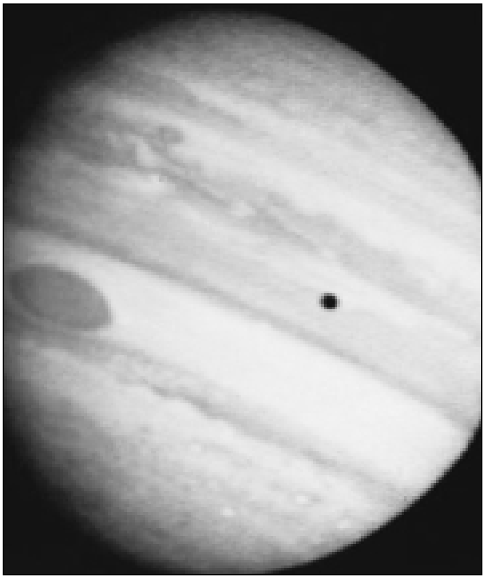

CHAPTER FOUR

TRACKING AND DATA ACQUISITION/ SPACE OPERATIONS

CHAPTER FOUR

TRACKING AND DATA ACQUISITION/ SPACE OPERATIONS

Introduction

NASA's tracking and data acquisition program provided vital support for all NASA flight projects. NASA also supported, on a reimbursable basis, projects of the Department of Defense, other government agencies, commercial firms, and other countries and international organizations engaged in space research activities.

The tracking and data acquisition program supported sounding rockets and balloons, research aircraft, Earth orbital and suborbital missions, planetary spacecraft, and deep space probes. The support included:

- Tracking to determine the position and trajectory of vehicles in space
- Acquisition of scientific and Earth applications data from on-board experiments and sensors
- Acquisition of engineering data on the performance of spacecraft and launch vehicle systems
- Transmission of commands from ground stations to spacecraft
- Communication with astronauts
- Communication of information among the various ground facilities and central control centers
- Processing of data acquired from launch vehicles and spacecraft
- Reception of television transmission from space vehicles

NASA established three types of support capabilities:

- The Spaceflight Tracking and Data Network (STDN) supported low-Earth orbital missions.
- The Deep Space Network (DSN) supported planetary and interplanetary flight missions. It also supported geosynchronous and highly elliptical missions and those in low-Earth orbit not compatible with the Tracking and Data Relay Satellite System (TDRSS).
- The TDRSS provided low-Earth orbital mission support and reduced NASA's need for an extensive network of ground stations.

By the late 1980s, a worldwide network of NASA ground stations and two tracking and data relay satellites in geosynchronous orbit tracked and acquired data from spaceflight projects. The two tracking and data relay satellites worked with a single highly specialized ground station at White Sands, New Mexico. Ground communications lines, undersea cables, and communications satellite circuits, which were leased from domestic and foreign communications carriers, interconnected the ground stations.

Together, NASA referred to the STDN and the DSN as the Ground Network. TDRSS was called the Space Network. NASA was able to phase out a number of the STDN ground stations when the TDRSS had three spacecraft in place—two operational and one spare.

NASA also maintained computation facilities to provide real-time information for mission control and to process into meaningful form the large amounts of scientific, applications, and engineering data collected from flight projects. In addition, instrumentation facilities provided support for sounding rocket launchings and flight testing of aeronautical and research aircraft.

The Last Decade Reviewed

Three types of networks operated from 1969 to 1978: the Manned Spaceflight Network (MSFN), the STDN, and the DSN. The MSFN supported the Apollo program. It was consolidated with the Space Tracking and Data Acquisition Network (STADAN) in 1972 to form the STDN. NASA supplemented the ground stations with a fleet of eight Apollo Range Instrument Aircraft for extra support during orbital injection and reentry.

When the MSFN and STADAN consolidated into the STDN, the network acquired use of the tracking stations and equipment that had been used by the MSFN as well as added some new facilities. In 1972, the total network consisted of seventeen stations. By the end of 1978, fourteen stations remained in operation. During that time, NASA added new hardware to several of the stations. Goddard Space Flight Center in Greenbelt, Maryland, which managed and operated the STDN, improved the facilities at the center, adding a new telemetry processing system, modifying the control center to allow participating project scientists to manipulate their experiments directly, and improving the Image Processing Facility with new master data units.

The DSN continued to be operated by the Jet Propulsion Laboratory in Pasadena, California. The network depended primarily on three stations—at Canberra, Australia, in the Mojave Desert in California (Goldstone), and near Madrid, Spain. The network was equipped with a variety of antennas; the largest could communicate with spacecraft near the most distant planets.

NASA also began developing the TDRSS in the 1970s. Planned to support the Space Shuttle and other Earth-orbiting satellites, the TDRSS would rely on two synchronous orbit satellites and an on-orbit spare rather than a network of ground stations. Planners anticipated that this system would reduce the dependence on ground stations. Feasibility studies were completed during the 1970s, and contracts for the user antenna system and the three multiplexer-demultiplexers were awarded in 1976. Western Union Space Communications, Inc., was selected as the prime contractor for the system.

Management of the Tracking and Data Acquisition Program

The management organization of NASA's tracking and data acquisition activities could be considered in two phases: the first before the establishment of the Space Network and the second phase following the establishment of the Space Network. During both phases, NASA's tracking and data acquisition activities were centered in the Office of Space Tracking and Data Systems (OSTDS), designated as Code T. In 1987, NASA reorganized the OSTDS into the Office of Space Operations (OSO).

Phase I—Pre–Space Network

William Schneider led OSTDS from 1978 until April 1980, when Robert E. Smylie replaced him. Smylie led the office until Robert O. Aller took over as associate administrator in November 1983.

Three program divisions were in place in 1979: Network Operations and Communications, Network Systems Development, and Tracking and Data Relay Satellite System. The Network Operations and Communications Division was led by Charles A. Taylor. Frederick B. Bryant led the Network Systems Development Division. Robert Aller headed the TDRSS Division.

A 1980 reconfiguration eliminated Network Operations and Communications and Network Systems Development Divisions and established the Network Systems Division, led by Charles Taylor, and the Communications and Data Systems Division, headed by Harold G. Kimball. TDRSS continued as a division, and Robert Aller remained with the program until November 1983 when he became OSTDS associate administrator.

In April 1981, NASA established the Advanced Systems Office under the direction of Hugh S. Fosque. In January 1982, H. William Wood replaced Taylor as head of the Network Systems Division. He remained at that post until May 1984, when Charles T. Force was appointed to the position.

When Robert Aller became associate administrator in 1983, Wood was also given responsibility as acting TDRSS director until May 1984, when Jack W. Wild became director of that division. He remained with TDRSS until 1987. Figure 4–1 shows the organizational configuration during most of Phase I.

Phase II—The Space Network Becomes Operational

In 1984, OSTDS was reorganized to reflect the increasing importance of TDRSS. The new Space Networks Division replaced the TDRSS Division and had responsibility for implementing and operating TDRSS, for acquiring, operating, and maintaining the TDRSS ground terminals,

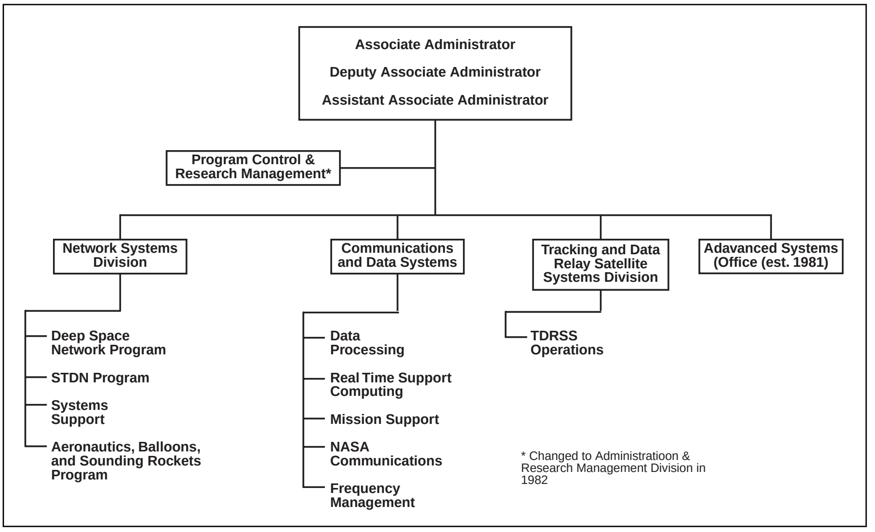

Figure 4–1. OSTDS Organizational Configuration (Pre–Space Network)

and for handling other activities and functions in support of the Space Network. The Network Systems Division was replaced by the Ground Networks Division, which had responsibility for all NASA ground networks, including the Goddard Space Flight Center Ground Network, the Jet Propulsion Laboratory Deep Space Network, the Wallops Orbital Tracking Station, and the Dryden Flight Research Facility and other tracking and data acquisition facilities. The Communications and Data Systems Division continued with its responsibility for all communications and data systems services for mission operations. Figure 4–2 shows the organizational configuration during this period.

In August 1984, Charles Force moved to the Ground Networks Division. He stayed there until 1987. Harold Kimball left the Communications and Data Systems Division in 1984, and the position remained vacant until S. Richard Costa became division director in November 1986.

Another reorganization took place in January 1987 when OSTDS became the Office of Space Operations (OSO). The office was responsible for developing a plan to manage NASA's increasingly complex space operations, with initial priority given to human-related space operations. The functions of OSTDS were integrated into OSO.

Also in 1987, Eugene Ferrick took over as director of TDRSS, and Robert M. Hornstein became acting division director for the Ground Networks program. In late 1988, S. Richard Costa left the Communications and Data Systems Division; John H. Roeder became acting division director.

The Mission Operations and Data Systems Directorate (MO&DSD) at Goddard Space Flight Center managed and operated the Ground Network, the Space Network (TDRSS), NASA worldwide communications, and

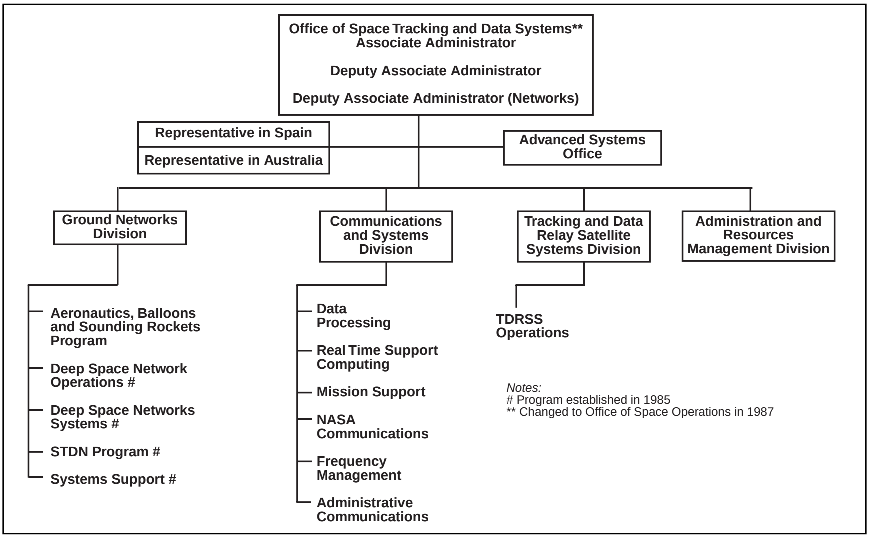

Figure 4–2. OSTDS Configuration During the Space Network Period

other functions necessary to the communications, data capture, processing and distribution, and orbit and attitude computations in support of space exploration and related activities. The Flight Dynamics Division performed orbital computations, spacecraft attitude determination, and flight maneuvering. The Operations Control Center commanded the spacecraft and monitored their health and safety. The Space and Ground Networks Division provided tracking services and relayed commands to and data from the user spacecraft through the Network Control Center. The NASA Communications (NASCOM) network provided data transport services. Data Processing captured and processed raw data to create usable information products for end users. The Technology Applications Division advanced the quality and effectiveness of the Data System by applying state-of-the-art technologies to system enhancements.

The Jet Propulsion Laboratory managed and operated the DSN. Its Office of Telecommunications and Data Acquisition had responsibility for twelve deep space stations located at three deep space communications complexes, the Network Operations Control Center at Pasadena, California, and the network's Ground Communications Facility.

Money for Tracking and Data Acquisition/Space Operations

The budget for NASA's tracking and data acquisition activities increased more than two and a half times from 1979 to 1988. This growth exceeded the rate for the entire NASA budget, which less than doubled, during the decade, the combined Research and Development (R&D) and Space Flight, Control, and Data Communications (SFC&DC) budget.

In 1988, tracking and data acquisition activities totaled approximately 10 percent of the NASA budget and 12.5 percent of the combined R&D

and SFC&DC budget. This increased from 1979, when tracking and data acquisition activities totaled approximately 6.5 percent of the NASA budget and 8.7 percent of the R&D budget. The growth can be primarily attributed to the costs associated with the TDRSS.

A comparison of most other budget elements cannot be done at a meaningful level because of the extensive reordering of budget categories that occurred during the decade. Budget items that had been in the Operations or Systems Implementation Program, when all tracking and data acquisition activities were in the R&D appropriation, were combined and put into one of three major categories (Space Networks, Ground Networks, or Communications and Data Systems) when the SFC&DC appropriation was established in 1984. However, it is possible to look at the budget activity in two groups: one before the SFC&DC appropriation began and one after that time.

The reader should note that all budget amounts reflect the value of the money at the time the budget was submitted and approved and funds were allocated. See Tables 4–1 through 4–37.

Tracking and Data Acquisition System Description

From 1979 to 1988, NASA's space tracking and data systems transitioned from a totally ground-based network mode of operation to a system with space-based capabilities for monitoring and commanding low-Earth orbital spacecraft and ground-based capabilities for deep space missions and particular types of low-Earth orbital missions. The following sections describe the Ground Network and the Space Network as they existed from 1979 to 1988.

Ground Network

The NASA Ground Network consisted of the STDN, the DSN, and the Aeronautics, Balloons, and Sounding Rocket Network. From 1979 to 1988, the Ground Network reduced the number of tracking stations while adding to the facilities and increased the capabilities at the remaining stations. Table 4–38 summarizes the locations and capabilities of the tracking stations.

Spaceflight Tracking and Data Network

The STDN was operated, maintained, and controlled by the Networks Division of the Goddard Space Flight Center in Greenbelt, Maryland. It provided tracking, data acquisition, and associated support for low-Earth orbital missions. The network was operated through NASA contracts and interagency and international agreements that provided staffing and logistical support. The Networks Division also operated the Network Control Center and NASA Ground Terminal. The division was responsible for testing, calibrating, and configuring network resources to ensure network support capability before each mission. It coordinated, scheduled, and directed all network activity and provided the necessary interface among Goddard elements and other agencies, centers, and networks.

The STDN was composed of the White Sands Ground Terminal and the NASA Ground Terminal in White Sands, New Mexico; NASCOM, the Flight Dynamics Facility, and the Simulation Operations Center at Goddard; and the ground network. The ground elements were linked by voice and data communications services provided by NASCOM. The prime operational communications data were formatted into 4,800-bit blocks and transmitted on the NASCOM wideband data and message switching system. Other communications traveled by teletype and facsimile facilities. Each ground station in the network provided coverage for approximately 20 percent of a satellite's or spacecraft's orbit and was limited to brief periods when the satellite or spacecraft was within the line of sight of a given tracking station. The various antennas at each STDN site accomplished a specific task, usually in a specific frequency band.

To provide reliable, continuous, and instantaneous communications support to the Space Shuttle, NASA added new sites and upgraded some of its existing facilities and capabilities for the Shuttle test phase and early Shuttle flights. In 1981, new sites for UHF air-to-ground voice were added in Dakar in Senegal, Botswana, and Yarragardee in Australia. Also added were three Shuttle-unique stations in Florida, California, and New Mexico. Department of Defense tracking and telemetry elements also supported the Shuttle flights. The Dakar UHF air-to-ground voice station was upgraded in 1982, before the STS-4 mission, to an S-band telemetry, voice, and command station. The change allowed for continuous telemetry data coverage between Bermuda and Hawaii for all due-east launches beginning with STS-4. This mid-point station allowed for the analysis of initial Orbital Maneuvering System burn data and provided for crew updates in case of an abort.

The network for the Shuttle orbital flight test program (STS-1 through STS-4) consisted of seventeen ground stations equipped with 4.26-, 9.14-, 12.19-, and 25.9-meter S-band antenna systems and C-band radar systems, NASCOM augmented by fifteen Department of Defense geographical locations providing C-band support, and one Department of Defense 18.3-meter S-band antenna system. In addition, six major computing interfaces—the Network Operations Control Center at Goddard, the Western Space and Missile Center at Vandenberg Air Force Base in California, the Air Force Satellite Control Facility in Sunnyvale, California, the White Sands Missile Range in New Mexico, and the Eastern Space and Missile Center in Florida—provided real-time network computational support. The stations that closed during this period were at Winkfield, England, at Rosman, North Carolina, which was turned over to the Department of Defense at the start of 1981, and at Quito, Ecuador, which closed in 1982 and transferred its equipment to the Dakar station.

The STDN stations were at Ascension Island, Bermuda, Botswana (beginning with STS-3), Buckhorn (Dryden Flight Research Facility) in

California, Dakar (beginning with STS-3), Fairbanks in Alaska, Goddard Space Flight Center, Goldstone (Ft. Irwin, California), Guam, Kokee in Hawaii, Madrid in Spain, Merritt Island in Florida, Orroral Valley (Canberra, Australia), Ponce de Leon in Florida (added for Shuttle program), Quito (closed in 1982), Santiago in Chile, Seychelles in the Indian Ocean (added for Shuttle program), Tula Peak in New Mexico, Wallops Orbital Tracking Station in Virginia, and Yarragardee (added for Shuttle program). Tula Peak, which initiated operations in 1979, was designated as a tracking support site for Shuttle orbital flight test landing activities. It initially suspended operations following STS-2, because of budget restrictions, but it was forced to reactivate its facilities on very short notice when STS-3 had to land at White Sands, New Mexico, rather than at Edwards Air Force Base in California because of bad weather in California.

Several instrumented U.S. Air Force aircraft, referred to as advanced range instrumentation aircraft, also supported the STDN. They were situated on request at various locations around the world where ground stations could not support Space Shuttle missions.

The Merritt Island, Florida, S-band station provided data to the Launch Control Center at Kennedy Space Center and the Mission Control Center at Johnson Space Center during prelaunch testing and terminal countdown. During the first minutes of launch, the Merritt Island and Ponce de Leon, Florida, S-band and Bermuda S-band stations, respectively, provided tracking data, both high speed and low speed, to the control centers at Kennedy and Johnson. The C-band stations located at Bermuda, Wallops Island in Virginia, the Grand Bahamas, Grand Turk, Antigua, and Cape Canaveral and Patrick Air Force Base in Florida also provided tracking data.

The Madrid, Indian Ocean Seychelles, Australian Orroral and Yarragardee, and Guam stations provided critical support to the Orbital Maneuvering System burns. During the orbital phase, all the S- and C-band stations that saw the Space Shuttle orbiter at 30 degrees above the horizon provided appropriate tracking, telemetry, air-ground, and command support to the Johnson Mission Control Center through Goddard.

During the nominal reentry and landing phase planned for Edwards Air Force Base, California, the Goldstone and Buckhorn, California, S-band stations and the C-band stations at the Pacific Missile Test Center, Vandenberg Air Force Base, Edwards Air Force Base, and Dryden Flight Research Center provided tracking, telemetry, command, and air-ground support to the orbiter. These locations also sent appropriate data to the control centers at Johnson and Kennedy. The tracking station at Ponce de Leon Inlet, Florida, provided support for the Space Shuttle during powered flight because of attenuation problems from the solid rocket booster motor plume.

In 1983, after supporting the STS-8 night landing, the Buckhorn special-purpose tracking station at Dryden Flight Research Center in California was phased out and operations terminated. This station had been established to support the Space Shuttle approach and landing tests and the operational flight test landings. Equipment from the Buckhorn site was moved a short distance to the Aeronautical Training Facility at Dryden, which already had been used to support NASA's aeronautics activities. This site was then also used to support STS missions.

When the first Tracking and Data Relay Satellite (TDRS-1) began tracking Shuttle missions in 1984, the White Sands Ground Terminal acquired the ground terminal communications relay equipment for the command, telemetry, tracking, and control equipment of the TDRSS (see the "Space Network" section below). The NASA Ground Terminal was co-located with the White Sands Ground Terminal. The NASA Ground Terminal, in combination with NASCOM, was NASA's physical and electrical interface with the TDRSS. The NASA Ground Terminal provided the interfaces with the common carrier, monitored the quality of the service from the TDRSS, and provided remote data quality to the Network Control Center.

The STDN consolidated its operations as the TDRSS took over the function of tracking most Earth-orbiting satellites. The facilities at Fairbanks, Alaska, were transferred to the National Oceanic and Atmospheric Administration in 1984. The STDN relinquished its Goldstone, Madrid, and Canberra stations and transferred them to the DSN sites. It gave the DSN support responsibility for spacecraft above the view of the TDRSS and for older spacecraft that were incompatible with the TDRSS. If the second TDRS had been successfully placed in orbit in 1986 as planned, the closure of additional STDN tracking stations would have occurred. However, the loss of the spacecraft in the *Challenger* explosion delayed the TDRS deployment by two years, and the reduction in STDN facilities was put on hold until the launch of TDRS-3 in September 1988.

At the time of the TDRS-3 launch, STDN tracking stations remained at Ascension Island, Bermuda, Canberra, Dakar, Guam, Kauai, Merritt Island, Ponce de Leon, Santiago, and Wallops Flight Facility. After the TDRSS was declared operational in 1989, the STDN decreased to stations at Wallops Island, Bermuda, Merritt Island, Ponce de Leon, and Dakar.

Deep Space Network

In 1988, the DSN consisted of twelve stations positioned at three complexes: Goldstone in southern California's Mojave Desert, near Madrid, and near Canberra. The Network Operations Control Center, at the Jet Propulsion Laboratory in Pasadena, California, controlled and monitored operations at the three complexes, validated the performance of the DSN for flight project users, provided information for configuring and controlling the DSN, and participated in DSN and mission testing. The DSN's Ground Communications Facility provided and managed the communications circuits that linked the complexes, the control center in Pasadena, and the remote flight project operations centers. The NASCOM network at Goddard Space Flight Center leased the communications circuits from

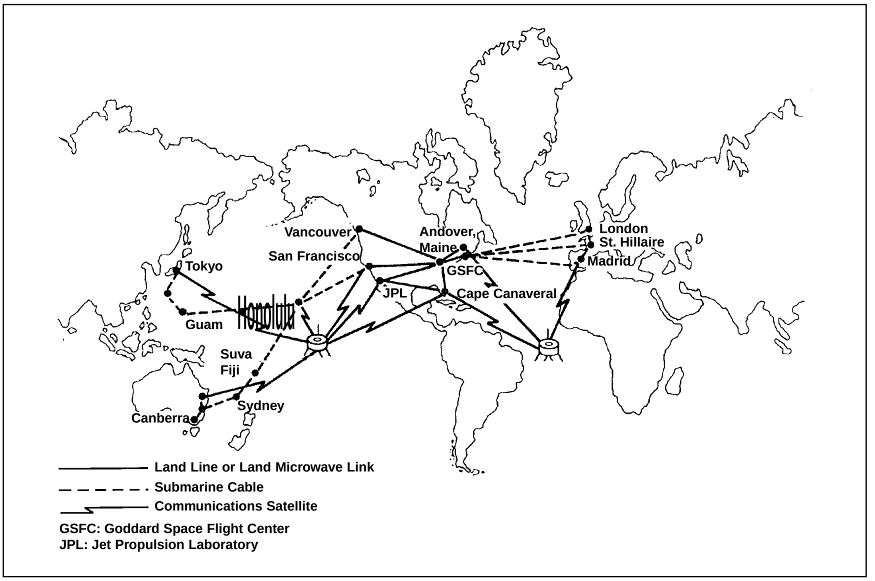

Figure 4–3. The Deep Space Network Ground Communications Facility Used Land Lines, Microwave Links, Satellite Cables, and Communications Satellites to Link the Network's Elements

common carriers and provided them as needed to all NASA projects, centers, and facilities. Figure 4–3 shows the elements that the Ground Communications Facility used to link elements of the network.

The DSN supported the unmanned spaceflight projects that NASA's Office of Space Science and Applications or other space agencies managed and controlled. The DSN received the telemetry signals from the spacecraft, transmitted commands that controlled the spacecraft operating modes, and generated the radio navigation data that were used to locate and guide each spacecraft to its destination. The DSN was also used for flight radio science, radio and radar astronomy, very long baseline interferometry, and geodynamics measurements.

The locations of the DSN complexes were approximately 120 degrees apart in longitude. This ensured continuous observation and suitable overlap for transferring the spacecraft radio link from one complex to the next. Each complex was situated in semi-mountainous, bowl-shaped terrain to shield against radio-frequency interference.

Each complex consisted of four deep space stations equipped with ultrasensitive receiving systems and large parabolic dish antennas. Equipment included two thirty-four-meter diameter S- and X-band antennas that had been converted from twenty-six-meter S-band antennas in 1980, one twenty-six-meter antenna, and one seventy-meter antenna. Figure 4–4 shows a twenty-six-meter antenna at Goldstone. In Canberra and Madrid, the seventy-meter antennas were extended in 1987 from their original sixty-four-meter-diameter configurations in preparation for the 1989 Voyager 2 encounter with Neptune. The extension of the sixty-four-

Figure 4–4. Twenty-Six-Meter Antenna at Goldstone

meter antenna at Goldstone took place in 1988. One of the 34-meter antennas at each complex was a new-design, high-efficiency antenna that provided improved telemetry performance needed for outer-planet missions.

The thirty-four- and seventy-meter stations were remotely operated from a centralized Signal Processing Center, which housed the electronic subsystems that pointed and controlled the antennas, received and processed the telemetry, generated and transmitted the commands, and produced the spacecraft navigation data. The twenty-six-meter stations required on-location operation.

Each antenna size formed separate subnets with different communications capabilities. The seventy-meter antenna subnet was the most sensitive and supported deep space missions. The twenty-six-meter subnet supported spacecraft in near-Earth orbit that were incompatible with the TDRSS, Shuttle flights, and geostationary launch service for space agencies worldwide. The two thirty-four-meter subnets supported both deep space and near-Earth orbital missions. The twenty-six-meter antenna stations were originally part of the STDN and were consolidated into the DSN in 1985, when it assumed that the added tracking responsibility for spacecraft in high elliptical Earth orbits that could not be supported by the TDRSS.

DSN support for inner-planet exploration began in 1962 with NASA’s Mariner series of missions to Venus, Mars, and Mercury. Support for the first outer-planet missions, the Pioneer 10 and 11 flybys of Jupiter and Saturn, began in 1972–1973.

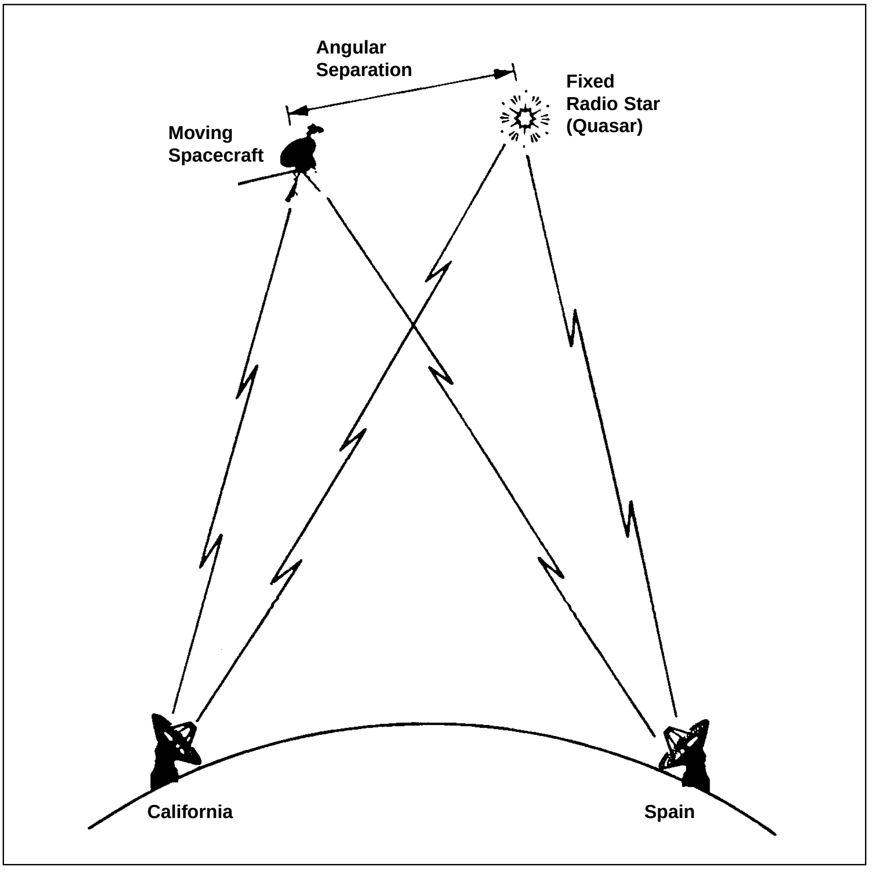

Figure 4–5. Very Long Baseline Interferometry Radio Navigation

The DSN's most complex support was for the Voyager mission. In the Voyager's 1981 encounter with Saturn, the DSN used differential very long baseline interferometry navigation to supplement the conventional Doppler and ranging navigation technique (Figure 4–5). The interferometry technique used two widely separated DSN stations on different continents to simultaneously receive signals from the spacecraft and from an angular nearby natural radio source (quasar) whose celestial coordinates were very well known. The data taken by the two stations were then correlated to provide a precise measurement of the angular separation between the spacecraft and the quasar. These measurements proved to have a repeatable precision of approximately fifty nanoradians, or five to ten times the angle measurement accuracy of the Doppler and range technique. This technology was especially important when missions required a close flyby of a planet to get an assist from that planet's gravity to alter trajectory and reduce travel time.

Another technique that improved the capability of tracking equipment over greater distances and the return data rates of planetary spacecraft was "arraying." This technique used two separate antennas to collect data from the spacecraft and then electronically added the signals together, producing the effect of a single antenna of larger diameter. NASA used this technique experimentally during the Voyager encounter with Jupiter and the Pioneer 11 encounter with Saturn, both in 1979. In 1980, NASA installed low-noise X-band maser antennas on existing sixty-four-meter antennas and integrated the enhancements by arraying the two antennas through a real-time combined assembly at each station complex. Electronically combining the spacecraft signals received by the two antennas provided about 35 percent more images from Saturn than could be obtained with a single sixty-four-meter antenna.[1]

In the 1986 Voyager 2 encounter with Uranus, the DSN carried the arraying technology farther by combining DSN antennas at each complex and augmenting the sixty-four-meter antenna at Canberra with the large radio telescope at Parkes, Australia. The weaker signals received at each antenna were combined into a single stronger signal, resulting in an increase of approximately fifty percent in the reception of Uranus data.[2] The construction of new-design, high-efficiency thirty-four-meter antennas at each complex permitted a three-element array, consisting of two thirty-four-meter antennas and one sixty-four-meter antenna. (The sixty-four-meter antennas were enlarged and redesigned as high-efficiency seventy-meter antennas before the Voyager encounter with Neptune.)

NASA would also use the arraying technique for the Voyager encounter with Neptune in 1989, combining two antennas at Goldstone with the Very Large Array (twenty-seven antennas) at Socorro, New Mexico.[3] Arraying Goldstone with the Very Large Array would result in more than doubling Goldstone's capability on its own. The arraying with the Very Large Array would also result in the most antennas ever arrayed anywhere at once, the largest fully steerable equivalent aperture ever used for a communications link (151 meters), the longest array (19,300 kilometers) ever used for communications, and the first arraying for telemetry via satellite.[4]

Radio interferometry was more commonly used to detect details of celestial objects. In 1987, NASA used the technique to observe Supernova 1987-A. A DSN antenna located in Tidbinbilla, Australia, was connected by microwave to Parkes Radio Telescope (of Australia's Commonwealth Scientific and Industrial Research Organization)

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[1] *Aeronautics and Space Report of the President, 1980* (Washington, DC: U.S. Government Printing Office, 1981), p. 32.

[2] "DSN Fact Sheet," Jet Propulsion Laboratory, NASA (on-line).

[3] The Very Large Array was operated by the National Radio Astronomy Observatory and sponsored by the National Science Foundation. It consisted of twenty-seven antennas, each twenty-five meters in diameter, configured in a "Y" arrangement on railroad tracks over a twenty-kilometer area.

[4] Edward C. Posner, Lawrence L. Rauch, and Boyd D. Madsen, "Voyager Mission Telecommunication Firsts," *IEEE Communications Magazine* 28(9) (September 1990): 23.

200 miles away. The two linked antennas formed a theoretical receiver the size of the distance between the two antennas. (The link had been put in place to observe the Voyager's encounter with Uranus.) NASA formed an even wider network using very long baseline interferometry that connected four antennas: Tidbinbilla, Parkes, a Landsat ground station at Alice Springs in central Australia, and a twenty-six-meter antenna at the University of Tasmania on the island of Tasmania.

NASA's DSN also supported international missions. In 1985, as part of a French-led international tracking network, the DSN tracked two Soviet-French balloon experiments that studied Venus' atmosphere and provided information on its weather dynamics. Two Soviet Vega spacecraft on their way to Halley's comet inserted the meteorological balloons into the Venusian atmosphere as they passed the planet. The tracking stations used very long baseline interferometry to measure the balloons' velocity and, therefore, the wind velocity with a precision of about 3 kilometers per hour at Venus' distance (about 108 million kilometers from Earth).

The DSN also provided navigation support to five international spacecraft that encountered Halley's comet in March 1986. The DSN supported Japanese efforts to track their two spacecraft, provided backup tracking of the European Space Agency's Giotto spacecraft, and tracked the Soviet Vega spacecraft as they approached the comet.

The Soviet Phobos project also received DSN support. Phobos 1 and 2 were launched in July 1988. The DSN tracked the spacecraft as well as the Martian moon Phobos to permit the landers to land on the moon. Scientists used very long baseline interferometry as well as Doppler and range tracking to pinpoint the position and motions of Phobos.

Aeronautics, Balloons, and Sounding Rockets

The Aeronautics, Balloons, and Sounding Rockets (AB&SR) Program provided fixed and mobile instrumentation systems to meet the tracking, data acquisition, and range safety requirements of NASA research vehicles using primarily suborbital vehicles. The principal facilities supporting this program were Wallops Island, the Dryden Flight Research Center and Moffett Field, the Poker Flats Research Facility, White Sands Missile Range, and the National Scientific Balloon Facility. Mobile facilities were used worldwide to meet varied scientific requirements.

In February 1987, the AB&SR program responded to the supernova discovery by establishing a sounding rocket capability in Australia, launching both balloons and sounding rockets. In 1988, the Office of Space Operations program continued support to the supernova program with balloon and sounding rocket launches from Australia. Major AB&SR activities during 1988 included thirty-three large rockets and forty-six large balloons with scientific payloads launched worldwide.

Space Network

The NASA Space Network was a space-based communications system composed of the TDRSS and supporting ground elements. These elements included a space-to-ground single ground terminal at White Sands, New Mexico, comprised of the Network Control Center, NASA Ground Terminal, Flight Dynamics Facility, and Simulation Operations Center. The system had a constellation of three data relay satellites—two operational and one spare—in geosynchronous orbit.[5]

The Space Network provided tracking, telemetry, and command services to the Space Shuttle, to other low-Earth-orbiting spacecraft, and to some suborbital platforms that had been supported by a number of ground stations throughout the world. From 1979 to 1988, two Tracking and Data Relay Satellites (TDRS) were deployed and became operational. The first, TDRS-1, was launched from STS-6 in 1983. TDRS-3 was launched from STS-26 when the Shuttle program returned to operational status in 1988. TDRS-B was lost in the *Challenger* explosion in 1986.

A third TDRS (TDRS-4) was launched in 1989 and was positioned as TDRS-East. At that time, TDRS-1 was moved to the spare position. NASA launched later tracking and data relay satellites in 1991, 1993, and 1995.

The system did not perform processing of user traffic. Rather, it operated as a "bent-pipe" repeater—that is, it relayed signals and data between the user spacecraft and ground terminal in real time. The system was characterized by its unique ability to provide bi-directional high data rates as well as position information to moving objects in real time nearly everywhere around the globe. The satellites were the first designed to handle telecommunications services through three frequency bands—S-, Ku-, and C-bands. They could carry voice, television, and analog and digital data signals. The tracking and data relay satellites could transmit and receive data and track a user spacecraft in a low-Earth orbit for a minimum of 85 percent of each spacecraft's orbit.

Background

NASA's satellite communications system was initiated following studies in the 1970s. These studies showed that a system of telecommunications satellites operated from a single ground station could support the Space Shuttle and scientific application mission requirements planned for the space program better than ground-based tracking stations. Ground-based tracking stations could track a satellite during only about

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[5] Deep space probes and Earth-orbiting satellites above approximately 5,700 kilometers used the three ground stations of the DSN, operated for NASA by the Jet Propulsion Laboratory in Pasadena, California. The DSN stations were at Goldstone in California, Madrid in Spain, and Canberra in Australia.

20 percent of its orbit and only when that satellite was in direct line of sight with a tracking station. Consequently, it was necessary to have ground stations around the globe and to continually "hand off" a satellite from one station to another.

In addition, the system was viewed as a way to halt the growing costs of upgrading and operating a network of tracking and communications ground stations around the world. It was planned that when the TDRSS became fully operational, ground stations of the worldwide STDN would be closed or consolidated, resulting in savings in personnel and operating and maintenance costs. The Merritt Island, Ponce de Leon, and Bermuda ground stations would remain open to support the launch and landing of the Space Shuttle at the Kennedy Space Center in Florida.

It was also decided that leasing a system was more desirable than purchasing it. In December 1976, NASA awarded a contract to Western Union Space Communications (Spacecom), which would own and operate the system. The principal subcontractors were TRW for the satellite development and system integration and The Harris Corporation for ground terminal development. The contract provided for ten years of service to NASA and included both space and ground segments of the system.[6] It also established a joint government-commercial program with one satellite intended to provide domestic communications services commercially. The development was to be financed with loans provided to the contractor by the Federal Financing Bank, an arm of the U.S. Treasury. NASA would make loan repayments to the bank once service began. Public Law 95-76, dated July 30, 1977, provided permanent legislation for the TDRSS.

In 1980, the contract was transferred to a partnership of Western Union, Fairchild, and Continental Telephone. In 1983, Western Union sold its share of the business to the other two partners, and in 1985, Fairchild sold its share, leaving Continental Telecom (Contel) as the sole owner of Spacecom. In 1990, a new contract transferred ownership of the system to NASA but retained Contel as the operator.[7]

The Tracking and Data Relay Satellite System

The full TDRSS network consisted of three satellites in geosynchronous orbits. TDRS-East was positioned at forty-one degrees west longitude. TDRS-West was positioned at 171 degrees west longitude. A third TDRS was positioned as a backup above a central station just west of South America at sixty-two degrees west longitude. The positioning of

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[6] See Linda Neuman Ezell, *NASA Historical Data Book, Volume III: Programs and Projects, 1969–1978* (Washington, DC: NASA SP-4012, 1988), for further information on the development of the TDRSS program.

[7] Donald H. Martin, *Communications Satellites, 1958–1992* (El Segundo, CA: The Aerospace Corporation, December 31, 1991), pp. 186–89.

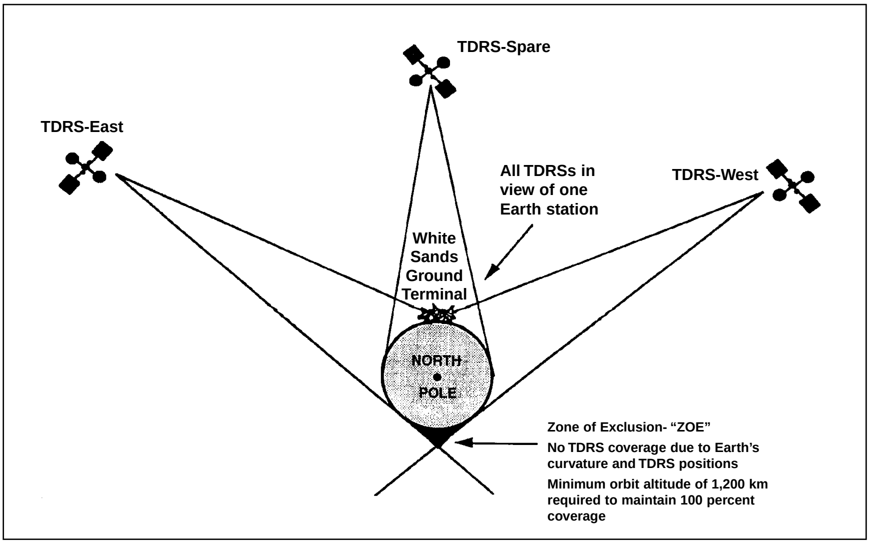

Figure 4–6. TDRSS Coverage Area

two tracking and data relay satellites 130-degree spacing reduced the ground station requirements to one station instead of the two stations required for 180-degree spacing. Figure 4–6 shows the coverage area of the TDRSS. The satellites were positioned in geosynchronous orbits above the equator at an altitude of approximately 35,880 kilometers. At that altitude, because the speed of the satellites were the same as the rotational speed of Earth, they remained fixed in orbit over the same location.

The TDRSS network had three primary capabilities: tracking, telemetry and data, and command. Network tracking determined the precise location of orbiting user spacecraft by measuring range (distance) and range rate (velocity) with respect to the known position of the TDRS. Ground-based stations determined the TDRS position.

The user spacecraft transmitted telemetry signals indicating certain operational parameters, such as power level and temperature. It also transmitted data signals that corresponded to the scientific or applications information collected by the spacecraft instruments. The tracking and data relay satellites relayed the telemetry and data signals from the user spacecraft to the White Sands Ground Terminal for use by the Goddard Space Flight Center and the user community. The White Sands Ground Terminal sent the raw data directly by domestic communications satellite to NASA control centers at Johnson Space Center (for Space Shuttle operations) and Goddard, which scheduled TDRSS operations and controlled a large number of satellites. Figure 4–7 shows the user data flow.

The White Sands Ground Terminal sent command signals via the tracking and data relay satellites to user spacecraft, ordering the spacecraft to perform certain functions. The commands originated from Goddard for unmanned spacecraft or from Johnson for manned spacecraft. Figure 4–8 shows the entire system.

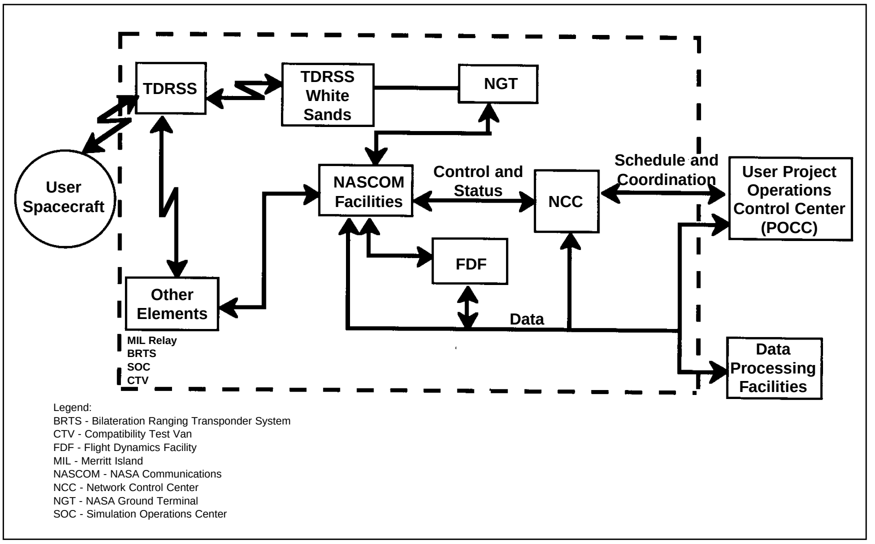

Figure 4–7. User Data Flow

The White Sands Ground Terminal was located at a longitude with a clear line of sight to the tracking and data relay satellites and very little rain, because rain could interfere with the Ku-band uplink and downlink channels. It was one of the largest and most complex communications terminals ever built. Many command and control functions ordinarily found in the space segment of a system were performed by the ground station, such as the formation and control of the receiver beam of the TDRS multiple-access phased-array antenna and the control and tracking functions of the TDRS single-access antennas.

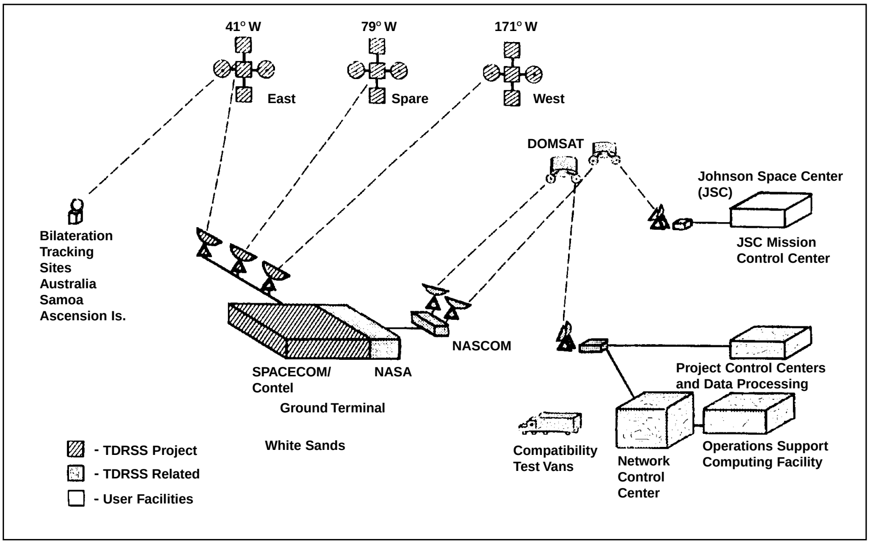

Figure 4–8. TDRSS Elements

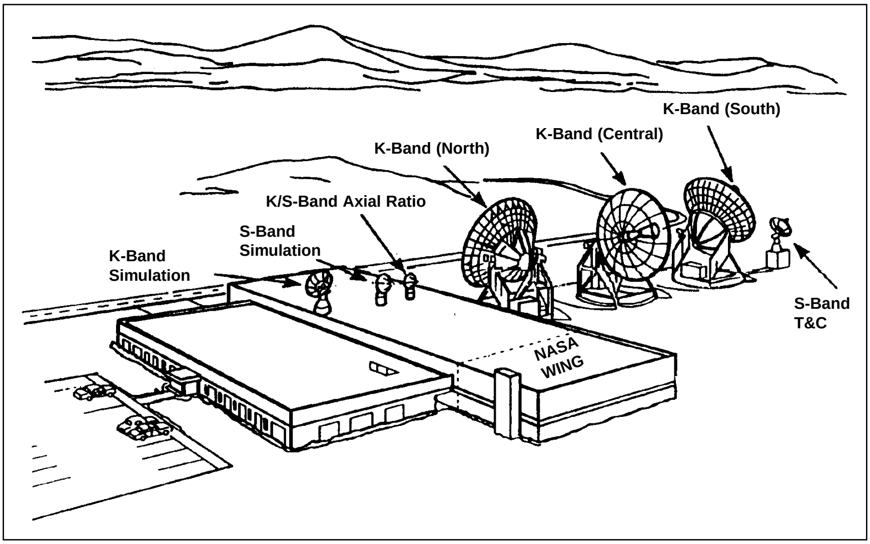

Figure 4–9. White Sands Ground Terminal

The most prominent features of the ground station were three eighteen-meter Ku-band dish antennas used to transmit and receive user traffic. Several other antennas were used for S- and Ku-band communications. NASA developed sophisticated operational control facilities at Goddard and next to the White Sands Ground Terminal to schedule TDRSS support of each user and to distribute user data from White Sands to the user (Figure 4–9).

In the mid-1980s, NASA identified the need for a second TDRSS ground terminal at White Sands. This ground terminal would provide a backup to the White Sands Ground Terminal in the event of a catastrophic failure or planned outages for system upgrades or repair. It would also provide expanded capability for the increased user demand that was expected for the 1990s. The TDRSS program office initiated competitive Definition Phase studies for the development of a second ground terminal in 1987. In 1988, General Electric Company received the contract to develop, fabricate, install, and test the second TDRSS ground terminal communications hardware and software. The complex was dedicated in 1990.

In addition to the Space Shuttle, the TDRSS could support up to twenty-six user satellites simultaneously. It provided two types of service: a multiple-access service, which could relay data from as many as twenty low-data-rate user satellites simultaneously, and a single-access service, which provided two high-data-rate communications relays. Tables 4–39 and 4–40, respectively, provide single-access and multiple-access link summaries.

The tracking and data relay satellites were deployed from the Space Shuttle at an altitude of approximately 296 kilometers, and inertial upper stage (IUS) boosters propelled them to geosynchronous orbit. The antennas and solar panels unfolded, and the satellite then separated from the

IUS and drifted in orbit to a position free from radio-frequency interference, where it was checked out. The TDRS was allowed to drift to the final orbital location, where it was maintained, monitored, and commanded by the ground segment of the Space Network.

Three-axis stabilization aboard the TDRS maintained attitude control. Body-fixed momentum wheels combined with body-fixed antennas pointing constantly at Earth, while the satellite's solar arrays tracked the Sun. Monopropellant hydrazine thrusters were used for TDRS positioning and north-south, east-west stationkeeping.

The tracking and data relay satellites were the largest privately owned telecommunications satellites ever built. They were composed of three modules: an equipment module, a communications payload module, and an antenna module. The equipment module consisted of the attitude control, electrical power, and thermal control subsystems. The attitude control subsystem stabilized the satellite so that the antennas had the proper orientation toward Earth and the solar panels were properly aimed toward the Sun. The electrical power subsystem consisted of two solar panels that provided a ten-year life span of approximately 1,700 watts of power. The thermal control subsystem consisted of surface coatings and controlled electric heaters. The communications payload module was composed of the electronic equipment and associated antennas required for linking the user spacecraft with the ground terminal.

The antenna module housed four antennas. For single-access services, each TDRS had two dual-feed S-band/Ku-band deployable parabolic antennas. They were just under five meters in diameter, unfurled like a giant umbrella when deployed, and attached on two axes that could move horizontally or vertically (gimbal) to focus the beam on orbiting satellites below. They were fabricated of woven molybdenum mesh and plated with 14K gold. When deployed, the antenna's 18.8 square meters of mesh were stretched tautly on sixteen supporting tubular ribs by fine thread-like quartz cords. The entire antenna structure, including the ribs, reflector surface, a dual-frequency antenna feed and the deployment mechanisms needed to fold and unfold the structure, weighed approximately twenty-three kilograms. Their primary function was to relay communications to and from user spacecraft. The high-bit-rate service made possible by these antennas was available to users on a time-shared basis. Each antenna simultaneously supported two user satellites or spacecraft (one on S-band and one on Ku-band) if both users were within the antenna's bandwidth.

For multiple-access service, the multi-element S-band phased array of helical radiators was mounted on the satellite body. The multiple-access forward link (between the TDRS and the user spacecraft) transmitted command data to the user spacecraft. In the return link, the signal outputs from the array elements were sent separately to the White Sands Ground Terminal parallel processors.

A fourth antenna, a two-meter parabolic reflector, provided the prime link for relaying transmissions to and from the ground terminal at Ku-band. The antenna was used to control the TDRS while it was in transfer orbit to geosynchronous altitude. Table 4–41 provides the TDRS characteristics.

TDRS-1. TDRS-A and its IUS were carried aboard the Space Shuttle *Challenger* on the April 4, 1983, STS-6 mission.[8] After it was deployed and the first-stage boost of the IUS solid rocket motor was completed, the second-stage IUS motor malfunctioned and left TDRS-1 in an elliptical orbit far short of the planned geosynchronous altitude. Also, the satellite was spinning out of control at a rate of thirty revolutions per minute until the contractor flight control team recovered control and stabilized it.

Later, the contractors and the NASA TDRSS program officials devised a procedure for using the small hydrazine-fueled Reaction Control System thrusters on TDRS-1 to raise its orbit. The thrusting, which began on June 6, 1983, required thirty-nine maneuvers to raise TDRS-1 to geosynchronous orbit. The maneuvers consumed approximately 408 kilograms of the satellite's propellant, leaving approximately 226 kilograms of hydrazine for the ten-year on-orbit operations.

During the maneuvers, overheating caused the loss of one of the redundant banks of twelve thrusters and one thruster in the other bank. The flight control team developed procedures to control TDRS-1 properly in spite of the thruster failures.

TDRS-1 was turned on for testing on July 6, 1983. The tests proceeded without incident until October 1983, when one of the Ku-band single-access-link diplexers failed. Shortly afterward, one of the Ku-band traveling-wave-tube amplifiers on the same single-access antenna failed, and the forward link service was lost. On November 19, 1983, one of the Ku-band traveling-wave-tube amplifiers serving the other single-access antenna failed. TDRS-1 testing was completed in December 1984. Although the satellite could provide only one Ku-band single-access forward link, it could still function.

Later tracking and data relay satellites were identical to TDRS-1 except for modifications to correct the malfunctions that occurred on TDRS-1 and a modification of the C-band antenna feeds. The C-band minor modification improved coverage for providing government point-to-point communications.

TDRS-2. Originally scheduled for launch in March 1985, a problem in the timing circuitry associated with the command system resulted in a launch delay. The spacecraft was subsequently lost on the STS 51-L (*Challenger*) mission.

TDRS-3. The launch of TDRS-3 went smoothly, and the IUS successfully boosted the spacecraft to the required orbit. When it was positioned at 171 degrees west longitude, it provided coverage to the eastern United States and westward into central China. The successful deployment of

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[8] Further information on the STS-6 mission can be found in Chapter 3, "Space Transportation/Human Spaceflight," in Volume V of the *NASA Historical Data Book.*

TDRS-3 allowed NASA to continue with the shutdown of additional tracking ground stations.

Communications and Data Systems

The elements of NASA's Communications and Data Systems Program linked the data acquisition stations and users. These elements included communications, mission control, data capture and processing, and frequency management and were organized into two major programmatic areas. The Communications program provided for communications required to link remote tracking stations with mission control and data processing facilities and for administrative services for NASA centers and Headquarters. The Data Systems program provided for real-time operational and postflight data processing support and mission operations crucial to determining the condition of spacecraft and payloads and to the generation of commands for spacecraft and payload control.

Communications Program

Two networks comprised NASA's communications facilities: the NASA Communications Network (NASCOM) and the Program Support Communications Network (PSCN). Other systems also provided communications support.

NASA Communications Network. NASCOM linked the elements of the Ground and Space Networks. The NASCOM network was a worldwide complex of communications services, including data, voice, teletype and video systems that were a mixture of government-owned and -leased equipment as well as leased services. The major NASCOM switching centers were at the Goddard Space Flight Center. From Goddard, personnel directed overall network operations, including those at supporting NASCOM switching centers in Madrid, Canberra, and the Jet Propulsion Laboratory in Pasadena, California. In addition, support activities were provided by Air Force communications centers at Cape Canaveral, Florida, and Vandenberg Air Force Base, California.

The communications network consisted of more than 2 million circuit miles of diversely routed communications channels. It used domestic and international communications satellites, submarine cable and terrestrial landlines and microwave radio systems to interconnect the tracking stations, launch and orbital control centers, and other supporting locations.

Numerous computers at the different ground tracking stations controlled the tracking antennas, handled commands, and processed data for transmission to the control centers at Johnson Space Center and Goddard. Mission data from all the tracking stations were funneled into the main switching computers at Goddard and rerouted to the users without delay by domestic communications satellites. Commands were transmitted to the main switching computers at Goddard and switched to the proper tracking station for transmission to the Space Shuttle or other spacecraft.

The Shuttle flights implemented a key change in the communications network. For the first time, two simultaneous air-ground S-band voice circuits in addition to UHF radio capability were provided. In previous Apollo missions, only one S-band circuit was provided. Telemetry data circuitry from tracking stations was increased in size to handle 128,000 bits per second (128 kilobits per second) in real time versus the 14–21 kilobits per second in previous programs. Correspondingly, the command data circuit to a station was increased from 7.2 kilobits per second to a 56-kilobyte-per-second capability.

A station conferencing and monitoring arrangement allowed various traffic managers to hold conferences with as many as 220 different voice terminals throughout the United States and abroad with talking and listening capability. The system was redundant, with a mission support reliability record of 99.6 percent. All Space Shuttle voice traffic was routed through this arrangement at Goddard.

Program Support Communications Network. The PSCN, which became operational in 1986, connected NASA centers, Headquarters, and major contractors to provide programmatic and administrative information. Its services included voice, voice conferencing, data, and facsimile. It also linked the NASA supercomputers at the Ames Research Center with those at other centers. It was a fully digital backbone network supporting both circuit switching and pocket switching over digital transmission facilities.

Time Division Multiple Access. This system, which also became operational in 1986, used advanced technologies developed by the communications industry. It provided operational circuits by way of satellites that could be used by NASA as workloads required.

Data Systems Program

This program planned, designed, developed, and operated systems that processed spacecraft telemetry for the worldwide science community. One of its major systems was the Spacelab Data Processing Facility. This facility processed and delivered extensive data received from the Spacelab missions. During the 1980s, the Data Systems program was also preparing to support the Hubble Space Telescope mission and, in 1985, completed the development of its Data Capture Facility.

Table 4–1. Total Office of Space Tracking and Data Systems Funding (in thousands of dollars) a

Year	Request	Authorization	Appropriation	Programmed (Actual)
1979	305,400	305,400	*b*	299,900
1980	332,400 *c*	332,800	*d*	332,100
1981	341,100 *e*	349,750	341,100 *f*	339,900
1982	402,100 *g*	408,180	415,200	402,100
1983	498,900 *h*	503,900	508,900	485,600
1984	688,200 *i*	700,200	690,200 *j*	674,000
1985	811,000 *k*	811,000 *l*	811,000 *m*	795,700
1986	675,900 *n*	717,500 *o*	717,500 *p*	660,400
1987	880,000 *q*	878,000	878,000	845,900
1988	902,500 *r*	943,000 *s*	912,000 *t*	879,400

a Beginning in FY 1984, the Office of Space Tracking and Data Systems (OSTDS) became part of the Space Flight, Control, and Data Communications (SFC&DC) appropriation. All major programs moved to SFC&DC except for Advanced Systems, which remained in R&D.

b Undistributed. Total 1979 R&D appropriation = $3,477,200,000.

c Amended budget submission. Original budget submission = $332,800,000. The reduction results from the congressional general reduction in the FY 1980 NASA R&D appropriation request. The revised submission reflects adjustments between the Operations and the Systems Implementation categories to consolidate funding for the more significant capabilities being implemented in the Space Tracking and Data Systems program.

d Undistributed. Total 1980 R&D appropriation = $4,091,086,000.

e Amended budget submission. Initial submission = $359,000,000.

f Appended appropriation (6-3-81) reflects the effect of General Provision, Sec. 412. Basic appropriation was $349,000,000.

g Amended budget submission. Initial submission = $435,200,000. The decrease reflects the general congressional reduction of the FY 1982 appropriation and FY 1983 decreases, including the closing of the Quito and Tula Peak tracking stations, the closure of the deep space twenty-six-meter antenna subnetwork, a reduction in staffing at a number of STDN tracking stations, an adjustment in the deep space systems implementation program based on requirements for the Deep Space Network configuration, a reprogramming to the Construction of Facilities appropriation for two thirty-four-meter antenna facilities, the decision to lease major computer replacement systems, and the rephasing of the space telescope data capture system.

h Amended budget submission. Initial submission = $508,900,000. The decrease reflects the application of a portion of the general congressional reduction in the FY 1983 appropriation request. The major portion of the reduction occurred in the Space Network budget line because of a revision in the date for the initiation of TDRSS loan repayments and a decrease in the projected amount to be borrowed under the Federal Financing Bank loan. A second portion of the decrease occurred in the Ground Network budget line item from decreased staffing and related support requirements in the STDN.

i This includes both the SFC&DC and R&D budget categories controlled by OSTDS. Revised SFC&DC amount = $674,000,000 (initial = $700,200,000); R&D amount = $14,200,000 (no revision). The decrease reflects a reduction in the payment to the Federal Financing Bank consistent with the FY 1984 HUD-Independent Agencies Appropriations Conference Agreement and the application of a portion of the general appropriation reduction to this program. Within the initial operating plan, adjustments were made primarily to accommodate the impact on the program resulting from the failure of the inertial upper stage to properly deploy the first TDRS to geosynchronous orbit in April 1983.

j This includes amounts for both the new SFC&DC appropriations category and R&D appropriations category. All Space Tracking and Data Acquisition activities moved to SFC&DC except Advanced Systems, which remained in R&D.

Table 4–1 continued

k This includes both the SFC&DC and R&D budget categories controlled by OSTDS. SFC&DC amount = $795,700,000; R&D amount = $15,300,000.

l This includes both the SFC&DC and R&D budget categories controlled by OSTDS. Revised SFC&DC amount = $660,400,000 (initial SFC&DC amount = $808,300,000); Revised R&D amount = $15,500,000 (initial R&D amount = $16,200,000).

m This includes both the SFC&DC and R&D budget categories controlled by OSTDS. SFC&DC amount = $795,700,000; R&D amount = $15,300,000.

n This includes both the SFC&DC and R&D budget categories controlled by OSTDS. SFC&DC amount = $808,300,000; R&D amount = $16,200,000.

o This includes both the SFC&DC and R&D budget categories controlled by OSTDS. SFC&DC amount = $701,300,000; R&D amount = $16,200,000.

p This includes both the SFC&DC and R&D budget categories controlled by OSTDS. SFC&DC amount = $701,300,000; R&D amount = $16,200,000.

q This includes both the SFC&DC and R&D budget categories controlled by OSTDS. Revised SFC&DC amount = $862,900,000 (initial SFC&DC budget submission = $798,900,000); R&D budget submission = $17,100,000 (no change between revised and initial submission).

r This includes both the SFC&DC and R&D budget categories controlled by OSTDS. Revised SFC&DC amount = $884,400,000 (initial SFC&DC amount = $948,900,000); R&D amount = $18,100,000. The reduction reflects a reduction of $40 million for the TDRSS Replacement and a general reduction consistent with congressional direction.

s Reductions from budget submission in SFC&DC budget categories. No change to R&D budget submission.

t Reductions from budget submission in SFC&DC budget categories. No change to R&D budget submission.

Table 4–2. Major Budget Category Programmed Funding History (in thousands of dollars)

Budget Category/Fiscal Year	**1979**	**1980**	**1981**	**1982**	**1983**
Tracking and Data Acquisition (R&D)	299,900	332,100	339,900	402,100	485,500
Operations	249,903	264,400	266,496		
System Implementation	40,497	57,100	62,105		
Advanced Systems	9,500	10,600	11,300	12,500	13,400
Space Network				21,800	104,300
Ground Network				237,457	242,920
Communications and Data Systems				130,343	138,280

Budget Category/Fiscal Year	**1984**	**1985**	**1986**	**1987**	**1988**
Space and Ground Networks, Communication, and Data Systems (SFC&DC)	674,000	795,700	660,400	845,400	879,400
Space Network	259,300	378,300	273,700	404,300	433,400
Ground Network	249,300	233,200	210,400	237,200	231,000
Communications and Data Systems	165,600	184,200	176,300	203,900	215,000
Tracking and Data Advanced Systems (R&D)	14,200	14,800	15,500	17,100	17,900
Advanced Systems	14,200	14,800	15,500	17,100	17,900

Table 4–3. Operations Funding (in thousands of dollars)

Year	Request	Authorization	Appropriation	Programmed (Actual)
1979	254,200	254,200	*a*	249,903
1980	264,500 *b*	275,800	*c*	264,400
1981	267,100 *d*	270,750	267,100 *e*	266,495
1982	300,500 *f*	*g*	305,500	*h*
1983	338,200	*i*	338,200	*j*

a Undistributed. Total 1979 R&D appropriation = $3,477,200,000.
b Amended budget submission. Original budget submission = $275,800,000.
c Undistributed. Total 1980 R&D appropriation = $$4,091,086,000.
d Amended budget submission. Initial submission = $271,500,000.
e Appended appropriation (6-3-81) reflected the effect of General Provision, Sec. 412. Basic appropriation was $270,000,000.
f Amended budget submission. Initial submission = $309,800,000.
g Undistributed. Total 1982 Tracking and Data Acquisition authorization = $408,180,000.
h Budget categories changed in FY 1984 Budget Estimate, which included FY 1982 programmed amounts.
i Undistributed. Total 1983 Tracking and Data Acquisition authorization = $503,900,000.
j Reordering of budget categories split Operations among Space Network (Table 4–17), Ground Network (Table 4–24), and Communications and Data Systems (Table 4–31).

Table 4–4. Spaceflight Tracking and Data Network (STDN) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	129,100 *a*	127,068
1980	136,400 *b*	130,530
1981	130,400 *c*	130,652
1982	143,600 *d*	*e*

a Revised budget submission. Original submission = $129,900,000.
b Revised budget submission. Original submission = $141,200,000. The decrease results primarily from the delay in the Shuttle orbital flight test schedule and termination of ATS-6 support.
c Revised budget submission. Original submission = $133,300,000. The decrease reflects the general reduction to FY 1981 appropriations that would result in the closure of telemetry links at Alaska and the Network Test and Training Facility, a one-shift reduction at the Hawaii station, and the consolidation of a mission control activity for HEAO-2 and HEAO-3.
d Revised budget submission. Original submission = $149,100,000.
e This became part of new Ground Network budget category. Most STDN costs moved to STDN Operations (Table 4–20). TDRSS-related costs moved to new TDRSS budget categories (Tables 4–18, 4–19, and 4–20).

Table 4–5. Deep Space Network Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	49,800	51,032
1980	49,500 *a*	58,200
1981	56,000 *b*	54,427
1982	63,400 *c*	*d*

a Revised budget submission. Original submission = $55,600,000. The decrease reflects the transfer of funding for Jet Propulsion Laboratory engineering efforts associated with specific projects from the Operations budget to the Systems Implementation budget so that budgeting for specific projects resides in one program area.
b Revised budget submission. Original submission = $54,100,000.
c Revised budget submission. Original submission = $64,400,000.
d See Table 4–28.

Table 4–6. Aeronautics and Sounding Rocket Support Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	4,900	4,516
1980	5,300 *a*	4,830
1981	5,500	6,025
1982	6,600 *b*	*c*

a Revised budget submission. Original submission = $4,800,000. The increase provides for operational communications in support of the tilt rotor program and Shuttle at Dryden Flight Research Center and the rehabilitation of heavy mechanical subsystems for the radar and antenna pedestals at Wallops Flight Facility.
b Revised budget submission. Original submission = $6,800,000.
c See Table 4–30.

Table 4–7. Communications Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	34,800 *a*	34,027
1980	37,700 *b*	35,130
1981	37,400 *c*	37,531
1982	39,800 *d*	*e*

a Revised budget submission. Original submission = $37,900,000.
b Revised budget submission. Original submission = $39,800,000. The decrease reflects the delay in the Shuttle orbital flight test schedule, which allowed for a delay in ordering up the wideband and video communications circuits required for Shuttle support and lower than originally estimated prices for some overseas wideband circuits.
c Revised budget submission. Original submission = $39,300,000.
d Revised budget submission. Original submission = $40,500,000.
e See Table 4–33.

Table 4–8. Data Processing Operations Funding History, 1979–1982 (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	33,000 *a*	33,260
1980	35,600 *b*	35,890
1981	37,800	37,860
1982	47,100 *c*	*d*

a Revised budget submission. Original submission = $31,700,000.

b Revised budget submission. Original submission = $34,400,000. The increase reflects greater-tan-expected costs associated with bringing the Image Data Processing Facility into full operation and the implementation of a domsat terminal for rapid handling of Landsat data.

c Revised budget submission. Original submission = $44,700,000.

d See Table 4–37.

Table 4–9. Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	41,300	41,300	*a*	40,497
1980	57,300 *b*	46,400	*c*	57,100
1981	62,700 *d*	67,700	62,700 e	62,105
1982	89,100 *f*	*g*	97,200	*h*
1983	96,000	*i*	96,000	*j*

a Undistributed. Total 1979 R&D appropriation = $3,477,200,000.

b Amended budget submission. Original budget submission = $46,400,000.

c Undistributed. Total 1980 R&D appropriation = $$4,091,086,000.

d Amended budget submission. Initial submission = $76,200,000.

e Appended appropriation (June 3, 1981) reflected the effect of General Provision, Sec. 412. Basic appropriation was $67,700,000.

f Amended budget submission. Initial submission = $112,900,000.

g Undistributed. Total 1982 Tracking and Data Acquisition authorization = $408,180,000.

h Budget categories changed in FY 1984 Budget Estimate, which included FY 1982 programmed amounts.

i Undistributed. Total 1983 Tracking and Data Acquisition authorization = $503,900,000.

j Budget category split among Space Network, Ground Network, and Communications and Data Systems budget categories.

Table 4–10. Spaceflight Tracking and Data Network (STDN) Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	13,000	14,085
1980	22,400 *a*	19,320
1981	20,700 *b*	22,775
1982	26,000 *c*	*d*

a Revised budget submission. Original submission = $15,100,000.
b Revised budget submission. Original submission = $22,600,000.
c Revised budget submission. Original submission = $22,900,000.
d Funding moved to STDN Operations and STDN Implementation budget categories. See Tables 4–25 and 4–26.

Table 4–11. Deep Space Network Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	12,500 *a*	10,115
1980	22,400 *b*	15,000
1981	23,100	20,165
1982	36,900 *c*	*d*

a Revised budget submission. Original submission = $14,800,000.
b Revised budget submission. Original submission = $15,100,000. The increase reflects the transfer of funding for the Jet Propulsion Laboratory engineering efforts for specific projects from the Operations budget to the Systems Implementation budget.
c Revised budget submission. Original submission = $41,800,000.
d See Table 4–27.

Table 4–12. Aeronautics and Sounding Rocket Support Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,500	4,052
1980	4,000 *a*	3,850
1981	3,500 *b*	3,345
1982	6,200 *c*	*d*

a Revised budget submission. Original submission = $3,700,000. The increase provides for increased costs associated with the upgrading of radar systems.
b Revised budget submission. Original submission = $4,100,000.
c Revised budget submission. Original submission = $6,400,000.
d See Table 4–29.

Table 4–13. Communications Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	5,100	4,815
1980	4,400 *a*	5,030
1981	3,100 *b*	3,100
1982	4,400	*c*

a Revised budget submission. Original submission = $3,700,000. The increase reflects greater-than-expected costs for the status and control system for the TDRSS multiplexer and fifty-megabyte-per-second transmission capability for the support of Spacelab and Landsat-D.

b Revised budget submission. Original submission = $5,600,000.

c See Table 4–30.

Table 4–14. Data Processing Systems Implementation Funding History, 1979–1982 (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	6,400 *a*	7,430
1980	9,500 *b*	13,900
1981	12,300	12,720
1982	15,600 *c*	*d*

a Revised budget submission. Original submission = $4,900,000.

b Revised budget submission. Original submission = $6,900,000. The increase results from the provision of redundant capability for critical parts of the Spacelab data processing system at Goddard Space Flight Center to ensure a reliable data processing capability.

c Revised budget submission. Original submission = $21,700,000.

d See Table 4–36.

Table 4–15. Advanced Systems Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	9,900	9,900	*a*	9,500
1980	10,600	10,600	*b*	10,600
1981	11,300	11,300	11,300	11,300
1982	12,500	*c*	12,500	12,500
1983	13,400	*d*	13,400	13,400
1984	14,200	14,200	14,200	14,200
1985	15,300	15,300	15,300	14,800
1986	15,000 *e*	16,200	16,200	15,500
1987	17,100	17,100	17,100	17,100
1988	18,100	18,100	18,100	17,900

a Undistributed. Total 1979 R&D appropriation = $3,477,200,000.
b Undistributed. Total 1980 R&D appropriation = $$4,091,086,000.
c Undistributed. Total 1982 Tracking and Data Acquisition authorization = $408,180,000.
d Undistributed. Total 1983 Tracking and Data Acquisition authorization = $503,900,000.
e Revised budget submission. Original submission = $16,200,000.

Table 4–16. Initial TDRSS Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1983	61,300	*b*	61,300	*c*

a The TDRSS was included as a major budget category for only one fiscal year. It became part of the Space Network budget category beginning with FY 1984. See Table 4–17.
b Undistributed. Total 1983 Tracking and Data Acquisition authorization = $503,900,000.
b See Table 4–18.

Table 4–17. Space Network Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1982		*a*		21,800
1983	498,900 *b*	—	—	104,300 *c*
1984	259,100 *d*	294,700	284,700 *e*	259,100
1985	378,300 *f*	386,500	386,500	378,300
1986	273,700 *g*	293,800 *h*	293,800	273,700
1987	407,300 *i*	374,300	407,300	404,300
1988	435,700 *j*	457,500	426,500 *k*	433,400

a No submission, authorization, or appropriation in this program category.

b Budget submission reflects reordering of budget categories and inclusion of Space Networks in SFC&DC appropriation that began at the time of the FY 1984 budget estimate (and revised FY 1983 budget estimate). This budget category included items from both former Operations and Systems Implementation categories. Authorization and appropriations did not yet reflect the new budget category.

c This reflects only the original R&D budget categories.

d Revised budget submission. Initial submission = $294,700,000.

e Moved to SFC&DC appropriations category. The reduction of $10,000,000 reflects a payment to the Federal Financing Bank.

f Revised budget submission. Initial submission = $386,500,000. The reduction results from the impact of the addition slip in the launch schedule of the TDRS-B and -C because of the inertial upper stage anomaly on TDRS-1 and adjustments in the operation of the NASA ground elements of the Space Network.

g Revised budget submission. Original submission = $400,800,000. The reduction reflects the net effect of the congressional direction to defer the FY 1986 principal payment of $107.0 million for the TDRSS to the Federal Financing Bank and the reallocation of $7.5 million to Ground Network and Communications and Data Systems. The adjustment was need to continue operation of the ground station network and necessary communications into late FY 1986.

h The $59,000,000 reduction from NASA's budget submission agreed to by both the House and Senate authorization committees in separate deliberations reflects the deferral of the scheduled $107 million principal payment to the Federal Financing Bank, an additional authorization of $48,000,000 to the TDRSS program, and the implementation of a general reduction of $4,000,000. The Conference Committee further reduced the authorization to$293,800,000 (a reduction of $107,000,000), eliminating the additional authorization to the TDRSS program.

i Revised budget submission. Initial submission = $374,300,000.

j Revised budget submission. Initial submission = $481,500,000.

k This reduction reflects a reduction of $40,000,000 from the amount requested for the replacement of a tracking and data relay satellite lost on *Challenger* and a reduction of $15,000,000 for general tracking and data acquisition activities.

Table 4–18. Tracking and Data Relay Satellite System Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1983	51,300 *a*	41,000
1984	204,300 *b*	204,300
1985	316,600 *c*	316,600
1986	210,500 *d*	205,600
1987	301,500	285,098
1988	318,900 *e*	318,900

a This reflects amounts from the TDRSS (Table 4–16) and Spaceflight Tracking and Data Network budget category.

b Revised budget submission. Original submission = $242,900,000. The decrease resulted from the restructuring of the TDRSS loans with the Federal Financing Bank and the schedule impact of an inertial upper stage anomaly. Included in the deferred activities because of the schedule impact are testing and some launch-related items.

c Revised budget submission. Initial submission = $319,900,000. The decrease resulted from a delay in the launch of TDRS-B and -C because of the anomaly experienced during the first launch.

d Revised budget submission. Initial submission = $335,600,000. The decrease includes a $107 million reduction in the payment of principal on the TDRSS loans to the Federal Financing Bank, consistent with congressional direction. The balance of the reduction resulted from adjustments in launch and production schedules because of the delay in the launch of the second and third spacecraft.

e Revised budget submission. Initial submission = $320,900,000. The decrease reflects a detailed reassessment of support requirements, leading to greater-than-anticipated savings during the STS standdown period.

Table 4–19. Space Network Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	8,400
1983	34,400 *b*	42,500
1984	31,300 *c*	31,300
1985	35,900 *d*	36,151
1986	40,500 *e*	40,500
1987	43,700	35,700
1988	42,700 *f*	40,400

a See Table 4–4.

b Revised budget submission. Initial submission = $33,500,000.

c Revised budget submission. Initial submission = $31,800,000. The decrease resulted from revised operational requirements for the Network Control Center.

d Revised budget submission. Initial submission = $40,800,000. The decrease was caused by the launch delay and changes in operational support requirements, primarily for the Operations Support Computing Facility and the Network Control Center. The delay in the TDRSS program, along with schedule slips in user programs, resulted in a reassessment of support requirements and a "stretchout" in the projected support workload.

e Revised budget submission. Initial submission = $37,100,000. The increase reflects the operational support requirements in the Space Network caused by the delay of the TDRSS program.

f Revised budget submission. Initial submission = $43,900,000. The decrease reflects revised budget estimate results from reduced contractor support required during the period, principally as a result of the STS standdown.

Table 4–20. Systems Engineering and Support Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	13,400
1983	18,100 *b*	20,800
1984	23,500 *c*	23,500
1985	25,800	25,549
1986	22,700 *d*	21,300
1987	28,100	26,404
1988	26,700 *e*	26,700

a See Table 4–4.

b Revised budget submission. Initial submission = $18,000,000.

c Revised budget submission. Initial submission = $20,000,000. The increase was because of additional engineering and software support for the Network Control Center, a higher rate switching capability for the NASA Ground Terminal, and an additional transponder required for the Bilateration Ranging Transponder System.

d Revised budget submission. Initial submission = $28,100,000.

e Revised budget submission. Initial submission = $25,600,000. The increase reflects the necessary advanced planning to support the development of space station operational concepts, interface definition for data handling and distribution, and support requirements definition.

Table 4–21. TDRS Replacement Spacecraft Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1986	*a*	4,900
1987	33,000	50,398
1988	35,800 *b*	35,800

a No submission.

b Revised budget submission. Previous submission = $75,800,000. The decrease reflects congressional action on the NASA FY 1988 budget request.

Table 4–22. Second TDRS Ground Terminal Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1986		1,400
1987	1,000	2,700
1988	7,600 *b*	7,600

a No submission.

b Revised budget submission. Previous submission = $9,100,000. The decrease reflects a rephasing of procurement activities planned for FY 1988 into FY 1989.

Table 4–23. Advanced TDRSS Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1987	*a*	4,000
1988	4,000	7,600

a No submission.

Table 4–24. Ground Network Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1982		*a*		237,457
1983	242,400 *b*	—	—	242,920
1984	249,300 *c*	231,500	231,500 d	249,300
1985	233,200 *e*	223,600	223,600	233,200
1986	210,400 *f*	219,300	219,300	210,400
1987	250,100 *g*	222,000	250,100	237,200
1988	232,200 *h*	257,100	257,100	231,000

a No submission, authorization, or appropriation in this program category.

b Revised budget submission. Initial submission = $243,500,00. This reflects reordered budget categories at the time of the revised submission. Congressional committees acted on former R&D budget categories.

c Revised budget submission. Initial submission = $231,500,000.

d Moved to SFC&DC appropriations category.

e Revised budget submission. Initial submission = $233,600,000. The increase resulted from program adjustments made to accommodate an additional six months of STDN station operations from April 1 through September 30, 1985. This extension resulted from the additional delay in the launch of TDRS-B and –C and in the availability of two fully operational TDRS spacecraft.

f Revised budget submission. Initial submission = $219,300,000.

g Revised budget submission. Initial submission = $222,000,000.

h Revised budget submission. Original submission = $257,100,000.

Table 4–25. Spaceflight Tracking and Data Network (STDN) Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	3,900
1983	6,000	6,000
1984	8,600 *b*	8,500
1985	6,600 *c*	6,400
1986	3,000 *d*	3,000
1987	3,900	3,800
1988	3,200 *e*	3,200

a See Table 4–10.

b Revised budget submission. Original submission = $8,100,000.

c Revised budget submission. Original submission = $6,300,000. The increase was for sustaining STDN systems and facilities for an extended time period because of the delay in the station closure dates.

d Revised budget submission. Original submission = $2,700,000.

Table 4–26. Spaceflight Tracking and Data Network (STDN) Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	120,536
1983	118,200 *b*	118,500
1984	120,800 *c*	119,800
1985	93,000 *d*	91,447
1986	53,200 *e*	53,960
1987	81,400	78,000
1988	70,100 *f*	68,000

a See Table 4–4.
b Revised budget submission. Original submission = $120,700,000.
c Revised budget submission. Original submission = $102,500,000. The increase results from the additional six months of tracking operations for Shuttle support in FY 1984 caused by the delay in the TDRSS reaching operational status (because of inertial upper stage problems), thus requiring the ground stations to provide Shuttle and other support until the TDRSS becomes operational.
d Revised budget submission. Initial submission = $83,300,000. The increase reflects the additional six months of tracking operations in FY 1985 for Shuttle and other support brought about by the delay in the TDRSS reaching operational status.
e Revised budget submission. Initial submission = $58,700,000.
f Revised budget submission. Initial submission = $84,600,000. The decrease reflects program adjustments made to accommodate a portion of the general reduction specified by Congress and a reallocation of funds for increased communications support requirements.

Table 4–27. Deep Space Network Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	36,900
1983	45,300 *b*	44,300
1984	38,100	38,800
1985	37,100	37,100
1986	43,000 *c*	42,765
1987	44,000	40,000
1988	46,200 *d*	46,200

a See Table 4–11.
b Revised budget submission. Original submission = $44,800,000.
c Revised budget submission. Original submission = $44,400,000.
d Revised budget submission. Original submission = $49,000,000. The decrease reflects the decision to defer various system upgrades.

Table 4–28. Deep Space Network Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	63,296
1983	61,300	61,300
1984	65,500	65,500
1985	76,800	77,661
1986	85,700 *b*	85,301
1987	93,300	87,700
1988	88,000 *c*	88,900

a See Table 4–5.

b Revised budget submission. Original submission = $88,900,000.

c Revised budget submission. Original submission = $94,100,000. The decrease reflects a reallocation of funds for increased communications support requirements and the rephasing of activities to accommodate a portion of the general reduction.

Table 4–29. Aeronautics, Balloon, and Sounding Rocket Support Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	6,255
1983	3,800	4,120
1984	8,100	8,600
1985	8,200	8,965
1986	10,500 *b*	10,434
1987	11,200	11,200
1988	8,200 *c*	8,200

a See Table 4–12.

b Revised budget submission. Original submission = $11,400,000.

c Revised budget submission. Original submission = $8,400,000.

Table 4–30. Aeronautics, Balloon, and Sounding Rocket Support Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	6,570
1983	7,800	8,700
1984	8,200	8,152
1985	11,500 *b*	11,627
1986	15,000 *c*	14,940
1987	16,300	16,500
1988	16,500 *d*	16,500

a See Table 4–6.

b Revised budget submission. Original submission = $11,900,000.

c Revised budget submission. Original submission = $13,200,000.

d Revised budget submission. Original submission = $16,300,000. The increase reflects support of the supernova sounding rocket campaigns in Australia.

Table 4–31. Communications and Data Systems Funding History (in thousands of dollars)

Year (Fiscal)	**Submission**	**Authorization**	**Appropriation**	**Programmed (Actual)**
1982		*a*		130,343
1983	139,300 *b*	—	—	138,280
1984	165,600 *c*	159,800	159,800 *d*	165,600
1985	184,200 *e*	185,600	185,600	184,200
1986	176,300 *f*	188,200	188,200	176,300
1987	205,500 *g*	202,600	205,500	203,900
1988	216,500 *h*	210,300	210,300	215,000

a No submission, authorization, or appropriation in this budget category.

b New SFC&DC budget category replaced former Communications Systems Operations (Table 4–7), Communications Systems Implementation (Table 4–13), and Data Processing (Table 4–8) budget categories.

c Revised budget submission. Original submission = $159,800,000.

d Moved to SFC&DC appropriations category.

e Revised budget submission. Initial submission = $185,600,000. The reduction reflects the net result of adjustments in program support and equipment deferrals required to fund an additional six months of communications costs for operating the STDN stations and the increases in the Ground Network.

f Revised budget submission. Original submission = $188,200,000.

g Revised budget submission. Initial submission = $202,600,000.

h Revised budget submission. Initial submission = $210,300,000.

Table 4–32. Communications Systems Implementation Funding History (in thousands of dollars)

Year (Fiscal)	**Submission**	**Programmed (Actual)**
1982	*a*	4,250
1983	5,600	5,600
1984	5,900 *b*	5,912
1985	6,500	6,500
1986	5,500 *c*	5,500
1987	7,400	6,800
1988	6,300	7,000

a See Table 4–13.

b Revised budget submission. Initial submission = $5,300,000.

c Revised budget submission. Original submission = $6,500,000.

Table 4–33. Communications Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	39,731
1983	45,600	45,700
1984	64,600 *b*	64,600
1985	73,000 *c*	73,000
1986	82,100 *d*	82,049
1987	91,700	16,500
1988	109,500 *e*	109,400

a See Table 4–7.

b Revised budget submission. Initial submission = $59,700,000. The increase reflects the need to provide communications with the overseas tracking sites for Shuttle support longer than planned because of the delay in the TDRSS becoming fully operational.

c Revised budget submission. Original submission = $68,200,000. The increase reflects the need to provide communications with the overseas tracking sites for Shuttle support longer than planned because of the delay in the TDRSS becoming fully operational.

d Revised budget submission. Original submission = $75,700,000. The increase reflects the need to provide communications with the STDN tracking sites for Shuttle support longer than planned because of the delay in TDRS launches.

e Revised budget submission. Original submission = $95,700,000. The increase reflects increased requirements in the Program Support Communications Network (PSCN) to meet user demands. The PSCN increase was partially offset by further NASCOM savings associated with the STS standdown.

Table 4–34. Mission Facilities Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	8,900
1983	10,900	10,900
1984	12,900 *b*	13,545
1985	12,400	12,675
1986	13,800 *c*	13,820
1987	12,200	12,200
1988	11,500 *d*	9,900

a No budget category.

b Revised budget submission. Original submission = $18,600,000.

c Revised budget submission. Original submission = $27,100,000.

d Revised budget submission. Original submission = $27,000,000. The decrease reflects the rephasing of mission support requirements.

Table 4–35. Mission Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	14,838
1983	17,800	16,200
1984	19,100 *b*	18,260
1985	21,900	21,200
1986	18,900 *c*	18,900
1987	23,700	23,300
1988	25,000 *d*	25,400

a No budget category.

b Revised budget submission. Original submission = $18,600,000.

c Revised budget submission. Original submission = $27,100,000.

d Revised budget submission. Original submission = $27,000,000. The decrease reflects the rephasing of mission support requirements.

Table 4–36. Data Processing Systems Implementation Funding History, 1982–1988 (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	15,492
1983	19,500	20,580
1984	22,400	23,683
1985	24,400 *b*	25,016
1986	21,100 *c*	21,100
1987	28,400	24,385
1988	21,500	22,200

a See Table 4–14.

b Revised budget submission. Original submission = $26,600,000. The decrease reflects a reduction in the number of Nimbus and Landsat data products to be processed.

c Revised budget submission. Original submission = $24,100,000.

Table 4–37. Data Processing Operations Funding History, 1982–1988 (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	47,082
1983	39,900	39,300
1984	40,700 *b*	39,600
1985	46,000 *c*	45,809
1986	34,900 *d*	34,931
1987	42,100	41,700
1988	42,700 *e*	41,100

a See Table 4–8.

b Revised budget submission. Original submission = $42,300,000.

c Revised budget submission. Original submission = $50,000,000.

d Revised budget submission. Original submission = $41,500,000.

e Revised budget submission. Original submission = $46,700,000. The decrease reflects the termination of Nimbus mission support and the rephasing of procurements planned for future Spacelab mission support.

Table 4–38. Tracking and Data Acquisition Stations (1979–1988)

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
Alaska (near Fairbanks	ALASKA	64º59'N 147º31'W	X		1962	1984	GRARR and MOTS; SATAN receivers and command; dish antennas (12, 14 and 26 m)	It was transferred to NOAA in 1984.
Ascension Island (South Atlantic)	ACN	7º57'S 14º35'W	X		1966	1989	9-m USB command and receive; SATAN VHF telemetry links; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, UHF air-to-ground, teletype, video, and high-speed data)	
Bermuda (Atlantic)	BDA	32º15'N 64º50'W	X		1961		C-band radar; two 9-m USB command and receive antennas (single link with dual antennas); telemetry links; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, UHF air-to-ground, teletype, video, and high-speed data)	Data received at Bermuda were crucial in making the go/no go decision for orbital insertion. The station also provided reentry tracking for Atlantic recovery situations.
Buckhorn Lake, CA (Dryden)	BUC	34º56'N 117º54'W	X		1975	1983	Two 4.3-m UHF air-to-ground, C-band radars for Shuttle support	The site was established to support Shuttle approach and landing test and flight test landings. It was closed after the STS-8 night landing. One 4.3-m antenna was moved to Dryden in 1985.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
Canberra (southeastern Australia)	CAN	35º24'S 148º59'E	X		1965	1984	FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, video, teletype, and high-speed data)	This was transferred to DSN in 1984. It was also called Tidbinbilla. The 26-m antenna moved from closed DSS 44 to the main DSN complex in Tidbinbilla.
	42 Weemala	35º24'S 148º58'E		X			34-m antenna; transmit and receive	This supported the Voyager spacecraft. It expanded from the 26-m antenna.
	43 Ballima	35º24'S 148º58'E		X	1973		70-m antenna; transmit and receive	The 70-m antenna was extended from the original 64-m antenna in 1987 to support the Voyager 2 encounter with Neptune.
	44			X	1965	1982	USB 26-m antenna	The antenna moved to Tidbinbilla in 1984 and became DSS 46. It originally was the Honeysuckle Creek antenna.
	45	35º23'S 148º58'E		X	1985		34-m antenna; receive only	This supported the Voyager spacecraft.
	46	35º24'S 148º58'E		X	1984		USB 26-m antenna	The 26-m antenna moved from Honeysuckle Creek in 1984. This Transferred from STDN in 1985.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
Dakar, Senegal	DKR	14º43'N 17º08'W	X		1982		4.3-m command and receive antenna; UHF voice air-to-ground, command and receive antenna	
Dryden Flight Research Facility ATF-2	DFRF	34º56'N 117º54'W	X		1978		Two C-band radars on Western range to provide Shuttle support; 4.3-m S-band antenna; 7-m antenna; communications (voice, UHF air-to-ground, teletype, video, and high-speed data)	This began operations in 1978 for the Shuttle program. It was providing aeronautics tracking earlier. It received one 4.3-m S-band antenna from the Buckhorn Lake site in 1985, making a total of two 4.3-m antennas at Dryden.
Gaberone, Botswana (southern Africa)	BOT	24º42'S 25º52'E	X		1981	1986	UHF air-to-ground voice system; Yagi command and receive	It was also called Kgale. Located near South Africa, Botswana could pick up many of the functions formerly handled by Johannesburg, which closed in 1975. Surplus equipment was donated to the Botswana National Museum.
Goldstone (California)								Located in the Mojave Desert, Goldstone has the largest concentration of NASA tracking and data acquisition equipment. All 26-m antennas were principally dedicated to deep space programs. Coverage was also available for transfer orbit operations and tracking and data acquisition for near-Earth orbital spacecraft.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	Type of Station DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
	GDS	35º20'N	X		1967	1985	26-m antenna; 9-m antenna; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, teletype, video, and high-speed data)	This was turned over to DSN in 1985 and redesignated as DSS 16 and DSS 17.
	ECHO 12	35º17'N 116º44'W		X	1960		34-m antenna; transmit and receive	The original 26-m antenna was extended to 34 m in 1979. This supported the Voyager spacecraft.
	MARS 14	35º25'N 116º44'W		X	1966		70-m antenna; transmit and receive	The 70-m antenna replaced the 64-m antenna in 1988 to support the Voyager 2 encounter with Uranus.
	PIONEER 11	35º23'N 116º44'W		X	1958	Early 1980s	26-m antenna	
	VENUS 13	35º23'N 116º53'W		X	1962		9-m antenna closed; 26-m antenna	This was a research and development facility.
	URANUS 15	35º25'N 116º42'W		X	1984		34-m antenna; receive only	This was used for the first time in 1986 to support the Voyager spacecraft.
	16	35º20'N 116º53'W		X	1965		USB 26-m antenna	The equipment was moved from STDN in 1985.
	17	35º20'N 116º53'W		X	1967		USB 9-m antenna; backup for DSS 16	This was transferred from STDN in 1985.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station: STDN	Type of Station: DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
Greenbelt, MD (NTTF)	BLT	38º59'N 76º51'W	X	X	1966	1986	18-m antenna used for IUE support given to the Naval Academy; 9-m antenna moved Wallops in 1986	Located at Goddard Space Flight Center, this became part of the operational network in 1974. In 1986, all orbital satellite tracking/telemetry operations were transferred to Wallops.
Guam (Pacific)	GWM	13º18'N 144º44'E	X		1966	1990	9-m USB command and receive antenna; VHF telemetry links; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, UHF air-to-ground, teletype, video, and high-speed data)	
Kohee Park (Hawaii)	KAUAIH or HAW	22º07'N 157º40'W	X		1961	1989	Two Yagi command; 4.3-m antenna; C-band radar; 9-m USB command and receive antenna; VHF telemetry links; FM remoting telemetry recording; data processing; communications (voice, VHF air-to-ground, teletype, video, and high-speed data)	The Manned Space Flight Network station began operations in 1961; it became the Space Tracking and Data Acquisition Network in 1965.
Madrid (Spain)								There were three individual NASA complexes near Madrid.
	MAD (became RID in 1984)	40º27'N 4º10'W	X		1967		26-m antenna; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, video, teletype, and high-speed data)	This was transferred to DSN in 1985 and redesignated as DSS 66.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
	61 Robledo-I	40º26'N 4º15'W		X	1965		34-m antenna; transmit and receive	This antenna was expanded from 26 m.
	62	40º27'N 4º22'W		X	1967	1969	26-m antenna	This was known as the Cebreros DSN station.
	63 Robledo-II	40º26'N 4º15'W		X	1973		70-m antenna; transmit and receive	This supported the Voyager spacecraft. The antenna expanded to 70 m from 64 m in 1987.
	65 Robledo-III	40º25'N 5º16'W		X	1987		34-m antenna; transmit and receive	This supported the Voyager spacecraft.
	66 Robledo-IV	40º25'N 5º16'W		X	1985		26-m antenna; transmit and receive	This was transferred from STDN in 1985.
Merritt Island (Florida)	MIL	28º25'N 80º40'W	X		1973		9-m command and receive antenna;C-band radar; VHF telemetry links; FM remoting telemetry; decommutators; telemetry recording; data processing; communications (voice, UHF air-to-ground, teletype, video, and high-speed data)	This was located near the Kennedy Space Center launch complex.
Orroral Valley (southeastern (Australia)	ORR	35º38'S 148º57'E	X		1965	1984	26-m antenna; two SATAN receivers and command; YAGI command; MOTS	The 26-m antenna was relocated to the University of Tasmania when Orroral closed in 1984.
Ponce de Leon (Florida)	PDL	29º04'N 279º05'W	X		1978		4.3-m command and receive antenna	This was used for Shuttle support only.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station STDN	Type of Station DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
Quito (Ecuador)	QUITOE	37ºS 78º35’W	X		1957	1981	12-m antenna; SATAN receivers and command; three Yagi command; MOTS	
Rosman, NC	ROSMAN	35º12’N 82º52’W	X		1963	1981	Two 26-m antennas; GRARR; three SATAN receivers and command; MOTS; ATS telemetry and command	This received high-data-rate telemetry from observatory-class satellites. It was turned over to the Department of Defense in 1981.
Santiago (Chile)	AGO	33º09’S 70º40’W	X		1957	1988	9-m antenna; 12-m antenna; GRARR; USB; two SATAN receivers; one SATAN command; Yagi command; MOTS	
Seychelles (Indian Ocean)	IOS	04º40’S 55º28’E	X		1981		18-m antenna	This military site supported the Shuttle.
Tula Peak (New Mexico)	TULA	33º01’N 117º09’W	X		1979	1982	4.3-m antenna; telemetry and command; UHF voice	This was used for STS-1 and –2. It was shut down after STS-2 but reopened to provide emergency support to STS-3.
Wallops Island (Virginia)	WOTS	37º55’N 75º31’W	X		1959		Two 7.3-m receive-only antennas; 6-m command-only antenna; 9-m command and receive antenna; 18-m command and receive antenna; SCAMP VHF command only (broadside array antenna—150 megacycles); SATAN VHF command only (broadside array antenna—150 megacycles); two SATAN VHF receive only	This began providing support for scientific satellites in 1986.

Table 4–38 continued

Station (Location)	Code Name or Number	Latitude Longitude	Type of Station: STDN	Type of Station: DSN	Est.	Out	Phased Equipment/Capabilities	Remarks
White Sands (New Mexico)	WHS	32º21'N 106º22'W	X		1961		Three 18-m Ku-band antennas; two S-band telemetry and command antennas; C-band radar; communications (voice and teletype)	Located on the U.S. Army's White Sands Missile Range, the station was equipped with Defense Department radar and NASA-owned acquisition aids. This was the site of the TDRSS ground station.
Winkfield (United Kingdom)	WNKFLD	52º27'N 00º42'W	X		1961	1981	4.3-m antenna; SATAN receivers and command; Yagi command; MOTS	This was operated by British personnel.
Yarragardee (Australia)	YAR	29º08'S 115º21'E	X		1980	1991	UHF voice air-to-ground command and receive antenna	This provided STS deorbit burn coverage.

Legend: ATF—Aeronautical Training Facility; ATS—Applications Technology Satellite; DSN—Deep Space Network; FM—frequency modulation; GRARR—Goddard range and range rate; MOTS—minitrack optical tracking system; SATAN—satellite automatic tracking antenna; SCAMP—satellite command antenna on medium pedestal; STDN—Spaceflight Tracking and Data Network; TDRSS—Tracking and Data Relay Satellite System; UHF—ultrahigh frequency; USB—unified S-band; and VHF—very high frequency.

Table 4–39. Single-Access Link Summary

Band	Forward Link (White Sands Ground Terminal to User Spacecraft)	Data Rate	Return Link (User Spacecraft to White Sands Ground Terminal)	Data Rate
S	2	0.1 to 300 kilobits per second	2	6 megabits per second maximum
K	2	1 kilobit per second to 25 megabits per second	2	300 megabits per second maximum
	Used for: 1. Commanding user spacecraft 2. Transmitting PN code for range and range rate		Used for: 1. Receiving spacecraft telemetry 2. Receiving PN code turnaround for range and range rate measurements	

PN—Pseudorandom noise.

Table 4–40. Multiple-Access Link Summary

Number of links per TDRS	Forward Link (White Sands Ground Terminal to User Spacecraft)	Data Rate	Return Link (User Spacecraft to White Sands Ground Terminal)	Data Rate
1		0.1 to 10 kilobits per second		
20		Command bit rate capability		0.1 to 50 kilobits per second
	Used for: 1. Commanding user spacecraft 2. Transmitting PN code for range and range rate		Used for: 1. Receiving spacecraft telemetry 2. Receiving PN code turnaround for range and range rate measurements	

PN—Pseudorandom noise.

Table 4–41. TDRS Characteristics

	TDRS-1	TDRS-3
Launch Date	April 4, 1983	September 29, 1988
Launch Vehicle	STS-6 (*Challenger*)/IUS	STS-26 (*Discovery*)/IUS
Range	Kennedy Space Center	Kennedy Space Center
Program Objectives	Establish a three-satellite geosynchronous orbit telecommunications satellite system to provide improve tracking and data acquisition services to spacecraft in low-Earth orbit, procured by NASA through a lease service contract with Spacecom	Establish and provide improved tracking and data acquisition services to spacecraft in low-Earth orbit through a system of two telecommunications satellites in geosynchronous orbit with one additional orbiting satellite to serve as a system space, procured by NASA through a lease service contract with a wholly owned subsidiary of Contel
Mission Objectives	Deliver the first of three TDRS satellites to a stationary geosynchronous orbit location with sufficient stationkeeping propulsion fuel on board to meet the NASA support requirements and initiate TDRS-A user support services	Deliver the second of three TDRS satellites to a stationary geosynchronous orbit location with sufficient stationkeeping propulsion fuel on board to meet the NASA support requirements and initiate dual TDRS satellite user support
Owner	Spacecom, leased by NASA	Contel, leased by NASA
Orbit Characteristics		
Apogee (km)	35,779	35,804
Perigee (km)	35,777	35,764
Inclination (deg.)	2.3	0.1
Period (min.)	1,436	1,434,8
Location	41 degrees W longitude over the equator	171 degrees W longitude over the equator
Weight (kg)	2,268 at launch (with IUS); 2,146 when built	2,224 at launch (with IUS); 2,103 when built
Dimensions	17.4 m across the solar arrays; 14.2 m across the antennas; two 4.9-m-diameter high-gain parabolic antennas	17.4 m across the solar arrays; 14.2 m across the antennas; two 4.9-m-diameter high-gain parabolic antennas
Communications	Two single-access S-/Ku-band antennas, C-band dish, S-band omni antenna, K-band space-to-ground dish antenna, 30-element multiple-access array, and additional K-band antenna mounted on the platform	Two single-access S-/Ku-band antennas,C-band dish, S-band omni antenna, K-band space-to-ground dish antenna, 30-element multiple-access array, and additional K-band antenna mounted on the platform
Power Source	Solar panels and nickel cadmium batteries that provide 1,700-watt peak power in sunlight and support an eclipse period average load of 1,400 watts	Solar panels and nickel cadmium batteries that provide 1,700-watt peak power in sunlight and support an eclipse period average load of 1,400 watts

Table 4–41 continued

	TDRS-1	TDRS-3
Primary Contractors	Spacecom; spacecraft—TRW Space and Technology Group; ground terminal equipment and antennas—Harris Government Communications Systems Division	Contel; spacecraft—TRW Space and Technology Group; ground terminal equipment and antennas—Harris Government Communications Systems Division
Remarks	A malfunction of the IUS left TDRS-1 in an elliptical orbit. A sequence of thruster firings raised the satellite to its proper altitude. It was placed into a geosynchronous orbit located at 67 degrees west longitude over the equator above northwest Brazil and later moved to its operating location at 41 degrees west.	The launch and positioning of TDRS-3 went without problems. The satellite was positioned over the Pacific to give NASA one satellite over each ocean.