a pre-prepared, pre-verified tape at the DSIF Station. In this situation, an SFOF command message goes to the DSS over a voice communication link. The CDC operator starts the command tape reader searching for the individual command or the command sequence for display. The SOC reads back the displayed information to the SFOF from where, in turn, oral notification is sent to the DSS as to whether or not the information is correct. If it is, the CDC operator executes the command (or command sequence). The OSDP routes the executed command by teletype to the SFOF-DPS for real-time display and confirmation.

Alternative 2 is used when there are no pre-prepared command tapes at the DSS for a certain command situation. In this case, all command messages are prepared by the *Surveyor* Command Preparation (SCP) and Command Verify/Transmit (CVT) computer programs in the SFOF, transmitted to the DSS over teletype lines, and received by the OSDP, which generates an output command tape for use by the CDC command subsystem. Teletype lines carry the returning command messages to the SFOF for verification by the CVT system. As verified commands are executed by the CDC operator, they are returned by teletype to the SFOF for confirmation by the CVT system.



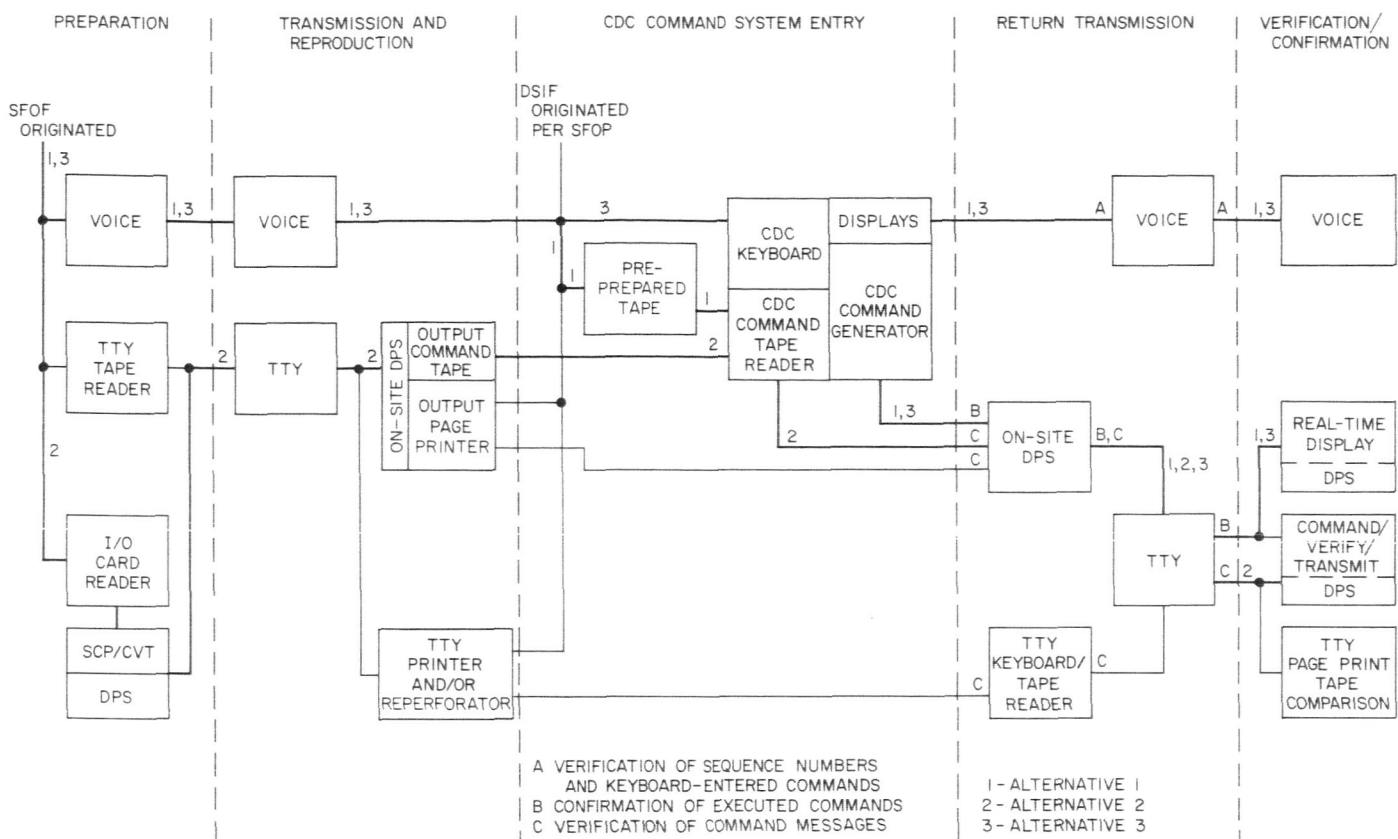


Fig. 30. Surveyor Command System alternatives

Alternative 3 is used in situations for which there are no pre-prepared command tapes and Alternative 2 cannot be used. Alternatives 3 and 1 differ only in the use of the CDC manual keyboard instead of the command tape reader for incoming command messages. However, a combination of the two alternatives is possible when the desired command sequence is a minor variation of a sequence existing on a pre-prepared tape. This tape can be entered in the CDC and special or changed commands entered on the CDC manual keyboard as required (Fig. 31).

The typical CDC installation at the DSIF Stations is illustrated in Fig. 32, which shows the Johannesburg, South Africa, crew operating their CDC during a test.

### 1. Command Verification

The command verification process is designed to ensure that commands are properly handled by the Command System prior to their transmission to the spacecraft. This is accomplished by checking and rechecking each

command message at every point where an error or mistake could occur. When the Alternative 2 method is used in the handling of commands, the CVT system is used for the verification process at the SFOF. The DSS return-transmitted command message enters the SFOF-DPS through direct electrical interface with the teletype link and is stored in the DPS disk file. The CVT system verifies DSIF Station instructions contained in the command message and command portions by comparing the returning and original messages bit by bit. (In a similar manner, the CVT computer program compares major and minor sequence command tapes prepared before launch with those pre-stored sequences common to the SCP and CVT programs.) The CVT system then notifies all SFOF user areas whether or not the command messages are identical. If any errors are found, they are printed out in the I/O console areas and in the SPAA, and are specifically identified in English language displays in the technical areas. The CVT system displays errors that are discovered during the comparison of pre-prepared command tapes in the manner described for errors it finds in the command portion of a command message.

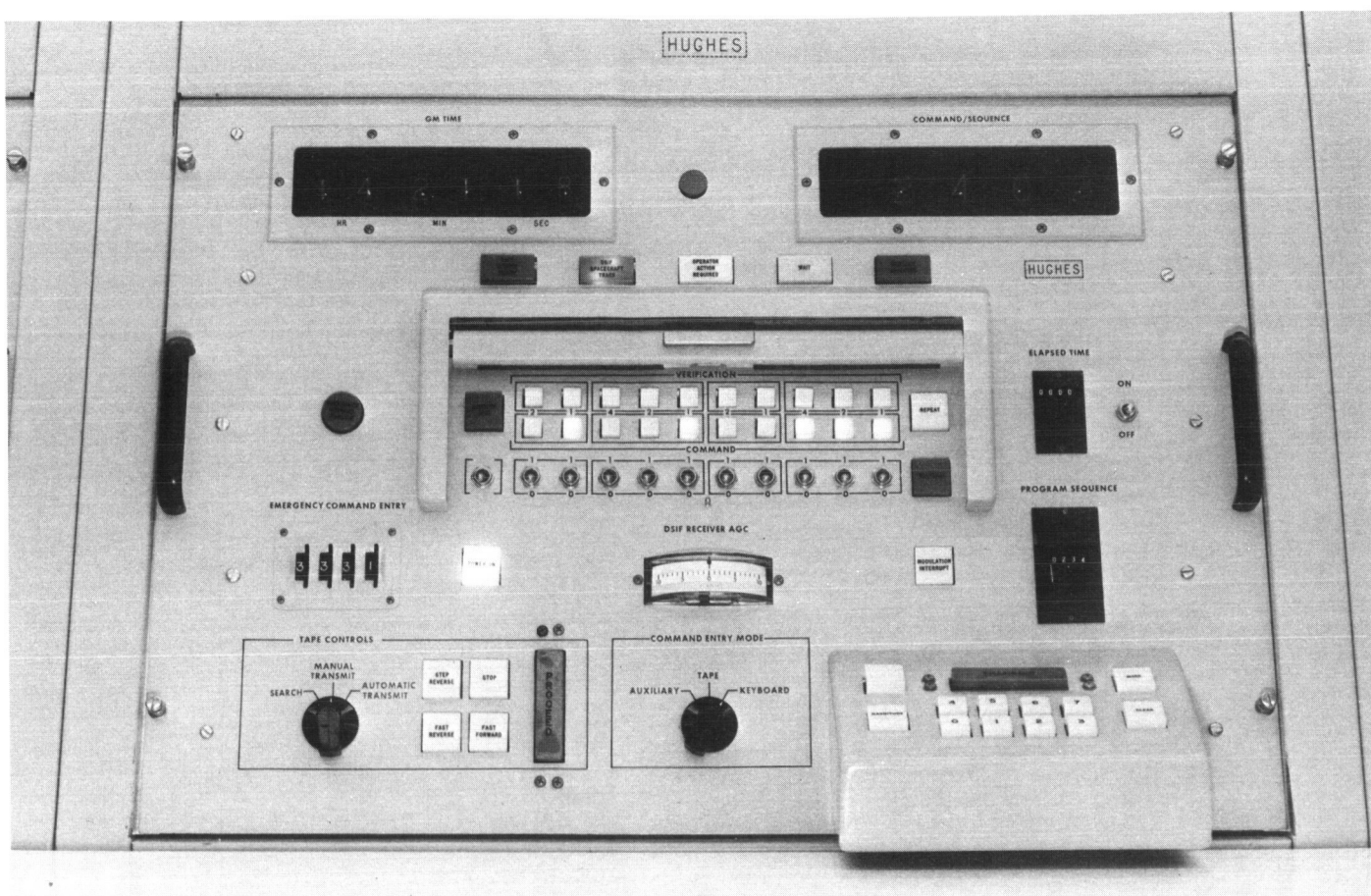


Fig. 31. CDC manual keyboard

SFOF personnel may bypass the CVT system and perform verification by visually comparing transmitted and return-transmitted teletype printouts. In all instances, however, a teletype tape comparator performs a tape comparison.

When voice communication is used for verification, SFOF and DSIF personnel orally compare the transmitted command message information.

## 2. Command Confirmation

The command confirmation process at the SFOF establishes that the correct command or series of commands was executed by the DSIF Station, that the quantitative commands were properly stored in the spacecraft, and that the spacecraft responded correctly to the direct commands.

As the spacecraft-received commands are returned to the SFOF, they enter the DPS 7044 computer for subsequent real-time display on a teleprinter in the SPAA. The 7044 computer also routes the incoming commands to the DPS disk file for later access by 7094 computer user programs. When operating in the 7094 computer, the CVT computer program transforms the commands to binary numbers and compares them, sequence by sequence, with a glossary of pre-stored sequences. This program identifies errors found during the confirmation process in the same way that it does when identifying errors found during command message verification, except that the individual commands are given DSS-assigned time tags. Commands returning from a DSS for confirmation are also written on magnetic tape for processing by the SFOF-DPS in nonreal time, if desired.

To confirm correct storage of quantitative commands in the spacecraft, the SFOF receives returning informa-

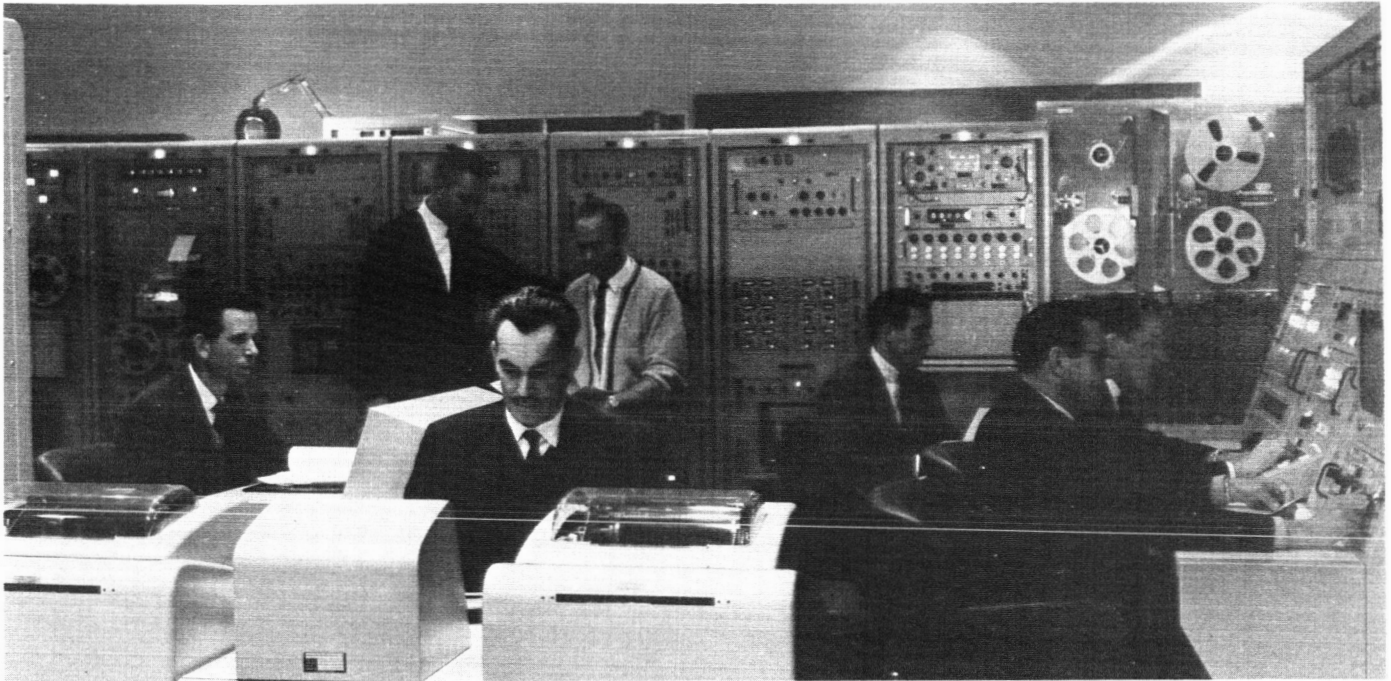


Fig. 32. CDC at DSS 51

tion from the DSIF Stations over either high-speed data line or teletype, but not over both simultaneously. Quantitative command information is routed through the SFOF-DPS (Telemetry Processing Station and 7044 computer if return-transmitted over high-speed data line, or through the 7044 computer only if return-transmitted by TTY) and is displayed in real time by a series of status display lights located in the SPAA. After it has been confirmed that the quantitative command has been correctly stored, the spacecraft is then ready for the direct command, which defines and initiates the particular space-

craft response to which the previously received quantitative command applies.

There are two methods of command confirmation that do not require full use of the DSIF and SFOF Data Processing Systems described previously. DSIF personnel may read command information from the automatic command printer and/or series of CDC status display lights and relay this information to the SFOF either orally or by a manually prepared TTY message for comparison.

## IV. MISSION OPERATIONS SYSTEM TEST PROGRAM

The final welding of the major elements of the MOS into a functional whole is accomplished by the test program. A master program comprising three basic categories of tests is used to train all mission personnel and to verify that the equipment and operational capabilities of the MOS are adequate to accomplish the *Surveyor* mission. In order to define and verify these capabilities, the *Space Flight Operations Test Plan*, EPD-234, was established. This test plan covers in detail all operational testing activities of the MOS. The first category is the Class A facility internal tests, which establish that support facilities function properly within themselves.

Class B functional compatibility tests ensure that the Earth-based facilities are functionally compatible with the spacecraft and with each other. Class C operational tests ensure that all elements of the MOS operate together, with simulated spacecraft data, to demonstrate readiness to support an actual space operation. The relationship of the three classes of tests is illustrated in Fig. 33.

### A. Class A Facility Internal Tests

Class A Facility Internal Tests are composed of Class A-1, operational training exercises, and Class A-2, verification tests. The tests are designed to ensure that *Surveyor* mission support equipment, computer programs, and personnel within a facility (any DSIF Station or the SFOF) have the required capability and are prepared to support subsequent tests. While these tests are generally internal to a facility, some extra-facility support may be required to allow a realistic evaluation of the interfaces as seen from inside the facility in which the test is being conducted. Simulated mission data for Class A tests is generated in the SFOF, utilizing the PDP-1 computer.

#### 1. Class A-1 Operational Training Tests

Class A-1 operational training tests begin in the SFOF and in each DSIF facility early in the testing program. They provide mission personnel with the opportunity and time to become completely familiar with their func-

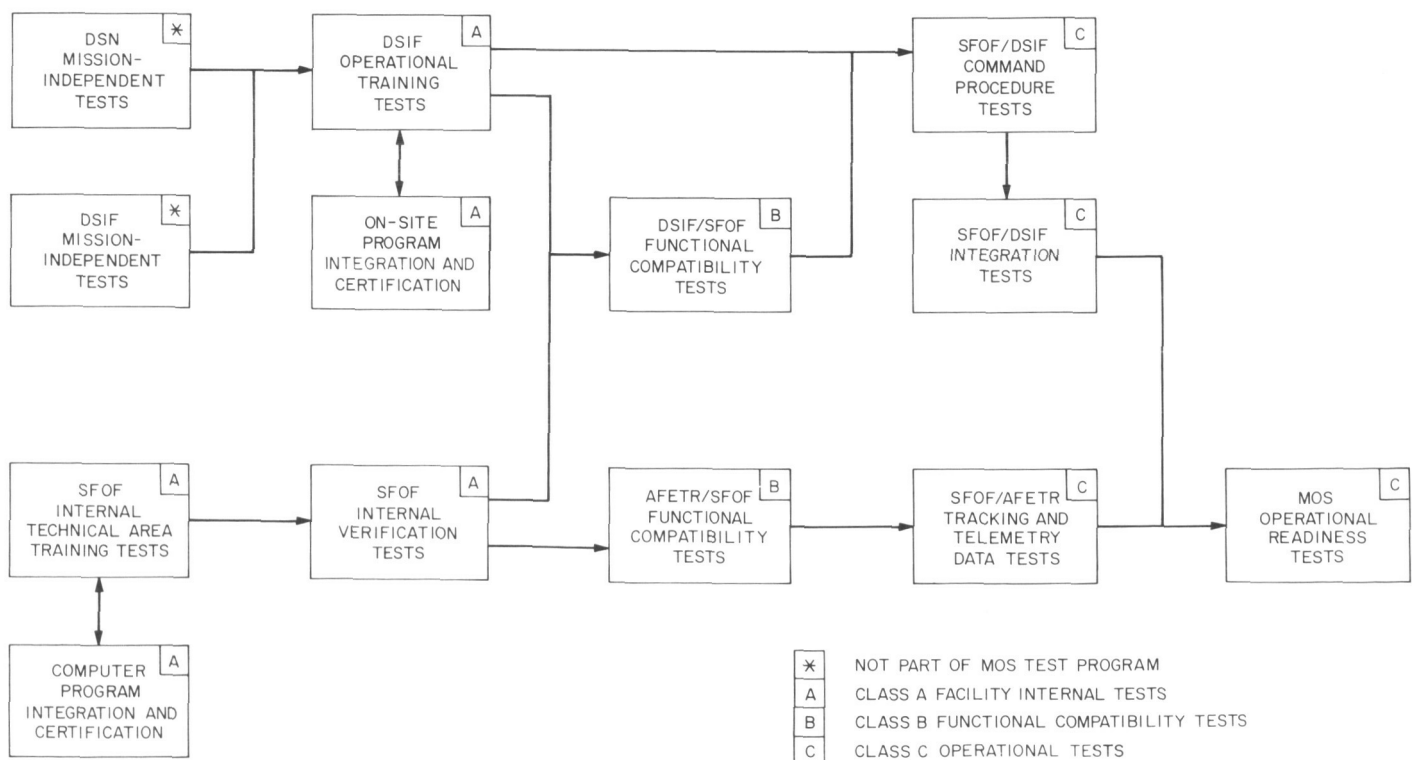


Fig. 33. Relationship of MOS tests

tions, working areas, equipment, methods of communication, and internal interfaces. Two classes of tests must be successfully completed before DSIF facilities can start Class A-1 training exercises. One class, the DSN mission-independent tests, includes acquisition training with test spacecraft. The other, DSIF equipment tests, determines that the CDC, system tester, S-band receiving and transmitting equipment, SCTV-GDHS, and DSIF instrumentation are functionally compatible.

DSIF operational training tests, conducted within the DSIF Stations under the direction of the individual Station Manager, provide an organized training program for the DSIF crews in preparation for Class B and Class C tests. Interfaces outside the station are simulated with test data packages. These tests also permit, to the extent possible, the evaluation of existing Detailed Operating Procedures and the stating of requirements for procedures not in existence.

## 2. Class A-2 SFOF Internal Verification Tests

These SFOF internal tests verify the capability of the integrated mission operations groups, computer programs, and equipment within the SFOF to control a *Surveyor* mission. The SPAC and SSAC tests are held in real time; the FPAC test is conducted in both real and nonreal time. The SFOF integration verification test exercises all SFOF personnel, equipment, computer programs, procedures, and operations techniques throughout an entire simulated mission.

*a. Computer program integration, checkout, and certification.* Computer program integration is the process of inserting a user program into the software environment of the SFOF system and making those changes necessary for the program to be compatible with the system. Program certification tests verify the operational status of the user programs for the mission. For each program, a test specification defines a series of cases exercising all options and interfaces with other computer programs. Successful completion of the test leads to program certification, the last step in the development of a *Surveyor* computer program.

The on-site data processing program checkout assembles and checks the various options of the *Surveyor* on-site computer program (SOCP) in order to find and correct program errors. The OSDP integration process, performed first at Goldstone, then simultaneously at Johannesburg and Tidbinbilla, consists of inserting SOCP into a checked-out hardware environment and verifying both the hardware/software interfaces and the program

options. Upon completion of program integration, training of DSN operators begins.

## B. Class B Functional Compatibility Tests

Class B functional compatibility tests verify that the separate elements of the *Surveyor* MOS can perform together in accordance with the functional requirements specified, and that these requirements are compatible with the actual spacecraft data configuration. During these tests, the MOS is exercised under a variety of conditions determined by the combinations of commutator modes, bit rates, command sequences, communications capabilities, equipment configurations, etc., which could occur during standard and certain nonstandard space operations. Class B tests also verify that all *Surveyor* DSN hardware and software interfaces are compatible by demonstrating acceptable MOS functional performance. It is not necessary that the tests be performed in real time, nor is rigid adherence to operational procedures required; however, the use of data from a spacecraft or facsimile is involved. Figure 34 shows the *Surveyor* at DSS 11 during a Class B test. Successful accomplishment of the Class B tests verifies that the MOS is functionally capable of supporting the *Surveyor* mission.

## C. Class C Operational Tests

Following the satisfactory completion of their Class B tests, all facilities participating in the mission are required to establish their operational readiness through the series of Class C tests. These tests are designed to exercise the personnel, hardware, and software to the maximum extent feasible, within the limitations of a simulated mission. The intent of this series of tests is to progressively increase personnel proficiency and demonstrate their operational readiness. The series begins with single-station tests and culminates with a total-system dress rehearsal. The test philosophy emphasizes the standard operating procedures. The personnel are exercised in the resolution of problems created by the insertion of simulated malfunctions or failures of the spacecraft and of the Earth-based equipment, including communication lines.

Each of the Class C tests consists of serially arranged truncated mission segments, chosen to achieve the stated objectives. The mission segments selected are:

*Phase I* Launch minus 60 min to approximately launch plus 3 hr, beginning with the initiation of spacecraft telemetry transmission



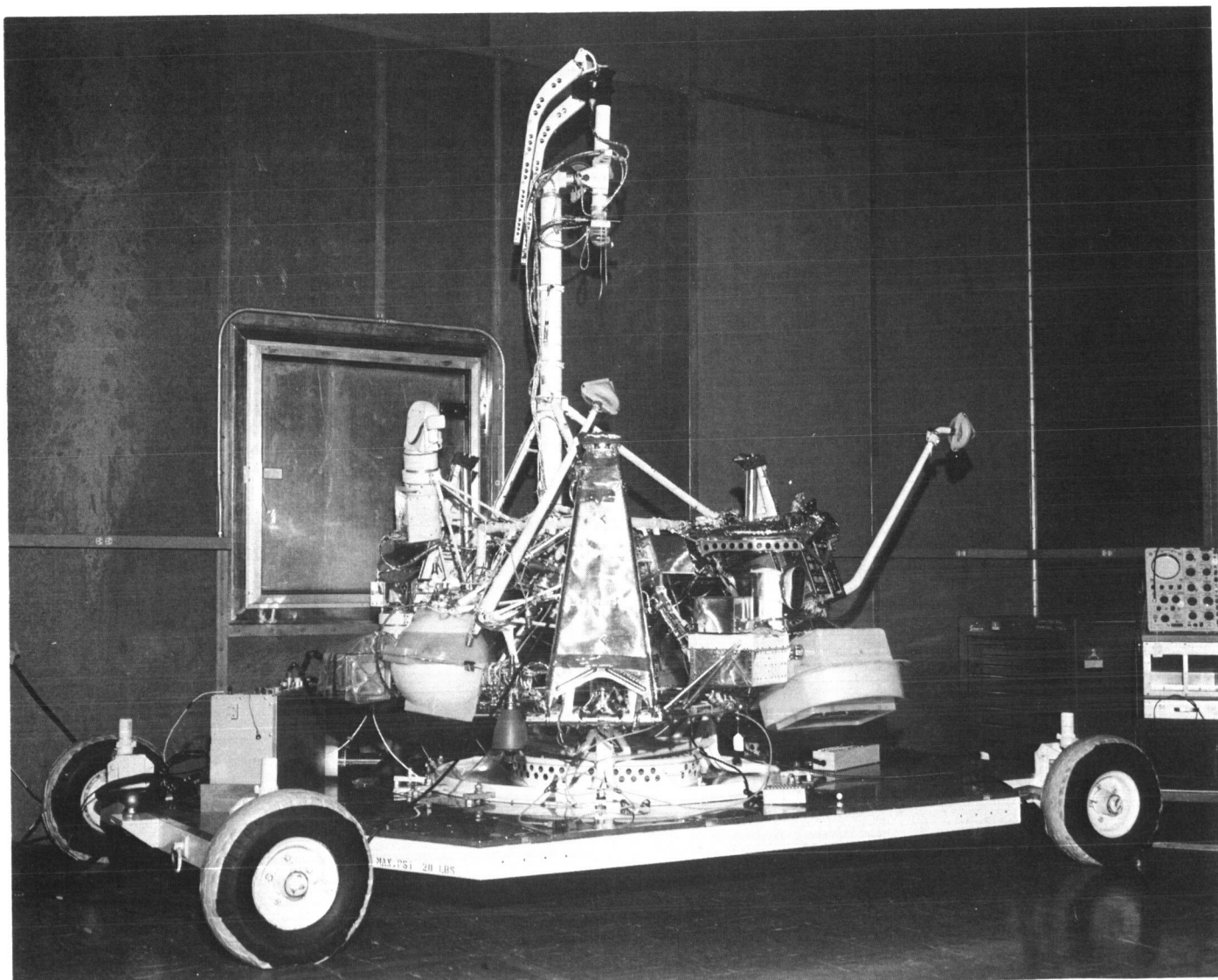


Fig. 34. Surveyor during test at DSS 11

from AFETR to the SFOF and ending with the completion of final Real Time Computing Center activities at AFETR. This phase includes spacecraft acquisition and tracking by DSS 51 or DSS 72 (Ascension Island), as appropriate.

**Phase II** Launch plus 3 hr to launch plus 11 hr; completion of Phase I to the end of DSS 51 or DSS 62 (Madrid, Spain) first view period.

**Phase III** Launch plus 11 hr to launch plus 19 hr, beginning with spacecraft acquisition by DSS 11 and ending with the successful completion of midcourse maneuver and Sun and star reacquisition. Sufficient time is included to recycle one time in the event of a midcourse maneuver abort prior to thrust execution. (This phase may include DSS 42 participation.)

**Phase IV** Retro maneuver minus 7 hr to touchdown plus 33 min, beginning with spacecraft acquisition by DSS 11 (or DSS 42) or initiation of the fifth orbit determination, whichever comes first, and ending with completion of the first post-landing spacecraft engineering assessment.

**Phase V** Touchdown plus 33 min to touchdown plus 3 hr for Mission A (this period will be longer for subsequent missions), beginning with the completion of Phase IV and ending with the conclusion of planned lunar post-landing activities.

The standard flight operations sequence used for the Class C tests is the SSE, Section V of the *Space Flight Operations Plan*, EPD-180, revised for each successive mission. A typical schedule for the Class C tests is presented in Fig. 35.

The Class C tests represent the culmination of the many man-hours invested in preparation for an actual space flight. As such, and because this series of tests gives a preview of each actual mission, a more extensive description than that devoted to Class A and B tests is warranted.

### 1. SFOF/DSS 11 Integration Test (C-1.1)

The primary objective of this test is to exercise SFOF and DSS 11 personnel in the execution of a midcourse

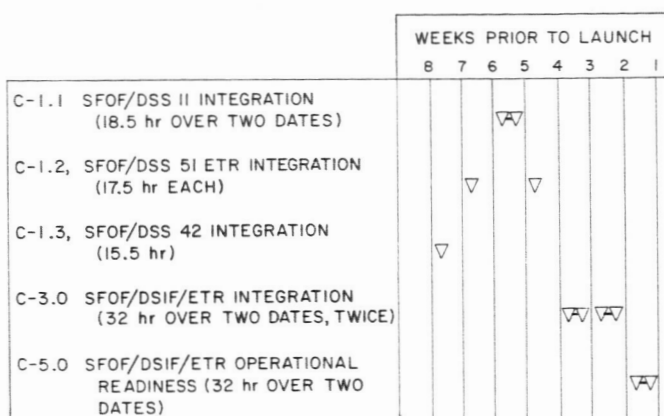


Fig. 35. Typical Class C test schedule

maneuver, a terminal descent, and post-landing lunar operations including a full TV sequence. The test encompasses Phases III, IV, and V. Figure 36 presents the test profile and participation required of each major organizational element.

The Phase III portion of the test will terminate with the successful completion of the midcourse maneuver and Sun and star reacquisition.

Phases IV and V are performed on the second day following Phase III in order to allow the computation of the new trajectory defined by the Phase III midcourse maneuver and the preparation of new data to be used in Phase IV.

Spacecraft or Earth-based equipment malfunctions or failures may be injected into this test at the discretion of the Test Coordinator.

### 2. SFOF/DSS 51/AFETR Integration Test (C-1.2)

The objective of this test is to exercise the SFOF, AFETR, and DSS 51 personnel in prelaunch, launch, and early flight activities, emphasizing AFETR interactions with FPAC and SPAC and SFOF/DSS 51 tracking and command activities. This test is performed twice: once, to exercise a normal flight profile from launch minus 1 hr to the successful completion of star acquisition and verification, and the second time to exercise the SFOF and DSS 51 in the execution of an early midcourse. This test encompasses Phases I and II.

Phase I is performed twice on the first test date, but only once on the second. The generalized test profile and participation requirements are shown in Fig. 37.

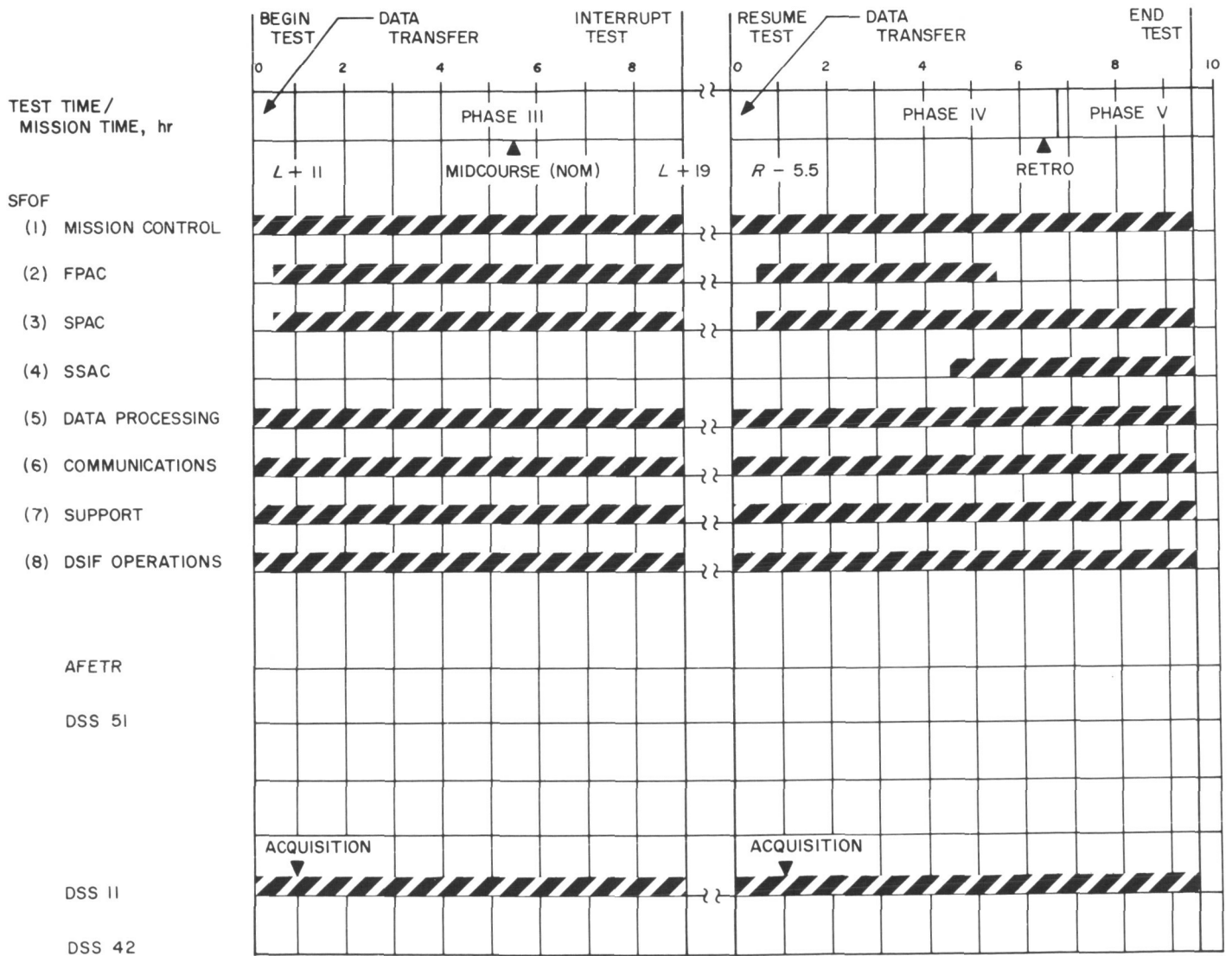


Fig. 36. Typical C-1.1 test participation

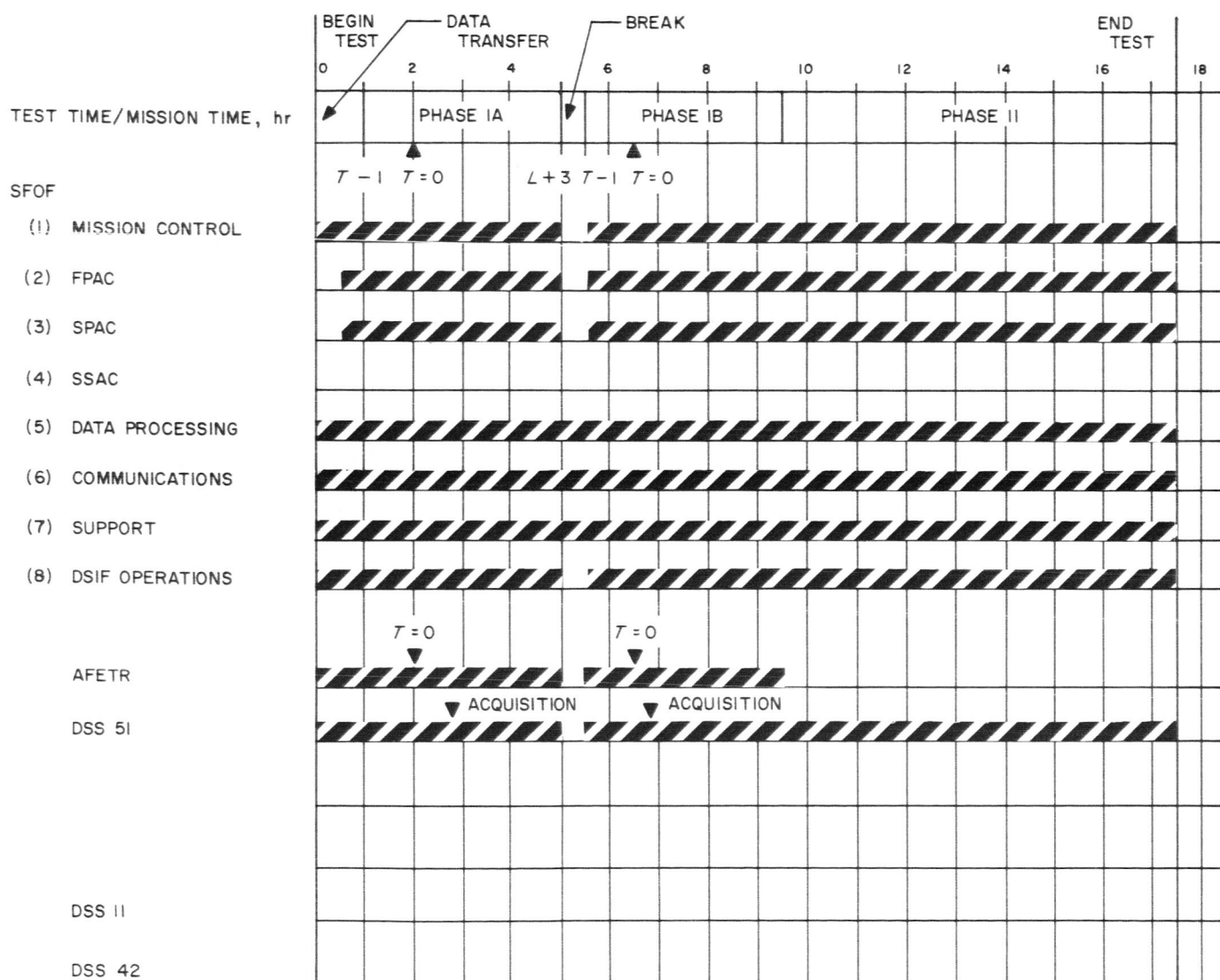


Fig. 37. Typical C-1.2 test participation

### 3. SFOF/DSS 42 Integration Test (C-1.3)

The primary objective of this test is to train DSS 42 personnel and exercise the SFOF/DSS 42 interface in the execution of critical mission phases for which they are normally expected to provide a backup capability to DSS 11.

The test profile duplicates that of test C-1.1 with DSS 42 substituted for DSS 11, except that no post-landing

TV sequence (Phase V) is performed. The test profile and participation requirements are shown in Fig. 38.

### 4. SFOF/DSIF/AFETR Integration Test (C-3.0)

The objective of this test is to exercise the total MOS in a simulated mission, emphasizing the sequential and simultaneous interactions between the SFOF and all DSIF Stations and AFETR. This is the final phase of training the SFO personnel for the mission. This test is a combination of tests C-1.1 and C-1.2, except that Phase I

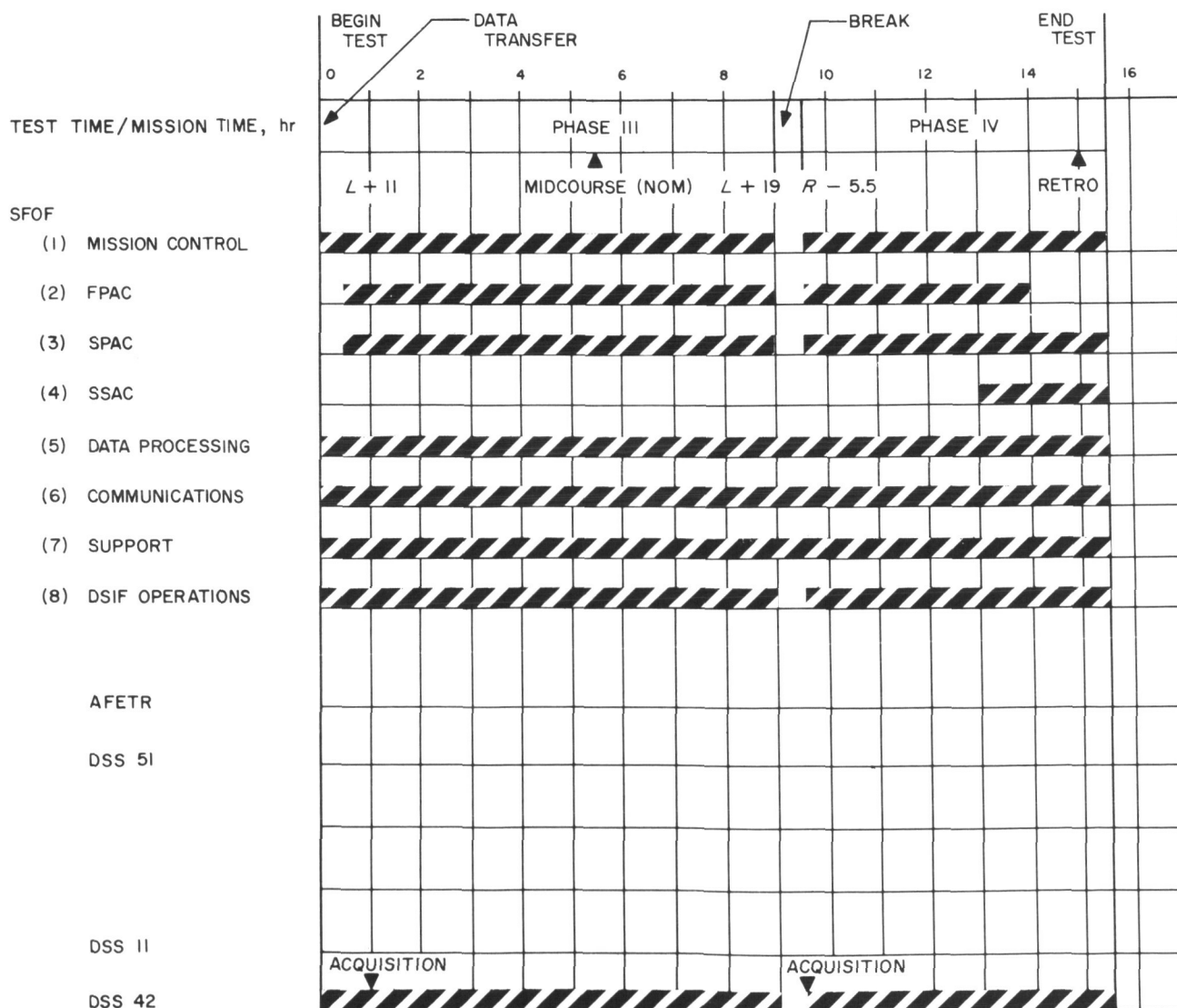


Fig. 38. Typical C-1.3 test participation



will be performed only once and DSS 42 will participate during its appropriate view period.

This test may include spacecraft or ground equipment malfunctions, at the discretion of the Test Coordinator. The test profile and participation requirements are shown in Fig. 39.

### 5. SFOF/DSIF/AFETR Operational Readiness Test (C-5.0)

The objective of this test is to provide a final pre-flight verification and demonstration of the adequacy of personnel proficiency and ground equipment capability to meet the requirements of the mission. This test is similar to the C-3.0 test (Fig. 39).

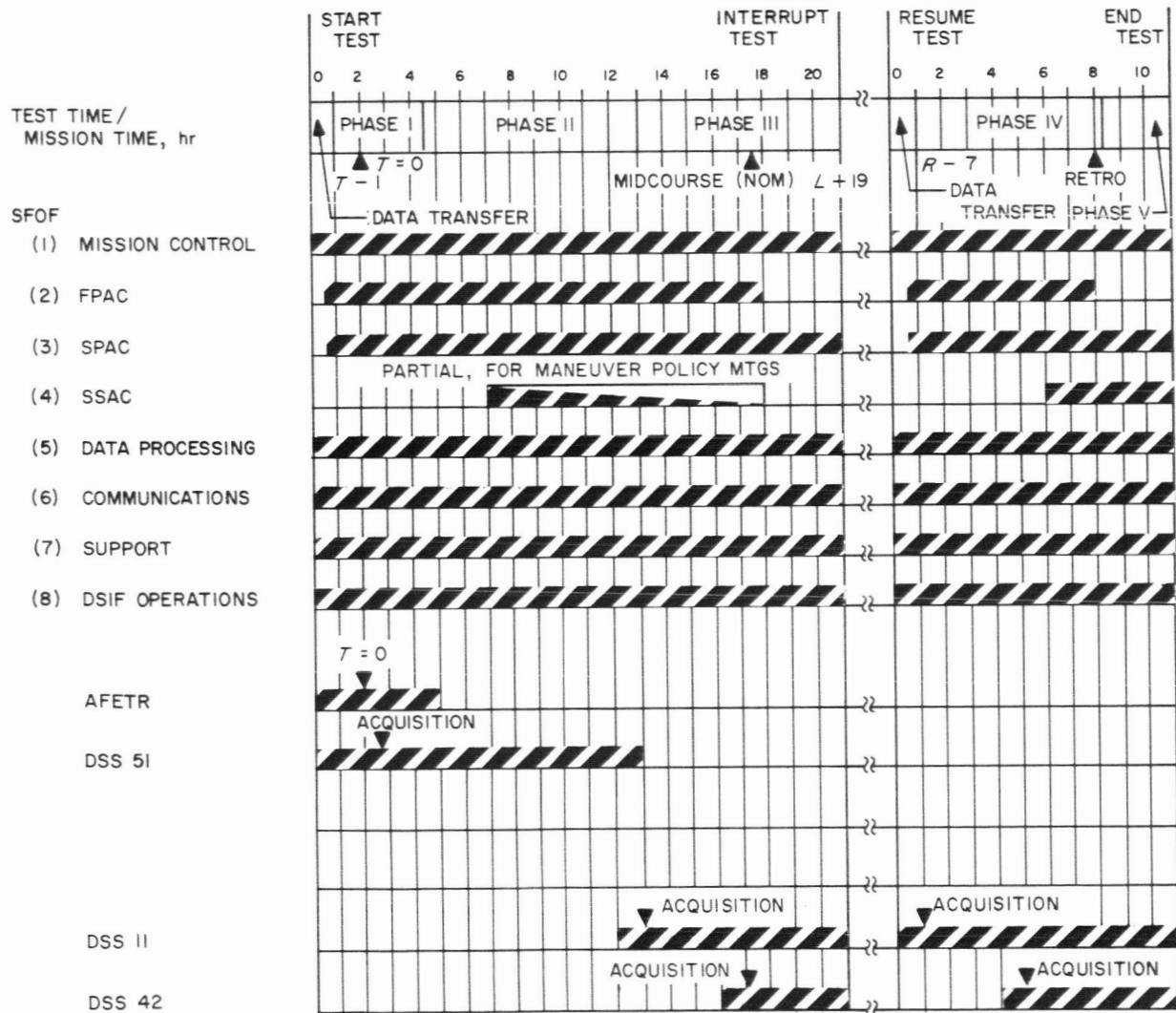


Fig. 39. Typical C-3.0 and C-5.0 test participation

## V. SPACE OPERATIONS

This section describes the MOS in its dynamic mode during a typical *Surveyor* mission. The mission description presented chronologically follows the events planned to take place during a normal mission and which are recorded in the Space Flight Operations Plan as the SSE. Since the MOS must maintain a continuous knowledge of the location of the spacecraft, monitor the performance of its subsystems, and command the spacecraft to perform according to the SFOP, a two-way communication between the MOS and the spacecraft is continuously maintained throughout the mission. Knowledge of the flow and nature of these communications is a prerequisite to a clear understanding of what takes place during the mission.

The basic communications are dividable into two categories: (1) signals passing between the MOS and the spacecraft and (2) communications required between, among, and within the Earth-based facilities used by the MOS. Figure 40 is a simplified diagram of the up- and down-links of signals passing to and from the spacecraft after it has separated from the *Centaur* second stage.

The Earth-based communications, comprised of teletype, high-speed data lines, and voice lines, connect the

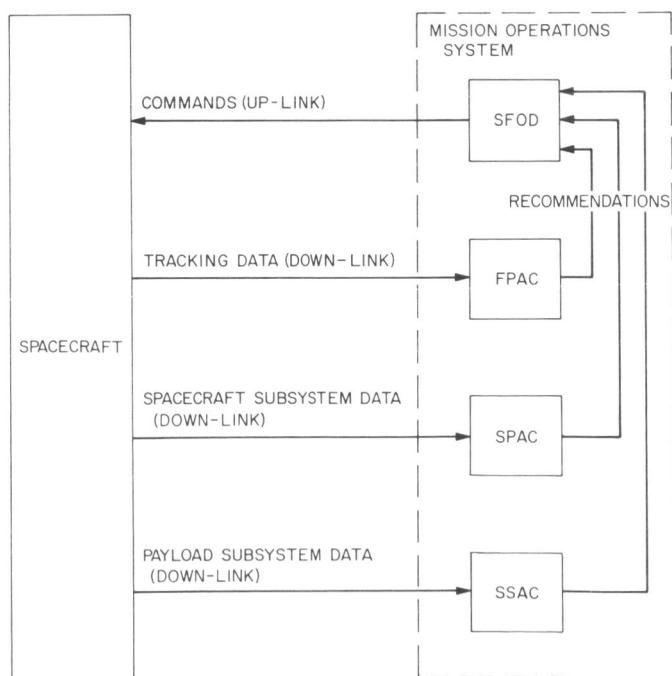


Fig. 40. Basic communication flows

SFOF to AFETR and to the DSIF Stations. The teletype lines are standard commercial two-way lines used for transmission of tracking data, administrative traffic, and for carrying MOS instructions between the SFOF and the other facilities. High-speed data lines are used for the transmission of telemetry data to the SFOF.

There are over ten independent voice networks combined to form the Operational Voice Communications System (OVCS) serving the *Surveyor* Project personnel within the SFOF. These networks can be connected to similar voice networks in the other mission-involved facilities by means of the voice lines between the communication centers of the SFOF and those of the respective facilities. Access to the OVCS is provided to key MOS personnel within the SFOF through the communications and control consoles located in the operational and technical areas. One such console is shown in Fig. 41. Other operational personnel are provided voice network instruments which allow them to use the OVCS. The majority of the voice networks is used for administrative operational traffic, e.g., relaying instructions, approvals, and reporting conditions. One voice network, known as the command net, is reserved for the handling of commands. This is a two-way circuit among the individuals responsible for commanding the spacecraft and a one-way (listen only) circuit for those who need only to follow the command operations.



Fig. 41. OVCS console

The additional communication line existing between the SFOF and the Goldstone DSS, the micro-wave link, is used to relay spacecraft engineering telemetry and television data at high transmission rates.

Communications involved most directly with the MOS activities are more easily seen by tracing the tracking and telemetry data through the SFOF, specifically through the technical support areas. Obviously the FPAC, SPAC, and SSAC activities are integrated during a mission; however, for purposes of clarity, the descriptions of their handling of the incoming data are treated separately in the following paragraphs.

#### **A. Communications Flowing To and From the FPAC**

One of the first datum of importance to be received by the FPAC is the actual liftoff time announced over the voice net from AFETR and later confirmed by teletype. This datum and subsequent AFETR-acquired raw tracking data (received over the TTY lines) are used by the TPG as the computer input in punched card form. The output of the computer is printed in page form by the bulk-printer in the FPAA. Copies of this printout go to the orbit determination group (ODG) to be used in their programs.

The raw tracking data, giving the position and velocity of the spacecraft, is actually a product of the data processing done at the DSIF Stations after two-way lock is achieved. Two-way lock occurs after the following conditions are obtained. First, the DSS transmitter signal, reaching the spacecraft, causes the spacecraft transmitter to operate at a frequency that is shifted by a fixed ratio from the received frequency. The DSS receiver then phase-locks on the spacecraft transmitted signal. This set of conditions constitutes two-way lock. The amount of frequency shift at the DSS, which is in addition to the fixed translation in the spacecraft, is a measure of the relative velocity between the DSS and the spacecraft and is displayed on the DSS equipment in terms of cycles of frequency shift in a doppler counting period. This number, together with antenna pointing angles and Greenwich Mean Time, is transmitted over the teletype data line to the FPAA in the SFOF. Here the data is printed out on one of the teletype printers and is used as input for the orbit determination program ODPX.

The tracking data thus obtained is used to form the predictions sent to the DSIF Stations instructing them where to point their antennas to pick up the spacecraft's

signal at the beginning of their next view period. The orbit of the spacecraft is determined by the FPAC Group's analysis of the tracking data.

In preparation for the midcourse maneuver, the FPAC Group computes the trajectory of the spacecraft a number of times, refining the computation as more tracking data becomes available. From this computation, a midcourse maneuver is determined that will redirect the spacecraft to the desired lunar landing site. The FPAC Group, in agreement with the SFOD and the SPAC and SSAC Directors, determines the commands necessary to achieve the desired maneuver and gives this information to the SPAC Group.

By a similar process, the flight path adjustment required during the terminal descent phase of the mission is derived. After the spacecraft has landed, the FPAC Group again analyzes the tracking data to determine as closely as possible the exact point of touchdown.

#### **B. Communications Flowing To and From the SPAC**

To enable the SPAC to carry out their functions, a continuous flow of telemetry data is received which contains information on the performance and condition of the spacecraft. Instruments in the spacecraft measure the significant conditions of the various subsystems. These measurements then are combined by the telecommunications subsystem into a complex time- and frequency-multiplexed signal which is telemetered to the SFOF via the DSIF. The incoming data is processed and distributed as depicted in the summary manner illustrated in Fig. 42.

The PA sub-group of the SPAC maintains a constant watch over all spacecraft subsystems. If incoming data shows an out-of-tolerance condition, or if deviations from the SSE are indicated, the PA sub-group forms a recommendation for the corrective action required; this recommendation is passed to the CP sub-group which generates the command message that will effect the necessary change.

The number of telemetry data channels operating simultaneously during the mission is controlled by commands generated by the SPAC Group. The channels required depend on the phase of the mission. At least one channel, however, is always a commutated channel that samples a number of sensors in sequence. There are seven commutated channels, as shown in Table 9. Transmitted in digital form, the commutated data, after being

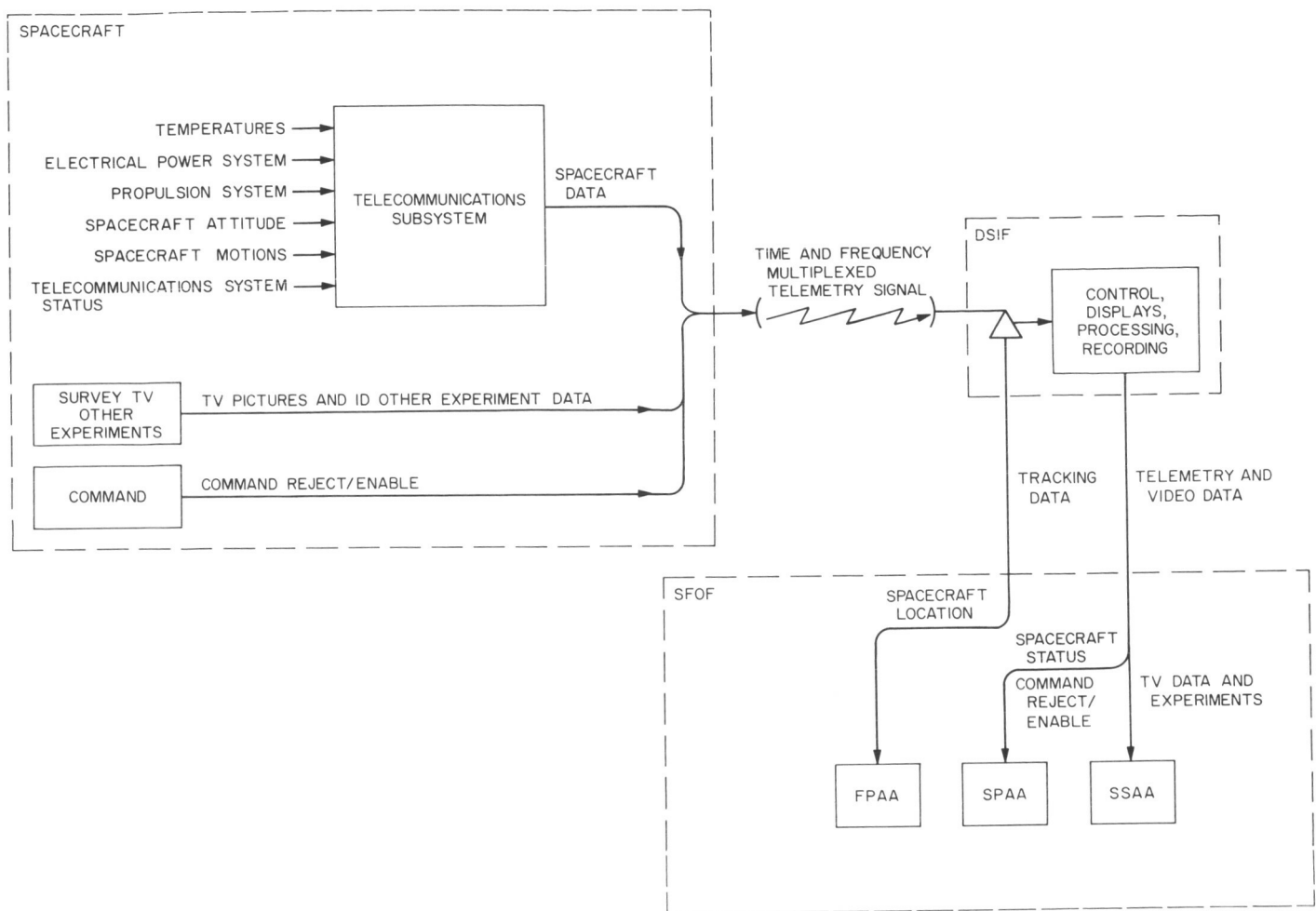


Fig. 42. Information flow from spacecraft to users during space operations

processed in the DPS, is printed out on the appropriate page printers or teletype printers. Analog data, such as accelerometer and strain gage information, is plotted on one of the analog recorders in the SPAA. Signals that indicate whether the landing gear is locked or the on-off condition of various equipment are binary and actuate appropriate status light displays in the SPAA. Scenes of the SPAA are shown in Fig. 43.

From time to time, commands are sent to change the rate at which the spacecraft transmits digital data. The commutators can be operated, on command from the SFOF, at any of the following bit rates: 17%, 137½, 550, 1100, and 4400 bits/sec. As the spacecraft gets closer to the Moon, the Earth-received signal becomes weaker and the bit rate must be reduced to maintain a usable signal-to-noise ratio when transmitting at low power. This relationship is shown, for the trans-

mitter low power and omnidirectional antenna combination, in Fig. 44. This is, of course, the limiting case. When TV pictures are being transmitted or other lunar surface operations are taking place, or during high activity periods of the transit phase, the transmitter high-power mode, with or without the high-gain antenna, may be used.

### C. Communications Flowing To and From the SSAC

Telemetry data relative to the TV subsystem is sent to the SSAC Group, which is primarily concerned with the survey TV. In preparation for the midcourse and terminal descent maneuvers, the SSAC Group also provides the FPAC and SPAC Groups with landing site priorities based on payload and mission objective considerations.

Table 9. Content of telemetry signals from spacecraft

| Data                             | Source                                                              | Significance                                                                                                                 | Number of points sampled | Form    | Comments                                                   |
|----------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------------|---------|------------------------------------------------------------|
| Commutator Mode 1                | Flight control, propulsion                                          | Provides data required for midcourse maneuver                                                                                | 100                      | Digital | Modes 1, 2, 3, and 4 used one at a time on command per SSE |
| Commutator Mode 2                | Flight control, propulsion, approach TV, AMR, RADVS                 | Provides data required for retro descent                                                                                     | 100                      | Digital |                                                            |
| Commutator Mode 3                | Inertial guidance, approach TV, AMR, RADVS, vernier engines         | Provides data required for vernier descent                                                                                   | 50                       | Digital |                                                            |
| Commutator Mode 4                | Temperatures, power status, telecommunications                      | Provides data required for miscellaneous transit and lunar surface operations                                                | 100                      | Digital | Used on command per SSE                                    |
| Cruise phase commutator (Mode 5) | Flight control, power status, temperature                           | Provides data required during cruise mode to determine general spacecraft status                                             | 120                      | Digital |                                                            |
| Thrust phase commutator (Mode 6) | Flight control, power status, AMR, RADVS, vernier engine conditions | Provides data required for backup of Modes 1, 2, and 3 during thrusting maneuvers                                            | 120                      | Digital | Used on command per SSE                                    |
| TV commutator (Mode 7)           | Survey TV camera                                                    | Provides frame identification while survey TV is operating                                                                   | 16                       | Digital | Frame ID alternates with analog video signals              |
| Vibration                        | Accelerometers                                                      | Indicates vibrations due to booster engine, main retrorocket, and vernier engine firings and mechanical shock during landing | 8                        | Analog  |                                                            |
| Shock absorber data              | Strain gages                                                        | Measures strain on landing gear due to landing shock                                                                         | 3                        | Digital | Samples are sequential for pitch, roll, and yaw axes       |
| Gyro speed                       | Inertial guidance unit                                              | Indicates change in attitude of spacecraft                                                                                   | 3                        | Analog  |                                                            |

One survey TV camera will be carried by each *Surveyor*. Under the direct control of the SSAC Group, TV pictures of the lunar terrain will be taken from the Moon's surface. Commands generated by the SSAC-TelPAC sub-group, at the direction of the SFOD, are sent to control the TV camera. Utilizing the extensive command capability, the operators control the camera in pan and tilt, in focal length of lens as well as focus, in exposure, and in filter color.

The members of the TSAC sub-group will evaluate the TV pictures as they appear on the monitors in the SSAA and will prepare mosaics of the video frames. They will also make preliminary real-time analysis of the topogra-

phy, geology, and other characteristics of the lunar surface.

#### D. Standard Sequence of Events

The activities of the MOS during space operations follow the SSE unless this is precluded by actual conditions. This series of events comprises the nominal 66-hr transit flight to the Moon and the subsequent surface operations (illustrated in the foldout at the back of this Technical Memorandum).

The *Atlas* booster engine cuts off and is jettisoned shortly after launch. Sometime before the *Atlas* sustainer and vernier engines burn out, commands from





Fig. 43. SPAC activities in SPAA

NOTE:  
TRANSIT TIME SCALE SHOWS, IN HOURS,  
THE INTERVAL BETWEEN THE TIME THE  
SPACECRAFT REACHES 10,000 km ( $10^4$ )  
AND WHEN IT IS AT THE MOON

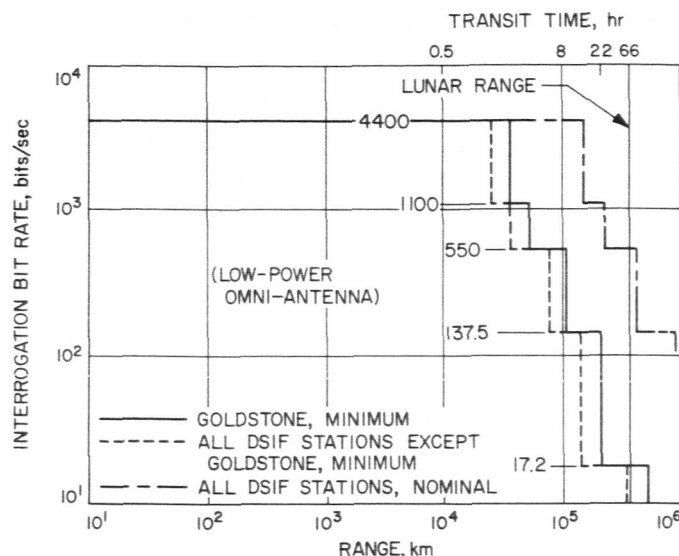


Fig. 44. Telemetry bit rate versus range (low power, omnidirectional antenna)

the *Centaur* programmer will initiate the ejection of the spacecraft shroud. After the *Atlas* sustainer and vernier engines have burned out, the *Centaur* (with the *Surveyor* spacecraft attached) separates from the *Atlas*. Then the *Centaur* engines ignite. At the conclusion of this burn the *Centaur* (with the spacecraft attached) is injected into the transit trajectory. On command from the *Centaur* programmer, the spacecraft landing gear and omnidirectional antenna extend, the spacecraft transmitter switches from low to high power, and the *Surveyor* spacecraft separates from the *Centaur*. This occurs approximately 12 min after liftoff at an altitude of approximately 90 nm for direct ascent trajectories. The *Centaur* telemetry system reports these events to the AFETR ground receivers.

After separation, the SFOD takes over command of the spacecraft (Fig. 45). The ensuing space flight operations are controlled entirely by the MOS personnel in the SFOF and DSIF Stations.

Immediately following the separation event, the solar panel automatically extends to its flight position and the cold gas attitude jets rotate the spacecraft about its roll axis until the Sun comes within the field of view of the Sun sensor. The jets stop the rotation when the spacecraft is aligned with the Sun and stabilize the spacecraft in the pitch and yaw axes. This activity is com-

pleted about the time that the spacecraft comes within view of the Johannesburg Station, DSS 51, which is approximately 12 min after injection.

At DSS 51, in anticipation of the rise of the spacecraft over the local horizon, the antenna is aligned in the predicted direction and scans that area of the sky. To establish the communication link, the DSS must locate the signal from the spacecraft and tune the DSS receiver to lock onto this signal. This condition is known as one-way lock. During this period the spacecraft will be transmitting telemetry data. The DSS begins the two-way lock procedure by tuning its transmitter until the spacecraft receiver locks to the DSS signal, causing the shift in the frequency as explained previously. The reception by the DSS of this change in frequency of the spacecraft signal verifies that two-way lock has been achieved.

Once lock is established between the DSS and the spacecraft, commands (either fill-in or actual) may be sent each 0.5 sec. If more than 0.5 sec passes during which the spacecraft does not receive a command, automatic circuits change the combination of receiver and central command decoder that is handling commands from the DSS. Thus, a failure of either a receiver or a decoder, or even one of each, would not impair the mission.

Once DSS 51 has acquired the spacecraft, the SPAC Group initiates the major command sequence that sets the spacecraft's transmitter to low power, turns off accelerometers and solar panel control circuits, obtains spacecraft system status information by interrogating Commutator Modes 1, 2, 3, and 4, and, finally, leaves the spacecraft transmitting the status information of the cruise phase commutator in the low-power transmitter state. Whenever a DSS is tracking the spacecraft, the DSS relays the telemetry data it received to the PA sub-group of the SPAC Group, and transmits tracking data to the FPAC Group. The DSS also records on magnetic tape all of the spacecraft's transmissions for later analysis at the SFOF.

While the SPAC Group examines incoming telemetry reports and analyzes the spacecraft performance with the aid of computer programs, the FPAC Group determines the spacecraft's flight path. As tracking data arrives, first from Johannesburg and then from the other stations as the mission progresses, the FPAC Group determines, with progressively greater accuracy, the actual trajectory of the spacecraft.



**Fig. 45. Space flight events**

Approximately 6 hr after launch, it is necessary that the spacecraft roll attitude be established. This is accomplished by first rolling the spacecraft at least one revolution to make a star map which will indicate star magnitude versus roll angle. Then, as the spacecraft continues to roll, the command is given for it to lock onto Canopus, a first magnitude star near the south celestial pole. The Canopus sensor, by directing discharges from attitude jets, establishes and maintains the desired roll attitude.

The spacecraft then cruises with its attitude fixed and controlled with respect to the Sun and to Canopus, providing a known, precise three-axis orientation. The transmitter operates at low power in the transponder mode to permit continuous two-way doppler tracking. The telecommunications subsystem transmits engineering data through one of the omnidirectional antennas at a rate commanded from Earth; the rate selected is consistent with the signal-to-noise ratio available at the ground receivers.

With the Sun lock achieved, the solar panel converts solar energy into electrical power. The total electrical

load for a typical mission is greater than the power available from solar energy conversion; therefore, the main battery will not be fully charged at the time of landing.

At intervals during this first cruise phase, the SPAC Group interrogates the spacecraft at 1100 bits/sec in Modes 1, 2, and 4, using the high-power transmitter as required, then returns the spacecraft's transmission to a lower bit rate and low power. The FPAC Group, during this phase, makes a series of orbit determinations to resolve the actual path of the spacecraft. When this is resolved, the FPAC computes the midcourse maneuver adjustment required to place the spacecraft on the desired lunar intercept trajectory (Fig. 46). The SPAC Group, with the FPAC Group, generates the appropriate command message for the maneuver.

The midcourse maneuver sequence begins approximately 15 hr after launch with the DSS 11 transmission of the quantitative roll command to the spacecraft. This time-magnitude command is stored in the spacecraft's flight control programmer and is telemetered back to the DSS

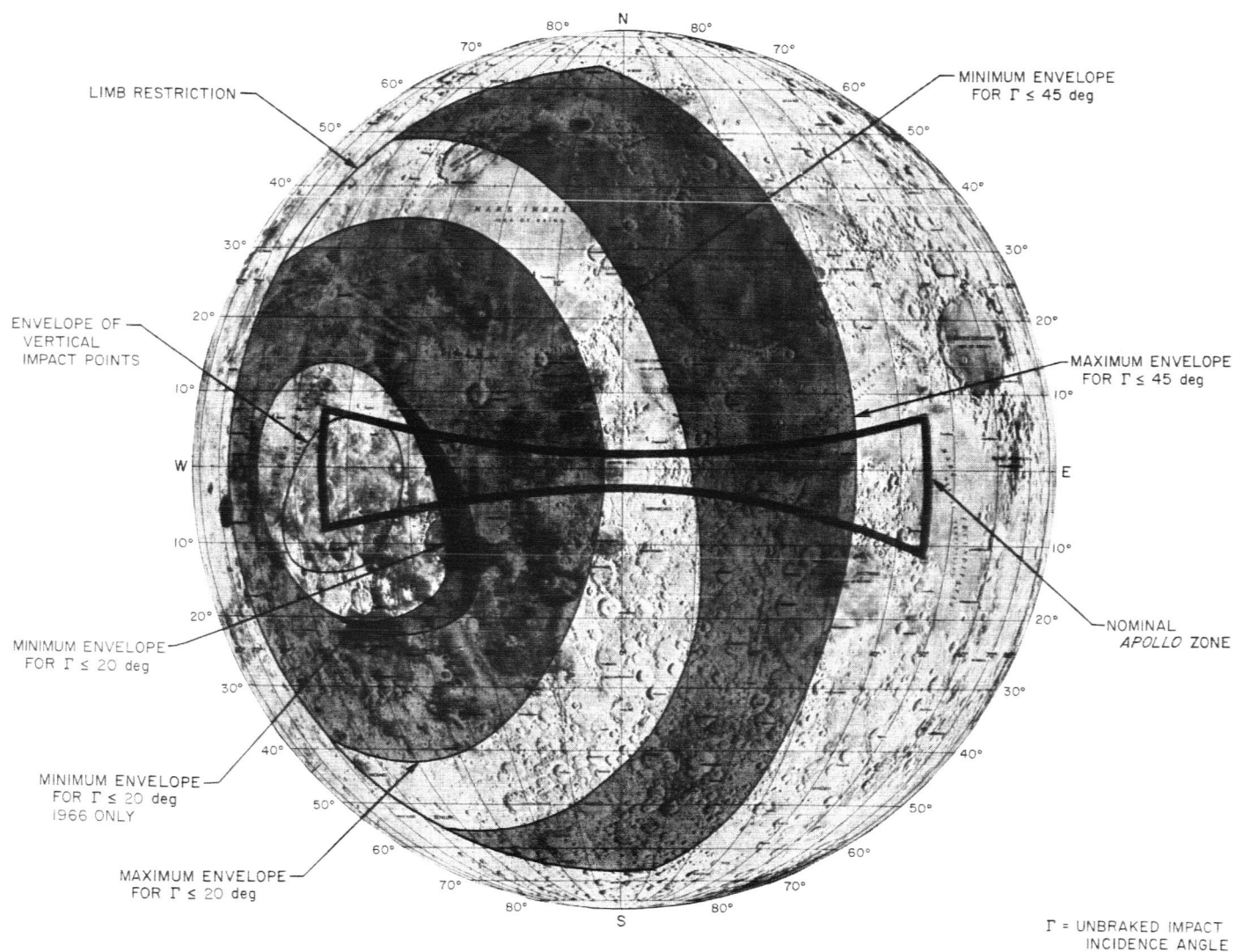


Fig. 46. Lunar landing areas



for verification. Upon verification, the spacecraft is sent the direct command to execute the roll maneuver that initiates the midcourse sequence. Normally, two maneuvers (roll and pitch or roll and yaw) are required to orient the spacecraft before applying thrust with the vernier engine. The second maneuver (pitch or yaw) is performed in a manner similar to the first. These maneuvers must be accomplished one at a time, since the flight control programmer can store only one magnitude command at a time.

Once the spacecraft has been oriented, the necessary velocity correction is made by quantitative and direct commands which cause the spacecraft vernier engines to thrust at a constant acceleration of 0.1 Earth  $g$  for the commanded time. It should be noted that both the magnitude commands and critical direct commands, such as "thrust execute," must be immediately preceded by an interlock command to enable the spacecraft to act upon the command that follows.

When the vernier engines are shut off, the spacecraft is commanded to reacquire the Sun and Canopus, either by performing attitude maneuvers of the same magnitude as those that initiated the midcourse sequence but in the opposite direction, or by acquiring the Sun and Canopus in the same manner as it did during the initial cruise phase.

The spacecraft, on its maneuver adjusted trajectory, enters the second cruise phase which extends to approximately 60 hr after launch. The SPAC Group continues to monitor, evaluate, and control the operation of the various subsystems aboard the spacecraft. The FPAC Group, by performing a number of separate determinations, ascertains the spacecraft's present flight path. Based on the new trajectory, the FPAC Group computes the terminal maneuver required, and the SPAC Group converts this information to a command message. Transmission of this message to the spacecraft starts approximately 27 min before touchdown and results in the spacecraft's changing its cruise phase attitude to its terminal phase posture. This change positions the spacecraft so that its landing gear is facing the Moon and the thrust axis of the main retro engine is aligned with the descent path of the spacecraft.

A retro-sequence time delay is then set into the spacecraft programmer by Earth command about 14.5 min before main retro-ignition (16.5 min before touchdown). When the spacecraft/Moon slant range is approximately 60 mi, the AMR puts a lunar altitude datum

into the programmer approximately 10 sec before main retro-ignition. Then the vernier engines ignite about 1 sec prior to main retro-ignition to permit the vernier engine thrust to stabilize.

Approximately 40 sec after ignition of the main retro engine, during which time the spacecraft is controlled to an inertial reference provided by integrating gyros, burnout occurs and the vernier thrust increases. At main retro engine burnout, the retro engine is automatically ejected. The spacecraft, as would be seen from the Moon at this particular time, is shown in Fig. 47. As the spacecraft approaches and passes the 1000-ft mark, commands sent by the DSS at Goldstone select Commutator Mode 3 and turn on the landing gear strain gage circuits, approximately 13 sec before touchdown, and the scale factor of the RADVS automatically changes to provide a higher degree of sensitivity. When the spacecraft reaches an altitude of 13 ft above the surface of the Moon, the engines automatically cut off and the spacecraft falls free the remaining distance. Touchdown nominally occurs approximately 2 min and 13 sec after the main retro engine is ignited; during this period, the velocity of the spacecraft has been reduced from approximately 9000 ft/sec to approximately 5 ft/sec.

Immediately after the spacecraft has landed, the SPAC Group sends a series of commands to prepare the spacecraft for lunar surface operations. To conserve electrical power, the first commands transmitted from Goldstone turn off the RADVS, the flight control electronics, the engineering cruise phase commutator, and the strain gages; the commands also lock the landing gear and vent the vernier engine system.

Having determined the thermal, power, and positional constraints on the spacecraft's performance, and that it is operating normally, the SPAC Group can now command the spacecraft to transmit at high power using the highest bit rate.

From this point on, the primary user of the spacecraft and its subsystems will be the SSAC Group. The SSAC Group will use the survey TV camera to take one or more pictures of the area surrounding one of the landing gear pads using the 200-line mode and an omni-antenna. This first sequence of TV pictures should be completed some 25 min after touchdown. Then the SPAC Group conducts the first post-landing engineering assessment. The cruise phase commutator is commanded on, the bit rate changed to 1100 bits/sec, and the spacecraft is exercised through a series of commands. This completes the SSE for Mission A, at a nominal 40 min after touchdown.



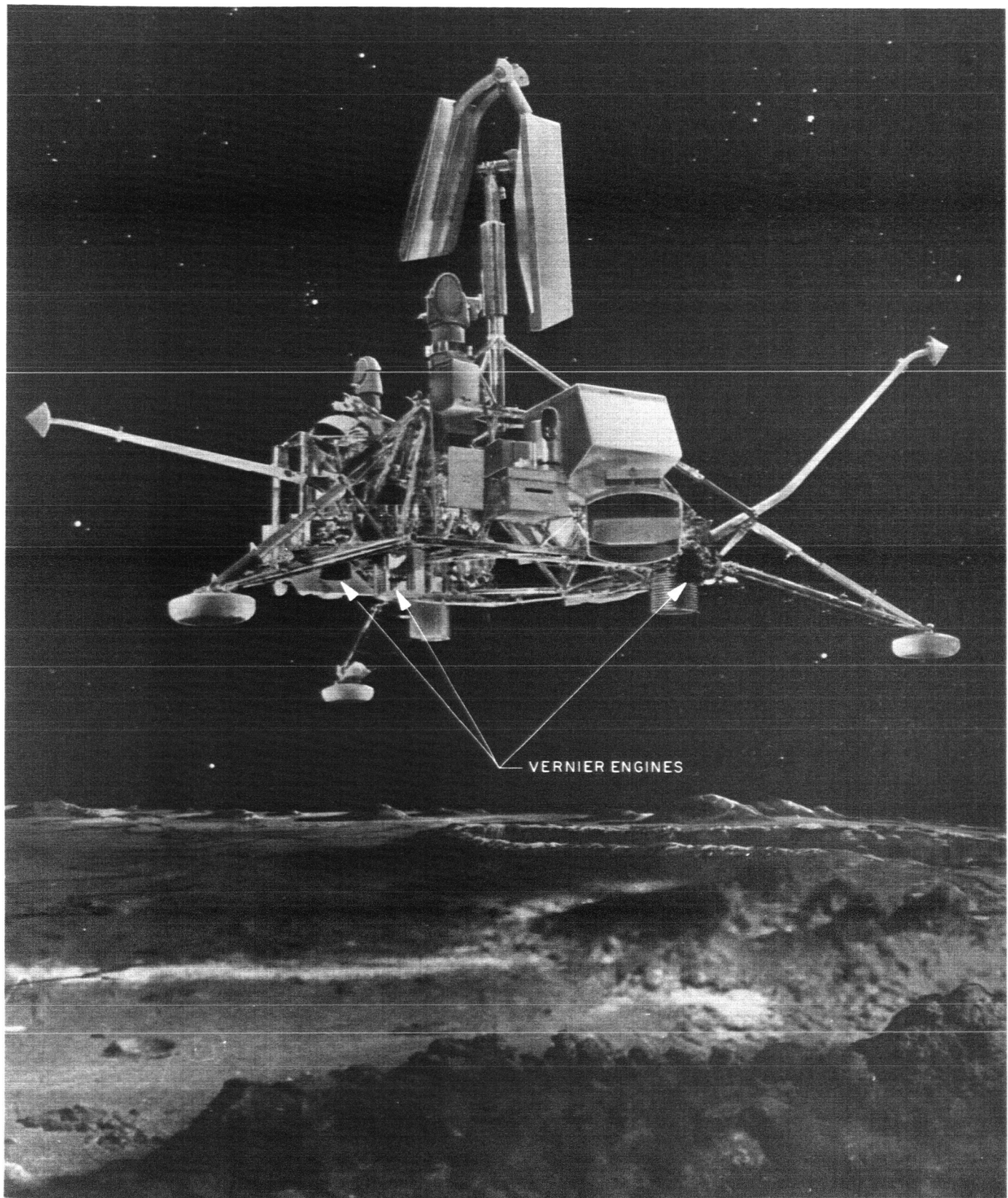


Fig. 47. Surveyor, as seen from the Moon during final descent phase

At this point a series of optional sequences will be considered, and selection will be made in real time based upon the condition of the spacecraft after landing. The number of optional sequences, and the extent of the MOS capability to execute them, will be increased for each succeeding mission starting with 16 optional sequences for Mission A, all of which will have been carefully designed and analyzed, and most of which will have been exercised to at least a limited extent.

Using the TV Command Generation Computer Program, the SSAC Group can control the TV camera on the Moon from their area of the SFOF. The program will interpret mnemonic abbreviations of English language commands, converting them to a form suitable to operate the camera. In this way the SSAC Group can control the azimuth and elevation at which pictures are taken, the focus, exposure, and filter used, and other variables. When the spacecraft is in view of the Goldstone DSS, each picture, accompanied by its frame identifying information, may be shown on the CCTV monitors in the SFOF in virtually real time. Polaroid prints are available in less than 0.5 min, as well as quick-look pictures for mosaic presentations; multiple prints of any TV frame are available in about 30 min.

Under the power and temperature constraints managed by the SPAC Group, the MOS team will operate

the survey TV camera as long as the spacecraft systems and lighting conditions permit.

### **E. Post-Mission Operations**

When the spacecraft has completed its mission on the Moon, the functions of the MOS, it would seem, would also be concluded. This is the case insofar as the immediate mission; however, the second major phase of MOS work is just ready to begin. During the approximately 3 days of space flight and the several days of lunar surface operations, all telemetry reaching the DSIF Stations, all commands sent, all nonstandard operations that were necessary (in short, every detail of the mission) were recorded on magnetic tape or film. These records are shipped to the SFOF to serve as the basis for the thorough post-mission analysis of the flight. During the weeks following the mission, these data records are carefully reviewed by the MOS teams. By analyzing the significant events of the mission, the decisions made and their effects, the mission experience gained can be applied to the next *Surveyor* space flight and lunar surface operations. This empirical knowledge is used to optimize succeeding *Surveyor* missions toward achieving the broad goals of the *Surveyor* Project—advancing the frontiers of man's knowledge of his nearest celestial neighbor, while preparing the way for manned landings on the Moon.

## ABBREVIATIONS

The following abbreviations are used throughout this Technical Memorandum and are included for reference.

|           |                                                              |        |                                                                   |
|-----------|--------------------------------------------------------------|--------|-------------------------------------------------------------------|
| AFETR     | Air Force Eastern Test Range                                 | DSS 62 | Madrid DSIF Station                                               |
| AGC       | Automatic Gain Control                                       | DSS 72 | Ascension Island Station                                          |
| AGCM      | AGC Calibration (Computer Program Mnemonic)                  | ECPO   | Engineering Computer Program Operations (Sub-group of SPAC Group) |
| AMR       | Altitude Marking Radar                                       | EDRS   | Engineering Data Reduction (Computer Program Mnemonic)            |
| ASFOD     | Assistant Space Flight Operations Director                   | EPD    | Engineering Planning Document                                     |
| CCTV      | Closed-Circuit Television                                    | EPMS   | Engineering Programs Submonitor (Computer Program Mnemonic)       |
| CDC       | Command and Data Handling Console                            | FM     | Frequency-Modulated                                               |
| CP        | Command Preparation (Sub-Group of SPAC Group)                | FPAA   | Flight Path Analysis Area                                         |
| CPPM      | Telecommunications (Computer Program Mnemonic)               | FPAC   | Flight Path Analysis and Command Group                            |
| CS        | Computing Support (Sub-Group of FPAC Group)                  | GCS    | Ground Communication System                                       |
| CVT, CVTS | Command Verify/Transmit (Computer Program Mnemonic)          | GSFC   | Goddard Space Flight Center                                       |
| DAPFS     | Booster Model (Computer Program Mnemonic; Same as DPES)      | HPPS   | <i>Surveyor</i> Trajectory Processor (Computer Program Mnemonic)  |
| DDP-24    | Model Designation of a Computer Control Co. digital computer | HSDL   | High-Speed Data Line                                              |
| DOP       | Detailed Operating Procedures                                | I/O    | Input/Output                                                      |
| DPCA      | Data Processing Control Area                                 | IBM    | International Business Machines                                   |
| DPES      | Booster Model (Computer Program Mnemonic; Same as DAPFS)     | MAC    | Maneuver Analysis and Command (Computer Program Mnemonic)         |
| DPPE      | Data Processing Project Engineer                             | MAG    | Maneuver analysis group (Sub-group of FPAC Group)                 |
| DPS       | Data Processing System                                       | MCD    | Mission Control Directive                                         |
| DRS       | Data Recovery Subsystem                                      | MCR    | Mission Control Room                                              |
| DSIF      | Deep Space Instrumentation Facility                          | MCSS   | Media Conversion Subsystem of the SCTV-GDHS                       |
| DSN       | Deep Space Network                                           | MOS    | Mission Operations System                                         |
| DSS       | Deep Space Station                                           | MSB    | Mission Status Board                                              |
| DSS 11    | Goldstone Pioneer DSIF Station                               | MTGS   | Midcourse Maneuver Analysis (Computer Program Mnemonic)           |
| DSS 42    | Tidbinbilla DSIF Station                                     | NASA   | National Aeronautics and Space Administration                     |
| DSS 51    | Johannesburg DSIF Station                                    | NASCOM | NASA World-Wide Communication Network                             |
|           |                                                              | NSP    | Nonstandard Procedure                                             |

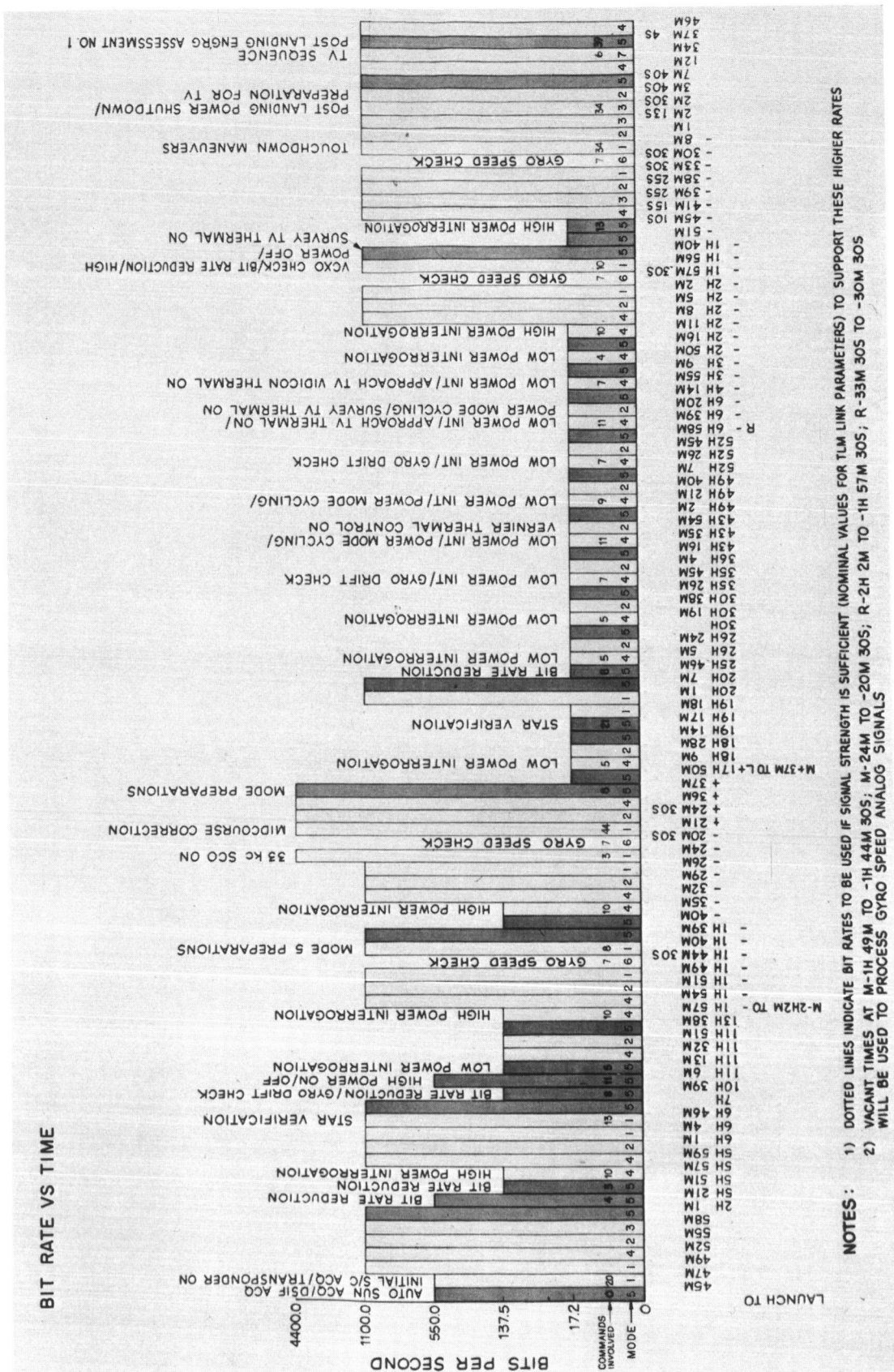
## ABBREVIATIONS (Cont'd)

|           |                                                                     |           |                                                                       |
|-----------|---------------------------------------------------------------------|-----------|-----------------------------------------------------------------------|
| OD        | Orbit Determination                                                 | SFOP      | Space Flight Operations Plan                                          |
| ODG       | Orbit Determination Group (Sub-group of FPAC Group)                 | SFOS      | Space Flight Operations System                                        |
| ODG, ODGX | Orbit Data Generator (Computer Program Mnemonic)                    | SOC       | <i>Surveyor</i> Operations Chief                                      |
| ODP, ODPX | Utility Orbit Determination (Computer Program Mnemonic)             | SOCP      | <i>Surveyor</i> On-Site Computer Program (Computer Program Mnemonic)  |
| OPM       | Operating Procedures Manual                                         | SOP       | Standard Operating Procedure                                          |
| OSDP      | On-Site Data Processor                                              | SPAA      | Spacecraft Performance Analysis Area                                  |
| OSFR      | On-Site Film Recording                                              | SPAC      | Spacecraft Performance Analysis and Command Group                     |
| OVCS      | Operational Voice Communication System                              | SSAA      | Space Science Analysis Area                                           |
| PCM       | Pulse-Code-Modulated                                                | SSAC      | Space Science Analysis and Command Group                              |
| PA        | Performance Analysis (Sub-group of SPAC Group)                      | SSE       | Standard Sequence of Events                                           |
| PD        | Project Document                                                    | T&DA      | Tracking and Data Acquisition                                         |
| PDP-1     | Model Designation of Digital Equipment Corporation Digital Computer | TDA       | Tracking Data Analysis (Sub-group of SPAC Group)                      |
| PDP-4     | Model Designation of Digital Equipment Corporation Digital Computer | TDAS      | Tracking and Data Acquisition System                                  |
| PE        | Project Engineer                                                    | TDP, TDPX | Tracking Data Processor (Computer Program Mnemonic)                   |
| PLAS      | Post-Landing Attitude Determination (Computer Program Mnemonic)     | TelPAC    | Television Performance Analysis and Command (Sub-group of SSAC Group) |
| PM        | Phase-Modulated                                                     | THM       | Thermal Management (Computer Program Mnemonic)                        |
| PWR       | Power Management (Computer Program Mnemonic)                        | TIM       | Tracking Instruction Manual                                           |
| RADVS     | Radar Altimeter and Doppler Velocity Sensor                         | TIRS      | TV ID Response Monitor (Computer Program Mnemonic)                    |
| SCAT      | Spacecraft Analysis Team (Sub-group of SPAC Group)                  | TPG       | Trajectory Prediction Group (Sub-group of FPAC Group)                 |
| SCP       | <i>Surveyor</i> Command Preparation (Computer Program Mnemonic)     | TPS       | Telemetry Processing Station (Also a Computer Program Mnemonic)       |
| SCTV-GDHS | Spacecraft Television Ground Data Handling System                   | TRJX      | Trajectory (Computer Program Mnemonic)                                |
| SFO       | Space Flight Operations                                             | TRW       | Tape Read/Write (Computer Program Mnemonic)                           |
| SFOD      | Space Flight Operations Director                                    | TSAC      | Television Science Analysis and Command (Sub-group of SSAC Group)     |
| SFOF      | Space Flight Operations Facility                                    |           |                                                                       |

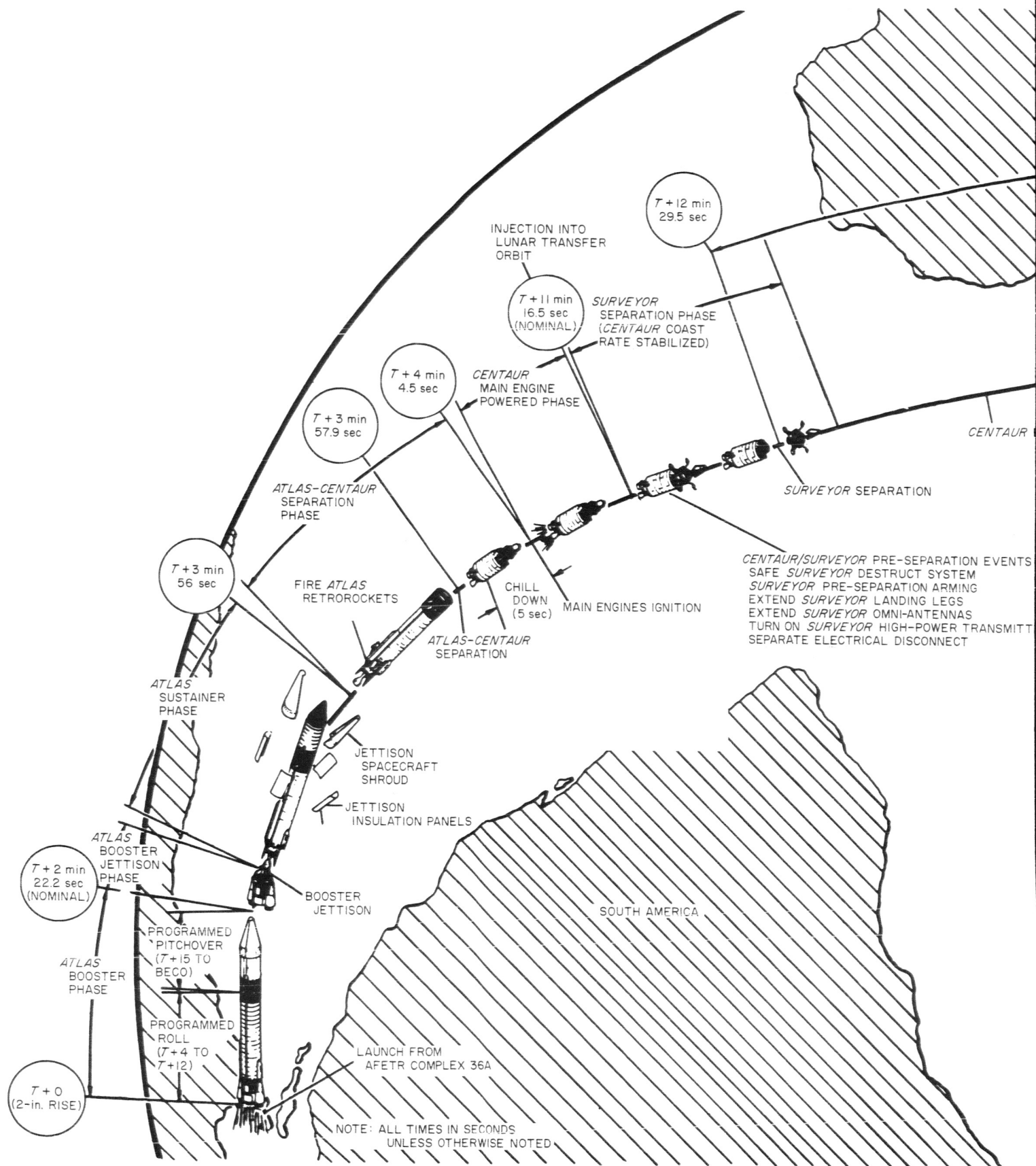
## ABBREVIATIONS (Cont'd)

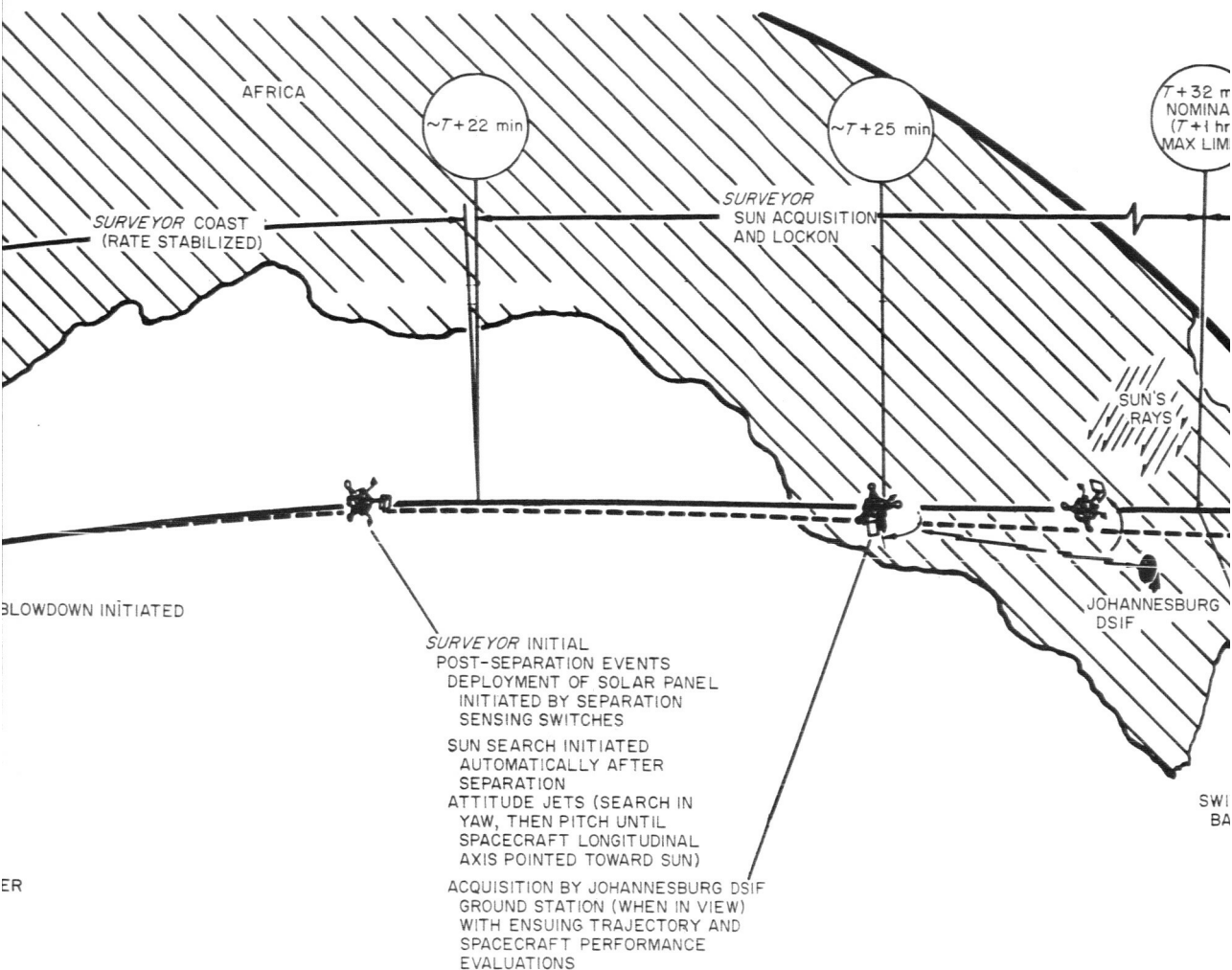
|      |                                                   |      |                                                                          |
|------|---------------------------------------------------|------|--------------------------------------------------------------------------|
| TTY  | Teletype                                          | VHF  | Very High Frequency                                                      |
| TV   | Television                                        | 7044 | Model Designation of an International Business Machines Digital Computer |
| TVCS | TV Command Generation (Computer Program Mnemonic) | 7094 | Model Designation of an International Business Machines Digital Computer |



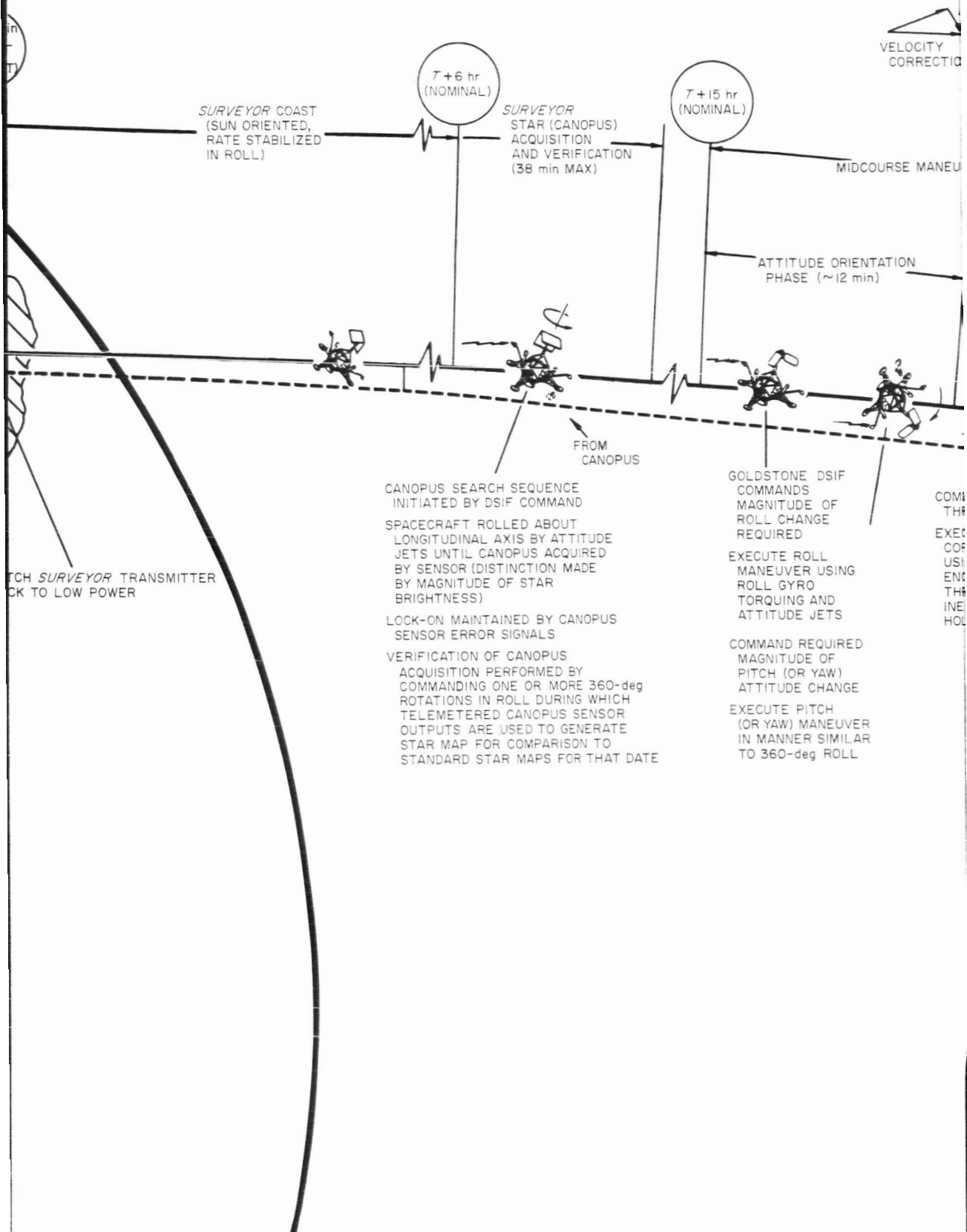


Surveyor Mission A Flight Profile

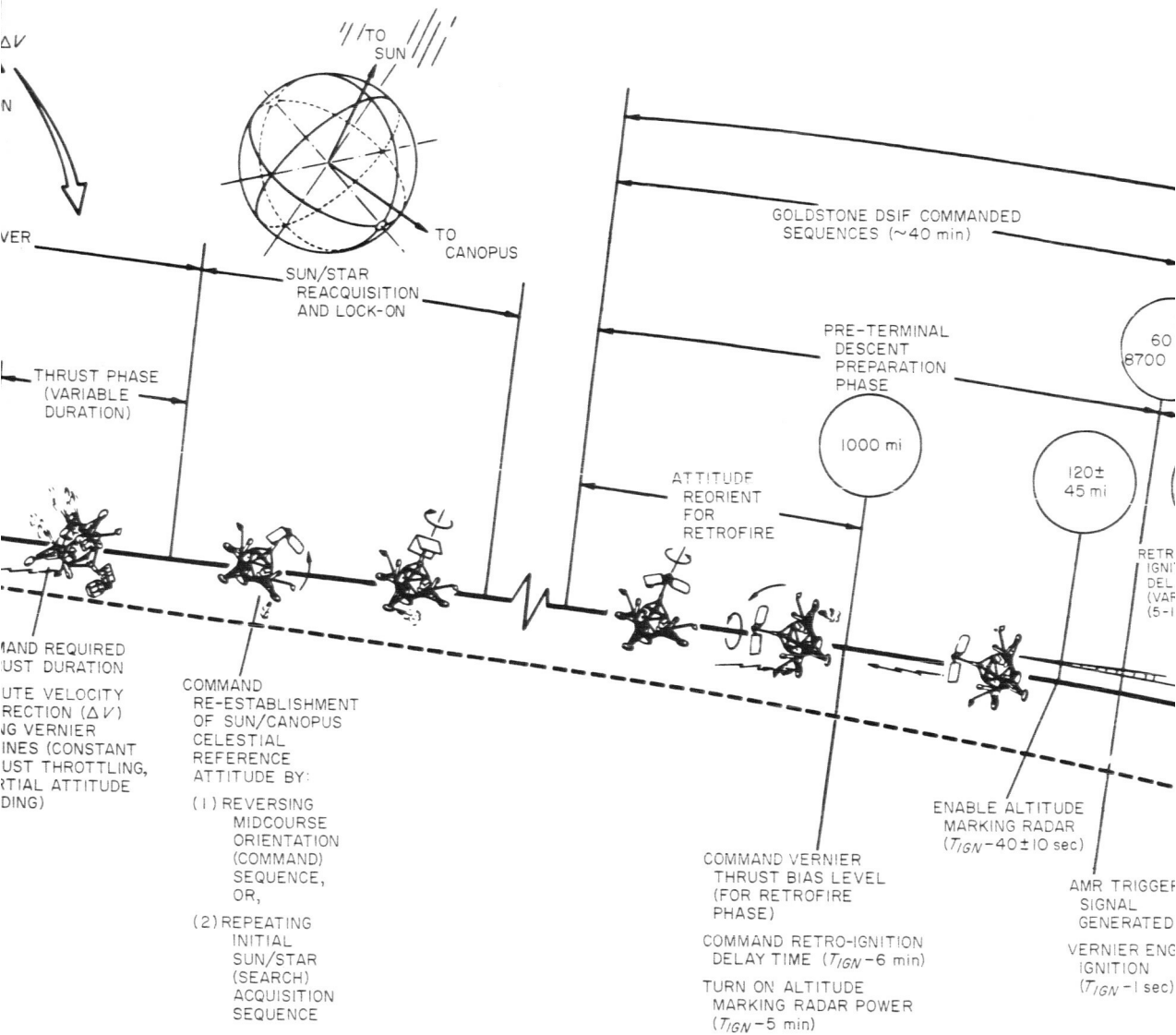




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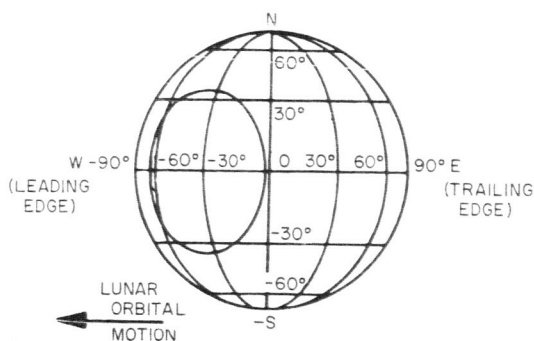
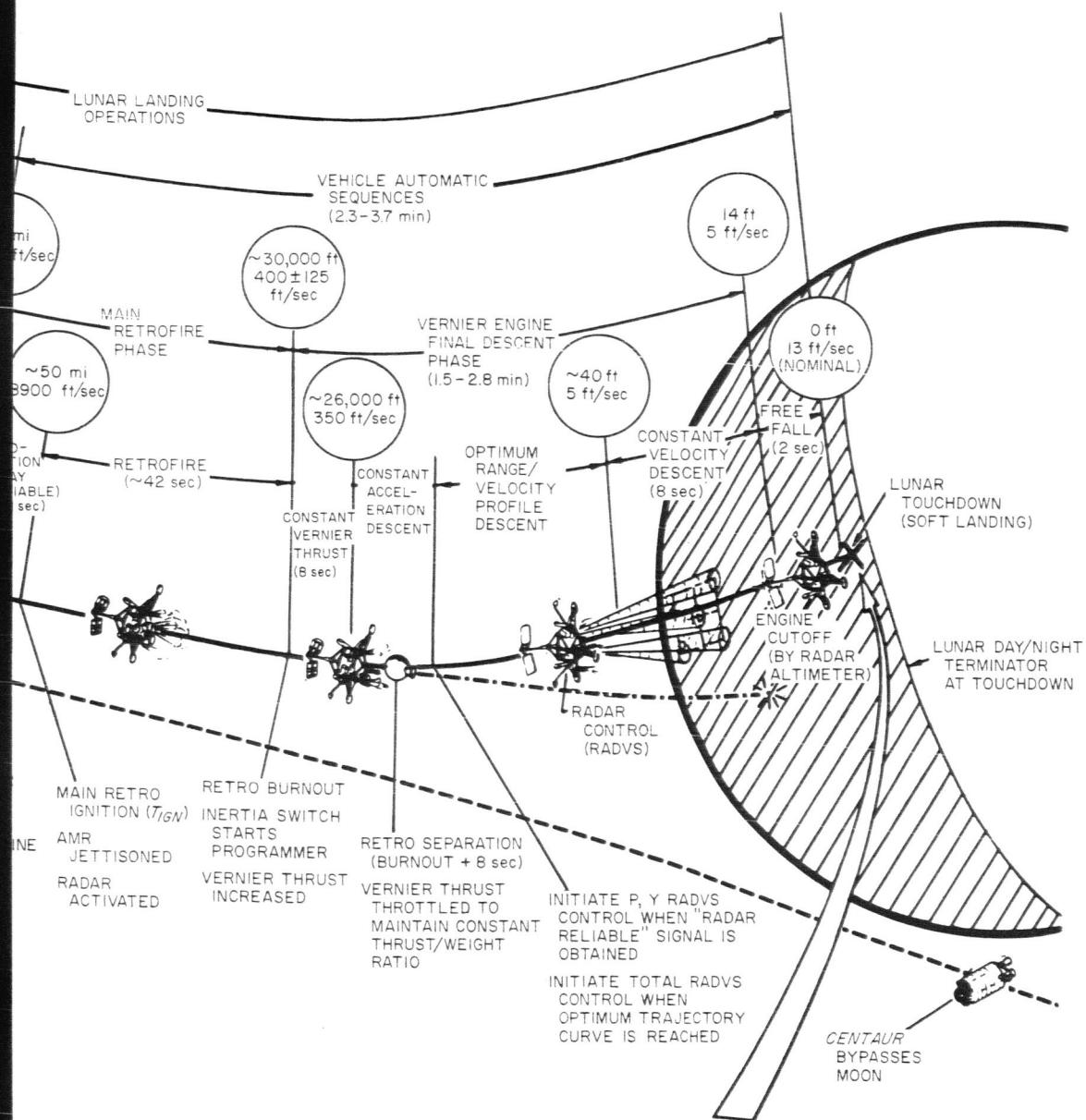


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*SURVEYOR* LUNAR LANDING ENVELOPE