SP-4012 NASA HISTORICAL DATA BOOK: VOLUME III

PROGRAMS AND PROJECTS 1969-1978

**CHAPTER SIX**

**TRACKING AND DATA ACQUISITION**

**INTRODUCTION**

[**385**] Simply defined, tracking is the process of determining the location and motion (speed and direction) of a vehicle during all phases of flight. Initial tracking observations of any, flight are especially important; from these data controllers near the launch site determine if the vehicle is on the proper flight path and if it subsequently attains its prescribed flight path. During a mission, either manned or unmanned, knowing the exact location of the spacecraft at certain times is likewise critical to mission success, for antennas, scientific instruments, and cameras have to be in just the right place pointing just the right way. Tracking can be accomplished, optically or by one of several radio wave techniques. [**1**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.1)

Data acquisition is the reception at a ground station of scientific and engineering data generated by a spacecraft. The process of conveying data from spacecraft to earth via radio waves is called radio telemetry. Raw data, often stored on spacecraft recorders until it can be conveniently relayed, are coded and converted into usable information by data reduction equipment at ground stations. Information is sent to a spacecraft (uplinked) in a similar fashion. The process of sending messages to a spacecraft and receiving information from it is generally known as command and control.

**The First Decade Reviewed**

When NASA was established in 1958, it inherited along with several satellite and probe projects four rudimentary systems for tracking and acquiring data: the Naval Research Laboratory's Minitrack radio interferometer system built for the International Geophysical Year (1957-1958); the Jet Propulsion Laboratory (JPL) tracking scheme called Microlock developed to support the Army's Explorer project; JPL's large tracking antenna designed for the Pioneer lunar probe project; and the National Advisory Committee for Aeronautics' (NACA) X-series research aircraft tracking range. The NACA, along with its X-series partner, the U.S Air Force, had also begun to examine the tracking and data acquisition needs of the Air Force's proposed Dyna-Soar reusable earth orbital vehicle. Since the 1940s, the military had [**386**] supported missile research with tracking facilities built along several missile ranges. The Smithsonian Astrophysical Observatory was another organization that offered NASA its expertise in the tracking field. Its 12-station network was equipped with Baker-Nunn cameras capable of tracking satellites optically. From these several tracking schemes, NASA took what it needed to support its first ventures into space.

**Space Tracking and Data Acquisition Network**. The Naval Research Laboratory's Vanguard satellite project included a radio tracking network dubbed Minitrack, which used radio interferometers and Yagi antennas to obtain orbital data on satellites whose orbits did not incline more than 45 degrees.[**\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n1) Originally Minitrack was composed of nine stations, several of which were strung along the 75th meridian within 45 degrees north or south of the equator. In 1959 when NASA took over management of Vanguard, Minitrack had grown to include 12 stations. [**\*\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n2)But during the early 1960s, the satellite network was always changing. Stations were added to support spacecraft with orbits that took them further away from the equator; existing stations were improved; others were dropped from the net.[**2**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.2) In 1960, the network switched to a frequency of 136-137 megahertz, a range set aside by the International Telecommunications Union for space research. The Rosman, North Carolina, station, which opened in 1963, was the first of a second generation of satellite tracking facilities that did not require an interferometer. It sported a 26-meter pointable antenna, which supported the new observatory-class-satellite.

As NASA's satellites became more sophisticated, data' acquisition rather than tracking became the more critical of the network's tasks, and the equipment added to the stations reflected the change. Satellite Automatic Tracking Antennas (SATAN) - one type for telemetry reception, a second for command - replaced the Yagi arrays to serve either as a complement to the large dish antennas or as the prime receiver-command antenna at stations where there were no large dishes. Since the original Minitrack system could not track spacecraft sent into highly eccentric or synchronous orbits, specialists at the Goddard Space Flight Center, which had been assigned the satellite tracking and data acquisition task, devised an alternate tracking device called Goddard Range and Range Rate Equipment (GRARR). The GRARR sent a signal to the spacecraft, which replied through a transponder. By recording the time of signal transit to and from the satellite, distance could be determined, while doppler measurement could provide range rate. By 1964, NASA officials were using the name Space Tracking and Data Acquisition Network (STADAN) for this expanded, updated satellite network.[**3**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.3)

Improved tracking and data acquisition equipment and increased automation allowed NASA to work toward maintaining a minimum number of stations. From 22 stations in 1965, the system was reduced to 17 in 1968.[**\*\*\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n3) Goddard served as [**387**] mission control for the satellites that STADAN supported. The center was also the site of the Network Test and Training Facility (NTTF), where new-equipment bound for tracking stations was tested and new personnel were trained.

**Manned Spaceflight Network**. During the late 1940s, NACA's Pilotless Aircraft Research Station at Wallops Island, Virginia, was tracking experimental aircraft and rockets with radar. Additionally, the military had established missile ranges in the deserts of New Mexico and across the south Atlantic from Florida to the island of Barbados with radar and telemetry equipment at several locations. Equipment borne by aircraft and ships augmented the island-station system. In the 1950s, NACA and the Department of Defense established a joint high-speed research aircraft program that called for sophisticated tracking and communications gear, and in the opinion of many, the logical extension of this program was manned orbital flight. Accordingly, tracking specialists began to define the global tracking network such a mission would require.

The possibility of manned spaceflight was one of several programs that the new space agency began to address in 1958. Working first at the Langley Research Center in Virginia, formerly a NACA laboratory, and later at the Manned Spacecraft Center in Houston, the Space Task Group had a huge task ahead of it, of which tracking was only one of several critical parts. The Space Task Group's mission planners established the base requirements for manned flight tracking operations.[**\*\*\*\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n4) Mercury, the first step in NASA's manned program, demanded continuous coverage by all systems from launch to orbital insertion and again during reentry, two-way voice communications, telemetry trajectory measurements, and uplinked commands, and it made these demands around the globe.

Mercury tracking stations would be equipped with proven C-band (RCA FPS-16) and S-band (Reeves Instrument Corp. Verlort) radar units. Active acquisition aids would assist the narrow-band radars in locating the orbiting spacecraft, and transponders would ensure a strong return signal. UHF (ultrahigh frequency) radio was specified for the primary communications link between the spacecraft and ground stations, with an HF (high frequency) backup and a second set of UHF equipment available at each ground station. Communications on the ground (telemetry, commands, radar acquisition data, tracking data, voice messages, teletype) were to be real-time. A global network of 17 tracking stations was called for, some of which were already in existence as part of military ranges. New sites would connect the Pacific Missile Range with the Atlantic Missile Range, continue the net across Africa, the Indian Ocean, Australia, and the Pacific.[**\*\*\*\*\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n5) The Manned Spaceflight Network (MSFN) was operating by July 1961.

Like the satellite system, the Manned Spaceflight Network changed to meet new [**388**] mission profiles. For missions longer than the first Mercury flights, the network needed beefing up, especially in the Pacific. Additional instrumented ships assisted the network with both voice and telemetry operations, and DoD provided supplementary coverage from its ground stations. In addition, DoD aircraft with voice relay and radar equipment assisted the net during reentry and landing.

The Manned Spaceflight Network had to expand its operations even more during Project Gemini, which called for longer flights with two-man crews and rendezvous operations in earth orbit with two spacecraft. A move toward increased computerization and decreased voice support made possible a more centralized network with fewer primary stations and more secondary stations for Gemini, although those major facilities had to be better equipped. Some Mercury stations were dropped; many were supplemented with new hardware. All was ready in 1965 for the first manned Gemini flight.

Apollo, NASA's manned lunar exploration program, would include operations near earth, in cislunar space, in lunar orbit, and on the moon's surface, most of which was beyond the Manned Spaceflight Network's grasp as it was configured for Gemini. But NASA began to consult with deep space tracking experts regarding Apollo's requirements as early as 1961. The Jet Propulsion Laboratory in Pasadena, California had been in the tracking and data acquisition business since the early 1950s and had begun construction of its first 26-meter-diameter dish antenna for tracking lunar probes before NASA was established. The Mercury-Gemini stations could be adopted for Apollo's near-Earth operations, and JPL's 26-meter antennas or ones like them could reach out to Apollo spacecraft on the Moon. However, since there was some doubt as to whether or not there were enough conventional MSFN stations and because Apollo spacecraft would be sending back more telemetry than existing stations could receive, NASA uprated the equipment at its stations and augmented the ground communications system to ready the network for lunar missions.

For Apollo, NASA introduced a unified (and higher - 1550-5200 megacycles) frequency band, the S-band (USB), for communications. Existing Gemini stations were equipped with 9-meter USB antennas, and three 26-meter USB stations were constructed roughly 120 degrees apart around the globe, located near Deep Space Network antennas at Goldstone in California; near Canberra, Australia, and near Madrid, Spain. USB instrumentation and C-band radar were installed on five tracking ships and VHF/UHF and USB equipment was put on eight aircraft. As it had for Mercury and Gemini, DoD augmented the network with its stations, especially in the south Atlantic. For the first round of Apollo flights, the network was a large one, with 14 primary stations (11 of which were equipped with 9-meter USB antennas), 5 ships, 5 aircraft, 4 secondary stations, and 9 DoD support stations.[**\*\*\*\*\*\***](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n6) In December 1968, Apollo 8's crew orbited the moon, generating scientific and engineering telemetry, photographic images, and voice communications, all of which were received in good order on earth.[**4**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.4)

**Deep Space Network**. U.S. government officials became officially concerned with how to track an object beyond earth orbit in early 1958 when the [**389**] Advanced Research Projects Agency approved the Pioneer lunar probe series. The Jet Propulsion Laboratory's tracking-communications team was able to suggest two possible schemes for tracking spacecraft that would be operating at such distances from earth: a single station in the U.S. equipped with a large parabolic dish antenna, which would be in contact with the spacecraft during a single period daily when it was in view; or a similarly equipped three-station network located roughly 120 degrees apart in longitude, which would provide continuous support. Obviously, the three-station plan was preferable, but there was not enough time to implement it. JPL erected a 26-meter-diameter antenna (Pioneer Station) in southern California's Mojave Desert to support the early Pioneer missions, a series of unsuccessful probes.

JPL's tracking team spent the next several years building and improving the three components of their deep space tracking system: a mission control center at JPL; a communications system that linked the tracking stations with mission control and operated as part of the broader NASA Communications System; and the network of stations. In addition to Goldstone, where a second 6-meter antenna was built, Deep Space Network (DSN) stations were put into operation in Spain (Robledo and Cerebros near Madrid), Woomera and Tidbinbilla, Australia, and South Africa. A 64-meter antenna was under construction as early as 1963. JPL's Space Flight Operations Facility was the functional center of the network.[**+**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n7)[**5**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.5)

**Managing the Tracking and Data Acquisition Program**

Overall management authority for the Office of Tracking and Data Acquisition (OTDA) at NASA Headquarters was assumed by Gerald M. Truszynski for most of the agency's second decade. Truszynski joined the National Advisory Committee for Aeronautics (NACA), NASA's predecessor organization, as an instrumentation specialist, first at the Langley Memorial Aeronautical Laboratory and later at the Edwards Air Force Base-NACA High-Speed Flight Station complex, where he helped develop the X-series aircraft tracking range. In 1960, he came to NASA Headquarters as a staff member of OTDA, becoming Associate Administrator for Tracking and Data Acquisition in 1968. Reporting to Truszynski and his deputy, H. R. Brockett, 1969-1974, and Norman Pozinsky, 1975-1978, were directors for program coordination and management resources (Thomas V. Lucas, 1969-1974, and Richard L. Stock, 1975-1978), network operations and communications (Charles A. Taylor), and network support and systems development (Pozinsky, 1969-1975, and Frederick B. Bryant, 1976-1978). Chiefs for network operations (James C. Bavely), communications and frequency management. (Paul A. Price, 1969-1973, Elbert L. Eaton, 1974-1977, and Harold G. Kimball, 1978), and data processing (Kenneth Webster) further fleshed out the management framework. In 1978, William Schneider took over for the retiring Truszynski. Schneider had been Deputy Associate Administrator for Space Transportation Systems since 1974. (See table 6-1 for details on how the management of the tracking and data acquisition program changed at NASA Headquarters during the decade.)

[**390**] The two centers most directly involved with tracking and data acquisition were the Goddard Space Flight Center in Maryland and the Jet Propulsion Laboratory (JPL) in California. Goddard's activities were managed by two directorates: networks and mission and data operations. Of interest to Goddard managers and engineers were network engineering, facilities and services, computing and analysis, operations, and procedures and evaluation, communications, the Tracking and Data Relay Satellite System, information processing, and advanced data systems. The Space Tracking and Data Acquisition Network and the NASA Communications System were managed at Goddard. Overseeing tracking operations in deep space was assigned to the Jet Propulsion Laboratory, where an assistant laboratory director supervised the Office of Tracking and Data Acquisition. Managers for tracking and data acquisition programs, planning, technology development, mission sup port, program control, operations, and facilities kept the Deep Space Network operating to support interplanetary missions.

* [Table 6-1](http://history.nasa.gov/SP-4012/vol3/table6.1.htm). Two Phases of Tracking and Data Acquisition Management, NASA Headquarters, 1969-1978.

[**391**] **BUDGET**

**Money for Tracking and Data Acquisition**

The Office of Tracking and Data Acquisition's budget was divided three ways: network operations, equipment or systems implementation, and supporting research and technology or advanced systems. Network operations and equipment/systems implementation monies were divided among the Manned Spaceflight Network (through FY 1970), the Space Tracking and Data Acquisition Network, the Deep Space Network, aeronautics and sounding rocket support, communications, and data processing. When the MSFN was disbanded, the cost of maintaining the former manned tracking stations that would now support unmanned missions as well was assigned to the STADAN. Supporting research and technology was renamed the Advanced Systems Program in FY 1971. While most of OTDA's research tasks were carried over in the new program, some of the budget categories were reorganized, dropped, or renamed. For a more detailed breakdown of the tracking and data acquisition budget than is provided in the following tables, consult the NASA annual budget estimates. Consult table 6-3 for a budget summary of the three major program areas and table 6-4 for a summary of the money programmed for the individual networks.

As will be discussed elsewhere in this chapter, NASA made plans during the 1970s to lease rather than buy a Tracking and Data Relay Satellite System, which would simplify tracking operations during the 1980s. The agency funded advanced design studies for the system under a supporting research and technology/advanced systems budget category (table 6-21, New Systems/Spacecraft-to-Ground Communications, Telemetry, and Command). Only in FY 1975 were funds programmed for TDRSS as a distinct program (table 6-28).

Review the bottom notes of the following tables carefully before making conclusions about totals for any single year or for any particular aspect of a program. It would also be useful to review the introduction to the budget section of [chapter 1](http://history.nasa.gov/SP-4012/vol3/ch1.htm) for general information on NASA's budget and on the sources and format used for the budget tables in this book.

* [Table 6-2](http://history.nasa.gov/SP-4012/vol3/table6.2.htm). Total Tracking Data and Acquisition Funding History (in thousands of dollars).
* [**392**] [Table 6-3](http://history.nasa.gov/SP-4012/vol3/table6.3.htm). Programmed Cost by Tracking and Data Acquisition Program Areas (in thousands of dollars).
* [**393**] [Table 6-4](http://history.nasa.gov/SP-4012/vol3/table6.4.htm). Programmed Costs by Network/System (in thousands of dollars).
* [**394**] [Table 6-5](http://history.nasa.gov/SP-4012/vol3/table6.5.htm). Tracking and Data Acquisition Operations Funding History (in thousands of dollars).
* [Table 6-6](http://history.nasa.gov/SP-4012/vol3/table6.6.htm). Tracking and Data Acquisition Operations Manned Spaceflight Network Funding History (in thousands of dollars).
* [Table 6-7](http://history.nasa.gov/SP-4012/vol3/table6.7.htm). Tracking and Data Acquisition Operations -Space Tracking and Data Acquisition Network Funding History (in thousands of dollars).
* [**395**] [Table 6-8](http://history.nasa.gov/SP-4012/vol3/table6.8.htm). Tracking and Data Acquisition Operations-Deep Space Network Funding History (in thousands of dollars).
* [Table 6-9](http://history.nasa.gov/SP-4012/vol3/table6.9.htm). Tracking and Data Acquisition Operations -Aeronautics and Sounding Rocket Support Funding History (in thousands of dollars).
* [Table 6-10](http://history.nasa.gov/SP-4012/vol3/table6.10.htm). Tracking and Data Acquisition -Communications Funding History (in thousands of dollars).
* [**396**] [Table 6-11](http://history.nasa.gov/SP-4012/vol3/table6.11.htm). Tracking and Data Acquisition Operations -Data Processing Funding History (in thousands of dollars).
* [Table 6-12](http://history.nasa.gov/SP-4012/vol3/table6.12.htm). Tracking and Data Acquisition Equipment/Systems Implementation Funding History (in thousands of dollars).
* [Table 6-13](http://history.nasa.gov/SP-4012/vol3/table6.13.htm). Tracking and Data Acquisition Equipment/Systems Implementation - Manned Spaceflight Network Funding History (in thousands of dollars).
* [**397**] [Table 6-14](http://history.nasa.gov/SP-4012/vol3/table6.14.htm). Tracking and Data Acquisition Equipment/Systems Implementation - Space Tracking and Data Acquisition Network Funding History (in thousands of dollars).
* [Table 6-15](http://history.nasa.gov/SP-4012/vol3/table6.15.htm). Tracking and Data Acquisition Equipment/Systems Implementation- Deep Space Network Funding History (in thousands of dollars).
* [Table 6-16](http://history.nasa.gov/SP-4012/vol3/table6.16.htm). Tracking and Data Acquisition Equipment/Systems Implementation Aeronautics and Sounding Rocket Funding History (in thousands of dollars).
* [**398**] [Table 6-17](http://history.nasa.gov/SP-4012/vol3/table6.17.htm). Tracking and Data Acquisition Equipment/Systems Implementation - Communications Funding History (in thousands of dollars).
* [Table 6-18](http://history.nasa.gov/SP-4012/vol3/table6.18.htm). Tracking and Data Acquisition Equipment/Systems Implementation Data Processing Funding History (in thousands of dollars).
* [Table 6-19](http://history.nasa.gov/SP-4012/vol3/table6.19.htm). Tracking and Data Acquisition Supporting Research and Technology/Advanced Systems Funding History (in thousands of dollars).
* [**399**] [Table 6-20](http://history.nasa.gov/SP-4012/vol3/table6.20.htm). Tracking and Data Acquisition Supporting Research and Technology/Advanced Systems -Receiving and Transmitting Subsystems/Tracking, Orbit Determination and Ground-Based Navigation Funding History (in thousands of dollars)
* [Table 6-21](http://history.nasa.gov/SP-4012/vol3/table6.21.htm). Tracking and Data Acquisition Supporting Research and Technology/Advanced Systems-New Systems/Spacecraft-to-Ground Communications,Telemetry, and Command Funding History (in thousands of dollars)
* [Table 6-22](http://history.nasa.gov/SP-4012/vol3/table6.22.htm). Tracking and Data Acquisition Supporting Research and Technology/Advanced Systems-Network Performance and Operations Funding History (in thousands of dollars)
* [**400**] [Table 6-23](http://history.nasa.gov/SP-4012/vol3/table6.23.htm). Tracking and Data Acquisition Supporting Research and Technology/ Advanced Systems -Data Handling and Processing Funding History (in thousands of dollars)
* [Table 6-24](http://history.nasa.gov/SP-4012/vol3/table6.24.htm). Tracking and Data Acquisition Supporting Research and Technology-Integrated Systems Analysis, Development, and Test Funding History (in thousands of dollars)
* [Table 6-25](http://history.nasa.gov/SP-4012/vol3/table6.25.htm). Tracking and Data Acquisition Supporting Research and Technology Antenna Subsystems Funding History (in thousands of dollars)
* [Table 6-26](http://history.nasa.gov/SP-4012/vol3/table6.26.htm). Tracking and Data Acquisition Supporting Research and Technology Spacecraft Subsystems Funding History (in thousands of dollars)
* [**401**] [Table 6-27](http://history.nasa.gov/SP-4012/vol3/table6.27.htm). Tracking and Data Acquisition Supporting Research and Technology - Data Processing and Reduction Funding History (in thousands of dollars)
* [Table 6-28](http://history.nasa.gov/SP-4012/vol3/table6.28.htm). Tracking and Data Acquisition Tracking and Data Relay Satellite System Funding History (in thousands of dollars)

**NETWORK CHARACTERISTICS**

**Manned Spaceflight Network, 1969-1972**

As discussed above, the Manned Spaceflight Network (MSFN) was expanded significantly and its equipment uprated to support lunar exploration missions. In 1969, the network consisted of 10 stations with 9-meter antennas, 3 stations with 26-meter antennas, 1 transportable 9-meter antenna located at Grand Bahama Island, 5 instrumented ships, and 8 aircraft. Additional support could be counted on from the 3 Deep Space Network 26-meter antennas, the STADAN station at Tananarive, and DoD facilities at Point Arguello, the Eastern Test Range, and the White Sands Missile Range.

Apollo 11, the first manned lunar landing, took place in July 1969, and the MSFN provided its support as planned. The 9-meter united S-band antennas were used during near-earth operations, with the 26-meter USB antennas taking over for cislunar and lunar activities. After the successful completion of the first landing, the Apollo mission schedule was revised to reflect a renewed concern by Congress over NASA's budget. Significant changes in the network configuration were also possible for the next flight: only one tracking ship and four aircraft were required, and fewer ground stations were put on line. This smaller network adequately supplied Apollo 12 (1970) with tracking and data acquisition services and served the crew of Apollo 13 when an onboard system failure forced them to make an emergency return trip home. Apollo 14 and 15 were conducted in 1971, with the latter mission giving the trackers an additional piece of apparatus to watch: the Lunar Roving Vehicle. A new Lunar Communications Relay Unit served as a portable relay station between [**402**] the astronauts and the network stations, freeing the astronauts from relying exclusively on the lunar module as their only communications link.

During 1972, the MSFN and the STADAN networks were consolidated as one Spaceflight Tracking and Data Network (STDN). With the increasing trends toward high-data-rate satellites and real-time control requirements for unmanned spacecraft, the small number of manned flights planned for the post-Apollo years, and the always urgent requirement to avoid duplication and unnecessary costs, the agency could not justify operating two distinct nets. Eleven MSFN stations continued to provide for the tracking and data acquisition needs of Apollo and Skylab missions on a priority basis but also began to work with unmanned satellites. The 11 stations transferred to the spaceflight network were located at Cape Kennedy, Bermuda, Ascension Island, Grand Canary Island, Carnarvon, Guam, Kauai; Corpus Christi, Madrid, Canberra, and Goldstone. Additionally, the net retained four instrumented aircraft and one tracking ship. The transportable antenna was moved from Grand Bahama to St. John's, Newfoundland, to provide Skylab launch support.

To test the tracking network as configured for Apollo and to train the ground personnel, NASA launched two Test and Training (TETR) satellites in 1967 and 1968. Also called TTS, TETR I and 2 provided targets for checkout and training of equipment and operations personnel. They were launched as secondary payloads with Pioneer 8 and Pioneer 9, respectively. NASA attempted to launch an additional TETR satellite on August 27, 1969, with Pioneer E. These two satellites failed to orbit because the launch vehicle was destroyed by the range safety officer when it began behaving erratically eight minutes after launch. Another launch on September 29, 1971, with the satellite Orbiting Solar Observatory 7, was successful. The 18-kilogram tracking target TETR 3, was used by the Apollo network personnel to test the net as modified late in the Apollo program.

* [Table 6-29](http://history.nasa.gov/SP-4012/vol3/table6.29.htm). NASA Manned Spaceflight Network Stations, 1969-1972.

[**403**]



Figure 6-1. Tracking network as configured to support Apollo 17 in 1972.

[**404**]



Figure 6-2. AP0LL0 Range Instrumentation Aircraft.

Where there were no ground stations, NASA relied on a fleet of eight Apollo Range Instrumentation Aircraft (ARIA) for extra voice and telemetry support during Apollo orbital injection and reentry. Douglas Aircraft Company and Bendix Corporation prepared Air Force C-135s for their new role by adding a bulbous nose, which accommodated a 2-meter antenna and weather radar, and by installing telemetry and communications hardware in the body (see figure 6-2 above). ARIA, first tested in 1966, was capable of S-band telemetry and voice reception, S-band voice transmission, air-to-ground voice relay on VHF, and telemetry recording. After the conclusion of the Apollo program, the Air Force continued to fly ARIA to support its own and NASA's tracking needs, but the first letter of the acronym came to stand for "Advanced" rather than "Apollo." Two ARIA supplemented the operations of the Space Tracking and Data Acquisition Network (STADAN) during the 1970s.

[**405**] **Spaceflight Tracking and Data Network, 1969-1978**

Throughout the 1970s, NASA continued to streamline its satellite tracking network, improving the equipment at primary stations and dropping other facilities from the system. Even though the average daily workload for the satellite trackers at the Goddard Space Flight Center was 40 spacecraft, NASA was able to close 3 stations in 1969 (Lima, Toowoomba, and Darwin) and 2 in 1970 (St. John's and Guaymas).

In 1972, the agency merged the Manned Spaceflight Network and the Spaceflight Tracking and Data Acquisition Network into one single operation, the Spaceflight Tracking and Data Network (STDN). The merger was primarily a money-saving tactic, for there was no approved manned flight schedule for the immediate post-Apollo years to justify keeping a tracking network intact exclusively for manned missions; and unmanned applications and scientific satellites such as the Earth Resources Technology Satellites (ERTS), which were designed to return high rates of data, could make use of stations and equipment assigned to the MSFN. Eleven stations, four AIRA instrumented aircraft, and one tracking ship, the USNS Vanguard, were transferred to the new STDN, bringing the total number of stations in the combined network to 17: Alaska, Ascension, Bermuda, Canary Island, Canberra, Carnarvon, Goldstone, Guam, Johannesburg, Kauai, Madrid, Merrit Island, Quito, Rosman, Santiago, Tananarive, and Winkfield.[**++**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n8) Goddard's Network Testing and Training Facility continued to serve as the training and new equipment testing center. A new Image Processing Facility also opened its doors at Goddard in 1972. This data processing center was built to handle the large quantities of video data transmitted by ERTS.

The STDN continued to fill the tracking and data acquisition needs of approximately 40 satellites each day plus Apollo 16 and 17 in 1972, the Skylab missions in 1973, and the Apollo-Soyuz Test Project in 1975. All the while, NASA continued to draw the net in closer, because for each station it phased out the agency realized a substantial savings in operating funds but did not lose personnel, since the stations were manned by contractor employees.[**+++**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n9) In 1974, the Minitrack facility at Goldstone was closed, along with Carnarvon and Canary Island, but Goddard came on line as an operational station. Two other stations were dropped the following year, one unexpectedly.

The Tananarive tracking station on Madagascar, off the east coast of Africa, was built in 1964 to give manned spacecraft ground controllers additional information on Gemini spacecraft orbital injection. [**++++**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n9.1) As with most of NASA's agreements with foreign countries that allowed the agency to build a facility on its soil, there was no exchange of funds. No rent was exacted for the site. The 10-year memorandum of understanding between the U.S. and the Malagasay Republic stressed the international benefits of space research to all mankind. And the tracking station would generate much-needed weather forecasts that would give the Republic maximum [**406**] coverage, especially during hurricane season, and would provide jobs for some 200 local residents. The station proved critical to the MSFN and was transferred to the STDN in 1972. In February 1975, the chief of state of Malagasay was assassinated, and a rival government took control of the islands. Negotiations in the coming months between NASA and the new rulers centered on the Malagasay demand for rent on the station site: $1 million per year retroactive to 1963. The U.S. could not agree to such a demand, and on July 14th, the Supreme Council of Revolution of the Malagasay Republic ordered the station closed and placed it under the control of the armed forces. NASA and Bendix employees were allowed to evacuate, but all equipment was left behind.[**+++++**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n10) So that support for the Apollo-Soyuz Test Project would not be disrupted, NASA made use of the orbiting Applications Technology Satellite 6 to serve as a relay link. The workload from other satellites was shifted to other stations. Early trajectory support of launches was provided by increased use of ARIA and the USNS Vanguard.

The other closing in 1975 also took place in the shadow of politics. South Africa was one of the sites identified by the Naval Research Laboratory tracking specialists in the late 1950s as necessary for Project Vanguard. A Minitrack station was erected 26 kilometers northeast of Johannesburg in 1958. NASA followed suit and built a Deep Space Network 26-meter antenna 64 kilometers northwest of the city at Hartebeesthoek in 1961 and moved the satellite tracking equipment to the same general location, later adding a 14-meter antenna.[**++++++**](http://history.nasa.gov/SP-4012/vol3/ch6.htm#n11) The Johannesburg station was an important one for both earth orbital and interplanetary missions during the 1960s. Late in the decade and in the early 1970s, the existence of an American government facility in a country that practiced apartheid became a focal point of Congressional debate over NASA's budget. Each year a small but growing number of lawmakers would propose omitting funds for operating the Johannesburg station from the space agency's authorization. In 1973, NASA announced that for technical reasons it would phase out its South African facilities. Because the Deep Space Network could utilize its Madrid station, whose new 64-meter antenna had just been completed, that part of the Johannesburg complex was closed in 1974. The STDN facility could not be shut down until 1975 because it was vital-to Project Viking near-earth operations.

New hardware was added to three STDN stations in 1075. To support Landsat/ERTS, special wideband equipment for handling higher data rates was installed at Alaska, Goldstone, and Goddard stations.

Also in 1975, the Office of Tracking and Data Acquisition established a special-purpose laser tracking network in support of Geos 3, whose mission was to measure the geometry of the ocean surface. Lasers were located at Wallops Flight Center (Virginia), Bermuda, Grand Turk Island, and the Eastern Test Range. The laser tracking system was implemented in 1976 in conjunction with -Project Lageos to apply the science of plate tectonics to studying continental drift.

[**407**] Tracking and data acquisition specialists also were involved in planning for the next-generation space transportation system -Shuttle. The telemetry facility at the Dryden Flight Research Center, located near Edwards Air Force Base in California, was built to support the flight testing of high-speed research aircraft for NASA and the Air Force. It was being modified to support Shuttle approach and landing tests, which were scheduled to begin in 1977. Tracking and data acquisition for Shuttle during earth orbital operations in the 1980s was being studied as well. NASA hoped to have a Tracking and Data Relay Satellite System in place in time for the first Shuttle flights (see discussion below).

STDN personnel closed out the second decade by further improving their operation at the Goddard Space Flight Center. A new telemetry processing system eliminated the need for tape recording data at each station. As of 1977, data entered a mass storage system directly from communications lines, eliminating delays in recording and then in shipping the tapes from stations to Goddard. In 1978, the Goddard control center was modified to allow participating project scientists to manipulate their experiments directly, working with the trackers and controllers in real time. And the Image Processing Facility was improved with new master data processing units. These additions and improvements were necessary, for the Spaceflight Tracking and Data Network was monitoring and commanding some 50 spacecraft daily by the end of NASA's second 10 years.

**Deep Space Network, 1969-1978**

The Deep Space Network continued operations through the second decade much as it had started the first, depending primarily on a three-station network. At Canberra, Australia, in the Mojave Desert in California, and near Madrid, Spain, NASA's 26-meter and 64-meter deep space antennas serve as the communications link with interplanetary probes, satellites, and landers. A fourth facility near Johannesburg, South Africa, was closed in 1974 (see discussion above). At the Goldstone tracking complex in California, there were four distinct DSN stations: Echo (26-meter), Mars (64-meter), Pioneer (26-meter), and Venus (9- and 34-meter). At Madrid, there were two: Robledo (26- and 64-meter) and Cebreros (26-meter). The first of the second-generation giant 64-meter facilities had become operational in 1968 at Goldstone, with the second and third being readied in 1973 at Canberra and Madrid. These two classes of antennas were used successfully in the 1970s with few modifications.

In 1969 and 1970, the DSN kept scientists in touch with Mariner 6 and 7 spacecraft as they flew by Mars. Pioneer missions to the more distant planets returned photographs and scientific data through the network for most of the decade. Mariner 9 and 10, probe missions to Venus and Mercury, demanded several midcourse trajectory changes from the trackers. But the event that caused the most excitement among deep space trackers and interplanetary scientists was the 1976 landing on Mars by two Viking spacecraft. For the first time, a spacecraft on the surface of another planet was controlled, commanded, and interrogated. The DSN proved flexible to the scientists' and engineers' changing needs during the complex mission operations.

Goldstone's 64-meter antenna was also used for radio astronomy experiments, several of which were designed to provide Project Viking personnel with more....

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Figure 6-3. Spaceflight Tracking and Data Network, 1975.

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Figure 6-4. STDN Tracking Ship. NASA contracted with General Dynamics in 1964 to convert three retired World War II T-2 tankers into instrumented tracking ships for Apollo. Measuring 181 meters overall and 23 meters at the beam, they carried 9-M USB antennas, radar units, and telemetry and command equipment. The ships were operated by civilian crews of the military sea transport group. (1) Log Periodic Antenna, (2)Medium Gain UHF Telemetry Antenna, (3) Unified S-Band Antenna,.(4) Star Tracker Dome., (5)C-Band Tracker Antenna, (6) SATCOM Terminal Antenna, (7) HF Whip Antenna, (8) Command Control Antenna.

[**410**] ....information on the Martian surface. In 1970, radio astronomers demonstrated the use of radar at planetary distances. By the next year, they had mapped the Martian surface. In 1973, the 64-meter dish was put to work conducting the first radar probe of Saturn.

At two other Deep Space Network stations, tracking and data acquisition experts tested equipment and theories and experimented with new equipment and procedures. The Compatibility Test Station was located at Cape Kennedy. At the Goddard Venus station, the network's research and development center, advanced research projects, such as the conversion of a 26-meter antenna to a dual-frequency (S- and X-bands) 34-meter antenna, took place.

The 26-meter-diameter steerable parabolic dish antennas erected first at Goldstone deep space station were patterned after the radio astronomy antennas in use at the Carnegie Institute and elsewhere in the late 1950s with three significant modifications. A closed-loop device for automatically pointing the antenna at the target was added, as was an electrical feed apparatus for driving the servocontrol system, which responded to signals from the spacecraft. The antenna's gear system was simplified for the space tracking role. A polar mount steered the antenna from. one horizon to the other at a sidereal rate; a smaller declination gear wheel controlled pivot movement up and down. Made of aluminum, the parabolic dish offered a focal length of about 11 meters and a pointing accuracy of better than 0. 02 degrees. The acquisition antenna had a diameter of 1.8 meters. The entire structure weighed over 45 000 kilograms and stood 37 meters tall. Precision operation was possible in winds up to 32 kilometers per hour; accurate operation was still feasible in winds up to 48 kilometers per hour. The antenna could survive in any position during 113-kilometer-per-hour winds, and it could be stowed in a survival position (reflect at zenith) to withstand harsher conditions. Operating at a radio frequency band of 2090-2120 megahertz for transmission and 2270-2300 for reception, the antenna had an average power capability of 20 kilowatts, 40 kilowatts at peak. Goldstone's Venus antenna had a special high-power transmitter. DSN 26-meter antennas were used at Goldstone (2), Canberra, Johannesburg, Madrid (2), and Woomera.

The Deep Space Network extended its range to the most distant planets of the solar system with the addition of three 64-meter-diameter antennas. These parabolic antennas could maintain spacecraft communications to a distance of 2 1/2 to 3 times the range achieved by the 26-meter antennas and had 6 1/2 times more transmitting and receiving capability. Standing 71 meters tall, the structure weighed 7.2 million kilograms. Its azimuth-elevation mount and motors (1300 horsepower) could move the giant dish from a horizon-pointing attitude to a straight-up position in three minutes. Goldstone's Mars station went into operation in 1968 and Madrid's Robledo and Canberra's Tidbinbilla in 1973. The stations in Spain and Australia have 100-kilowatt transmitters; at Goldstone the uplink signal can be radiated at up to 400 kilowatts.

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Figure 6-5. Deep Space Network 2-meter Antenna.

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Figure 6-6. Deep Space Network 64-meter Antenna.

[**413**]



Figure 6-7. NASA's Goldstone Space Communications Station in southern California's Mojave Desert was the site of the largest collection of NASA tracking and data acquisition equipment. In addition to the Mojave STADAN station (14-m antenna) and the Apollo station (26-m antenna), there were four deep space stations at this location: Mars (64-m antenna), Pioneer (26-m antenna), Echo (26-m antenna), and Venus (9- and 34-m antennas). These. facilities were built on a 176-square-kilometer plot of land leased by NASA from DoD. The station was managed by the Jet Propulsion Laboratory.

* [**414**] [Table 6-30](http://history.nasa.gov/SP-4012/vol3/table6.30.htm). Spaceflight Tracking and Data Acquisition Network /Spaceflight Tracking and Data Network Stations, 1969-1978.
* [Table 6-31](http://history.nasa.gov/SP-4012/vol3/table6.31.htm). Deep Space Network Stations, 1969-1978.
* [**415-423**] [Table 6-32](http://history.nasa.gov/SP-4012/vol3/table6.32.htm). Tracking and Data Acquisition Stations, 1969-1978.

[**424**] **Tracking and Data Relay Satellite System**

Studies for a tracking and data acquisition system that relied on synchronous orbit satellites rather than a network of ground stations date back to the early 1960s, when the Air Force contracted with the Lockheed Missiles and Space Company and the General Electric Company to investigate the feasibility of an "Instrumentation Satellite." In 1964, Goddard Space Flight Center tracking personnel requested that the NASA Headquarters Office of Tracking and Data Acquisition consider funding an orbiting tracking and data station as a supporting research and technology task. Managers in Washington were intrigued with the idea but suggested that the subject was better suited for an advanced study. Two years later in April 1966, RCA Astro-Electronics Division and Lockheed were awarded six-month contracts to define the characteristics of an "Orbiting Data Relay Network." By the fall of 1967, OTDA was convinced that the tracking satellite had a place in the tracking net of the future and established at Goddard a Data Relay Satellite System (DRSS) Requirements and Interface Panel, which included specialists from the manned spaceflight and space science and applications offices. The panel's assignment was to oversee the definition phase of such a system.

The general consensus called for a two-satellite network, with the spacecraft placed in geosynchronous orbit about 130 degrees apart over the equator (over the northeast corner of Brazil-the east satellite-and southwest of Hawaii-the west satellite). The planners hoped that a system could "be developed to augment and, to the extent practical, to replace certain of the facilities that now comprise NASA's tracking and data acquisition network."[**6**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.6) The agency hoped to have a tracking satellite system in orbit by 1974-1975.

In May 1971, Goddard issued a request for proposals to industry for an analysis and conceptual design for a Tracking and Data Relay Satellite System (TDRSS), which was answered by Hughes Aircraft and North American Rockwell. Before these two contractors finished their studies in 1973, NASA's budget conscious leaders realized that Congress would not support a development effort that would lead to a system ready for flight within two years. In an effort to get the project started without committing the agency to a future purchase of several satellites, OTDA began to consider the possibility of leasing rather than buying a satellite system. Since TDRSS was planned as a support facility rather than a research and development project, NASA considered leasing to be a viable option. All the technology required to implement the TDRSS was labeled as either off-the-shelf or in such an advanced state of development that it was considered state of the art .**[7](http://history.nasa.gov/SP-4012/vol3/notes.htm%22%20%5Cl%20%226.7)**In September 1973, Administrator James C. Fletcher wrote to individual members of Congress advising them of the agency's budget needs for FY 1975. Among the new starts listed was TDRSS. He wrote, "Our studies have shown that the only way to meet our future tracking and data acquisition needs with reasonable expenditure of funds will be through a ... TDRSS. Such a system will improve our earth orbital tracking and data acquisition capabilities and meet the high data rates anticipated when the space shuttle is in operation, while at the same time permitting the elimination of most of the ground stations in the present ... STDN." Fletcher went on to explain that this approach, while a cost saver for the future, would require "large government expenditures for development and construction of ground terminals in the FY 1976-78 period when space shuttle development expenditures will be at their [**425**] peak." The alternative was leasing the services from an industry-established system, including both the satellites and the ground station. NASA had already identified six companies that were interested in the project, but it needed the assistance of Congress to "develop the necessary legislative language to authorize NASA to enter" into this type of contractual arrangement.[**8**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.8) Congress debated the wisdom of such a relationship through the spring of 1974, but finally authorized it in May.

NASA had the authority to lease a satellite system from a contractor for 10 years. By October 1974, 27 companies or teams of companies had indicated their interest in bidding for the design, fabrication, and operation of TDRSS, the first launch of which was now scheduled for 1979. On February 7, 1975, Goddard issued a request for proposals for two or more Phase A (detailed system design and cost proposal) studies. RCA Global Communications, Inc., and Western Union Telegraph Company teamed with TRW Systems Group were awarded contracts in June. Hughes Aircraft was set to work defining the antennas required for the spacecraft that were to be tracked.[**9**](http://history.nasa.gov/SP-4012/vol3/notes.htm#6.9)

In addition to the two active satellites in the system, there would also be an in-orbit spare. The trackers would be equipped with VHF, UHF, S-band, X-band, and KU-band capability and high and low data rate user service for a maximum of 28 users per satellite. These capabilities would eliminate the need for spacecraft on-board tape recorders, which would increase spacecraft usefulness because of the relatively short lifetime of these recorders. The satellites, which would serve primarily those spacecraft operating below 5000 kilometers, were to be designed to last five years. One continental U.S. ground station would be built at White Sands Test Facility, New Mexico, with an 18-meter parabolic dish antenna. The TDRSS control center also would be located at White Sands. Additionally, Canberra, Alaska, Goldstone, Rosman, and Madrid ground stations would provide orbital support. In 1974, NASA predicted that it would initially employ Delta 2914 launch vehicles for TDRSS, with Shuttle being used for future launches.

By September 1976, Western Union and RCA were competing for a Phase B TDRSS contract; their bids were due in December. Hughes was awarded the contract for the user antenna system, and other potential contractors competed for the contract for three multiplexer-demultiplexers for ground communications support. On December 12, NASA chose Western Union Space Communications, Inc., as the prime contractor for TDRSS. Subcontractors included TRW and the Electronics Systems Division of Harris, Inc. The fixed-price contract ($79.6 million per year for 10 years) called for six spacecraft with components for a seventh, but no money would be forthcoming until the system was operational. That date had been pushed back to 1980, and the launch vehicle for the first two satellites had been changed to Atlas-Centaur, with all subsequent TDRSS launches to be handled by Shuttle.

For the next several years, the schedule and means for launching TDRSS, its escalating budget, a renewed debate over the lease-versus-buy issue, and Shuttle schedule delays combined to cast a shadow over the satellite tracking system. And the first launch, which would not occur until 1983, did not mark the end of the project's problems.

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Figure 6-8. Tracking and Data Relay Satellite TDRSS, which would be inserted into a geosynchronous orbit, was equipped with three-axis stabilization and monopropellant hydrazine thrusters. Its power was realized from two solar arrays (3.94 x 3.62 m) with NiCd battery storage. The 198 000-kg satellite had a hexagonal main body (2.4 x 1.27 m) and was equipped with two dual frequency S-band and K-band steerable 4.9-meter antennas, one C-band 1.47-meter fixed antenna, and one K-band space-ground link steerable 2-meter antenna. It had one 20-user S-band multiple access return channel and one time-shared S-band multiple access forwarding channel. The satellites were to last 5 to 10 years.

Source: NASA Hq., "Fact-Sheet, NASA's Tracking and Data Relay Satellite System," Release, 82-186, Dec. 1982.

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Figure 6-9. 1980 TDRSS Network.

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Figure 6-10. TDRSS Concept.



Figure 6-11. White Sands Ground Terminal.

**\***A radio interferometer consists of two or more radio telescopes (antennas) separated by known distances, which can pinpoint sources of radiation such as a signal in the radio range transmitted by a beacon fixed on a vehicle in space. Yagi antennas were fixed so that they could track satellites from horizon to horizon (rockinghorse antennas).

**\*\*** Antigua, Antofagasta, Blossom Point, Fort Stewart, Grand Turk, Havana, Johannesburg, Lima, Quito, San Diego, Santiago, and Woomera.

**\*\*\***Alaska, Carnarvon, Darwin, Fort Myers, Goddard NTTF, Johannesburg, Kauai, Lima, Mojave, Orroral Valley, Quito, Rosman, Santiago, St. John's, Tananarive, Toowoomba, and Winkfield.

**\*\*\*\*** In 1959, the tracking group was established as the Tracking and Ground Instrumentation Unit (TAGIU), an organizational entity at Langley separate from the Space Task Group. In 1961, many TAGIU personnel were transferred to the Goddard Space Flight Center.

**\*\*\*\*\*** NASA contractors began constructing new stations in 1959 at Bermuda; Canton Island; Corpus Christi, Texas; Grand Canary Island; Guayman, Mexico; Kano, Nigeria; Kauai, Hawaii; Muchea and Woomera, Australia; and Zanzibar. NASA-owned equipment was sent to Cape Canaveral, Grand Bahama lsland, Grand Turk Island, Eglin Air Force Base, Point Arguello, and the White Sands Missile Range. DoD contributed additional ground support and two tracking ships.

**\*\*\*\*\*\***The primary stations included Antigua, Ascension Island, Bermuda, Grand Bahama, Merritt Island, Grand Canary, Madrid, Carnarvon, Canberra, Guam, Kauai, Goldstone, Guaymas, and Corpus Christi.

**+** For more information on the first 10 years of NASA's tracking and data acquisition program and the three networks see Linda N. Ezell, NASA Historical Data Book, 1958-1968, vol. 2, Programs and Projects, NASA SP-4012(02) (Washington, 1987), chap. 5.

**++** Ft. Myers station was closed in 1972.

**+++** Bendix and Ford Aerospace and Communications provided most of the personnel for the tracking stations. There were usually one or two NASA employees per station.

**++++** This permanent station replaced a mobile facility (Majunga station) that began operations in 1963.

**+++++** A NASA inspection team was allowed to return to the station in September 1978 to determine what equipment the agency would like to recover. Agreement over removal of the hardware was reached in October 1979, and the equipment was repatriated in March 1980. The remaining property was turned over to the Malagasay Republic by diplomatic note.

**++++++** South Africa was also the site of a Smithsonian Astrophysical Observatory precision optical station at Olifantfontein and a DoD missile tracking station near Pretoria.