16.895J Engineering Apollo
Interview Report

Deep Space Network Support for the Apollo Missions

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About the Interviewee

This report is based on a telephone interview conducted with Mr. Douglas Mudgway, supplemented by my own research. Mr. Mudgway was born in New Zealand. He graduated from the University of New Zealand in Mathematics and Physics. At the end of the Second World War, he took a job in radar development with the New Zealand government. In 1948, he was sent to Australia to work on a Commonwealth guided missile testing program. For the next 15 years he worked in Australia developing radar tracking and guidance systems for guided missiles. In 1962 he was recruited by JPL and brought to Pasadena to work for the Deep Space Network (DSN), which was then called the Deep Space Instrumentation Facility (DSIF). Mr. Mudgway worked in the DSIF office as an engineer till 1964. By 1964, JPL was transitioning to a contractor-built (as opposed to in-house) spacecraft model and he was appointed the DSN project officer working with Hughes Aircraft on the Surveyor lunar landing probes. Subsequently, he was appointed to manage tracking and data acquisition for the Viking Mars landers. After the successful completion of the Viking program in the late 1970's, he took over tracking and data acquisition responsibilities for the Galileo spacecraft to Jupiter. In 1991, he retired from active service but was retained by JPL as a consultant to the DSN. He was particularly interested in relationships of JPL and the DSN to NASA headquarters. In the mid 1990's, he won a contract from NASA headquarters to write the history of the DSN. This appeared as "Uplink/Downlink" in 1997 [1]. In 1999, he started writing his next book, about the people who built NASA's large dish antennas. This was published as "Big Dish" in April 2005 [2]. He is currently working on a biography of William Pickering, the first director of JPL and a fellow New Zealander.

Introduction

Maintaining reliable communications between the Apollo spacecraft and the ground was a technologically challenging task. This was because of two main factors. Firstly, the great distances involved. Before Apollo, no manned spacecraft had ever left Earth orbit. The height record was 851 miles above the surface, held by Gemini XI. In contrast, Apollo spacecraft would travel to lunar distances – over 250,000 miles from Earth. This imposed a whole new set of requirements on the tracking networks needed for the Apollo program. Secondly, there were multiple spacecraft involved during part of the mission. During the lunar landing phase, the Command and Service Module (CSM) and Lunar Module (LM) were independent entities that had to be tracked separately. This added an element of complexity to Apollo program requirements that had been absent in earlier manned space missions. Fortunately, by the mid 1960's NASA had accumulated a considerable amount of experience with tracking multiple unmanned spacecraft at great distances. This body of expertise resided with the Deep Space Network (DSN) and would prove to an important contributor to the success of the Apollo program.

History of the Deep Space Network

The Deep Space Network began life as the Deep Space Instrumentation Facility (DSIF) in the late 1950's. Originally an ARPA (Advanced Research Project Agency) project under the Department of Defence, the network was designed and operated by the Jet Propulsion Laboratory (JPL), which was then part of the Army. Its original purpose was to communicate with the Pioneer lunar probes, the first American spacecraft to leave Earth orbit. Late in 1958, JPL, including the DSN, was transferred to NASA, the newly created civilian space agency. The first Earth stations of the DSN global network were set up at three locations spaced approximately 120° apart in longitude. This ensured that at least one station would be visible to a distant spacecraft at all times as the Earth turned. The three stations were located at Goldstone, California; Woomera, Australia and near Johannesburg, South Africa. By 1965, two more DSN stations had been established near Madrid, Spain and Canberra, Australia. At the time, the primary antennas at these stations were parabolic dishes 26m (85 ft) in diameter. In addition, a single large 64m (210 ft) antenna known as the Mars station was commissioned at Goldstone in 1966. Designed to communicate with distant interplanetary probes, this antenna would have an important role to play in the Apollo 13 saga.

The location of the overseas DSN sites was based on a number of factors. The site itself had to have physical features that tended to suppress radio frequency interference from unwanted sources. A flat basin surrounded by hills tended to have desirable characteristics. The overseas stations were built by NASA, which owned all the equipment, but were staffed and operated by local personnel. The country for the site was chosen based on availability of trained scientific and technical manpower, ease of communication (use of the English language) and suitable political situation. In the case of South Africa, for example, the political fallout of Apartheid forced the closure of the station soon after the Apollo missions ended, in 1974.

Figure 1: The 64m (now 70m) Mars dish at Goldstone, California. This antenna was used in a backup role during the Apollo missions. The entire 3650m^2 surface area of the dish is precise to within 1cm of its ideal shape.

Ranger, Surveyor and Orbiter Lunar Missions

These new DSN facilities were immediately put to use in supporting the Mariner planetary probes to Mercury, Venus and Mars (1962-73), and the Ranger (1961-65), Lunar Orbiter (1967) and Surveyor (1966-1968) lunar probes. During this period, the DSN gained experience with providing communication support to multiple spacecraft simultaneously. This would prove useful during the Apollo missions. In addition, data collected by the unmanned lunar probes, particularly Orbiter and Surveyor, was crucial for planning and executing successful manned lunar landings. The Surveyor lunar lander project was managed by JPL for NASA and resulted in five successful landings. The Surveyor spacecraft returned thousands of pictures of the lunar surface and conducted several lunar surface experiments. Surveyor landing sites were primarily chosen for their interest to the Apollo program. The Lunar Orbiter missions, managed by the NASA Langley Research Center, captured the first high quality images of the lunar surface from orbit. Orbiter and Surveyor data were put to good use; for example, Apollo 12 later landed within 200m of Surveyor 3. Harrison Schmitt, the first and so far only geologist to walk on the moon (Apollo 17) says in [12]

> In advance of Apollo, given the state of our knowledge and the state of consensus about the surface of the Moon in several respects, Ranger and Surveyor were of tremendous importance… the first clear pictures that were coming from the Moon, just prior to the impact of the Ranger vehicles, did a lot to lay a psychological base within this country for us to go on and do other things. In addition, Surveyor began to outline the broad chemical parameters that we were going to deal with in our analysis of the lunar samples. And Surveyor, of course, also added to the psychological confidence that we could do it…and Lunar Orbiter continued that tradition.

Mr. Mudgway was the JPL liaison with Hughes Aircraft, who built the Surveyor probes. In this capacity, he was the DSN project officer responsible for all tracking and acquisition of Surveyor data. He still recalls the excitement in the mission control room when the first pictures from Surveyor started coming in. In addition to increasing the ‘psychological base’ for the Apollo missions, Surveyor and Orbiter data was of course directly put to use in planning manned landing sites. The approximate resolution of the Orbiter pictures was 100m, which allowed reasonably flat areas with no large rocks to be selected as landing sites. The resolution however was not good enough for an automatic landing – the LM still had to be piloted down to the surface.

NASA Tracking Networks

It is important to realize that the system requirements for tracking distant spacecraft are quite different from those required to track low altitude vehicles in Earth orbit. Distant spacecraft move slowly relative to the Earth, so the tracking antennas only need to move slowly. However, ultra sensitive low noise receivers and large diameter antennas are required to pick up the extremely weak signals. Data rates in uplink and downlink are low, and a single mission may last a decade or more. On the other hand, spacecraft in Earth orbit move rapidly, requiring a large number of ground tracking stations spread around the globe. Antennas at these stations must be able to track rapidly, but can be much smaller in size. Additionally, communication data rates are much higher.

NASA has always had a number of independent tracking networks to meet this large spread in requirements. Each network is focused on a different regime of operations. Today, these networks consist of the DSN and the Tracking and Data Relay Satellite System (TDRSS). The DSN is focused on deep space tracking of unmanned planetary probes, while TDRSS focuses on communicating with satellites in low earth orbit. TDRSS uses a network of 10 geostationary communication satellites and a single ground station at White Sands, New Mexico. Before TDRSS became fully operational in the mid

1980’s, earth orbit spacecraft were tracked using a network of ground based antenna stations. These stations were closed after TDRSS became operational, but during the Apollo missions, they were the primary means of communicating with the spacecraft, with the DSN being assigned a supporting/backup role. Astronauts were well aware of the contributions made by the dedicated men and women who manned these ground stations and called themselves ‘Range Rats’. Buzz Aldrin (Apollo 11) has said:

> I salute - from my space helmet - the Range Rats, the unsung heroes of the space race to the future.

The way NASA’s ground based earth orbit tracking network was organized changed several times during its history. Ground tracking networks began as military projects to track Inter-Continental Ballistic Missiles (ICBM’s) during the early 1950’s, such as the SAGE air defence system. The need for a tracking network to communicate with the first U.S. satellites led to the establishment of 14 MINITRACK stations worldwide. The MINITRACK network became operative in October 1957 and was used for communicating with the Vanguard satellites. The Vanguard program was designed to be America’s contribution to the International Geophysical Year (IGY) 1957-58. It was run by the Naval Research Laboratory (NRL), who also built the MINITRACK stations. These stations operated in the VHF band (136-137MHz). MINITRACK was handed over to NASA in 1958 as part of the Eisenhower administration’s commitment to a civilian space program. MINITRACK was soon supplemented by other ground stations, including several tracking ships, and divided into two organizational entities: the Satellite Tracking and Data Acquisition Network (STADAN) for supporting unmanned scientific satellite programs, and the Manned Space Flight Network (MSFN) for supporting manned spacecraft. The new stations had receivers and antennas designed for operating at higher frequencies: L-band (UHF around 960MHz) and S-band (around 2.2GHz) and data rates. Computer and network support for both networks was handled by NASA’s Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. The MSFN provided the primary communication interface with manned spacecraft during the Mercury, Gemini and Apollo missions. During the early 1970’s, following the completion of the Apollo missions, STADAN and MSFN were combined into a single entity known as the Spaceflight Data Tracking Network (STDN). STDN was eventually supplanted in the mid 1980’s, as we have already seen, by the satellite-based TDRSS system that is operational today.

During this whole period, the DSN has existed as an independent, specialized entity managed by JPL for NASA and dedicated to communicating with distant spacecraft. Its capabilities have been continuously upgraded. Antennas have been enlarged and improved and receiver sensitivities increased. In addition, better digital coding schemes and higher frequency bands have been brought into use. The result has been increased data rates and improved tracking precision and reliability. The DSN’s interactions with the manned space program have been relatively minor, but occasionally significant. We have talked about the importance of the Surveyor and Orbiter lunar probes, which were tracked by the DSN, to the success of Apollo. In addition, the unique communication challenges of the Apollo program were solved with the help of the DSN. We shall talk about this issue next.

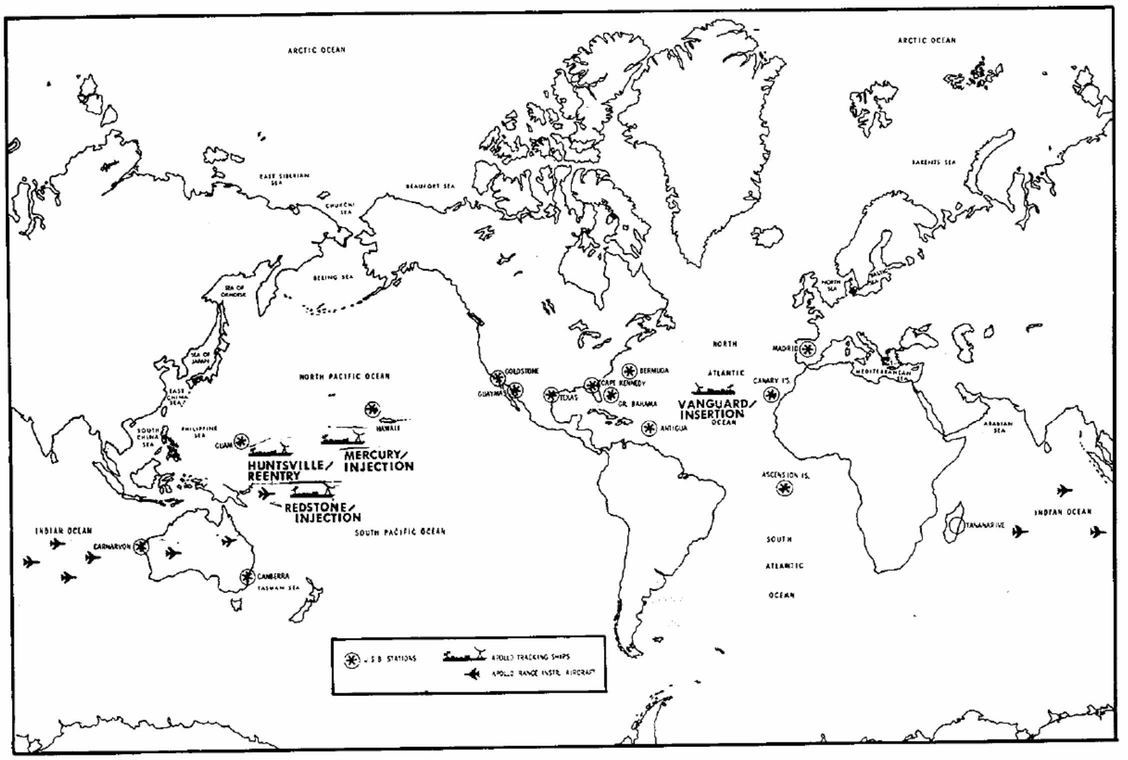
The Apollo Missions

As mentioned before, providing communications for the Apollo spacecraft involved a number of technical challenges that were not present during the Earth orbiting Mercury and Gemini missions. Only limited experience with providing support to multiple spacecraft simultaneously had been obtained during the Gemini 6/7 combined flight. MSFN stations were not equipped with antennas large enough to provide sufficient communication bandwidth to spacecraft in lunar orbit. To support the Apollo manned lunar-landing program while spacecraft were in the vicinity of the Moon, the MSFN thus installed three large 26m antennas at Goldstone, California; Honeysuckle Creek, Australia; and Fresnedillas, Spain. Being equidistant around the globe, at any one time at least one of these dishes would always have a direct line of sight with the moon and the spacecraft. These sites were near the DSN stations at Goldstone, Tidbinbilla and Robledo de Chavela, which had been sited for similar reasons and were already equipped with similar 26m antennas. MSFN wings (control rooms) were also added to these DSN stations to allow them to function as complete MSFN stations. This resulted in an effective total of 6 MSFN stations equipped for spacecraft communications at lunar distances. The dual sets of stations were needed because of the narrow beam width of the antennas at S-band when the Apollo spacecraft were near the Moon - one antenna covered the orbiting CSM and the other, the LM on the surface of the Moon.

Thus the MSFN worked closely with the DSN during this period to upgrade its capabilities for the Apollo missions. The antennas used by the MSFN stations were very similar to those used by the preexisting DSN stations. At the three DSN stations where MSFN wings were added, the MSFN shared the same 26m tracking antennas with the DSN. In addition, the receivers used by all six MSFN stations were in fact designed by JPL as derivatives of the DSN receivers. They were built by Motorola and Westinghouse and were known as Unified S-Band Receiver/Exciter/Ranging Systems. These S-band receivers provided a clear communications channel for voice and data from the spacecraft to the stations, in contrast to the noisy communications link with the previous Mercury and Gemini manned spacecraft.

Tracking, command and communication for Apollo spacecraft was performed in two broad phases. For the first phase, the MSFN depended largely on its worldwide chain of stations equipped with 10m antennas, supplemented by tracking ships and four Apollo Range Instrumentation Aircraft (ARIA) equipped with 2.2m parabolic antennas (see Figure 2). These stations (up to 14 of them) were often upgraded MINITRACK stations and had been successfully used during the Mercury and Gemini missions. During Apollo, they were used just after launch, while Apollo was still in Earth orbit. ARIA aircraft were also used to track the Apollo spacecraft during the critical Trans Lunar Injection (TLI) and re-entry maneuvers.

The second tracking phase began when the spacecraft moved out more than 10,000 miles above the surface. At this time the new 26m MSFN antennas brought their greater power and accuracy into play and took over primary communication responsibilities. These antennas were also used for television reception throughout the mission. However, television, even at the low resolutions used during the Apollo missions, is bandwidth intensive (500KHz was required in this case). This made television coverage from large (lunar) distances difficult even for the 26m MSFN/DSN antennas. Hence the 64m DSN 'Mars' antenna at Goldstone and the Commonwealth Scientific and Industrial Research Organization (CSIRO) radio telescope at Parkes, Australia, because of their much larger size, were routinely used to augment Apollo television coverage while near and on the Moon.



MANNED SPACE FLIGHT TRACKING NETWORK

Figure 2: The facilities used by MSFN during the Apollo missions

DSN Support during Apollo

The six MSFN stations established for the Apollo program supported all the manned Apollo missions from Apollo 7 to Apollo 17 (1967-72). After supporting the very complex Skylab missions in 1973 and 74, the MSFN stations and their associated antennas, receivers and other equipment were transferred to the DSN, which used them to support various space-probe and high-altitude-satellite missions. As mentioned previously, the MSFN itself was merged with STADAN to form the STDN soon after. In 1985, the antennas at Honeysuckle Creek (Figure 2, upper photo) and Fresnedillas (Figure 2, left photo) were moved to the DSN sites at Tidbinbilla and Robledo (Figure 2, right photo), respectively. The Apollo antenna at Goldstone remains at its original site (Figure 2, lower photo). I believe all these antennas are still in use today for tracking Earth orbit spacecraft.

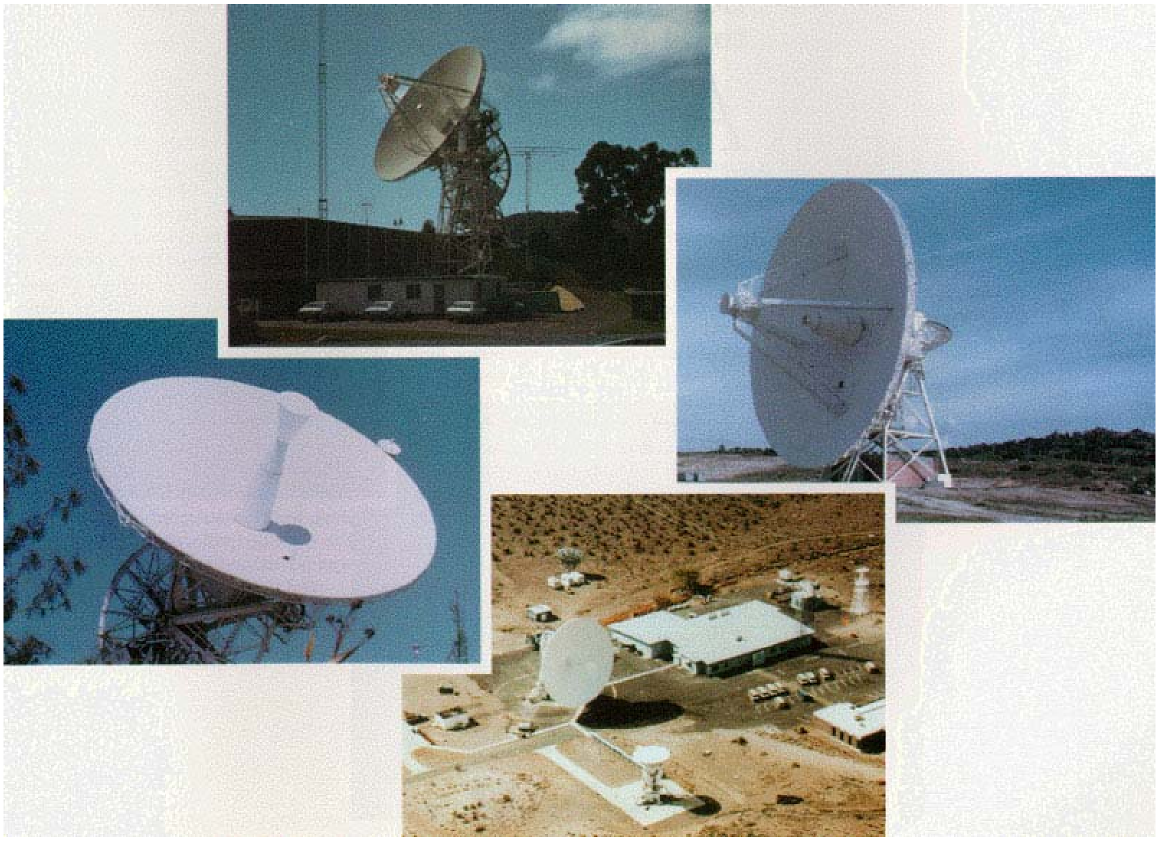


Figure 3: The 26m MSFN antennas used for primary communications with Apollo while beyond Earth orbit.

As we have said previously, the DSN was only involved in a supporting role during project Apollo. Surveyor and Orbiter data was useful for picking landing sites, its expertise was used in building and operating the 26m MSFN tracking stations, and the big 64m DSN 'Mars' dish was used to augment television coverage while the Apollo spacecraft were at lunar distances from Earth. There was one episode, however, where the DSN's unique capabilities proved to be immediate and vital to the success of an Apollo mission. This happened during Apollo 13.

During the Apollo 13 episode, mission control was forced to instruct the astronauts to switch off all non-essential systems in the spacecraft (CSM and LM) to conserve power. For example, the high-gain S-band antenna normally used for communicating with the ground had to be switched off and a low gain omnidirectional backup antenna used instead to save power. This resulted in decreased signal power reaching the ground tracking antennas, and the 26m MSFN stations could not provide clear voice channels to the spacecraft. However, mission controllers also had access to the 64m DSN 'Mars' antenna at Goldstone. This large antenna's unique capabilities enabled clear voice communications with Apollo 13 to be maintained continuously; it was one of the major contributors to the eventual success of the mission.

The Future

Today, the DSN continues in its backup role for Earth orbiting manned and unmanned spacecraft, providing support to TDRSS when necessary. For example, certain spacecraft on elongated eccentric orbits use DSN antennas for communication while at apogee. This is secondary to its main role, which remains tracking and control of deep space planetary probes. The separate but cooperative roles of NASA's different spaceflight tracking networks documented in this report are likely to continue well into the future. Fundamentally different system requirements and priorities results in this arrangement being both mutually acceptable and efficient.

With the announcement of the new Moon/Mars Initiative, NASA's focus is again on extended duration exploratory manned spaceflight. It is fairly safe to say that the expertise of the DSN will again be called upon to support communications for the planned return to the Moon, and especially for eventual manned Mars missions. However, this will likely only be a supporting role. Primary communication responsibilities for such missions will probably be handled by a separate entity, or possibly an expanded TDRSS. The situation will be similar to that during the Apollo missions, with the unique capabilities of the DSN being utilized during specific situations, such as emergencies.

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References

[1] Uplink-Downlink: A History of the Deep Space Network, 1957-1997
Mudgway, Douglas J.; Launius, Roger
NASA Center for AeroSpace Information (CASI)
NASA/SP-2001-4227; NAS 1.21:4227; LC-00-058220 , 20010101; 2001

[2] Big Dish: Building America's Deep Space Connection to the Planets
Mudgway, Douglas J.
University Press of Florida
ISBN: 0813028051, April 7, 2005

[3] A history of the deep space network
Corliss, W. R.
NASA Center for AeroSpace Information (CASI)
NASA-CR-151915 , 19761101; Nov 1, 1976

[4] Histories of the Space Tracking And Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM)
Corliss, W. R.
NASA Center for AeroSpace Information (CASI)
NASA-CR-140390 , 19740601; Jun 1, 1974

[5] The evolution of the Satellite Tracking And Data Acquisition Network (STADAN)
Corliss, W. R.
NASA Center for AeroSpace Information (CASI)

NASA-TM-X-55658; X-202-67-26; GHN-3 , 19670101; Jan 1, 1967

[6] The NASA tracking and data acquisition networks - Their history and their future
Force, Charles T.
NASA Center for AeroSpace Information (CASI)
IAF PAPER 87-418 , 19871001; Oct 1, 1987

[7] Deep space network support of the Manned space flight network for Apollo, 1962 - 1968, volume 1
Flanagan, F. M.; Goodwin, P. S.; Renzetti, N. A.
NASA Center for AeroSpace Information (CASI)
NASA-CR-116801; JPL-TM-33-452-VOL-1 , 19700715; Jul 15, 1970

[8] Deep space network support of the manned space flight network for Apollo, volume 2 Technical memorandum, 1969 - 1970
Flanagan, F. M.; Hartley, R. B.; Renzetti, N. A.
NASA Center for AeroSpace Information (CASI)
NASA-CR-118325; JPL-TM-33-452-VOL-2 , 19710501; May 1, 1971

[9] Deep space network support of the manned space flight network for Apollo, volume 3; support for Apollo 14, 15, 16, and 17 flights
Hartley, R. B.
NASA Center for AeroSpace Information (CASI)
NASA-CR-137347; JPL-TM-33-452-VOL-3 , 19740301; Mar 1, 1974

[10] Mission support: Interplanetary, planetary, and manned space flight projects and radio science experiments
Siegmeth, A. J.; Goodwin, P. S.; Laeser, R. P.; Davis, E. K.; Hartley, R. B.; Linnes, K. W.
NASA Center for AeroSpace Information (CASI)
The Deep Space Network, Vol. 5, p 4-44 , 19711015; Oct 15, 1971

[11] Journey into Space: The First Three Decades of Space Exploration
Bruce Murray
Publisher: W W Norton & Co Inc; 1st ed edition (July 1, 1989)
ISBN: 0393026752

[12] 'Before This Decade Is Out...': Personal Reflections on the Apollo Program
Swanson, Glen E.
NASA Center for AeroSpace Information (CASI)
NASA/SP-1999-4223; NAS 1.21:4223; LC-99-23780 , 19990101; 1999