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ABSTRACT

"Tracking, Telemetry, Command, Control and Data Acquisition of NASA Flight Programs"

NASA's space programs ground support requirements have grown from simple, single radio link tracking and telemetry missions of brief experimental requirements to lengthy, multiple link spacecraft control and data acquisition problems requiring real-time data acquisition control and processing.

Present-day spacecraft require specialized multiple command and control operations at extremes of range and bandwidth. The entire complex of global ground stations are coupled with a central experiment control point so that an "observatory in space" is contacted, oriented, maintained and exercised on an immediate and direct basis. Utilizing high speed data and voice communications, the experimenters are brought into direct and immediate contact with their scientific sensors, extending the space laboratory to encompass the earth-bound scientist in the environment he explores.

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"Tracking, Command, Control and Data Acquisition of NASA Flight Programs"

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During the six years since 1958, NASA's flight program requirements for ground support have increased in amazing proportions. The Tracking & Data Acquisition support required for Vanguard I was CW tracking on a single frequency beacon coupled with relatively accurate frequency measurements of the same beacon to measure space temperatures. No command capability or special telemetry reception was required.

Today NASA's programs require a system of three world-wide tracking and data acquisition networks. The Manned Space Flight Network, specifically instrumented for manned spacecraft support, began with the highly successful "Mercury" Program and will soon support the Gemini and Apollo Projects.

A second, the "Deep Space" Network, is especially located and equipped for lunar and planetary exploration by spacecraft projects such as Mariner, Ranger and Voyager.

The third network called the "Space Tracking & Data Acquisition Network" or STADAN, is the oldest operating U. S. network and the only network which is required to handle multiple spacecraft missions simultaneously. Both the Manned

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Space Flight Network and the Deep Space Network are designed to handle a single spacecraft mission at any given time.

This "work horse" network, the STADAN, is required to support multiple scientific spacecraft and probes in orbit around the earth extending out as far as the moon.

This multiple purpose network, supporting 25 different spacecraft in orbit at the end of December, 1964, will be the example for discussion in this presentation.

Tracking

Historically, the first functional system to be constructed for satellite tracking was the Minitrack system. This system was transferred to NASA at the time NASA was established and formed one of the basic building blocks of the present NASA Space Tracking & Data Acquisition Network. Minitrack uses radio interferometers which measure two of the three direction cosines of a line from the system center to a transmitting satellite, as a function of time, while the satellite passes through the beam pattern of the receiving antennas. The reference lines for these measurements are orthogonal in the plane of the ground antennas. The third direction cosine is thus implicitly defined, and the angular position of the satellite is determined. From a series of independent angle measurements made at various ground stations, satellite orbits can be determined to a great accuracy by computer methods.

Minitrack performs its angular position measurements by phase comparison techniques to measure the difference in arrival time of the wavefront from a satellite source at each antenna of a pair of antennas separated by known distances in wavelengths. Measurement of this radio path difference is accomplished by a comparison of the phase angle of the signal received at one antenna to that received at another. Antenna pairs are aligned along east-west and north-south baselines to form a convenient coordinate system.

Since the accuracy of the measurement of the angles increases as the length of the baseline between the antennas increases, two pairs of antennas are aligned along orthogonal baselines many wavelengths long to obtain good angular resolution. As a radio source travels through the antenna pattern, the relative phase will cycle from zero to 360 electrical degrees for each wavelength added to the radio path difference. Because the phase meters repeat their readings every wavelength, a number of different space angles produce identical phase readings during a satellite transit. This ambiguity is resolved by employing several progressively shorter baselines which produce fewer integral numbers of wavelength changes while the satellite moves through the antenna beam.

While the Minitrack system functions extremely well with conventional earth satellite orbits, spacecraft with highly eccentric orbits do not lend themselves well to tracking by an angle-measuring system. An eccentric orbit can mean an orbital period of many hours, and such relatively slow angular motion at or near apogee, as to exceed the precision of the basic angular measurements by radio interferometers. Satellite orbital parameters must be determined as rapidly as possible in order to extract maximum usuable data from the spacecraft. Range and range rate systems can provide more direct and meaningful measurements than space angle measurements when working with highly elliptical orbits. Accordingly, a range and range rate measurement system has been developed and is operational. The range and range rate system functions as a high precision spacecraft tracking system capable of accurately determining the range and radial velocity of a spacecraft from near earth orbits out to cislunar distances.

The range of spacecraft can be determined by measuring the travel time of an electromagnetic wave. Knowledge of the propagation velocity gives the distance. This can be accomplished either by using a pulse as in the radar principle, or by measuring the phase of the electromagnetic wave traveling from a transmitter to the spacecraft and back to the ground station receiver by means of a ranging transponder in the spacecraft. The latter principle is applied here and is known as sidetone ranging. A carrier is modulated with several mathematically related frequencies, and measuring the phase of these related frequencies after transmission to the spacecraft and return enables the determination of range. This in essence is a time measurement.

Since the carrier is a CW signal, its Doppler shift can be measured very accurately, particularly at frequencies above one gigacycle where the effects of the ionosphere are small. Since the Doppler shift is proportional to the range rate, the range rate can likewise be measured with great precision, provided that the short term stability of the ground based oscillator, during the travel time of the transmission from to spacecraft and return is very good.

Because this system involves no angular measurements, tracking errors at great distances are minimized. Furthermore, the use of a coherent CW system offers another twofold advantage over a pulse system. Extremely narrowband techniques are permissible which make for improved signal-to-noise conditions and greatly reduced power requirements.

Each range and range rate station employs two distinct systems: an S-band system and a VHF system. For use with the S-band system, a three-channel ranging transponder is installed in the spacecraft. This permits tracking computations from data supplied by a single ranging station, or computations from data supplied simultaneously by a complex of two or three stations. The VHF system is used primarily for acquisition, but is also used for ranging when the spacecraft cannot carry the S-band, three-channel transponder. In this case, a VHF transponder is used which functions as a command receiver, telemetry transmitter, and a single-channel ranging transponder.

Thus the tracking configuration may be either that of a single range and range rate station operating independently, or a complex of up to three stations operating simultaneously.

Each ranging station can measure spacecraft range with a resolution of ±15 meters, and range rate with a resolution of 0.1 meter per second.

At those stations equipped with a Minitrack phase interferometer system, the equatorially-mounted astrographic camera, used for periodic aircraft calibration of the interferometer system, has been adapted for optical tracking of earth satellites. The camera has an ultra-linear f/5.0, 40-inch focal length lens, and uses 8 x 10 inch spectroscopic plates, affording an ultimate star resolution accuracy of better than one second of arc over an 11 x 44 degree field of view. The camera is driven at a sidereal rate, thus permitting stars as faint as eleventh magnitude to be photographed. A serial time code developed from the station's time standard is used to actuate a solenoid which moves a plunger to displace the film plate within its holder. The satellite photographs as a trail of light against a star background interrupted by breaks corresponding to time code pulses. The photographic plates are compared to star charts, and preliminary reductions are made at the tracking stations. Whenever possible, photographs are taken while the satellite is in the main antenna beam of the Minitrack interferometer system, and the corresponding radio records are mailed to Goddard along with the photographic plates for correlation of radio and optical tracking data. This tracking system has proven extremely successful with the Echo satellites, achieving accuracies within a few seconds of arc.

Optical tracking is used for only a very small percentage of tracking information. The major optical tracking for NASA flight programs is accomplished by the Smithsonion Astrophysical Observatory's Optical Network using the specially designed "Baker-Nunn" Camera System.

Command

Command interrogation requirements for present and future spacecraft are both varied and complex. Simple "playback" or "turn-on" command requirements have been replaced with multiple command, address-execute and command verification sequences exercising a variety of spacecraft sensors. Such detailed programs often require computer programming of command sequences, either in advance of actual spacecraft contact, or in real-time activity during spacecraft contact and data acquisition.

Ground support transmitters, operating at discrete frequencies in the area from 120 to 155 Mcs, are located throughout the world-wide network of ground stations. Transmitters capable of outputs of 200 watts, 3 kilowatts and 5 kilowatts are presently in use and installation of variable outputs transmitters capable of delivering 250 watts to 2.5 kilowatts is planned in the very near future.

In the past, systems used for transmitting commands to satellites have utilized elementary tone-actuated devices. These have been used to relay one or two simple switching commands and have been adequate for the purpose. However, current and future satellites require more complex interrogations, necessitating multiple tones. Reasonable separation of the audio frequencies is mandatory, thereby placing a limit upon the number of frequencies available within the command band.

In anticipation of an eventual saturation point, a more versatile type of digital coding was devised.

These digital encoders are capable of working at a postdetection signal-to noise ratio of 1 to 1. This, in itself, is a great advantage over the tone system which requires a 20- to 30-db signal-to-noise ratio.

The system may be operated in any one of three modes: manual tone command selection, manual digital command selection, and automatic tape reader control for either tone or digital command sequences.

The tone encoder generates 30 tone bursts between 1,025 and 11,024 cycles. The digital encoder produces a total of 90 separate digital commands. The

Commands are PCM coded and are used to either modulate the transmitter carrier to produce the PCM/AM/AM mode, or to key the transmitter "on" during pulses and key it "off" between pulses to produce the PCM/AM mode.

Even more advanced digital command encoders are being used for the "Observatory" class of spacecraft. Command sequences require transmitting an "address" command to reach the correct experiment area in the spacecraft, followed by a "function" command which will activate the correct experimental unit or device. In some cases, the "address" and "function" commands are received by the spacecraft, and held until verified at the ground station by a transmission from the spacecraft before a final "execute" command is transmitted to initiate the desired experimental activity. Many such sequences of command programming are executed in less than milliseconds during "contact" periods that may extend to many hours for one spacecraft assignment at a single ground station.

The major command antenna system utilizes an antenna array coupled to an X-Y mounted, hydraulically driven pedestal. The antenna drive system can be slaved to a separate acquisition antenna, or driven by a tape programmer console.

The broadband,, high power command antenna consists of an array of nine disk-on-rod structures each composed of 14 disks above a crossed-dipole driver. These arrays are capable of transmitting 5 kilowatts of average power and of operating over the frequency band from 120 to 155 megacycles.

Other command antennas use a single disk on rod type element mounted on the edge of a large parabolic data acquisition antenna or multiple element yagi arrays on electric motor-driven mounts.

Data Acquisition

Operational data acquisition for present and future spacecraft necessitates earlier and more reliable acquisition of telemetry signals, coupled with automatic aiming capability to maintain accurate contact during long periods of experimental data retrieval. To meet this need, Automatic Tracking Antennas have been implemented to provide the network stations with telemetry antennas capable of fast, accurate positioning and full sky coverage, over a variety of spacecraft telemetry bands.

One basic telemetry array consists of four quadrants of Yagis, each quadrant composed of four Yagis, individually consisting of five parasitic elements above a driven element. The Yagi spacing in each quadrant is one wavelength, and the quadrants are spaced two wavelengths on centers. The pedestal is a hydraulically-driven X-Y mount. The antenna is designed for operation on a center frequency of 136.5 Mcs, for use over the 136 - 137 Mc band.

Three servo operational modes are possible: automatic, manual and slave. Separate autotrack and telemetry-data receivers are employed. Flexible selection of antenna polarization and receiver frequency is also provided. The autotrack receivers provide control voltages to the servo-system. An angular error between the antenna pointing direction and the satellite line-of-sight results in a phase difference in the RF signals received by antennas of the array; this phase difference is converted to error voltages which serve to correct the antenna position, and maintain automatic aiming on the orbit path.

This general purpose telemetry antenna, used for 136 Mc telemetry support has a gain of 22.5 db and covers the entire sky hemisphere above 7 degrees from the horizon.

Some satellites already launched by the National Aeronautics & Space Administration, and many satellites to be launched in the near future, use very wide bandwidths for transmission of data to the ground stations. Since the receiver noise and sky noise in the telemetry link is proportional to the bandwidth used for reception, either a very high transmitter power in the satellite or a very high antenna gain on the ground must be used for a wideband telemetry link to achieve good signal-to-noise ratios. The satellite transmitter powers are somewhat restricted due to payload weight constraints and consequently, it is necessary to use very high-gain antennas at the ground station for reception of wideband telemetry signals. These satellites will use several of the frequency bands assigned for space use. Therefore, the high-gain antenna must have the capability of operating at several frequencies. The antennas that best satisfy these requirements of high-gain and multiple frequency operation are parabolic antennas of 40 or 85 feet in diameter. The high-gain parabolic antennas are required for reception from such diverse satellites as the polar orbiting Nimbus series, the low-inclination, low eccentricity Orbiting Astronomical Observatories (OAO), and the highly eccentric Geophysical Observatories (EGO).

The 40-foot diameter parabolic antennas installed in the network have a focal length of 16 feet. The surface consists of double-curved aluminum sheet panels, separated from the reflector structure so that the antenna panels can be adjusted independently. The rms deviation from the least square, best fit paraboloid does not exceed 1/32 inch. The aluminum surface of the reflector is painted with a special white paint to scatter solar radiation.

The antenna is X-Y mounted. It is capable of tracking at rates from 0.005 degrees to 5 degrees per second, and can be accelerated up to 5 degrees per second squared as required. Pointing accuracy is ±60 seconds of arc. The antenna has five operational modes: automatic tracking, programmed drive, slaved to an acquisition antenna, and various scan modes for initial acquisition.

The antenna feed is supported above the reflector above a quadripod. The feed system for automatic tracking is a cluster of two monopulse systems on 136 and 400 Mcs.

The largest data acquisition antenna in this network is an 85-foot diameter paraboloid of revolution with a focal length of 36 feet. The surface consists of double-curved aluminum sheet panels, or parabolic sections of honey-combed aluminum construction. This surface is also separated from the reflector structure so that it can be independently adjusted. Experience with two antennas of this type indicated that the antenna surface can be more accurately adjusted and will maintain a tolerance of less than 1/16 inch deviation from the least square determined, best fit paraboloid. The aluminum surface of the reflector is also painted with a special flat white paint for scattering of solar radiation.

The antenna reflector is mounted on an X-Y type mount designed specifically for tracking satellites. An X-Y mount has two transverse roll axes. The advantage of this type mount for tracking satellites is that there are no gimbal-lock positions in the sky area above the horizon. This allows optimum tracking of satellites without requiring excessive shaft velocities from the antenna drive system.

The antenna is capable of tracking at rates from zero to 3 degrees per second, with accelerations up to 5 degrees per second per second. The pointing accuracy is ±40 seconds of arc. The antenna has five operational modes. It will automatically track on a satellite signal, it can be driven by a teletype drive tape input, can be manually operated, slaved to an acquisition antenna, or operated in various search modes for initial acquisition.

The antenna data system provides for the measurement, digital encoding and readout of the antenna shaft angles for feeding into the servo system, and are also readout by teletype punch for transmission to the computing center. These position and data quality codes are punched onto five-level paper tape in teletype code once each ten seconds. The console displays and the servo system receive these data once per second. The resolution of the digital encoder is 0.002 degree and the rms accuracy is 20 seconds of arc. The data system includes a small computer and associated electronics which accept antenna drive tape predictions (received via teletype), and generates one-second predictions by interpolation. The data system then compares the one-second predictions to the actual antenna position and generates a velocity error signal for operation of the servo system while in the program mode.

The antenna feed system has been equipped to provide autotrack capability in 136, 400 and 1700 Mc bands. This feed system is a cluster of three feed systems for monopulse operation to provide automatic tracking. The feeds operate in autotrack mode in any of four polarizations: two orthogonal polarizations are provided, either linear or circular. For 136 and 400 Mcs, the operator at the control console can select the polarization desired by positioning a switch on the console. For 1700 megacycle operation the desired polarization is manually selectable by component substitution in the antenna feed network. Standard monopulse circuitry with coaxial hybrids is used for obtaining the sum channel and tracking channel outputs from the array of four polarization diversity elements.

The support for the antenna feed system on the reflector surface is a quadripod. The head of the quadripod is a hollow structural square cylinder designed to hold an integral feed and receiver box. The receiver box is four feet square and six feet long. The 400 Mc and the 1700 Mc feeds are mounted on the reflector end of the receiver box. This box slides into the support cylinder on the quadripod from the outside of the structure. The box is positioned by alignment mechanisms so that the receiver box and antenna feed can be easily removed for servicing and then returned to precisely the same position. This provision eliminates the necessity for alignment and boresight adjustments after a replacement of the receiver package. The 136 Mc feed system is mounted on the actual quadripod legs due to the larger size of the antenna elements at this frequency.

Telemetry Link Concept

The massive quantities of telemetry data transmitted from today's multiple experiment spacecraft, coupled with numerous spacecraft in orbit at any one time, require extremely flexible, and widely versatile telemetry links in the ground network. A basic telemetry link requires a suitable antenna system; a signal detection, and amplification telemetry receiver system; data conditioning and data handling equipment; plus a data recording system. Each ground station does not contain a single telemetry system but is equipped with two, three or even four basic telemetry links. Additionally, the components of a telemetry link are not constantly connected to a particular data acquisition configuration, but all telemetry link equipment is available to be electrically switched or coupled into any arrangement of antenna, receiver, data handling and recording complex required. Telemetry link switching and configuring consoles are "preprogrammed" by plug-in boards which indicate, by illuminated displays, the particular telemetry link configuration needed for a specific spacecraft in orbit. The required equipments are then switched into the specific telemetry link that matches the support requirement. In this manner, the maximum capability for spacecraft data acquisition is maintained throughout the network. Redundant component equipments are included to guarantee uninterrupted data flow and to allow suitable maintenance servicing without depreciating over-all data acquisition capability.

Available for use with any of the previously described antenna systems are the following basic components needed to complete a variety of telemetry links:

Telemetry Receivers

The Minitrack Mod I telemetry receiver system is tunable over a frequency range of 136 to 137 Mcs in 1 kilocycle steps. It was designed and constructed to provide maximum accessibility and flexibility of operation. Each receiver is backed up by a second identical receiving system.

The Mod I telemetry receiver is a triple conversion, vacuum tube, receiver with IF outputs brought out after each conversion stage. The second and third IF stages each provide two selectable bandwidths, making a total of five predetection bandwidths from 10 kilocycles to one Mc to permit suitable bandwidths matching the sideband construction of various telemetry signals.

Both vertical and horizontal polarization outputs from the data acquisition antenna are fed into a low-noise, dual-channel preamplifier mounted on the antenna proper. This unit establishes the system noise figure at about 2.5 to 3.5 db, provides sufficient gain to overcome losses in the transmission lines and associated components, and provides part of the filtering necessary for image rejection.

The horizontal and vertical outputs of the preamplifier are brought into the operations building on coaxial cables and into a polarization differentiation unit which allows simultaneous selection of four modes of polarization: horizontal, vertical, and right and left circular. To assure correct polarization differentiation, the electrical length and relative phase of both transmission lines, from the antenna output terminals to the polarization selector box, are made precisely equal by means of a mechanical "line stretcher."

A solid state diversity telemetry receiving system is the most recent addition to the network and is designed to provide polarization diversity reception of satellite telemetry signals. Tunable in one kilocycle steps, the basic receiver is capable of reception in the region from 130 to 140 Mcs simultaneously on both channels. When operated in conjunction with fixed tuned converters, it is capable of reception in the 400 and 1700 megacycle bands as well. To permit matching to signal sideband content, six predetection bandwidths between 10 kilocycles and 3 Mcs are selectable. The system features AM and FM demodulation, post-detection diversity combining, predetection output capabilities, and a visual presentation of the signal spectrum.

Data Handling Equipment

A Pulse Code Modulation (PCM) signal conditioning console is used to achieve bit synchronization and signal reconstruction of serial PCM signals as detected by the receivers. The data and clock outputs from the signal conditioner may then be recorded or used for real-time display of significant spacecraft measurements by peripheral equipment. The console also contains a signal simulator and comparator for checkout and performance analysis of the signal conditioner, by the operator, prior to a spacecraft pass. To completely close the loop on performance evaluation the console has a single channel decommutator and error counter to enable the operator to observe any one data channel during the entire spacecraft passage over the ground station.

The PCM data handling equipment is a universal PCM telemetry data handling system capable of accepting serial PCM data from a number of sources including telemetry receivers, magnetic tape recorders, or the PCM simulator within the system itself.

The input to the signal conditioner is PCM video in serial form from various sources. The signal-to-noise ratio is optimized by appropriate filtering. This unit then detects and reconstructs the serial signal pulse train and develops the master clock signal from the incoming data, phase coherent with the incoming bit rate. The bit rate is selectable from one bit per second to 200,000 bits per second.

Provision is made to handle either return to zero (RZ), non-return to zero (NRZ) or split phase (S/P) signal formats. The regenerated output of this unit is always in the NRZ form.

The synchronizer subunit accepts the regenerated serial data from the signal conditioner and formulates this data into two major types of outputs: a serial data train and a parallel data character. The serial data train consists of a telemetry data word, its word and frame address, and a nine bit identification word. Thirty-seven bits make up the parallel data character which consists of one or more telemetry words and parity bits.

The serial data is ultimately used to drive displays and recorders, while the parallel data character output is available for entry into a computer when required.

Each data word selector (DWS) is a self-contained unit used to extract individual data words from the serial output of the synchronizer. Each data word selector contains three nine bit, programmable, pattern recognizers. The data word selector accepts serial input signals until the selected words are recognized, accepted and stored. By using multiple units set for the same recognition pattern, data words of greater than nine bits may be selected and stored.

Information from the data word selectors is displayed and/or recorded in three different ways: as an analog representation on an eight-channel chart recorder, as a decimal number displayed on a counter or as a third display on a bar-graph oscilloscope.

Data Recording System

Data recording is performed using a seven track, one-half inch magnetic tape recorder. It features modular, plug-in, solid state electronics which provide a high degree of operational flexibility. The tape transport accommodates either 10 1/2 inch or 14 inch diameter tape reels. With standard production machines, four tape speeds are available: 60, 30, 15 and 7 1/2 inches per second; however, the recorders on station have been modified to run at 3 3/4 and 1 7/8 inches per second as well. Later modification has increased the tape speed to 120 inches per second to provide a 500-kilocycle recording capability.

Strip chart graphic recording instruments are used which employ galvanometers driving hot wire styluses over plastic-coated paper. They serve as tracking data recorders in the Minitrack system, and are also used to record locally recovered telemetry data for "quick-look" purposes. A serial code readout of time from the station's digital clock is displayed in the margin of the chart.

A variety of auxilliary systems, too numerous to describe here, are used for antenna calibration and collimation, receiving system test and calibration and similar needs.

Control

Spacecraft operations control is a continuous and varied requirement when more than one type of spacecraft is in orbit at the same time. Accordingly, a central control area has been provided called the "Spacecraft Operations Facility."

The establishment of the Spacecraft Operations Facility at Goddard Space Flight Center in Greenbelt, Maryland, provides a central, integrated facility for the operation and control of space flights and provides supporting orbital computations and data processing and reduction services in connection with the experiments.

The central facility contains the following constituent elements:

1. An Operations Control Center containing facilities for the display and dissemination of information relative to the over-all operations being conducted, and which acts to support the various operational projects.

2. Individual Project Operations Control Centers designed to the specific needs of a particular project.

3. An Intercommunication and Interdisplay System with the capability to handle the communication and data flow to and from all support areas.

4. A Computational Facility to determine and predict the orbits of assigned space vehicles and disseminate these data in diverse forms.

5. A Data Processing Center to process, store and disseminate scientific data in the form most suited to the needs of the experimenter.

6. A Communications Center which will provide data and voice links to and from stations of the network.

7. Ancillary facilities to sustain operational self-sufficiency on a 24-hour basis.

The Operations Control Center is the central point for effecting the coordination of all operational elements of the Goddard tracking and data systems: tracking, command, data acquisition and data transmission. This area maintains cognizance at all times of the status of the over-all networks and related facilities. In this area, ultimate operational problems or conflicts are resolved. This is a function markedly distinct from those of the Project Operations Control Centers, wherein all information acquired and all control exercised is of specific relevance to a particular spacecraft project.

Information from and to the outlying Project Operations Control Centers is made available in the Operations Control Center by means of the closed circuit television system which functions then as an extension of the intrinsic communications, display and data system provided in the project centers as an integral part of the spacecraft project.

The Project Operations Control Centers are established, as needed, to centralize the operations and control support required for particular spacecraft projects. The staffing and equipment utilized varies from the very simple to the very complex, depending upon the support requirements.

Typical spacecraft requiring Project Operations Control Centers are application satellites, such as communications and meteorological satellites; observatory satellites, such as Orbiting Geophysical, Astronomical and Solar Observatories; a variety of Space Physics satellites; and lunar and planetary exploration satellites as well as manned flight spacecraft.

The Communications Center supporting the activities of the Spacecraft Operations Facility handles all traffic requirements of the network. The Communications Center encompasses a number of areas or sections functioning as follows:

1. Automatic Switching - This area contains equipment to perform automatic switching of digital transmissions (teletype, data, etc.), automatic circuit and facilities assurance, automatic routing selection, automatic traffic and outage analysis.

2. Station Conferencing and Monitoring Arrangement (SCAMA) - This system controls and monitors world-wide voice communications.

3. Data Terminal - Controls circuits used for audio bandwidth data transmissions, including facsimile transmissions.

4. Wideband Terminal - This area contains equipment required to control circuits used for video and wideband data transmission.

The Computing Center performs computational functions in support of both general orbit calculation programs and specific project missions. The general orbit calculations involve the determination and prediction of satellite orbital elements from which acquisition predictions are derived and issued to the tracking stations.

The objectives of the Data Processing Center are to provide rapid and accurate processing of the essential data with the minimum possibility of alteration or deletion of significant events. The ground processing system consists of four broad functions: editing and quick-look, conversion and formating, reduction and analysis.

The translation of specific project requirements, through a versatile and flexible data processing facility, to meaningful and useful results in finished form depends upon the effectiveness and availability of each element of this support. A variety of telemetry formats must be accommodated, as well as certain custom formats. This has led to the development of a Satellite Telemetry Automatic Reduction System (STARS) that is capable of handling any required format with significant improvement in speed and ease of operation. Twelve of these complete STARS systems are to be used in the Data Reduction Area.

Combining all of these capabilities, both at the ground stations and at the control area into a smooth functioning, multi-spacecraft support mechanism is the mission established to effectively utilize and obtain meaningful results from NASA's flight programs. This presentation is much too brief to detail the complexities of each area and only general information can be covered, but perhaps the basic outline of over-all space flight program support can be visualized and understood from this effort.

The establishment, operation and maintenance of this program requires stations in ten foreign countries as well as the United States and involves over 1000 NASA employees, more than 700 contract employees and in excess of 300 foreign nationals. The efforts of these people have produced, and will continue to produce a truly international program of peaceful, scientific exploration of space.