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Technical Memorandum 33-452

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Deep Space Network Support of the Manned Space Flight Network for Apollo

1969-1970

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PREFACE

The work described in this report was performed by the Network Operations Team of the Tracking and Data Acquisition Organization of the Jet Propulsion Laboratory (JPL). It is the second volume in a continuing series and reports the support of the network for 1969 and 1970. It covers the Apollo missions 9 through 13.

During these flights, Deep Space Network (DSN) operations are limited to the cislunar and lunar phases. The DSN provided network control activity in the Space Flight Operations Facility (SFOF), the three 26-m stations at Goldstone, Madrid and Canberra, and the Mars station at Goldstone with its 64-m antenna.

ACKNOWLEDGMENT

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ABSTRACT

This report summarizes the Deep Space Network (DSN) activities in support of Project Apollo during the period of 1969 and 1970. Beginning with the Apollo 9 mission and concluding with the Apollo 13 mission, the narrative includes a mission description, the NASA support requirements placed on the DSN, and a comprehensive account of the support activities provided by each committed DSN deep space communication station. Associated equipment and activities of the three elements of the DSN (i. e., the Deep Space Instrumentation Facility (DSIF), the Space Flight Operations Facility (SFOF), and the Ground Communications Facility (GCF)) in meeting the radio-metric and telemetry demands of the missions are documented. Recent scientific and engineering developments and plans are also discussed which will have a direct effect on future DSN Apollo support plans.

I. INTRODUCTION

Volume I discussed the development of the Apollo project, the unified S-band communication system, the dual DSN and MSFN deep space communication stations so that the DSN could act as a backup to the MSFN, and the flights of Apollo 4 through Apollo 8. These were the major milestones that were to lead to the flight of Apollo 11 and the first successful manned lunar landing on the moon in June 1969.

This report, Volume II, summarizes and provides a historical account of the operational support activities provided to the MSFN by the JPL DSN in support of Apollo Missions 9 through 13.

The narrative is presented in chronological order and includes the following subject matter:

(1) Mission Description - a recapitulation of significant events of the mission from launch through splashdown.

(2) Requirements for DSN Support - the technical objectives of the mission which the DSN was required to meet.

(3) DSN Mission Support - a chronology of DSN premission and mission operational activities.

(4) Future Plans - a discussion on recent scientific and engineering developments and their affect on future DSN Apollo support plans.

Figure 1 illustrates the location of the Apollo 11, 12, and 13 lunar landing sites. The locations of the DSN deep space communication stations which provided operational support for the Apollo missions are shown in Fig. 2.

A. Mission Description

Apollo 9 was the third manned Apollo mission and the second manned mission flown aboard the three-stage Saturn V launch vehicle. With astronauts James A. McDivitt (spacecraft commander), David R. Scott (command module pilot), and Russell L. Schweickart (lunar module pilot), Apollo 9 was placed in a 10-day earth orbit with the primary objective of checking out the lunar module prior to undertaking an actual lunar mission.

On March 3, 1969, at 16:00:01.07 GMT, Apollo 9 was launched on an azimuth of 72° from Pad 39-A at Cape Kennedy. The S-IVB third stage successfully inserted the spacecraft into a 190-km circular earth orbit. The Command Service Module (CSM) separated from the S-IVB third-stage booster at 02:43 GET and withdrew at a rate of 30.48 cm/s to a distance of approximately 12 m. At this distance the velocity of the CSM was nulled, and the CSM pitched 180 deg and returned to successfully dock with the Lunar Module (LM) which was still attached to the third stage. Subsequently, the LM attachment bolts were released, and a 3-s Service Module Reaction Control System (SMRCS) burn separated the CSM/LM from the third stage. The third stage J-2 engine was later restarted and the burn lasted 4 min. Passivation of the S-IVB commenced with the residual propellants being propulsively vented to place it in an earth escape trajectory and into solar orbit.

The docked CSM/LM remained in earth orbit while numerous checkouts were made on the CSM and especially the LM spacecraft. A 110-s SPS burn at 22:13 GET placed the CSM/LM in a 353 × 209-km orbit. At 25:17 GET, this orbit was changed to 501 × 212 km by a 277-s SPS burn.

One of the highlights of the Apollo 9 mission was to be a 2-h Extravehicular Astronaut (EVA) activity to be performed by Schweickart, the Lunar Module Pilot (LMP). Because of an earlier illness experienced by the LMP, the EVA activities were revised to 1-h and restricted to an egress through the forward hatch to the "golden slipper" foot restraints on the LM "front porch" to photograph various components of the two spacecraft. EVA activities began at 72:55 GET and were terminated at 73:50 GET. EVA activities were followed at 74:57 GET until 75:13 GET by a live TV transmission from inside the LM while it was over the United States.

On March 7, at 92:39 GET, undocking of the CSM from the LM occurred, and the CSM RCS placed the CSM in a circular orbit of 240 km. This was followed by a LM Descent Propulsion System (DPS) burn, placing the LM in a 266 × 218 km orbit. Approximately an hour and a half later, the LM descent engine was ignited, simulating an lunar Descent Orbit Insertion (DOI) burn, which placed the LM in a 264 × 261-km orbit. After jettisoning the LM descent stage, propulsive maneuvers were performed with the LM Ascent Propulsion System (APS) prior to a successful rendezvous and docking with the CSM at 98:57 GET. After successfully docking, the LM crew returned to the CSM and, at 101:30 GET, the LM ascent stage was jettisoned. Twenty-two minutes later, a APS burn-to-depletion command was initiated from MCC-H. The remainder of the mission was spent by the three-man crew doing multispectral terrain photography for earth resources studies, spacecraft systems exercises, etc.

The Apollo 9 mission was originally scheduled for 150 revolutions around the earth, but because of bad weather conditions and an unfavorable sea state in the planned western Atlantic recovery area, the mission was extended for an additional revolution in order to place the point of impact in a more favorable sea. At 240:36 GET (March 13, 1969, 16:31 GMT), the Service Propulsion System (SPS) deorbit burn occurred over Hawaii on the 151st revolution. Approximately 5 minutes later, the CM separated from the Service Module (SM) to start the reentry sequence. Splashdown occurred at 17:00 GMT, 23.14° N, 68.00° W, and approximately 4.83 km north of the recovery ship USS Guadalcanal. The Apollo 9 mission was successfully concluded when the astronauts were landed safely aboard the recovery ship.

B. Requirements for DSN Support of Apollo 9

Other than the countdown and launch-phase support provided the Apollo project by the Spacecraft Monitoring Station at Cape Kennedy, the DSN is not committed to support Apollo earth-orbital missions. However, in the case of Apollo 9, the Manned Spacecraft Center placed a requirement on the MSFN, operated by the Goddard Space Flight Center, to have the MSFN Wing at Tidbinbilla, Australia participate in Apollo 9 during the rendezvous portion of the mission, which was planned for revolutions 58 through 61. The two spacecraft would be separated sufficiently to be outside the beamwidth of the MSFN Honeysuckle Creek (Canberra, Australia) Apollo prime 26-m antenna station.

The initial requirement was for both radio metric data and telemetry voice data from either the command service module or the lunar module, as circumstances dictated during the mission. Both the MSFN and the DSN expressed concern in their ability to meet this requirement due to two problem areas that had been experienced on the previous missions, especially Apollo 8. These were:

(1) The Apollo spacecraft angular tracking rates in earth orbit exceeded the DSN stations' capability to track (i.e., rates in excess of 0.85 deg/s).

(2) The strong signal strength received on an 26-m antenna from a spacecraft in earth orbit overloaded the receiver front end and created an instability in the angle channels when in the auto-track mode.

In the weeks preceding Apollo 9 launch, numerous techniques were proposed to overcome these limitations provided certain compromises could be made with respect to either the emphasis upon the radio metric data or the emphasis upon the telemetry voice portion of the requirement. After careful consideration, the Manned Spacecraft Center selected the technique proposed by the

Tidbinbilla station. This technique was to use the acquisition aid antenna for the entire pass, using a computer program drive mode with boresight offsets.

The station would acquire the spacecraft on the horizon with the boresight of the acquisition aid antenna leading the spacecraft by one-half the beamwidth (or about 9 deg), and the antenna would be programmed to keep this boresight offset as the spacecraft rose on the station's horizon until the spacecraft angular rates exceeded the mechanical limitation of the antenna (0.85 deg/s), at which time the spacecraft would advance into the acquisition beamwidth at a differential rate between the actual spacecraft velocity and the mechanical velocity limit of the antenna servo. Tracking would be continued until the spacecraft disappeared out of the acquisition antenna's beamwidth, thereby obtaining the largest possible percentage coverage during the pass.

The preflight expectation was that the rates would be such that the antenna would not be able to catch up with the spacecraft before its set on the outgoing station horizon. While this technique would invalidate the angular radio metric data, the critical factor of the other data was such that this technique would be satisfactory. This technique simultaneously optimized the angular-rate problem while reducing the tendency for receiver front-end saturation because of the lower gain of the acquisition antenna compared to that of the 26-m antenna. It had the further advantage that the modifications were all procedural and that no hardware changes would be required to implement the plan. As noted in Section C, below, the technique proved to be 100% successful with horizon-to-horizon tracks being obtained by the Tidbinbilla/MSFN Wing on revolutions 58 through 61.

C. DSN Mission Support

1. Spacecraft Monitoring Station Support. The DSN Spacecraft Monitoring Station supported the Apollo 9 prelaunch and launch activities in a manner identical with the support previously provided for Apollos 4 through 8. The station was reconfigured in a manner identical to that of the Apollo 4 mission, i.e., the CSM S-band downlink was received at the Spacecraft Monitoring Station, and the detected phase-modulated telemetry baseband was relayed to the MSFN Merritt Island Station (MILA) for processing. This arrangement provides backup during the launch in case the MSFN MILA station experiences signal-level difficulties due to either multipath propagation phenomena or flame attenuation phenomena from liftoff to loss-of-signal at the horizon.

Activities commenced at the Spacecraft Monitoring Station on February 12, 1969 with the countdown demonstration test from 17:00 to 24:00 GMT. During this test, telemetry was processed from the receiver to the MSFN MILA station and five photographs were taken of the received spectrum. During February, the station also participated in the Mariner Mars 1969 spacecraft F prelaunch and launch activities. The next Apollo activity occurred on February 18 when the Spacecraft Monitoring Station participated in a second countdown demonstration test (wet) from 11:00 until 20:40 GMT. The telemetry output was processed to the MSFN MILA station and photographs were obtained of the received spectrum.

The Spacecraft Monitoring Station participated in the third countdown demonstration test (dry) on February 19 from 11:20 until 17:51 GMT, with the same data being provided as for the February 18 test. On February 25 and 26, the station completed the DSN-specified Apollo configuration verification test, and the results were sent to the appropriate project engineers. On March 3, the station participated in the Apollo 9 terminal countdown and launch, from 04:00 to 16:08 GMT. The telemetry output of the receiver and spectral analyses plus 31 photographs of the received spectrum were provided to the MSFN MILA station. The received signal strengths at the station from launch to loss-of-signal at horizon are shown in Table 1. No anomalies were experienced during this entire period.

2. Tidbinbilla/MSFN Wing Support. Premission activities at Tidbinbilla/MSFN wing started on February 11 with a computer and data flow test. Additional computer and data flow tests, antenna position programmer drive tests, and acquisition antenna angle calibrations were interspersed between Pioneer IX tracks up to Apollo 9 launch. After Apollo 9 launch, the Tidbinbilla station continued to support Pioneer IX in the DSN configuration, except that the station did track Apollo 9 in revolutions 13, 14, and 15 in the MSFN configuration to evaluate the various tracking options. A decision was made to use the station configuration described in Section B, above. Both revolutions 14 and 15 produced rates of the order of 1 deg/s, which the station successfully tracked-thereby proving the technique to be practicable for use during revolutions 58 through 61. Tidbinbilla resumed Pioneer IX support in the DSN configuration up to the time it became necessary to perform a class A countdown prior to revolution 58.

To support the rendezvous portion of Apollo 9 (revolutions 59 through 61), the Tidbinbilla/MSFN wing was configured as shown in Table 2. The acquisition-of-signal and loss-of-signal times are shown in Table 3, along with the servo mode for each of the revolutions.

a. Revolution 58. Since the maximum elevation angle of the spacecraft with respect to the station was expected to be only 13 deg, no hour-angle offsets were included in the program drive for this pass. The actual maximum antenna tracking rates were 0.7 deg/s in hour angle, and 0.2 deg/s in declination. The CSM and LM were not separated during this pass. The CSM was acquired at a signal level of -132 dBmW, rising to a maximum of -105 dBmW. The LM signal-level maximum was -108 dBmW. Several losses of lock were experienced due to the rolling motion of the spacecraft, but these were momentary. There were no station anomalies during revolution 58.

b. Revolution 59. Since a maximum elevation angle of 30 deg was anticipated for revolution 59, an initial hour-angle offset of 9 deg was set into the antenna position programmer. The CSM was acquired at a signal level of -135 dBmW, rising to a maximum of -94 dBmW. The CSM and LM were separated for this pass. The maximum signal received from the LM was -124 dBmW. The servo-mode control changes for this revolution are shown in Table 3. The boresight offsets and the angular rates experienced during revolution 59 are shown as a function of time in Fig. 3. A change in CSM omniantennas resulted in a receiver loss-of-lock for a period of 8 s during this revolution. No ground equipment anomalies were noted for this pass.

c. Revolution 60. A transmitter water-load interlock trip, which could not be reset, occurred at 15 min prior to spacecraft rise. At 5 min prior to spacecraft rise, the battle-short override was applied and the station was green for acquisition at spacecraft rise. The initial programmer hour-angle offset was 8 deg for this revolution since a maximum elevation angle of angle of 30 deg was anticipated. Due to spacecraft attitude and omnidirectional antenna changes, there were several periods of receiver loss-of-lock during revolution 60. Table 3 shows the servo-mode control change times, and Fig. 4 depicts the performance of the tracking system as a function of time during revolution 60. Except as noted above, there were no other anomalies during this revolution.

d. Revolution 61. Since the maximum elevation angle anticipated for revolution 61 was only 10 deg, no hour-angle offsets were inserted for this pass. During the pass, a real-time request was made to change the station configuration to have system 3, receiver 6 connected to the main 26-m antenna via maser 1. This was accomplished and a corresponding CSM signal-level increase from -103 to -76 dBmW resulted. One anomaly occurred 10 min before spacecraft rise when the transmitter power amplifier beam voltage overload tripped; this was reset and no further difficulties were experienced.

The spacecraft coverage provided by the Tidbinbilla/MSFN wing during revolutions 58 through 61 is depicted in Fig. 5. The periods of good and bad data are shown. The station was released from further Apollo support on March 7 at 17:38 GMT, and the station was reconfigured and participated in the next Pioneer 9 tracking in the DSN configuration.

3. Conclusion. The Apollo 9 mission was completely successful in every respect, thereby paving the way for further evaluation of the LM in orbit about the moon on the Apollo 10 mission. While the DSN/MSFN wing support requirements for Apollo 9 were considerably less than those for Apollo 8, because Apollo 9 was an earth-orbital type mission, Apollo 9 did present a very interesting challenge to the Tidbinbilla station to operate in a mode that was not contemplated when the facility was designed. The high degree of success attained during the rendezvous phase of Apollo 9 points up the importance of the human resources of the MSFN and DSN.

Table 1. Spacecraft monitoring station time vs signal level for Apollo 9 launch (March 3, 1969)

GMT, h:m:s	Receiver 1 automatic gain control, dBmW	GMT, h:m:s	Receiver 1 automatic gain control, dBmW	GMT, h:m:s	Receiver 1 automatic gain control, dBmW
16:00:00	69.5	16:03:00	128.6	16:06:00	124.8
:10	67.9	:10	119.3	:10	117.7
:20	73.2	:20	116.7	:20	136.0
:30	97.6	:30	116.9	:30	140.0
:40	91.5	:40	98.4	:40	144.3
:50	88.6	:50	100.3	:50	134.3
16:01:00	81.8	16:04:00	102.7	16:07:00	144.8
:10	89.4	:10	101.5	:10	134.9
:20	85.5	:20	100.7	:20	132.4
:30	91.0	:30	100.6	:30	131.8
:40	96.7	:40	101.0	:40	132.0
:50	100.0	:50	102.0	:50	129.7
16:02:00	102.4	16:05:00	105.2	16:08:00	130.7
:10	145.6	:10	105.4	:10	131.0
:20	128.1	:20	107.3	:20	131.0
:30	102.0	:30	109.6	:30	130.7
:40	101.0	:40	125.5	:40	132.2
:50	117.6	:50	128.4	:52	Out of lock

[a]The automatic gain control values were recorded at a standard 50-Hz $2\text{-}B_{LO}$ receiver bandwidth.

Table 2. Ground receiver configuration, Tidbinbilla/MSFN wing

System	Receiver	Spacecraft telemetry
3	5	Command/service module phase-modulated
	6	Command/service module phase-modulated
4	7	Lunar module phase-modulated
	8	Command/service module frequency-modulated

[a]Systems 1 and 2 (receivers 1 through 4) refer to MSFN *Apollo* prime station, while systems 3 and 4 (receivers 5 through 8) refer to DSN/MSFN-wing station.

Table 3. Tracking event times, Tidbinbilla/MSFN wing

Revolution	Tracking mode	Acquisition-of-signal time[b]	Select-manual-velocity time	Select-program time	Loss-of-signal time[b]	Transmitter-on time	Transmitter-off time
58	3-way	11:58:08	—	—	12:02:43	—	—
59	2-way	13:31:44	13:34:21	13:35:48	13:37:04	13:30:59	13:40:00
60	2-way	15:05:37	15:07:59	15:09:28	15:10:27	15:04:29	15:14:30
61	2-way	16:39:34	—	—	16:44:14	16:39:59	16:47:00

[a]All times quoted are GMT, h:m:s.

[b]Acquisition-of-signal and loss-of-signal times are defined as horizon times given in 29-point predict messages.

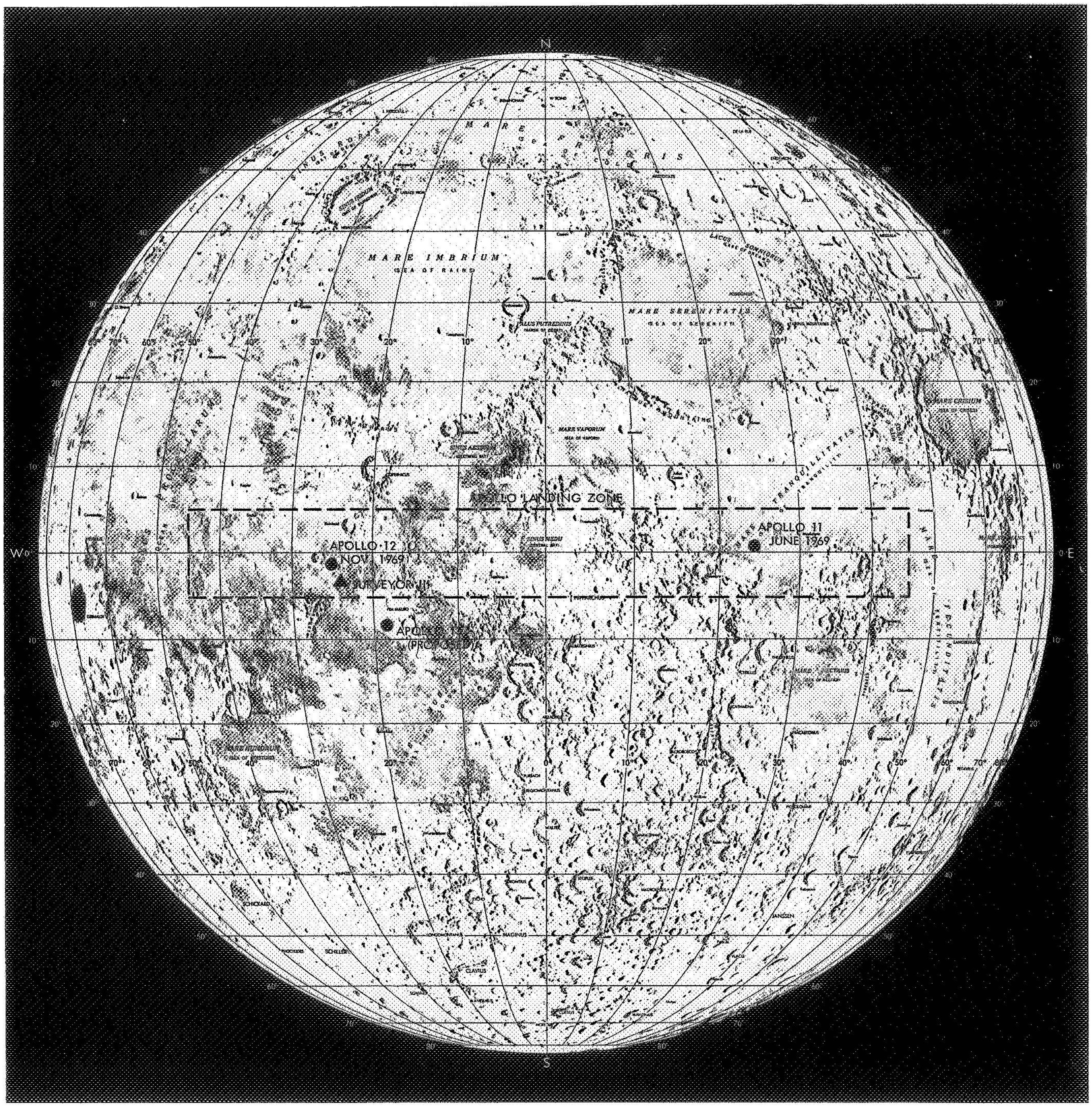


Fig. 1. Apollo lunar landing sites

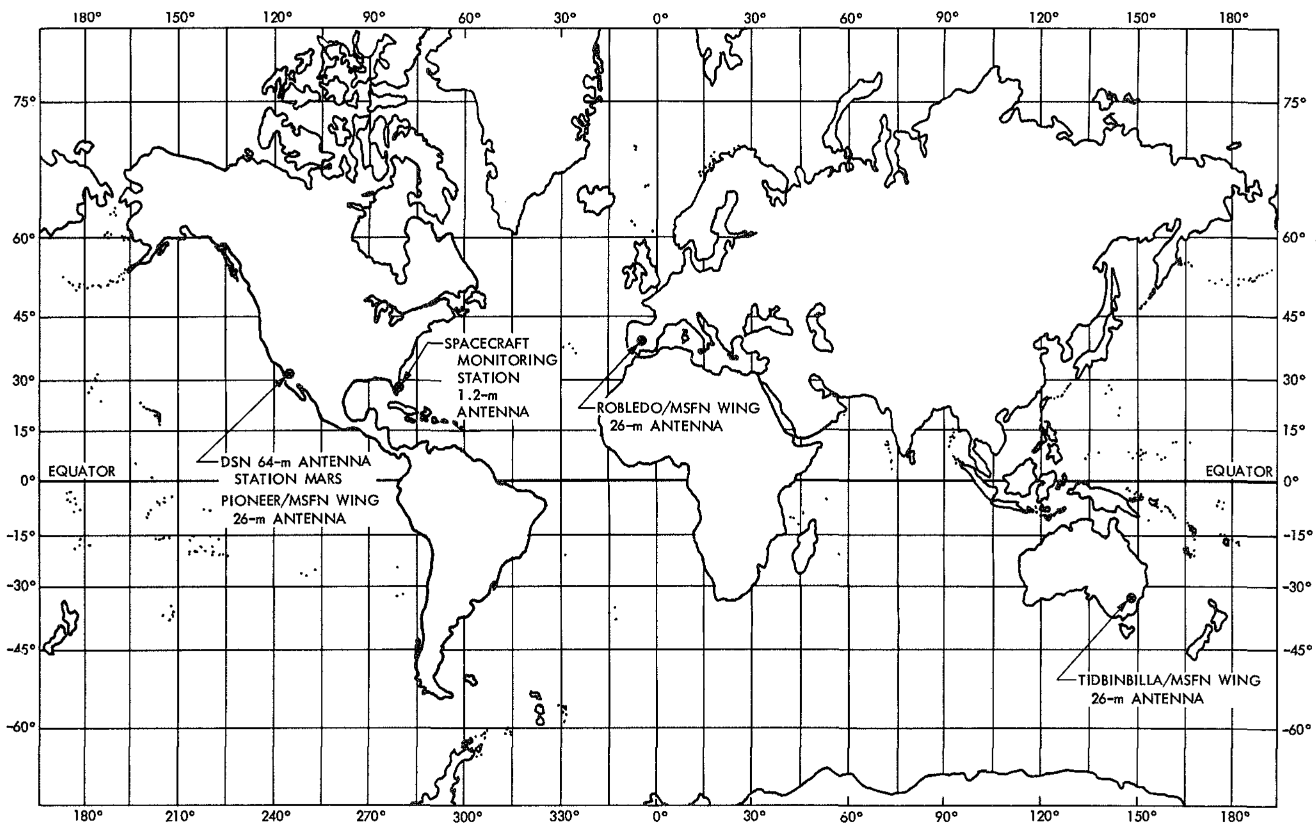


Fig. 2. Location of dual DSN/MSFN wing stations for Apollo support

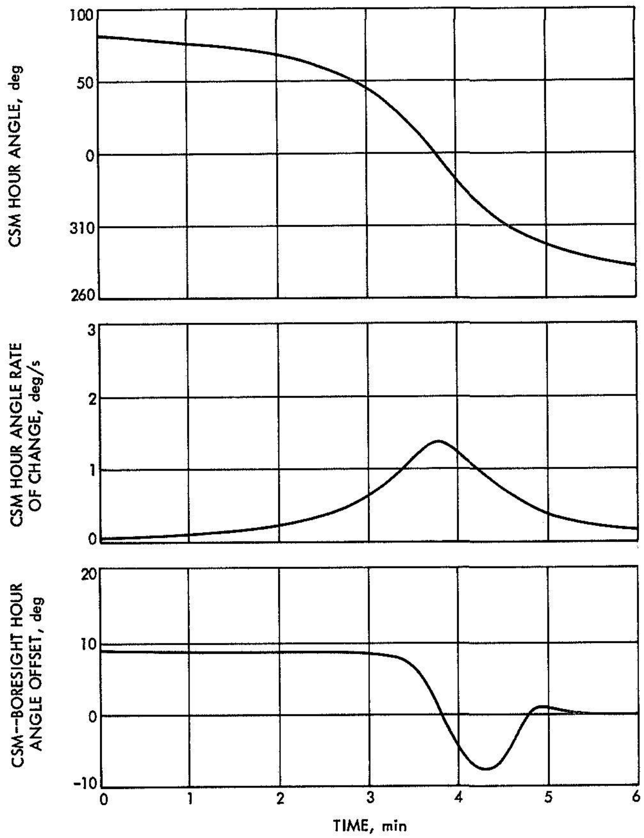


Fig. 3. Tracking system performance as a function of time (Apollo 9, revolution 59), Tidbinbilla/MSFN wing

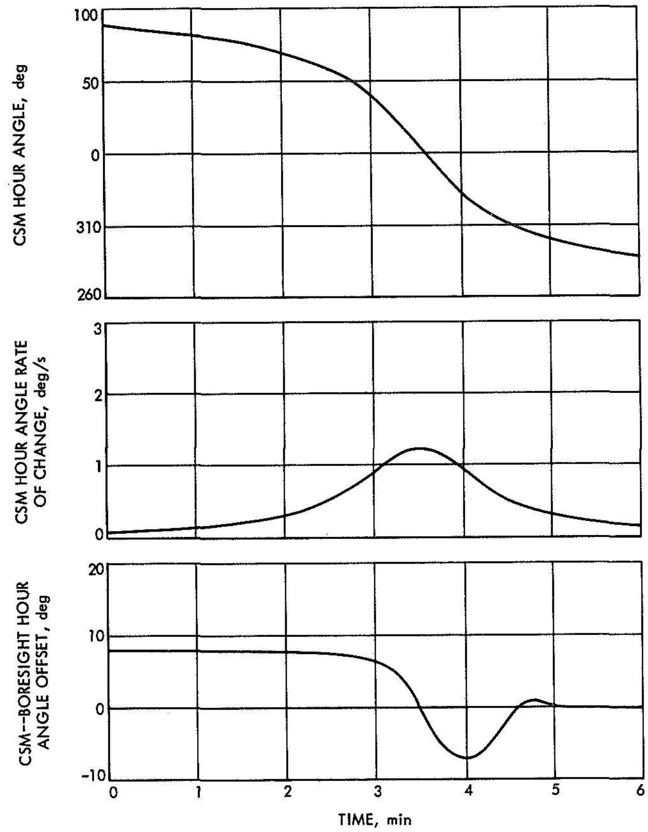


Fig. 4. Tracking system performance as a function of time (Apollo 9, revolution 60), Tidbinbilla/MSFN wing

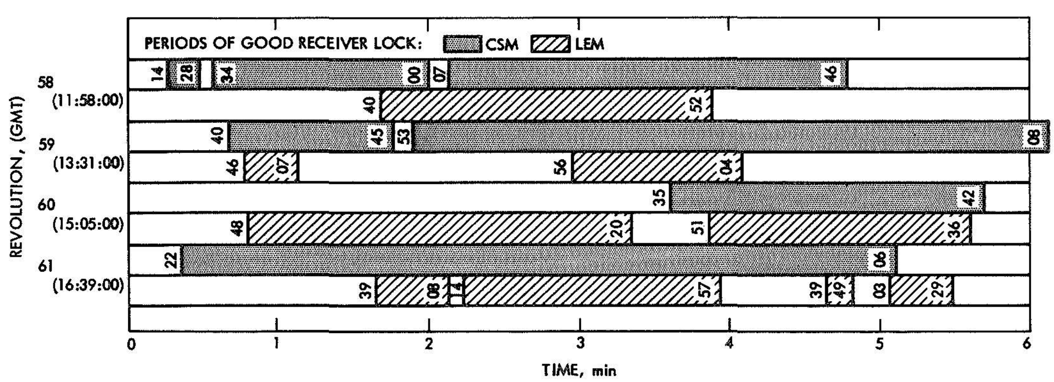


Fig. 5. Apollo 9 operational activity, Tidbinbilla/MSFN wing

A. Mission Description

Apollo 10 was the first lunar flight of the complete Apollo spacecraft, the third manned mission flown aboard the Saturn V launch vehicle, and the second to go to the moon and return. With astronauts Thomas P. Stafford (spacecraft commander), John W. Young (CM pilot), and Eugene A. Cernan (LM pilot), Apollo 10 compiled the following list of achievements:

(1) First mission launched from Launch Complex 39-B.
(2) First real-time color TV transmission from moon.
(3) First mission to place two manned spacecraft in orbit around the moon.
(4) First mission to rendezvous at the moon.
(5) First mission to inject a spacecraft (LM ascent stage) into heliocentric orbit from lunar orbit.
(6) Man's closest approach to the moon (16 km).
(7) Man's longest stay in lunar orbit (61.5 h).

Launched on May 18, 1969, at 16:49 GMT from Pad 39-B at Cape Kennedy, Apollo 10 was an 8-day mission to qualify the combined CSM and LM in the lunar environment. The primary objectives of the mission were to demonstrate rendezvous and docking of the CSM and LM in the lunar gravitational field and the evaluation of docked and undocked lunar navigation. With the exception of an actual descent to the lunar surface, the timelines used (Table 4) were those proposed for an actual lunar landing mission. Eleven minutes after launch, the S-IVB third stage successfully inserted the spacecraft into an earth parking orbit of 190 by 184 km. After 2-1/2 h of spacecraft system checkout activities, translunar injection (TLI) occurred (S-IVB third stage re-ignited) over Australia. Shortly thereafter, the CSM separated from the S-IVB and the spacecraft launch vehicle adapter (SLA) panels surrounding the LM were explosively jettisoned from the S-IVB. The CSM, having pitched 180 deg, returned to successfully execute the docking maneuver with the LM. After the docking latches were secured, the tunnel joining the two spacecraft was pressurized and the combined CSM/LM was ejected from the S-IVB. A separation maneuver using the Service Module Reaction Control System (SMRCS) was then performed, and the residual propellants were propulsively vented to place the S-IVB into solar orbit. The first of many real-time color TV broadcasts from the CSM showed the complete docking sequence. Additional real-time color TV broadcasts were made from the CSM en route to the moon (Table 5). Because of the precision of the translunar injection, the first midcourse correction option was not exercised. Instead, a passive thermal control technique, similar to that used on the Apollo 8 mission, was initialized to stabilize onboard temperatures. At 26:30 GET, only a slight, approximately 1524 cm/s, midcourse maneuver was performed to adjust the Apollo 10 translunar trajectory to coincide with the lunar landing trajectory planned for Apollo 11 in July. Figure 6 shows the complete mission profile for Apollo 10.

Apollo 10 arrived in the vicinity of the moon on May 21, 1969, and the first lunar occultation occurred at 20:37:00 GMT. The first lunar orbit insertion (LOI) burn by the CSM engine occurred while the two spacecraft were behind the moon. This retrograde burn placed the CSM/LM into an elliptical lunar orbit of 111 × 314 km. The second LOI burn occurred at the end of lunar orbit 2 while the vehicles were behind the moon. This placed Apollo 10 into a 109 × 112 km circular orbit about the moon. The crew made lunar landmark navigational sightings and conducted a color TV broadcast, then retired in preparation for the lunar module descent phase starting on orbit 12.

While in orbit 12, astronauts Stafford and Cernan, aboard the LM, separated from the CSM containing astronaut Young (Fig. 7).

During the front-side pass of the moon, the two spacecraft kept reasonably close proximity and performed a mutual inspection of the other vehicle. At the conclusion of orbit 12, while the spacecraft were behind the moon, the LM started the decent to its perilune altitude of 14,000 km above the lunar surface (Fig. 8), which occurred over the Apollo 11 proposed landing site in the Sea of Tranquility. This was during lunar orbit 13. Once past perilune, the LM descent engine burned again to perform what is called a phasing maneuver which placed the LM in a 359 × 21 km orbit (Fig. 9). On lunar orbit 14, the LM jettisoned its descent stage prior to reaching perilune, and then, having passed perilune, burned its ascent propulsion system to change the apolune to 83 km (Fig. 10). Thereafter, the LM reaction control system engines were ignited several times during orbits 14, 15 and the beginning of 16, to effect rendezvous and docking (Fig. 11) during orbit 16. The LM crew then transferred themselves and their photographic equipment back into the CSM. During orbit 17, they separated the now-unmanned LM from the CSM.

After separating from the CSM, the LM ascent stage was reignited to place the vehicle into a heliocentric orbit. As noted above, this is the first time that a heliocentric orbit has been achieved starting from lunar orbit. The Apollo 10 CSM continued in lunar orbit for a total of 31 revolutions around the moon, during which time the crew continued to do landmark surveillance and additional color TV transmissions to earth. At the end of the thirty-first orbit, the CSM service propulsion system was ignited again behind the moon to perform the trans-earth injection (TEI) burn. This burn was so precise that only one small midcourse correction was required enroute back to earth. The Apollo 10 crew performed additional color TV broadcasts on the return to earth. The Apollo 10 CSM reentered earth's atmosphere at 121,914 m and splashed down in the Pacific Ocean 621 km east of Samoa and approximately 4632 km south of Hawaii. Both the crew and the Apollo 10 CSM were successfully recovered by the Carrier USS Princeton. Television coverage of the reentry was carried live and in color by the commercial networks broadcasting from the deck of the Carrier USS Princeton via satellite to the United

States. The mission was completely successful and paved the way for the manned lunar landing of Apollo 11.

B. DSN Mission Support

1. DSN Premission Activities.

a. DSN/MSFN Wing Stations. Deep space stations, Pioneer (Calif.), Tidbinbilla (Australia), Robledo (Spain), were placed into the MSFN configuration and went on Apollo 10 mission status May 6, 1969, at 00:01 GMT. Prior to this time, ferrite isolators had been installed in the transmitter waveguide at the Pioneer station in an attempt to correct the intermodulation product problem that had been noted in previous missions when two simultaneous uplink carriers were radiated. Subsequent testing showed that the isolators did not cure the intermodulation product problem, so that the isolators intended for installation at Tidbinbilla and Robledo were not installed prior to Apollo 10. The intermodulation products are an intermittent problem, and as of this writing a solution has not been found (see Section VII for further discussion).

b. Spacecraft Monitoring Station. The Spacecraft Monitoring Station supported the prelaunch and launch activities of Apollo 10 in a configuration identical to that used for the Apollo 4 through 9 missions.

c. Impending Requirements for the DSN 64-m Antenna at Mars. On April 9, 1969, the Office of Tracking and Data Acquisition informed the DSN that Apollo 10 might possibly carry a color TV camera in addition to the regular black and white slow-scan camera. A decision regarding the color TV camera was not anticipated prior to May 1, 1969. However, if the color TV were to be flown aboard Apollo 10, it would necessitate the use of the DSN 64-m antenna to receive the signals because of the telecommunications circuit margins involved. Prior to the April 9 notification, it had been assumed that the 64-m antenna would not be required for Apollo support prior to the first lunar-landing mission.

Since there was very little time remaining prior to the Apollo 10 launch anticipated for May 18, 1969, the DSN proceeded on the assumption that color TV would be flown and the 64-m antenna would be required to support the mission. Also, since there were no formally established detailed requirements for the 64-m antenna support of Apollo 10, the DSN proceeded on the assumption that the requirements would be very similar, if not identical, to those of Apollo 8. Support by the Mars station was scheduled as shown in Table 6. However, the station configuration could not be identical with that used for Apollo 8 because the signal data demodulator assembly, which was borrowed from the Goldstone MSFN Station for Apollo 8, would not be available for Apollo 10. In addition, the GSFC which operates the MSFN was in the process of installing a direct microwave link between Mars and the Goldstone MSFN station in preparation for Apollo 11.

By May 1, 1969, it was apparent that only one of the two channels in this new microwave link would be available for service. The installation of this new direct microwave link necessitated the installation of a new intersite microwave tower at Mars (Fig. 12) and also a new tower at the Goldstone MSFN station, shown in Fig. 13. The terminal equipment for the new direct intersite microwave system was installed adjacent to the existing DSN-Goldstone-DSCC intersite microwave in the communications room at Mars, as shown in Fig. 14. The one channel of this new microwave link that would be operational on May 1 would be capable of transmitting either the black and white or color TV signal from Mars to the Goldstone MSFN station. However, it would not be capable of simultaneously carrying the phase-modulated telemetry signal if that should become a requirement for Apollo 10 (which it did later, as noted below). Therefore, the decision was made to also implement the DSN intersite microwave system as was done for Apollo 8 in order to be able to forward the phase-modulated telemetry signal from the 64-m antenna over to the MSFN station for processing.

The resulting configuration for Apollo 10 is shown in block diagram form in Fig. 15. As was the case for Apollo 8, it would again be necessary to have station predicts available for Apollo 10, because the Mars station does not have an autotrack capability. The station predicts for Mars would be generated from state vectors furnished by the MSC and/or the GSFC. These predicts would be generated in the SFOF and forwarded to the station via teletype. As a backup to this technique, the MSFN generated a 29-point acquisition message that would be received by the MSFN Wing at Pioneer, be converted in the Wing's 1218 computer, and sent via a pony teletype circuit to Mars for further processing into an antenna drive tape.

d. Doppler Resolver Requirement. On May 7, 1969, the DSN received a request to provide high-resolution doppler resolver data during the LM perilune passes while the vehicles were at the moon. The DSN proposed two configurations to meet this requirement. The first was at Pioneer where it was proposed to operate the DSN tracking data handling system in parallel with the MSFN Wing's tracking data processor, since the latter did not contain a doppler resolver. This special configuration is shown in Fig. 15. However, this configuration was not actually employed during the Apollo 10 mission because, during the LM perilune passes, the MSFN Wing at Pioneer was instructed to track the CSM instead. The other configuration proposed by the DSN to meet the doppler resolver requirement was at Mars. As is standard throughout the DSN, the Mars tracking data handling system (TDH) does contain a doppler resolver. Therefore, to meet this requirement it was merely necessary to activate the TDH and provide the requested 1 sample/s data during the LM perilune period of Apollo 10. This difference in configuration over that used for Apollo 8 is also noted in Fig. 15.

e. Color TV Requirement. A teletype message from NASA Headquarters to GSFC and JPL on May 12, 1969 (6 days before launch) stated the following: "Apollo 10 TV (color) coverage from the Goldstone 64-m antenna is now required. Coverage interval times in reference to ground elapsed time from launch are 27:15, 54:00, 72:20, 80:45, 98:15, 106:00, 108:35, 126:20, and 152:35." These TV color coverage times were in agreement with the tentative coverage times that had been supplied by GSFC via teletype message on May 10, 1969.

An additional TV requirement was added via teletype message on May 16, 1969, from GSFC to JPL. This message stated in part: "Also request that this facility (Mars) participate in the TV transmission presently scheduled for launch day, starting at approximately T plus 8:00. Video should be remoted as is planned for subsequent TV periods."

f. Requirement for Time Synchronization at Goldstone DSCC. On May 12, 1969, the DSN received a requirement to employ the Goldstone-Standards Laboratory portable cesium clock to synchronize the clocks at the stations participating in Apollo 10 prior to and after each of the passes during which the LM was separated from the CSM. This requirement was not only to remove the timing bias in the doppler resolver data, but also to correct a suspended timing error at the Goldstone MSFN station.

g. Lunar Module Omniantenna to 64-m Antenna Communication Test. On May 18, 1969, at 01:28 GMT, the DSN received a requirement to perform the subject test. This test involved, among other things, the passing of the Apollo 10 telemetry signal from the Mars to the MSFN Station. Although the requirement was anticipated, as mentioned previously, it came only 15 h and 21 min prior to launch. This test, which had an important bearing on MSC's design of the Apollo 11 mission, was for lunar orbit 4, which occurred some 82 h into the mission. Even so, there would not have been time to implement the necessary intersite microwave connections if a possible requirement for Apollo 10 telemetry had not been anticipated by the DSN.

h. DSN Operational Readiness Test (ORT). It was planned that only one DSN ORT would be conducted prior to launch to verify the readiness of integrated DSN elements. Since the concept was to duplicate as closely as possible the exact support conditions expected during mission operations, GSFC and MSC participation was required. Rather than schedule this support separately for the DSN ORT, the test was scheduled to be run concurrently with the MSFN/MSC Network Simulation on May 12, 1969, but subsequently slipped to May 13, 1969. GSFC and MSC agreed to cooperate fully to meet the following DSN test objectives and requirements. The sequence of events (3) and the results (4) follow the listing of objectives (1) and requirements (2), below.

(1) Objectives:

(a) Verify Mars capability to reconfigure from Mariner or Pioneer support to the Apollo configuration and complete station checkout and countdown within 3 h.
(b) Verify DSN/Mars procedures for recording and transmitting doppler resolver data.
(c) Verify SDA procedures for validating doppler resolver data.
(d) Verify operational performance of the DSN intersite microwave link between Mars and Pioneer/MSFN Wing and the Mars interface with the MSFN direct microwave link as a function of data condition upon receipt at Apollo Prime Station.
(e) Verify GSFC/MSC transmission of required state vectors to JPL, addressed to JNEC and JTNC.
(f) Verify performance of SFOF computer system, using state vectors, to generate and transmit predicts to Mars.
(g) Verify procedures for release and transmission of predicts to Mars.
(h) Verify operational adequacy of voice and TTY circuits between GSFC and JPL, between the SFOF and Mars, and between Mars and Apollo Prime Station.
(i) Verify staffing, interfaces, procedures, and internal communications for the DSN Apollo Operations Team.
(j) Verify Pioneer/GDSX interface and Pioneer procedures for providing doppler resolver data.

(2) Requirements:

(a) Mars: Configured in accordance with DSIF Configuration Document, Vol. VI, 609-22, dated May 1, 1969. Add TDH/doppler resolver data configuration unless otherwise deleted prior to the test.
(b) Pioneer: Communications support for circuits routed through Pioneer communications room.
(c) GCF: Configured in accordance with GCF Operating Procedures and Communications Configuration, Vol. IV, 609-12, Revision A, dated May 1, 1969, except for deletion of Spacecraft Monitoring Station requirements.
(d) SFOF:

(1) DSN Operations Control Area: OCT, DSN PE, DSN Manager, Apollo Track, Track Advisor, and Communications PE consoles. Displays, Apollo time/clock, OVCS, CCTV.
(2) Mariner FPAC Area: SDAPE operations area, computer I/O, keypunch, OVCS.
(3) NAT Area: TTY RO, JTNC and JNEC.
(4) Computer Area: 7044-7094 Mode 2.
(5) DACON support.

(e) GSFC/MSC:

(1) Transmit state vectors to JPL (JTNC and JNEC) at required times as established for the Apollo 8 mission.
(2) Provide voice circuit patches to SFOF voice circuits:

(a) DSN OPS — NOM/Goddard OPS. voice loop.
(b) GSFC/MSC computer coordination loop.
(c) GOSS conference loop 2, listen only.

(f) MSFN Goldstone Apollo Prime Station:

(1) Provide microwave operator at Mars and intersite direct microwave link.
(2) Provide test signals for data flow tests.
(3) Validate condition of test data received.
(4) Exercise Prime — MARS operational voice circuits regarding mission/network procedures and direction.
(5) Provide timing correlation for use with Mars doppler resolver data.

(3) Sequence of Events:

Although this test, tabulated below, was conducted during the Apollo 10 Network Simulation, it was a separate, DSN controlled exercise. It was understood that the May 13 Network Simulation would encompass the CSM-LM lunar orbit rendezvous portion of the mission and occur between 04:00 and 21:00 GMT with "plus count" activities starting around 13:00 GMT.

(4) Results:

At 09:00 GMT May 13, 1969, Mars completed a Mariner 69 track and started station turnaround for Apollo. Post calibrations and countdown were easily completed by 12:00 GMT, meeting test objective (1)(a).

Test objectives (1)(b) and (1)(c) were met. It was recommended that the DSIF Operational Procedures for Apollo be updated to specifically state detailed procedures exercised during the test.

Test objective (1)(d) was partially met in that the Mars interface with the MSFN direct microwave link was well exercised. Color TV transmissions were conducted at various signal levels to determine threshold values. However, the MSFN Prime Station did not have time to evaluate PM telemetry data transmissions via the DSN microwave link. Therefore, both S-band receivers were tuned to and supporting FM video tests. This resulted in an undiscovered receiver output mispatch in the Mars communications room that wasn't detected until the first translunar pass. (What would normally be PM receiver output was patched to the MSFN FM microwave link, and FM receiver output was patched to the DSN PM microwave link.)

Item	Time (GMT)	Event
a.	09:00	Communication up. Status reports.
b.	09:00	Start test with Mars station in Pioneer or Mariner configuration.
c.	09:00	Start Mars reconfiguration for Apollo and station countdown.
d.	12:00	Complete reconfiguration and station countdown. Status reports.
e.	12:00-13:00	Conduct Mars-Prime data flow tests. Prime provide data source.
f.	11:00 (estimate)	GSFC/MSC provide initial state vector to SFOF covering period to be simulated, at least 1 h prior to planned track sims.
g.	12:00 (estimate)	SDA generate and transmit predicts to Mars. Status reports.
h.	—	Mars simulate acquisition and drive antenna per predicts. Transmit data to Prime. Prime provide simulated data.
i.	—	GSFC/MSC provide state vector updates as required during test.
j.	—	SDA provide update predicts for Mars as required during test.
k.	—	During lunar orbit pass, Mars/Pioneer record one sample per second doppler resolver data, standard short format. Transmit one sample per 10 s doppler resolver data, standard short form to JSFO. Mars use preamble 14/52/40, Pioneer use preamble 11/52/40.
l.	—	SDA "validate" doppler resolver data.
m.	19:45	Test end.
n.	19:45-20:00	Test critique.

Although the ORT critique recommended that PM telemetry data flow test be conducted prior to launch, incompatible schedules between Mars and MSFN Prime prevented this.

Test objective (1)(e), (f), and (g) were basically met after much difficulty. The initial state vector received from MSC was approximately three hours late. Predicts generated from this state vector indicated that the probe impacted the moon. Through coordination and analysis it was determined that the ZDOT value should have had a negative rather than a positive sign. A corrected state vector was received, and predicts generated and transmitted to Mars. It was recommended that Mars continue to rely on the 29-point acquisition message/Wing 1218 computer output as a backup source of acquisition information.

Objective (1)(h) was met. Difficulty in raising GSFC and MSC at times during the test was a result of inadequate network monitoring rather than communications problems.

Objective (1)(i) was met.

Objective (1)(j) was met after real-time coordination with GSFC to obtain authorization for connecting previously laid cables to the Wing's doppler extractor.

2. DSN Apollo 10 Mission Activities.

a. Spacecraft Monitoring Station. Most of the support activities of the Spacecraft Monitoring Station occurred before launch. As required, the station provided data acquisition and spectrum analysis support during the countdown demonstration tests (CDDT), terminal count, and launch phases. At the request of the DSN, the station also observed the CSM FM downlink during the test color TV transmissions from the vehicle on the pad. The purpose was to determine if any special procedures or techniques would be required for the upcoming Mars 64-m antenna color TV support. (There proved to be none.) The station prelaunch activities are summarized in Table 7. The postlaunch signal strengths reported by the station are given in Table 8. No problems were encountered in providing this launch support.

b. Pioneer, Tidbinbilla, and Robledo Stations. The subvehicle points of the first earth revolution of Apollo 10 were such that the spacecraft was briefly in view of Tidbinbilla and Pioneer stations. Although the stations are not formally committed to support the earth-orbital phase of Apollo missions, attempts are made to acquire the spacecraft. Experience on the earth-orbital phase of previous missions has shown that the angular tracking rates frequently exceed the antenna's capability of 0.8 deg/s, and that the high signal strengths saturate the front end of the receiving system, producing tracking instability. At Tidbinbilla, the Apollo 10 spacecraft was in view for about 4 min during the first orbit. (See Table 9 for view periods.) To avoid any tracking instability during the pass, the 26-m antenna was fed directly into receiver 5, bypassing the maser, while the acquisition aid antenna was fed into receiver 6. Signal strengths for receivers 5 and 6 were -82 and -110 dBmW, respectively. The maximum antenna rate observed during revolution 1 was 0.71 deg with no tracking instability noted.

The Pioneer station supported the first earth-orbital pass with none of the tracking problems mentioned above, because the elevation angle was very low. After loss of signal, the station had a failure of the electronic governor on diesel-powered generator 1. The hydraulic governor switched in automatically. There was no adverse effect, and the generator remained on the hydraulic governor during the mission.

The three trans-lunar passes of Apollo 10 were fully supported by the MSFN Wings at Pioneer, Tidbinbilla, and Robledo. The Tidbinbilla MSFN Wing was in the three-way mode for the entire trans-lunar phase and encountered no problems. The MSFN Wings at Pioneer and Robledo tracked in both the three-way and two-way modes, and no equipment failures occurred during this phase of the mission. Near the end of the second trans-lunar pass over Goldstone DSCC, a test of the combined Pioneer tracking data handling (TDH) System/MSFN Wing Tracking Data Processor interface for providing precision doppler was conducted. The results were not satisfactory. The problem was traced to a low signal level between the MSFN Wing receiver and the Pioneer TDH. An amplifier was added, and the test was completed satisfactorily during the third trans-lunar pass.

The Pioneer MSFN Wing supported lunar orbits 1 through 5 in the three-way mode. An O-ring ruptured in the high-pressure hydraulic line 1 min prior to loss of signal on orbit 3. Repairs were completed prior to orbit 4 with no loss of data. During the next lunar view period, the Pioneer MSFN Wing supported lunar orbits 12 through 17, and on the subsequent view period, orbits 24 through 30. During orbit 13, maser-1 gain decreased but was still usable. A magnet current setting was suspected and readjusted during occultation, but this did not solve the problem. Although maser 2 was available, the MSFN elected to continue on maser 1. Repairs to maser 1 were completed between lunar orbits 15 and 16 by replacing the magnet power supply.

The Tidbinbilla MSFN Wing tracked lunar orbits 3 through 8 in the three-way mode. The station also supported lunar orbits 16 through 20, all of which were in the two-way mode except for orbit 16. The station also supported lunar orbits 28 through 31.

The Robledo MSFN Wing tracked lunar orbits 7 through 14, a portion of which were in the two-way mode. During the station countdown for the next series of orbits, cross-head modulation was experienced on maser 1. The station switched to maser 2 and supported lunar orbits 20 through 26 in that configuration.

Each of the MSFN Wings at Pioneer, Tidbinbilla, and Robledo supported two passes during the trans-earth phase, providing full coverage. During the station readiness test for the first trans-earth pass at Tidbinbilla, transmitter 2 tripped off. The transmitter high-voltage power supply rectifier and cabinet door interlocks were reset with no subsequent failures.

The DSN MSFN Wing Stations were released from Apollo 10 mission status support on May 26, 1969, at 17:30 GMT.

c. Mars (64-m Antenna) Support of Apollo 10. Due to angular tracking rate limitations, Mars does not attempt to support Apollo earth-orbital passes. However, it was planned that the first two trans-lunar passes would be short training exercises for the station and the supporting elements within the DSN (Table 6). During the mission, these training passes were usurped by requirements to provide additional color TV support (Table 5).

Mars initially acquired Apollo 10 at 19:50 GMT, May 18, using a converted MSFN 29-point acquisition message. At 19:55 GMT, Mars momentarily broke track to change to a drive tape produced from predicts generated by the SFOF. Early in this pass, the Mars antenna rates were near the permissible maximum, and an elevation angle of 81 deg was reached. This is the highest elevation angle at which this station has ever tracked a spacecraft. During the first color TV broadcasts, difficulty was encountered in transmitting the video signals to the Goldstone MSFN Station. The difficulty was traced to crossed receiver output cables between the control room and the communications room at Mars. Corrections were made, and the color TV transmissions were supported as required.

Mars countdown for trans-lunar pass 2 was completed very quickly, and the station began tracking earlier than scheduled (Table 6). TV support was provided; the phase-modulated telemetry interface was verified; and the tracking data-handling system was exercised to provide a test of the configuration for acquiring the required high-resolution doppler data. During this pass, at 20:55 GMT, the frequency and timing subsystem jumped four days and four hours in time. This caused the antenna pointing system (APS) tape reader to advance all of the drive tape in search of the correct time, and diverted the antenna tracking from the spacecraft. The clock and tape were reset, and the spacecraft was reacquired at 21:05 GMT. This was the only equipment failure at the Mars station during the mission.

Mars support of trans-lunar pass 3 was also started early, this time due to an unscheduled color TV transmission from the Apollo spacecraft. Color TV transmissions were also supported on pass 4 as well as providing phase-modulated data to the MSFN Station via the DSN intersite microwave link at Goldstone DSCC. The data streams were continuous until Apollo 10 experienced its first lunar occultation at 20:37 GMT. Upon emergence from occultation, Apollo 10 was in lunar orbit and the station continued to support lunar orbits 1 through 4, providing both the CSM and LM data streams. During lunar orbit 4, Mars participated in the special LM omniantenna telecommunications test previously described. The results of this test were analyzed by the MSC, Houston, Texas. Mars TDH was again exercised on lunar orbits 2, 3 and 4 in preparation for the requirement to provide doppler resolver data on the perilune passes (13, 14 and 15). Spacecraft occultation at the end of lunar orbit 4 concluded the Goldstone DSCC view period for that day.

The next day, Mars acquired Apollo 10 near the end of lunar orbit 11, and continued to support the program through the orbit 17. A color TV transmission was supported during orbit 12, and the required high-resolution doppler data were provided during the LM perilune passes on lunar orbits 13, 14, and 15. The high-resolution doppler data from the lunar module perilune passes were transmitted to the SFOF in near real-time for validation purposes.

During the next Goldstone DSCC view period, Mars was requested to be on track 1 h earlier than scheduled and to extend the track to cover an unscheduled color TV show. Lunar orbits 24 through 29 were supported during this pass.

Mars continued to support Apollo 10 for one complete pass following post trans-earth injection. Two additional color TV transmissions were supported during this time period. Mars was released by MSC from further Apollo 10 support at end of track on May 25, at 02:08 GMT.

d. SFOF Participation. The SFOF areas and equipment involved in the DSN Apollo 10 operations included the operations center, the flight path analysis area, the displays, and the Mode II 7044-7094 computers. These areas and functions were staffed during all Goldstone DSCC view periods and at other times as required to support special activities, such as the generation of additional predict information for Mars. The predicts for Mars were both accurate and timely due to the receipt of over 60 state-vector updates from MSC and GSFC. No significant problems were encountered in the SFOF during the Apollo 10 mission.

e. GCF Participation. The DSN Ground Communications Facility provided voice and teletype circuits as required to support the operations, monitoring, and data transmission activities mentioned in the foregoing paragraphs. The communications configuration is shown in Fig. 16. There were no communications problems during the DSN support of the Apollo 10 mission.

Table 4. Sequence of events, Apollo 10 mission

Event	GET hr:min:sec	GMT May 1969
Range zero - 16:49:00 GMT, May 18, 1969		
Lift-off	00:00:00.6	18/16:49:00.6
Maximum dynamic pressure	00:01:22.6	18/16:50:22.6
S-IC outboard engine cutoff	00:02:41.6	18/16:51:41.6
S-II engine ignition (command)	00:02:43.1	18/16:51:43.1
Launch escape tower jettison	00:03:17.8	18/16:52:17.8
S-II engine cutoff	00:09:12.6	18/16:58:12.6
S-IVB engine ignition (command)	00:09:13.6	18/16:58:13.6
S-IVB engine cutoff	00:11:43.8	18/17:00:43.8
Parking orbit insertion	00:11:53.8	18/17:00:53.8

Table 4 (contd)

Event	GET hr:min:sec	GMT May 1969
S-IVB ignition (translunar injection)	02:33:28	18/19:22:28
Translunar injection (S-IVB cutoff + 10 sec)	02:39:21	18/19:28:21
Command and service module separation	03:02:42	18/19:51:42
First docking	03:17:37	18/20:06:37
Spacecraft ejection	03:56:26	18/20:45:26
Spacecraft separation maneuver	04:39:10	18/21:28:10
First midcourse correction	26:32:57	19/19:21:57
Lunar orbit insertion	75:55:54	21/20:44:54
Lunar orbit circularization	80:25:08	22/01:14:08
Undocking	98:11:57	22/19:00:57
Command and service module separation maneuver	98:47:17	22/19:36:17
Descent orbit insertion	99:46:02	22/20:35:02
Phasing orbit insertion	100:58:26	22/21:47:26
Lunar module staging	102:45:17	22/23:34:17
Ascent insertion maneuver	102:55:02	22/23:44:02
Coelliptic sequence initiation	103:45:55	23/00:34:55
Constant differential height maneuver	104:43:53	23/01:32:53
Terminal phase initiation	105:22:56	23/02:11:56
Second docking	106:22:02	23/03:11:02
Ascent stage jettison	108:24:36	23/05:13:36
Final separation maneuver	108:43:23	23/05:32:23
Ascent engine firing to propellant depletion	108:52:06	23/05:41:06
Transearth injection	137:36:29	24/10:25:29
Second midcourse correction	188:49:58	26/13:38:58
Command module/service module separation	191:33:26	26/16:22:26
Entry interface (120,675 km altitude)	191:48:55	26/16:37:55
Enter communications blackout	191:49:12	26/16:38:12
Exit communications blackout	191:53:40	26/16:42:40
Drogue deployment	191:57:18	26/16:46:18
Main parachute deployment	191:58:05	26/16:47:05
Landing	192:03:23	26/16:52:23

Table 5. Apollo 10 color TV log

Number		Ground-elapsed time to start of transmission		Transmission duration[a]		MSFN Station	Event
Planned	Actual	Planned	Actual	Planned	Actual		
1	1	$3^h03^m24^s$	$3^h06^m00^s$	15^m00^s	22^m00^s	Goldstone	Separation, transposition, and docking
	2	—	$3^h56^m00^s$	—	13^m25^s	Goldstone	CSM/lunar module ejection from S-IVB
	3	—	$5^h06^m34^s$	—	13^m15^s	Goldstone	View of earth and spacecraft interior
	4	—	$7^h11^m27^s$	—	24^m00^s	Goldstone	View of earth and spacecraft interior
2	5	$27^h15^m00^s$	$27^h00^m48^s$	15^m00^s	27^m43^s	Goldstone	View of earth and spacecraft interior
	6	—	$48^h00^m51^s$	—	14^m39^s	Madrid	View of earth and spacecraft interior (recorded)
	7	—	$48^h24^m00^s$	—	3^m51^s	Madrid	View of earth and spacecraft interior (recorded)
	8	—	$49^h54^m00^s$	—	4^m49^s	Goldstone	View of earth
3	9	$54^h00^m00^s$	$53^h35^m30^s$	15^m00^s	25^m00^s	Goldstone	View of earth and spacecraft interior
4	10	$72^h20^m00^s$	$72^h37^m26^s$	15^m00^s	17^m16^s	Goldstone[b]	View of earth and spacecraft interior
5	11	$80^h45^m00^s$	$80^h44^m40^s$	10^m00^s	29^m09^s	Goldstone	View of lunar surface
6	12	$98^h13^m00^s$	$98^h29^m20^s$	10^m00^s	20^m10^s	Goldstone	View of separation maneuver
7	—	$108^h35^m50^s$	—	15^m00^s	—	Goldstone	(Deleted)
8	—	$126^h20^m00^s$	—	40^m00^s	—	Goldstone	(Deleted)
	13	—	$132^h07^m12^s$	—	24^m12^s	Goldstone	View of lunar surface and spacecraft interior
9	14	$137^h45^m00^s$	$137^h50^m51^s$	15^m00^s	43^m03^s	Canberra	View of moon post TEI
	15	—	$139^h30^m16^s$	—	6^m55^s	Canberra	View of moon post TEI
	16	—	$147^h23^m00^s$	—	11^m25^s	Goldstone	View of receding moon and spacecraft interior
10	17	$152^h35^m00^s$	$152^h29^m19^s$	10^m00^s	29^m05^s	Goldstone	View of earth, moon and spacecraft interior
	18	—	$173^h27^m17^s$	—	10^m22^s	Goldstone	View of earth and spacecraft interior
11	19	$186^h50^m00^s$	$186^h51^m49^s$	15^m00^s	11^m53^s	Goldstone	View of earth and spacecraft interior

[a]Total planned transmission duration of $2^h55^m00^s$; total actual transmission duration of $5^h52^m12^s$.
[b]Additional support provided by the DSN Mars station (64-m antenna).

Table 6. Mars station planned tracking schedule

Scheduled Date/Time (GMT)	Actual
May 18/2000 - 19/0100 (Training only)	18/1950 - 19/0100
May 19/1900 - 20/0200 (Training only)	19/1745 - 20/0200
May 20/2200 - 21/0200	20/1845 - 21/0200
May 21/1600 - 22/0600	21/1735 - 22/0440
May 22/1800 - 23/0800	22/1824 - 23/0623
May 23/2100 - 24/0400	23/1921 - 24/0600
May 24/2100 - 25/0400	24/1955 - 25/0208

Table 7. Spacecraft monitoring station support activities

Date, 1969	Event
April 29-30	Observed color TV transmission. Test inconclusive due to lack of test status coordination between MSFN Merritt Island Station (MILA) and the Spacecraft Monitoring Station.
May 2	Observed color TV transmissions. Polaroid photos of spectrum and spectrum analysis of the color TV indicated no significant difference from black and white TV. This information given to Mars.
May 4-5	Participated in CDDT beginning at 19:30 GMT, May 4, and terminating at 14:43 GMT, May 5. The pulse-code-modulated (PCM) telemetry at baseband was transmitted to the MILA Station and polaroid pictures were made of the received spectrum.
May 6	Participated in the CDDT from 12:00 to 18:15 GMT with the same support provided on the previous CDDT.
May 17-18	For the terminal count and launch, the station was manned at 17:00 GMT, May 17. Intersite (Spacecraft Monitoring Station-MILA) voice and data circuits were made between 17:30 and 21:00 GMT. CSM S-band on at 01:27 GMT, and station receiver was phase-locked to the signal. Spectrum analysis of the CSM signal performed using the automatic spectrum analysis program. Plots were made at the carrier (2287.5 MHz) ±200 kHz, at 1.024 MHz unified S-band ±200 kHz, and at 1.250 MHz ±200 kHz. PCM bit stream was transmitted to MILA and polaroid pictures made of the received spectrum. At launch (16:49 GMT, May 18), the Spacecraft Monitoring Station's receiver was locked one way with the CSM. Phase lock was maintained until 16:56:30 GMT at which time tracking was terminated due to horizon loss of signal and support was completed.

Table 8. Apollo 10 signal levels measured at the spacecraft monitoring station test signal from launch to loss of signal

GMT, h:min:s	Signal level, dbm	Remarks
16:49:00	−69	At liftoff
16:50:00	−69	—
16:51:00	−88	—
16:51:15	—	In and out of lock
16:51:32	−118	—
16:52:00	−130	—
16:53:00	−115	—
16:54:00	−120	—
16:54:30	—	Receiver 1 out of lock
16:55:00	−135	Receiver 1 in lock
16:55:30	−150	—
16:56:00	—	Receiver 1 out of lock
16:57:33	—	Receiver 2 out of lock

Table 9. View periods for Goldstone, Honeysuckle and Madrid for Apollo 10

Station	Rise Time (GET)			Set Time (GET)			
	D	H	M	D	H	M	
GDS	0	2	50	0	13	46	
HSK	0	8	24	0	17	19	
MAD	0	15	38	1	7	2	
GDS	0	23	44	1	14	21	
HSK	1	8	53	1	18	4	
MAD	1	16	15	2	7	12	
GDS	2	0	6	2	14	29	
HSK	2	8	57	2	18	18	
MAD	2	16	27	3	3	38	
GDS	3	0	14	3	3	37	
Lunar Orbit Insertion							Lunar Orbit No.
GDS	3	4	12	3	5	37	1
MAD	3	4	12	3	5	37	1
GDS	3	6	20	3	7	45	2
MAD	3	6	20	3	7	17	2
GDS	3	8	29	3	9	41	3
HSK	3	9	2	3	9	41	3
HSK	3	10	28	3	11	39	4
GDS	3	10	28	3	11	39	4
HSK	3	12	26	3	13	38	5
GDS	3	12	26	3	13	38	5
HSK	3	14	24	3	15	36	6
GDS	3	14	24	3	14	42	6
HSK	3	16	23	3	17	34	7
MAD	3	16	57	3	17	34	7
MAD	3	18	20	3	19	32	8
HSK	3	18	21	3	18	52	8
MAD	3	20	18	3	21	30	9
MAD	3	22	17	3	23	28	10

Table 9 (contd)

Station	Rise Time (GET)			Set Time (GET)			Lunar Orbit No.
	D	H	M	D	H	M	
MAD	4	0	15	4	1	27	11
GDS	4	1	2	4	1	26	11
GDS	4	2	13	4	3	25	12
MAD	4	2	13	4	3	25	12
GDS	4	4	11	4	5	23	13
MAD	4	4	12	4	5	23	13
GDS	4	6	10	4	7	21	14
MAD	4	6	10	4	7	21	14
GDS	4	8	8	4	9	20	15
HSK	4	10	6	4	11	17	16
GDS	4	10	6	4	11	18	16
HSK	4	12	4	4	13	16	17
GDS	4	12	4	4	13	16	17
HSK	4	14	3	4	15	14	18
GDS	4	14	3	4	15	14	18
HSK	4	16	1	4	17	13	19
HSK	4	17	59	4	19	11	20
MAD	4	17	59	4	19	10	20
MAD	4	19	57	4	21	8	21
MAD	4	21	55	4	23	7	22
MAD	4	23	53	5	1	5	23
MAD	5	1	52	5	3	3	24
GDS	5	2	0	5	3	3	24
GDS	5	3	50	5	5	1	25
MAD	5	3	50	5	5	2	25
GDS	5	5	48	5	6	59	26
MAD	5	5	48	5	7	0	26
GDS	5	7	46	5	8	58	27
MAD	5	7	46	5	8	10	27
GDS	5	9	45	5	10	56	28

Table 9 (contd)

Station	Rise Time (GET)			Set Time (GET)			Lunar Orbit No.
	D	H	M	D	H	M	
HSK	5	10	1	5	10	56	28
HSK	5	11	42	5	12	54	29
GDS	5	11	43	5	12	54	29
HSK	5	13	41	5	14	52	30
GDS	5	13	41	5	14	52	30
HSK	5	15	37	5	16	51	31
GDS	5	15	39	5	15	40	31
Trans-Earth Injection							
HSK	5	17	29	5	20	43	
MAD	5	18	58	6	8	18	
GDS	6	2	39	6	15	42	
HSK	6	10	11	6	20	54	
MAD	6	19	14	7	8	22	
GDS	7	3	2	7	15	55	
HSK	7	10	30	7	23	48	

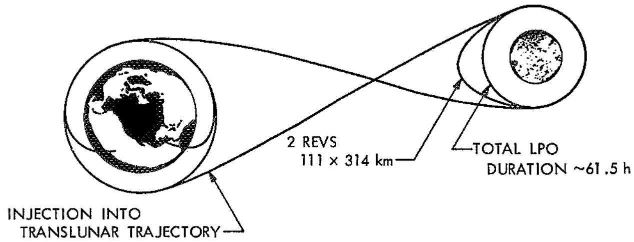


Fig. 6. Apollo 10 mission profile

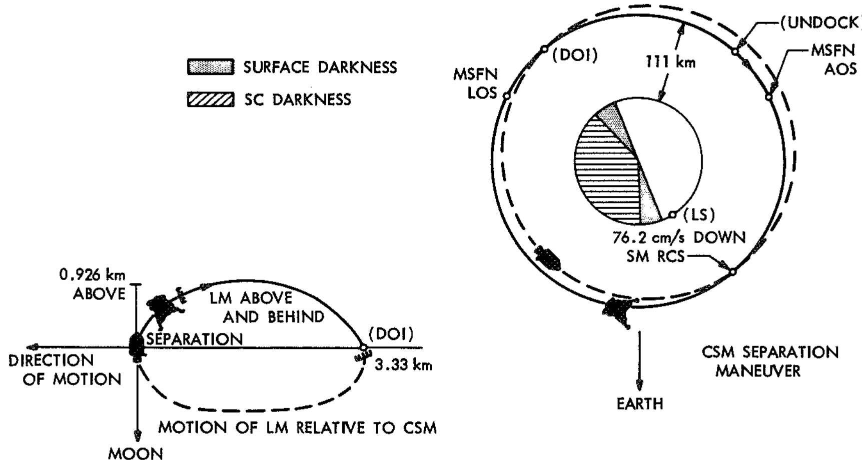


Fig. 7. Separation

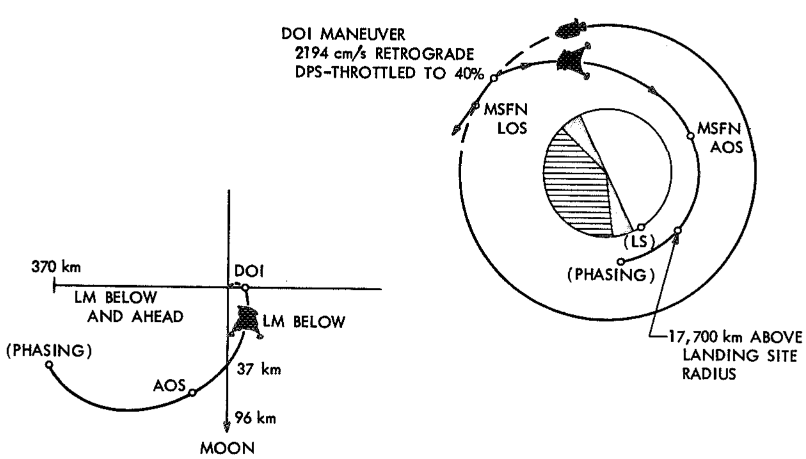


Fig. 8. Descent orbit insertion

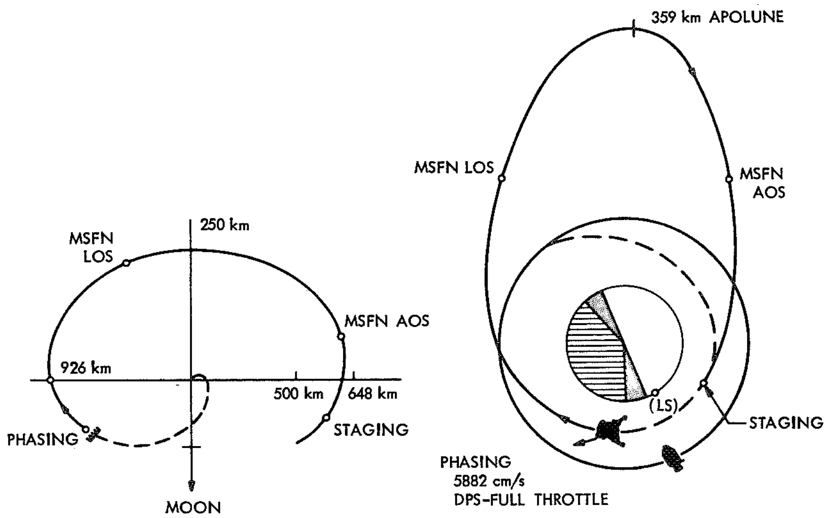


Fig. 9. Phasing

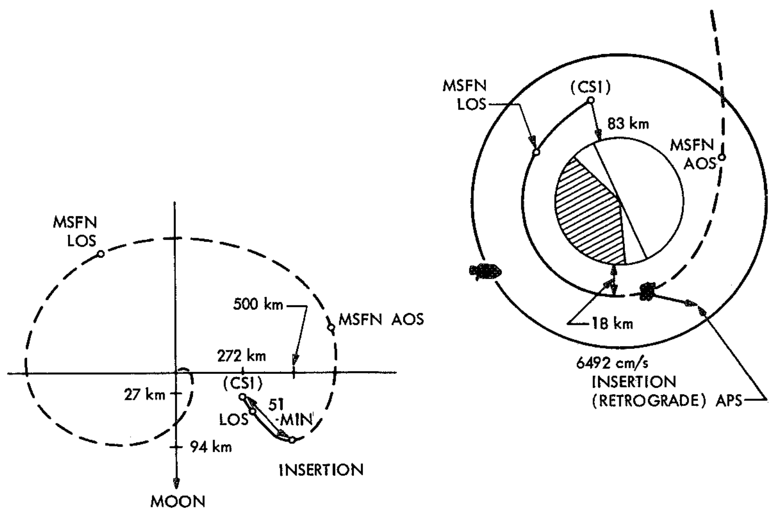


Fig. 10. Insertion

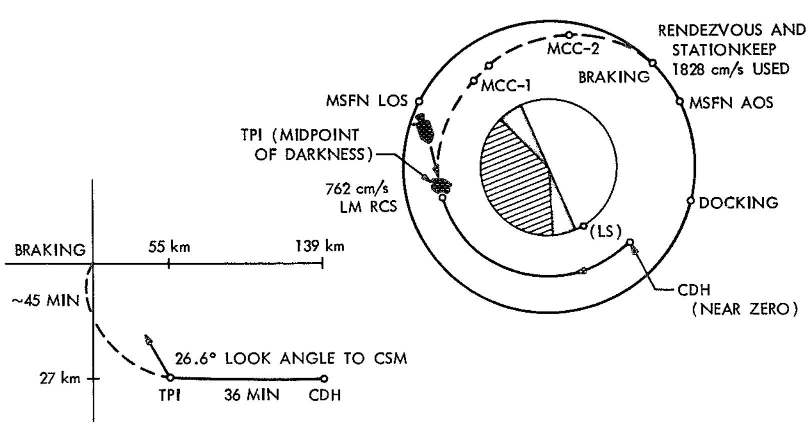


Fig. 11. Rendezvous and docking

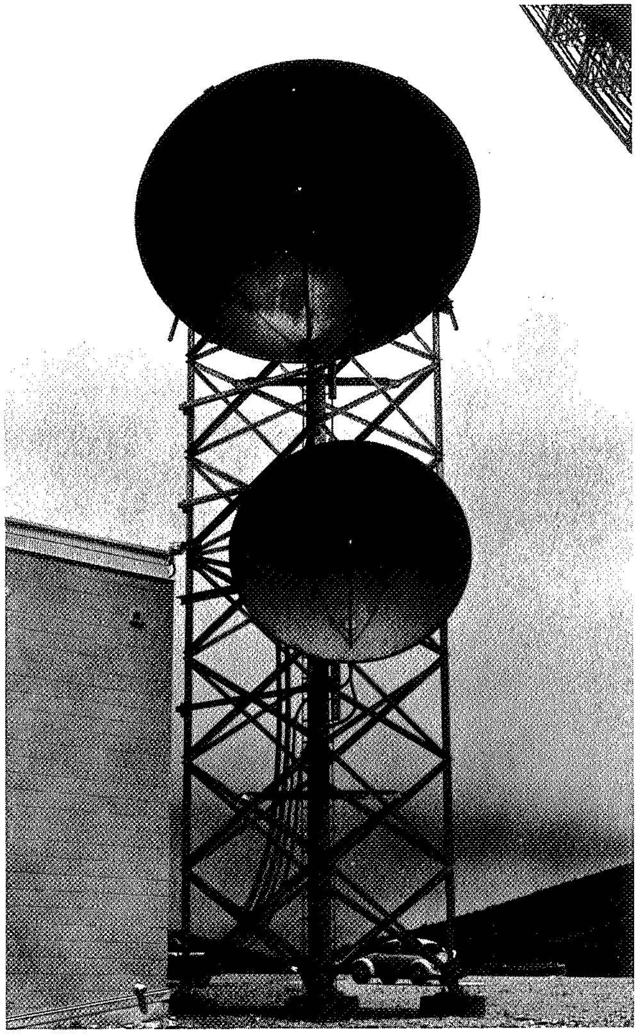


Fig. 12. MSFN intersite microwave tower at Mars station

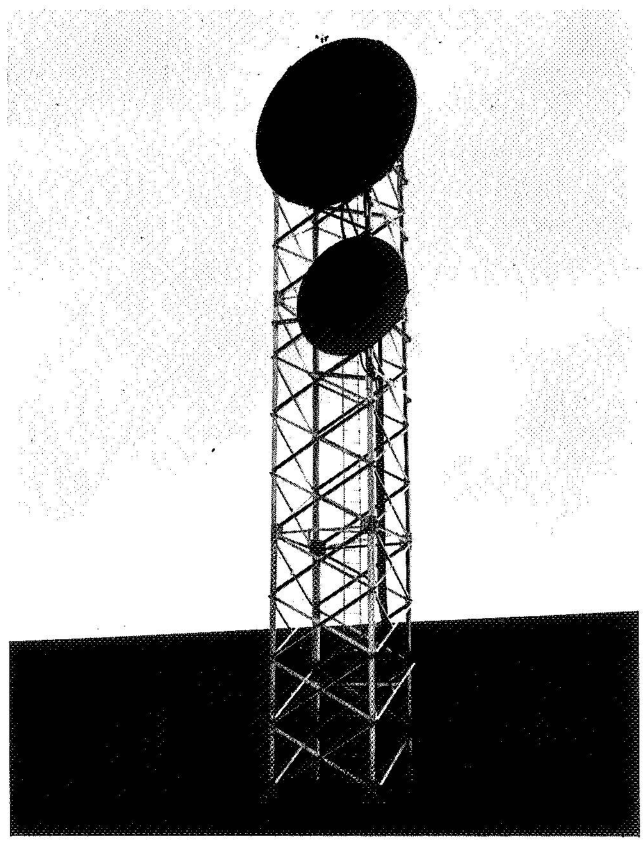


Fig. 13. Microwave tower at the Goldstone MSFN station

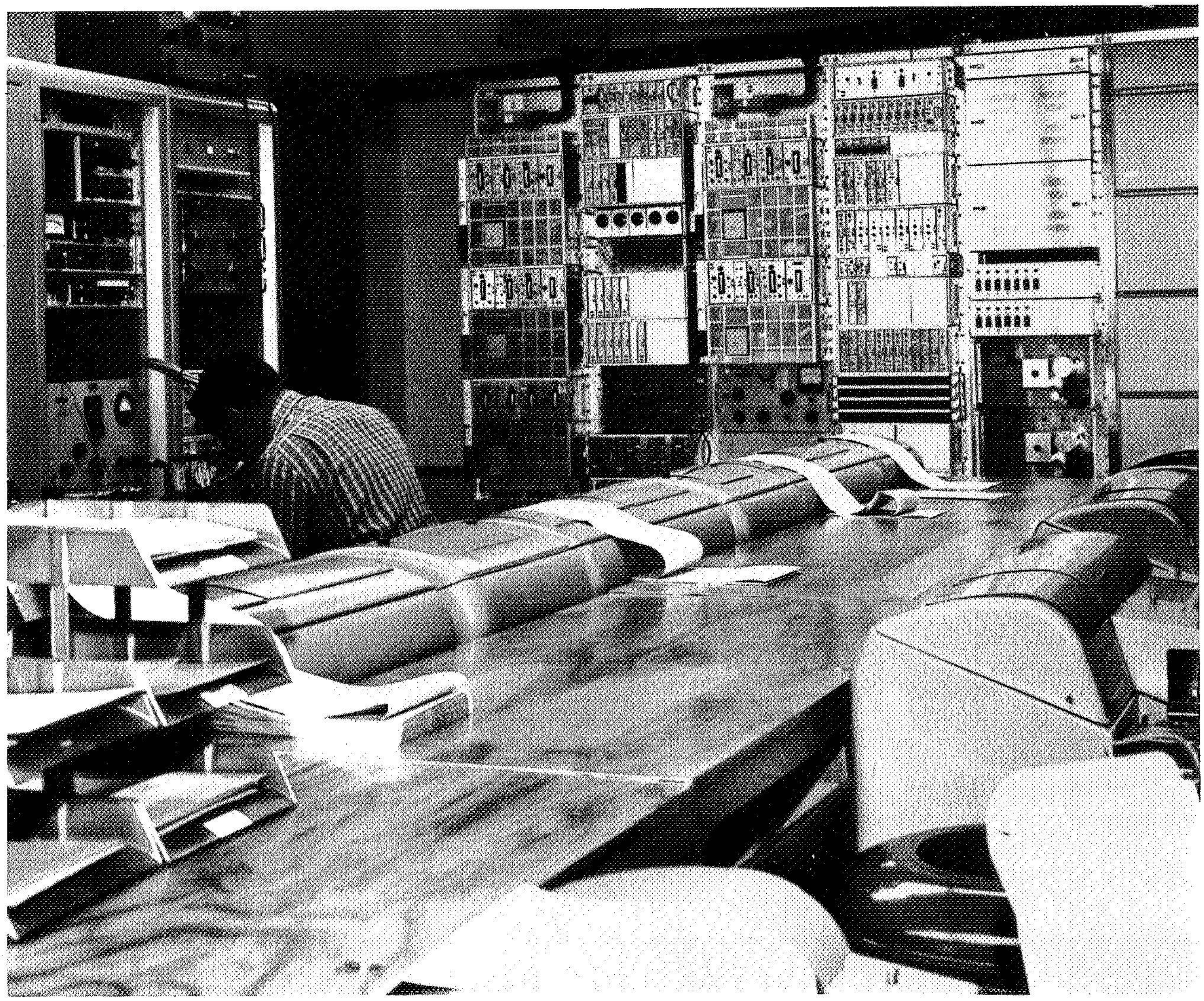


Fig. 14. Terminal equipment for MSFN intersite microwave system at Mars station

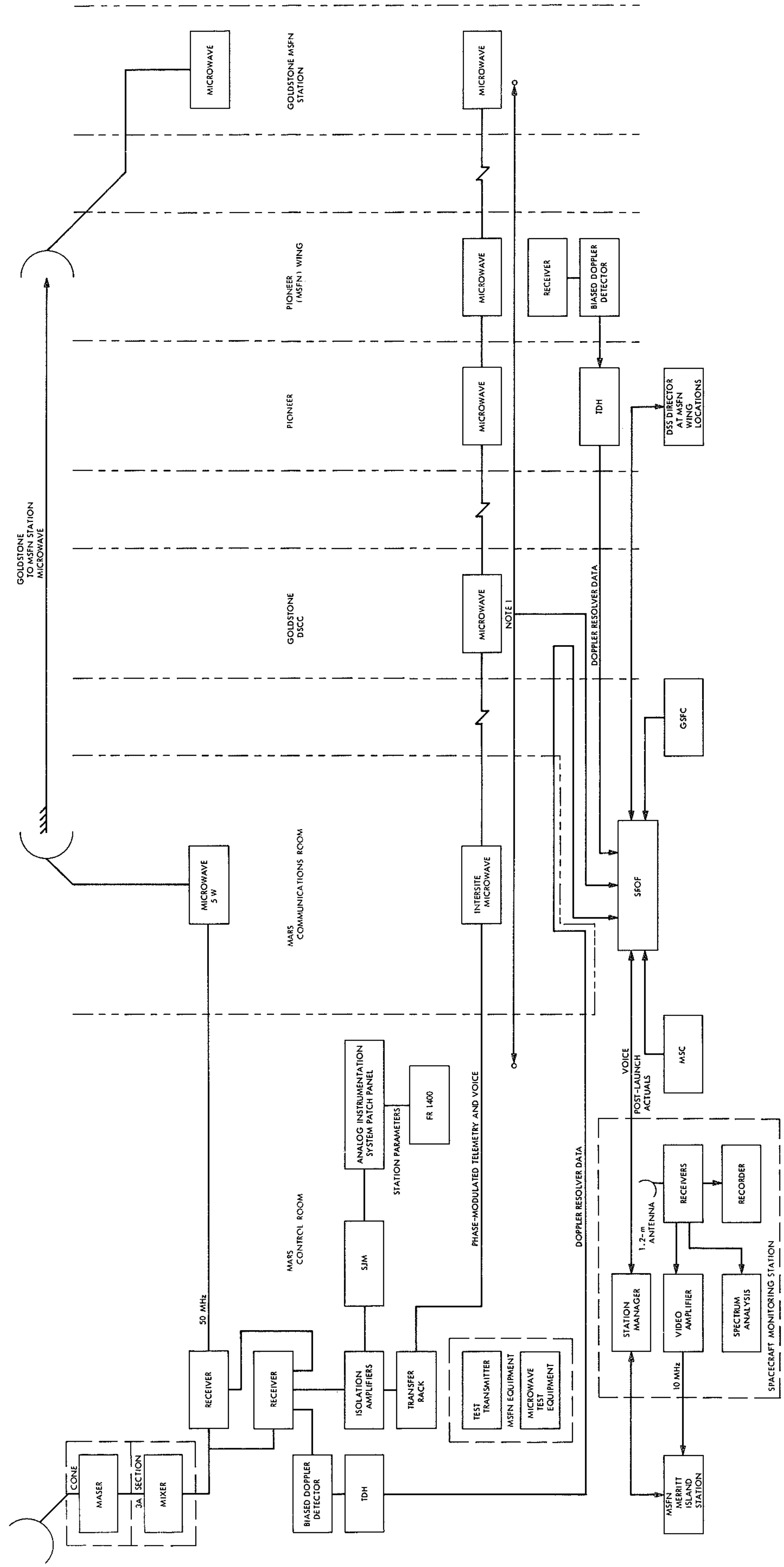
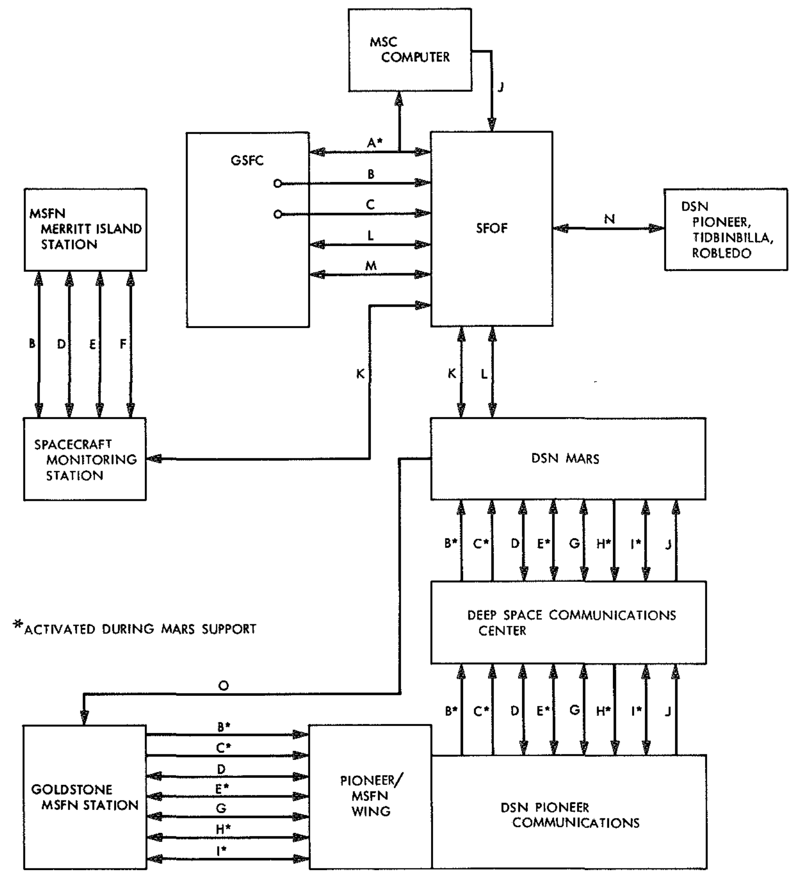


Fig. 15. DSN configuration for Apollo 10



A. VOICE, SDA–GSFC–MSC COMPUTER, STATE VECTOR COORDINATION

B. MSFN CONFERENCE LOOP NO. 2, MONITOR ONLY

C. MSFN CONFERENCE LOOP NO. 1 OR MISSION COMMENTARY MONITOR ONLY

D. MAINTENANCE AND OPERATIONS CONFERENCE LOOP, VOICE

E. UNIFIED S-BAND LOOP, VOICE

F. A2A VIDEO CIRCUIT

G. MAINTENANCE ORDER WIRE, VOICE

H. SPACECRAFT EMERGENCY VOICE

I. MICROWAVE DATA CHANNELS (2 DUPLEX)

J. TTY CIRCUIT, SIMPLEX

K. VOICE, STATION COORDINATION

L. TTY CIRCUITS, FULL DUPLEX

M. VOICE, NETWORK OPERATIONS MANAGER–DSN PROJECT ENGINEER

N. SIGNALING, CONFERENCING, AND MONITORING ARRANGING

O. MICROWAVE (MSFN)

Fig. 16. Apollo 10 communications requirements

IV. THE APOLLO 11 MISSION

A. Mission Description

The success of Apollo Missions 8, 9, and 10 made it possible for NASA to attempt the most daring mission of all -- the first manned lunar landing. On July 16, 1969, at 13:32 GMT, Apollo 11 was launched from Pad 39-A at Cape Kennedy with astronauts Neil A. Armstrong (spacecraft commander), Michael Collins (CM pilot), and Edwin E. Aldrin, Jr. (LM pilot) on board. The launch, insertion into earth orbit, injection into a lunar transfer trajectory, and the coast phase of the mission closely followed those of the Apollo 10 Mission. Seventy six hours after launch, Apollo 11 was inserted into a 111 by 314 km elliptical lunar orbit. Four hours later the lunar circularization maneuver was performed which placed the spacecraft in a 122 by 100 km orbit. At 100:12 GET, the LM undocked from the CSM. The descent orbit insertion maneuver was performed by the LM descent propulsion system at 101:30 GET. This critical phase of the mission was tracked by the DSNs 64-m antenna at Goldstone. Apollo 11's LM, nicknamed "Eagle," successfully landed on the moon's Sea of Tranquility at 102:45:39.9 GET, July 20, 1969, and Commander Armstrong immediately reported to Mission Control in Houston: "The Eagle has landed."

After donning their extra-vehicular spacesuits, the astronauts depressurized the spacecraft cabin and Armstrong descended the ladder to touch the lunar surface. Shortly thereafter, he was joined by Aldrin; then the two men set up the experiments that were to be left upon the lunar surface. This sequence was viewed around the world via live TV transmitted from the LM to the earth-based deep space communication stations and thence, via communications satellites, to the viewing audience. The astronauts remained on the lunar surface for 2 h, 14 min prior to reentering their spacecraft with the lunar-soil samples for return to earth.

Once within the spacecraft, the astronauts prepared for their planned ascent and rendezvous with the orbiting CM. After a successful launch from the lunar surface, docking with the CM was completed at 128:03 GET. After astronauts Armstrong and Aldrin had transferred, with the lunar samples and photographic film, from the LM to the CM, the ascent stage of the LM was jettisoned. The CM Service Propulsion System was ignited at 135:23:42 GET on July 22 to return the three astronauts to earth in what proved to be an almost perfect trajectory.

The Apollo 11 CM splashed down in the Pacific, southeast of the Hawaiian Islands, at 195:18:35 GET on July 24, thereby successfully completing man's first venture to the moon. For a complete sequence of major events refer to Table 10. All three astronauts and their space capsule were successfully recovered by the USS Hornet, where they were personally greeted by President Richard M. Nixon.

B. Requirements for DSN Support of Apollo 11

The requirements for DSN support of Apollo 11 were basically the same as those for Apollo 8 and 10. However, since Apollo 11 was to be a manned lunar landing mission, DSN deep space communication stations Pioneer, Tidbinbilla, and Robledo were committed to support the mission under direct MSFN/MSC control starting 2 weeks prior to launch through completion of mission. In addition, the MSFN requested that the Mars 64-m deep space communications antenna located at Goldstone be used in the support of Apollo 11 to receive and relay planned color TV transmissions (Table 11), portable life support system (PLSS) data, telemetry data, and voice data to the MSFN Prime station during the lunar surface operations. Mars was also required to be prepared to provide emergency support during a contingency situation. The LM descent phase was termed a potential contingency situation because a failure of the S-band steerable antenna would mean a loss of high bit-rate telemetry data to the 26-m antenna stations required to monitor the performance of the LM guidance system. Therefore, during the descent phase, Mars was required to be in a "standing ready" condition in order to have signal strength, voice, and telemetry data instantly available for the Prime station if necessary.

Armed with these requirements, the DSN developed a reasonable Apollo allocation time schedule for the Mars station (Table 12) between Apollo and the Mariner 69 Project whose Mars encounter phase would occur 10 days after the Apollo 11 lunar surface operations. Because additional Apollo support requirements were received later from NASA, this schedule had to be revised. These additional requirements called for the collection of precision doppler and signal strength data from the LM during descent, from the CSM on two or three lunar orbits, and an extension of tracking time from LM/CSM docking until one hour after LM/CSM docking. This extension of tracking time cut into the Operational Readiness Test (ORT) for the Mariner 69 encounter.

A requirement also existed for synchronizing the time standards at all participating Apollo stations at the Goldstone complex. On July 12, 1969, an agreement was reached on the following procedure:

(1) The portable cesium clock would be used to measure the frequency offset of the frequency combiner (and the cesium, if time permits). This measurement would be made with respect to the NBS-clock and to an accuracy of one part in 10^{12}. The measurement would be made at the Wing and the Prime site within 24 h prior to the mission, and within 24 h after the mission. Approximately two to three hours would be needed to obtain this accuracy of measurement.

(2) At the same times, a measurement would be made of the offset of the station clock with respect to NBS.

(3) A one-pulse-per-second tick would be distributed via microwave to Pioneer and Mars stations. This pulse originates from the DSIF standards lab, arrives at the sites with known offsets, and is

accurate to better than 5 μs. GDSX would be provided hardwire access to the time pulse at the Pioneer communications room.

(4) A TWX would be sent after each portable clock trip to a standard distribution list giving the results with respect to NBS and the expected NBS-USNO offset.

(5) If additional measurements were required due to failure, etc., the site should contact the DSIF timing expert at Goldstone, extension 269 or extension 363; home phone is 714-252-3645 for the DSIF timing expert. During the normal work day, normal response is within one hour; otherwise, approximately four hours is the response time.

(6) It was suggested that the time schedule for the measurements be coordinated between the GDS station director and the DSIF timing expert.

This plan was used for Apollo missions 11 through 13, and was subsequently modified in June 1970 (see *Section VII*). The actual measured values for Apollo 11 are noted in Table 13.

C. DSN Mission Support

1. DSN Premission Activities.

a. DSN/MSFN Wing Stations. Deep space communication stations Pioneer, Tidbinbilla, and Robledo were placed under configuration control for the Apollo 11 mission as of 00:01 GMT on July 4, and subsequently placed on mission status by the MSFN as of 00:01 GMT on July 7. Premission testing of these stations and operator training for the Apollo 11 mission were conducted by the MSFN.

b. Spacecraft Monitoring Station. The Spacecraft Monitoring Station supported the prelaunch and launch activities (Table 14) of Apollo 11 in a configuration identical with that used for the Apollo 4 to 10 missions. The station was placed under Apollo 11 configuration control at 00:01 GMT on July 4 and remained in that condition through launch until release at 19:00 GMT on July 17.

c. Mars. The Mars station was placed under configuration control for Apollo 11 at 00:01 GMT on July 4 and underwent Configuration Verification Testing on July 2/00:00 to 08:00 GMT and July 5/13:00 to 21:00 GMT. The Mars station interface with the MSFN/Apollo Network is shown in Fig. 17. The new MSFN microwave link between Mars and the Apollo Prime station was fully operational for this mission. However, since the second channel of this link had not been tested in a prior mission, a backup microwave link via the DSN Goldstone DSCC system through the GCF communications terminal, located at the Echo station, and thence to the Apollo Prime, was employed.

As was the case in the Apollo 10 Mission, the SFOF was configured to receive state vector data from GSFC and the Manned Spacecraft Center (MSC) and to generate predicts which were forwarded to the Deep Space Stations (DSSs) on a daily basis. In addition, Mars was configured to record high-speed doppler resolver data and high-speed automatic gain control (AGC) data during the LM descent phase in response to an MSC requirement. The configuration shown in Fig. 17 was tested during the DSN Operational Readiness Test (ORT) held on July 10 in collaboration with the Goldstone Apollo Prime and Pioneer MSFN Wing stations. An attempt was made to schedule this test concurrently with the MSFN Net Simulation, but MSFN schedule changes precluded the simultaneous testing.

2. DSN Apollo 11 Mission Activities.

a. Spacecraft Monitoring Station. The Spacecraft Monitoring Station joined the terminal count of Apollo 11 at 15:30 GMT on July 15 when the S-band signal was activated at T — 9 h, 30 min in the countdown. Spectral analyses of the S-band signal were taken and provided to the MSFN Merritt Island Station for further processing. The CTS support was continuous to launch at 13:32:00.78 GMT on a launch azimuth of 72.06 deg. The S-band signal strength at launch was —70.6 dBmW. Horizon loss-of-signal occurred at 13:40:28 GMT (8 min, 27 s ground elapsed time) at a signal strength of —143 dBmW (see Table 15). Three minor flame effect dropouts occurred after launch, but otherwise there were no anomalies and the station was released by the MSFN from further Apollo support.

b. Pioneer, Tidbinbilla, and Robledo Stations. The common equipment at Pioneer, Tidbinbilla, and Robledo Stations used by the MSFN Wings was operational at launch. These stations supported the earth-orbital, lunar-transfer, lunar-orbital, and earth-return phases of the mission (see Tables 16 through 19) with the following anomalies noted:

(1) Pioneer. While Apollo 11 was enroute to the moon, Pioneer experienced an infrequent and intermittent overload trip in transmitter 1 "beam and body current fault detector." Because of this, transmitter 2 was considered the prime link to the spacecraft and transmitter 1 was placed on standby status. Since both transmitters might have been needed during the time the CM was separated from the LM at the moon, the MSC released Pioneer from further tracking during lunar orbit 2 in order to trouble-shoot the problem prior to the LM descent phase of the mission.

The release was effective from 21:59 GMT on July 19 until spacecraft rise on the next pass. During this time period, station personnel replaced the klystron filament transformer, redressed the high-voltage leads in the klystron cabinet and the high-voltage power supply, and inspected every component for possible clues as to the cause of the intermittent overload trip. The unit was then baked continuously until start of precalibration for the following pass. However, these efforts were to no avail and the fault reoccurred twice on July 20. Fortunately, there was no loss of data. The cause of this intermittent difficulty is not known at this time. In fact, this anomaly continued to plague the station even during the Mariner VI and VII encounters, which followed the completion of the Apollo 11 mission.

During the track on July 21, water contamination interfered with the antenna personnel safety circuit, but there was no effect on the mission.

(2) Tidbinbilla. On July 18, while Apollo 11 was enroute to the moon, Tidbinbilla/MSFN Wing had a major failure in transmitter power supply 2 at 08:25 GMT while the station was tracking Apollo 11 in a three-way mode. Transmitter 1 was still operational at the time. A fire caused by a short in the primary 460-V, 3-phase system destroyed a large part of the power supply's control system. There was considerable damage to internal wiring, and some melting and fusing of metalwork and panels occurred (Fig. 18).

As soon as the power supply had sufficiently cooled, repair crews started to determine the extent of damage and replace the burned components. Fortunately, spares for critical, long-leadtime items were at the station. However, additional control circuit components and the primary heavy-duty, 3-phase wire were not immediately available. These were obtained by removing needed components from the obsolete "L" to "S" power supply still situated at the DSN Woomera station, and by airlifting the additional needed components and wiring from the Goldstone DSCC. The station crew, with assistance from the MSFN Prime station at Honeysuckle Creek, worked around the clock to repair the power supply. Full rf power became available on transmitter 2 at 13:30 GMT on July 19. As of that time, 177 manhours had been expended to repair the unit. The unit was then tested under full power until 22:20 GMT on July 19, at which time it was declared operational and the station reinstated to full Apollo support status. Tidbinbilla supported the lunar landing and Apollo 11's subsequent return to earth without further incident.

(3) Robledo. Apollo 11 operations at the Robledo/MSFN Wing were not entirely uneventful. During the launch countdown, at precisely 10 s before liftoff, a grass fire broke out next to the powerhouse. The wind carried the flames to within 457 cm of the building and filled the generator room with dense smoke to such an extent that the diesels were in danger of suffocating. However, the fire was rapidly brought under control and no harm was done.

During pre-calibrations for translunar injection pass 1, the combiner water load flow tripped off both transmitters due to air getting into the system. This problem was rapidly cleared and the station came up on time for the tracking. On two occasions, the high-voltage ac over current tripped and took out the prime transmitter. The first instance was during translunar coast pass 3 when the station was in the two-way mode; the second was during trans-earth coast pass 1 when the station was in a three-way mode. On both occasions, the standby transmitter was unaffected. Ambient temperatures in the transmitter power supply room were around 100°F at the time.

During translunar coast pass 3, the 400-Hz converter in the powerhouse failed and took out both transmitters during the two-way tracking. Ambient temperature in the powerhouse was 130°F and the converter was working only at half-rated capacity. However, the over-voltage relay tripped the output breaker and, within 2 s, the operator had switched over to the standby converter. Subsequently, both converters were paralleled and a fan installed to cool the relays and breakers.

In one case, the transmitter heat-exchanger over-temperature cutout tripped during pre-calibrations when the three-way (mixer) valve jammed open and bypassed the klystron coolant away from the radiator. This took out the standby transmitter just before translunar coast pass 4, but the problem was cleared in time for the tracking.

Most of the foregoing difficulties were directly or indirectly attributable to the high outside temperature that prevailed at the time of the mission, which also influenced the capability of the station's control-room air-conditioning system to keep the various equipment racks within their operating limits. Despite these difficulties, Robledo successfully supported the Apollo 11 mission.

(4) Mars. As mentioned earlier, the original requirement for Mars participation in the Apollo 11 mission was to provide TV coverage during lunar surface operations since the LM erectable high-gain antenna would not be carried on the first manned landing mission, and the additional gain of the Mars 64-m antenna over

that provided by the 26-m antenna stations would be necessary to receive the TV transmission via the LM 60-cm steerable antenna. However, the experience gained on the Apollo 10 mission caused a modification to the flight plan and its resulting support requirements from Mars.

It was discovered that during the LM descent phase, the spacecraft attitude changes that were necessary to perform a landing on the moon could cause dropouts in the high bit-rate telemetry stream into a 26-m antenna. Since such dropouts could cause the mission to be aborted, the MSC decided to delay the LM descent from lunar orbit 13 to lunar orbit 14 so that the descent would be visible from the Mars station thereby providing high bit-rate telemetry backup via the spacecraft omniantenna. In so doing, this would shift the nominal time-line for the astronauts' descent to the lunar surface and the lunar surface operations to very late in the Mars view period, with a much lower probability of TV coverage. To offset this latter condition, the MSFN made arrangements with the Australian government to utilize the Parkes-Australia 64-m radio astronomy antenna to provide the desired lunar surface TV coverage.

Since, during the actual mission, Commander Armstrong decided to advance the lunar surface operations to earlier in the time schedule, both the Mars and the Parkes 64-m antennas were able to provide coverage during that time period. Mission Control Center at MSC made an operational decision to have the Parkes antenna provide the TV coverage and the Mars antenna provide the very important portable life-support system (PLSS) telemetry coverage during this very critical period. Both 64-m antennas performed excellently.

The first Apollo 11 track at Mars was a training pass on July 17 (see Table 20). This was a short pass to check out the station configuration. However, a color TV transmission from the CM was supported and the data routed to the MSC. During this pass, Mars was directed by MSFN to track the SIV-B instrumentation unit (IU); however, no requirement had ever been established for Mars to track the discarded SIV-B. This mistake was quickly rectified and CSM tracking was resumed by Mars. A second training pass was supported late on July 17 and carried over to July 18, during which additional color TV was received from the Apollo 11 spacecraft. The July 18/19 training was preceded by an emergency track of the Pioneer VI spacecraft, which had been reported in difficulty.

However, Mars was able to reconfigure into an Apollo configuration and track the spacecraft in time for a scheduled color TV transmission. Apollo 11, at that time, was still enroute to the moon. Mars started the formal Apollo 11 support on July 19, at spacecraft rise at 18:01 GMT, while the spacecraft was traversing the front of the moon in its first lunar orbit. Lunar-orbit support continued with high-resolution doppler data being taken just prior to occultation on lunar orbits 2 and 3, during a communications test during lunar orbit 4, and during an additional high-resolution doppler test at occultation during lunar orbit 5. Mars then successfully tracked lunar orbit 6, which was the last scheduled track for the day.

In preparation for the critical LM descent to the surface, Mars began pre-calibrations at 11:30 GMT and completed them at 16:48 GMT on July 20. The station acquired the LM shortly after moonrise at 19:48 GMT while the LM was beginning its descent to the lunar surface and as it exited moon occultation. High-resolution doppler data and high-speed AGC records were taken from then until touchdown in accordance with MSC requirements. Prior to the powered descent, two short receiver dropouts occurred due to low received signal strength. The last 5 min prior to touchdown provided a good signal and Mars had solid receiver lock. After touchdown, the LM phase-modulated (PM) signal strength was stable at -93 dBmW through the cabin depressurization, which occurred at 02:26 GMT on July 21, and the opening of the hatch at 02:40 GMT. Mars supported the TV transmission showing man's first step on the moon at 02:56 GMT in collaboration with the Parkes-Australia 64-m antenna. Mars continued to support the surface operations and the astronauts' return to the vehicle up until the spacecraft set on Mars horizon at 05:43 GMT while the LM was still in the frequency-modulated (FM) mode. There were no anomalies experienced during this pass.

The Mars station next acquired Apollo 11 at moon rise at 20:07 GMT on July 21, at which time the LM was traversing the front of the moon during its ascent to rendezvous with the CM, which at that time was in lunar orbit 26. Mars supported lunar orbit 27 as the spacecraft exited moon occultation and continued through the docking of the two spacecraft, which occurred during lunar orbit 27. The successful completion of the docking maneuver completed Mars commitment to Apollo 11 and the MSFN released the station from further active support in order that the station might proceed with the Mariner VI pre-encounter activities, with the understanding that the station would respond within 4 h should it become necessary to support an Apollo 11 emergency -- which fortunately did not occur.

(5) SFOF Participation. The SFOF areas and equipment involved in the DSN Apollo 11 operations included the Operations Center, the Flight Path Analysis Area, the displays and the IBM 7044-7094 Mode II computers. These areas and functions were staffed during all Goldstone DSCC view periods, and at other times as required, to support special activities such as the generation of additional predict information for Mars. The predicts for Mars were both accurate and timely due to the prompt receipt of state vector updates from MSC and GSFC. No significant problems were encountered in the SFOF during the Apollo 11 mission.

(6) GCF Participation. The DSN GCF provided voice and teletype circuits similar to those for Apollo 10 (Fig. 16) as required to support the operations, monitoring, and data transmission activities mentioned in the foregoing paragraphs. No communications problems constrained the DSN support of the Apollo 11 mission.

Table 10. Sequence of events, Apollo 11 mission

Event	GET	GMT
Range zero - 13:32:00 GMT, July 16, 1969		
Lift-off	00:00:00.6	16/13:32:00
S-IC outboard engine cutoff	00:02:41.7	16/13:34:41.7
S-II engine ignition (command	00:02:43.0	16/13:34:43.0
Launch escape tower jettison	00:03:17.9	16/13:35:17.9
S-II engine cutoff	00:09:08.3	16/13:41:08.3
S-IVB engine ignition (command)	00:09:12.2	16/13:41:12.2
S-IVB engine cutoff	00:11:39.3	16/13:43:39.3
Translunar injection maneuver	02:44:16.2*	16/16:16:16.2
Command and service module/S-IVB separation	03:17:04.6	16/16:49:04.6
First docking	03:24:03.1	16/16:56:03.1
Spacecraft ejection	04:16:59.1	16/17:48:59.1
Separation maneuver (from S-IVB)	04:40:01.8*	16/18:12:01.8
First midcourse correction	26:44:58.7*	17/16:16:58.7
Lunar orbit insertion	75:49:50.4*	19/17:21:50.4
Lunar orbit circularization	80:11:36.8*	19/21:43:36.8
Undocking	100:12:00	20/17:44:00
Separation maneuver (from lunar module)	100:39:52.9*	20/18:11:52.9
Descent orbit insertion	101:36:14*	20/19:08:14
Powered descent initiation	102:33:05.2*	20/20:05:05.2
Lunar landing	102:45:39.9	20/20:17:39.9
Egress (hatch opening)	109:07:33	21/02:39:33
Ingress (hatch closing)	111:39:13	21/05:11:13
Lunar lift-off	124:22:00.8*	21/17:54:00.8
Coelliptic sequence initiation	125:19:36*	21/18:51:36
Constant differential height maneuver	126:17:49.6*	21/19:49:49.6
Terminal phase initiation	127:03:51.8*	21/20:35:51.8
Docking	128:03:00	21/21:35:00
Ascent stage jettison	130:09:31.2	21/23:41:31.2
Separation maneuver (from ascent stage)	130:30:01*	22/00:02:01
Transearth injection maneuver	135:23:42.3*	22/04:55:42.3
Second midcourse correction	150:29:57.4*	22/20:01:57.4
Command module/service module separation	194:49:12.7	24/16:21:12.7
Entry interface	195:03:05.7	24/16:37:05.7
Landing	195:18:35	24/16:50:35

*Engine ignition time.

Table 11. Planned color TV transmission coverage for Apollo 11

Date	Times of Planned TV GMT	GET	Prime Site	Event
July 17	23:32 - 23:47	34:00 - 34:15	Goldstone	Translunar Coast
July 18	23:32 - 23:47	58:00 - 58:15	Goldstone	Translunar Coast
July 19	20:02 - 20:17	78:30 - 78:45	Goldstone	Lunar Orbit (general surface shots)
July 20	17:52 - 18:22	100:20 - 100:50	Madrid	CM/LM Formation Flying
July 21	05:57 - 06:07	112:25 - 112:35	Goldstone	Landing Site Tracking
July 21	06:12 - 08:52	112:40 - 115:20	*Parkes	Black-and-White Lunar Surface
July 23	01:02 - 01:17	115:30 - 155:45	Goldstone	Transearth Coast
July 23	23:02 - 23:17	177:30 - 177:45	Goldstone	Transearth Coast

*64-m antenna at Parkes Observatory, Australia

Table 12. Mars station operation schedule for Apollo 11

Track Time (GMT)	Event
July 17/0030 - 17/0500	DSN Training Pass
17/2330 - 18/0500	DSN Training Pass
18/2330 - 19/0500	DSN Training Pass
19/1730 - 20/0430	Lunar Orbit Support
20/1800 - 21/0600	LM Descent and Surface
21/1930 - 22/0130	Rendezvous and Docking

Table 13. Clock synchronization measurements for Goldstone MSFN stations

Date (1969)	Lead (+) or Lag (-) Time Relative to NBS Clock 8 (Microseconds)			
	Apollo Prime Station		Apollo Wing Station	
	Clock A	Clock B	Clock A	Clock B
15 Jul	+2.7 (2308)	+2.8 (2311)	0.0 (2343)	0.0 (2345)
17 Jul	+3.5 (1628)	+3.6 (1631)	0.0 (1658)	0.0 (1658)
21 Jul	+5.5 (1615)	+5.6 (1619)	-0.1 (1643)	0.0 (1645)
23 Jul	+6.2 (1530)	+6.3 (1532)	-0.3 (1908)	-0.2 (1910)
24 Jul	+6.5 (0348)	+6.5 (0350)	-0.3 (0410)	-0.2 (0412)

NOTE: Values in parentheses give time of day of the measurement in GMT.

Table 14. Spacecraft monitoring station, Apollo 11 premission activities for Apollo 11

1969 date	Test	GMT	
		Start	End
6/27	CDDT[a] (wet)	13:00	19:00
7/1	CDDT (wet)	22:00	—
7/2	CDDT (wet)	—	12:00
7/3	CDDT (dry)	03:00	13:32
7/15	Countdown and launch	11:00	—
7/16	Countdown and launch	—	13:40

[a]Countdown demonstration test.

Table 15. Apollo 11 signal level vs time as recorded at spacecraft monitoring station

GMT	Signal Level	GMT	Signal Level
133200	-70.6 LIFTOFF	133600	-103.9
10	-68.0	10	-104.1
20	-69.6	20	-105.1
30	-68.6	30	-105.6
40	-73.1	40	-106.7
50	-75.8	50	-107.4
133300	-81.7	133700	-109.9
10	-71.3	10	-111.3
20	-76.3	20	-112.7
30	-80.8	30	-114.0
40	-85.8	40	-115.6
50	-95.4	50	-117.3
133400	-111.3	133800	-118.8
01	OUT-OF-LOCK	133802	OUT-OF-LOCK
32	-130.7	133915	IN-LOCK
40	-117.0	15	-134.6
50	-109.4	20	-135.6
133500	-111.9	30	-133.8
10	-117.0	40	-135.9
18	OUT-OF-LOCK	50	-136.6
27	IN-LOCK	134000	-137.2
27	-121.4	10	-135.1
49	-104.4	20	-143.0
		134028	OUT-OF-LOCK

Table 16. Pioneer tracking report

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
17 July Day 198	Earth Orbit 1 Earth Orbit 2 Translunar Coast	Unreported Unreported Unreported	One-way Three-way (CSM) Two-way (S4B) Three-way (CSM) Two-way (S4B)	During two-way track TXR 1 tripped off while increasing power from 2 to 10 kw. Off time less than one minute. Loss of data unknown. Operator error.
18 July Day 199	Translunar Coast	Unreported	Three-way	None.
19 July Day 200	Translunar Coast	Unreported	Two-way Three-way	None.
20 July Day 201	Lunar Orbits 1 and 2	Unreported	Three-way	Station released from track after 4-1/2 hours of a scheduled 10-1/2 hour pass to do maintenance on TXR 1.
21 July Day 202	Power Descent Initiation and Lunar Surface Tracking	Unreported	Two-way Three-way	During track antenna indicated emergency stop. Problem was water in switch box from recent rains. Total off time, 1 minute 18 seconds. No loss of data.
22 July Day 203	LM Orbits 26 thru 31	Unreported	Two-way	None.
23 July Day 204	Transearth Injection	Unreported	Three-way	None.

Table 16 (contd)

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
24 July Day 205	Transearth Coast	Unreported	Three-way	None.

NOTE: Pioneer had a problem with TXR 1 body over-current, arc detector and rectifier failure during each day from the start of mission support. The only times this problem affected mission support are noted above.

Table 17. Tidbinbilla tracking report

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
18 July Day 199	Translunar Coast 2	Unreported	Three-way	In spite of a fire in a transmitter power supply cabinet, there was no loss of mission support.
19 July Day 200	Translunar Coast 3	Unreported	Three-way	None.
20 July Day 201	Lunar Orbits 4 thru 9	Unreported	Three-way	None.
21 July Day 202	Lunar Oribts 17 thru 22	Unreported	Two-way (CSM)	None.
22 July Day 203	Transearth Coast 1	Unreported	Two-way Three-way	None.
23 July Day 204	Transearth Coast 2	Unreported	Three-way	None.

Table 18. Robledo tracking report

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
16 July Day 197	Translunar	AOS 165850Z LOS 2047Z	Two-way and Three-way	None.
17 July Day 198	Translunar Coast 2	AOS 094810Z LOS 213100Z	Two-way and Three-way	None.
18 July Day 199	Translunar Coast 3	AOS 101423Z LOS Unreported	Two-way and Three-way	1. Data lost when 400 cycle generator under-voltage relay failed. Result - lost both TXR's for 8 minutes and 12 seconds. 2. TXR 1 beam interlock tripped. Lost TXR for 15 seconds. Data lost for this 15 second period.

Table 18 (contd)

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
19 July Day 200	Translunar Coast 4	AOS 102350Z LOS 202149Z	Two-way and Three-way	None.
20 July Day 201	Lunar Orbits 10 thru 14	AOS 115317Z LOS 220700Z	Two-way and Three-way	None.
21 July Day 202	Lunar Orbits 22 thru 27	AOS 115317Z LOS 223100Z	Two-way and Three-way	None.
22 July Day 203	Transearth Coast 1	AOS 125914Z LOS 211700Z	Three-way	None.
23 July Day 204	Transearth Coast 2	AOS 132310Z LOS 223148Z	Two-way and Three-way	None.

Table 19. Goldstone, Honeysuckle and Madrid view periods for Apollo 11

Station	AOS (Day/GMT)	LOS (Day/GMT)
HSK	16/1431	1437
GDS	1500	1505
MAD	1651	2118
GDS	1626	17/0516
HSK	16/2354	17/1100
MAD	17/0927	17/2204
GDS	17/1713	18/0535
HSK	18/0004	18/1133
MAD	18/0955	18/2209
GDS	18/1731	19/0639
HSK	19/0006	19/1144
MAD	19/1005	19/2211
GDS	19/1751	20/0516
HSK	20/0010	20/1225
MAD	20/1046	20/2232
GDS	20/1834	21/0613
HSK	21/0034	21/1247
MAD	21/1335	21/2239
GDS	21/1934	22/0631
HSK	22/0113	22/1356
MAD	22/1226	22/2350
GDS	22/1953	23/0629
HSK	23/0058	23/1412
MAD	23/1248	23/2247
GDS	23/2023	24/0529
HSK	24/0109	24/1630

Table 20. Tracking support chronology, Mars station

Pass 1: 16/17 July 1969, Day 197/198	
GMT	Event
223730	Acquired S/C (CSM) using predicts set 102. Signal level high - approximately -70 dbm.
2250	S/C TLM being transmitted to Apollo Prime station for validation of system.
2311	Requested to track Instrumentation Unit (IU) instead of CSM.
2339	Requested to track CSM instead of the IU.
2345	Tracking CSM PM data at -101 dbm on RCVR 9. RCVR 10 on CSM FM channel. Predicts set 102 required no HA/DEC offset.
000610	Video being received and transmitted to Apollo Prime Station
002114	End of video sequence.
0420	Transmitting predicts set 103 for next day's use.
0445	LOS at -108 dbm. End of pass.
No hardware anomalies were experienced.	

Pass 2: 17/18 July 1969, Day 198/199.	
GMT	Event
183050	Acquired S/C at -107 dbm.
1914	Signal varying between -105 and -127 dbm slowly.
1958	Receiving video from S/C for test purposes. Picture snowy.
2001	Still recording video for test purposes.
2050	Lost carrier on RCVR 10 only.
2135	Using predicts set 103. Offsets reported as HA + 0.020 degrees and DEC -0.010 degrees.
2156	Started TDH at 1 and 10 second samples to exercise system.
230252	Started video test sequence with S/C. PM signal at -107 dbm.
231452	Video sequence terminated.
233133	Video sequence started with PM signal at -87 dbm.

Table 20 (contd)

Pass 2: 17/18 July 1969, Day 198/199 (cont'd)	
GMT	Event
000719	Video sequence ended with PM signal still at -87 dbm.
003712	S/C still on high gain antenna with signal at -87 dbm.
0133	S/C to low gain antenna. Signal varying from -108 dbm to -127 dbm.
0152	Momentary loss of signal.
0506	LOS at -118 dbm -- end of pass.
No hardware anomalies were experienced.	
Pass 3: 18/19 July 1969, Day 199/200.	
GMT	Event
2032	S/C acquired at signal strength of -91 dbm. S/C using high gain antenna.
204030	Receiving S/C video at a PM channel signal level of -91 dbm.
2216	Video ended. PM downlink at -90 dbm. Predicts set 110 in use show no offsets.
0240	Predicts set 111 being transmitted.
0351	MSFN conducting a TLM threshold test using Mars. Test reported as not successful. Attempting same test with Apollo Prime Station.
0458	Secured antenna due to high winds. Signal level at -113 dbm. End of pass.
No hardware anomalies were experienced.	
At termination of pass 3, Apollo Prime Station and Mars conducted a PLSS (Portable life support system) data flow test. Test was reported as successful.	

Table 20 (contd)

Pass 4: 19/20 July 1969, Day 200/201.	
GMT	Event
180131	S/C acquired at signal level of -95 dbm with S/C in lunar orbit #1.
191218	LOS at -119 dbm for orbit #1.
195542	AOS at -95 dbm for orbit #2 and receiving video.
1953	Predicts set 113 being transmitted.
202953	Video sequence ended at PM signal level of -93 dbm.
2116	TDH data for occultation experiment started.
211900	S/C data mode 8-Emergency voice. This data may affect the occultation TDH data.
212045	LOS on orbit #2. Signal level at -111 dbm.
220706	AOS on orbit #3. Signal level at -93 dbm. Predict offsets are zero.
2312	Occultation TDH data started. MSFN Hawaii was two-way during TDH period.
231715	LOS on orbit #3. Signal level at -118 dbm.
000300	AOS on orbit #4 at signal level of -118 dbm. Tracking CSM vehicle.
003822	Tracking LM at signal level of -118 dbm. Also conducted comm test with S/C using TLM, voice, and emergency voice modes. Comparison made with Prime Apollo and Mars. Test successful.
011538	LOS on orbit #4 at signal level of -115 dbm.
020210	AOS on orbit #5 on CSM vehicle. Signal strength -94 dbm.
03038	TDH started for the orbit occultation data.
031405	LOS for orbit #5 at signal strength of -94 dbm.
040225	AOS on orbit #6 on CSM at signal level of -95 dbm.
051225	LOS on orbit #6 still on CSM. Signal level of -95 dbm. End of pass.
No hardware problems were encountered during this pass.	

Table 20 (contd)

Pass 5: 20/21 July 1969, Day 201/202.	
GMT	Event
1940	Predicts set 114 being transmitted.
1948	AOS on orbit #14 on LM. Signal strength -116 dbm.
195049	Signal still in phase lock
195507	Out of lock
195525	In lock
200521	Out of lock
200558	In lock
201842	LM touchdown on lunar surface.
2025	Started playback to SFOF of TDH data recorded at 1950 GMT.
2110	Signal level of LM on lunar surface at -93 dbm.
0105	Good track at a signal level of -98 dbm (just like a Mariner track but higher in signal level).
0135	Signal still at -98 dbm.
0139	Started short test video sequence. PM downlink signal strength not available.
0144	Signal from LM at -98 dbm on PM downlink.
0212	Voice downlink now being used.
0222	Predicts offset at HA = 0.000 and DEC = +0.005 degrees.
025432	Video sequence started.
054330	Video sequence completed with LOS. End of pass.
0730	Completed transmission of predict set 116.
	There were no equipment anomalies during this pass.

Pass 6: 21/22 July 1969, Day 202/203.	
GMT	Event
200740	AOS on orbit #26. Receiving LM downlink at -92 dbm.
203703	LOS on orbit #26. LM downlink signal fade at -130 dbm.
212320	AOS on orbit #27 on LM. Signal -112 dbm.
223517	LOS on orbit #27 on LM. Signal at -94 dbm.
2240	Station released from NCG-725 support with the exception of emergency call up support.
	Instructions also given to the station to maintain Apollo configuration control until splash down.
	There were no equipment anomalies during this pass.

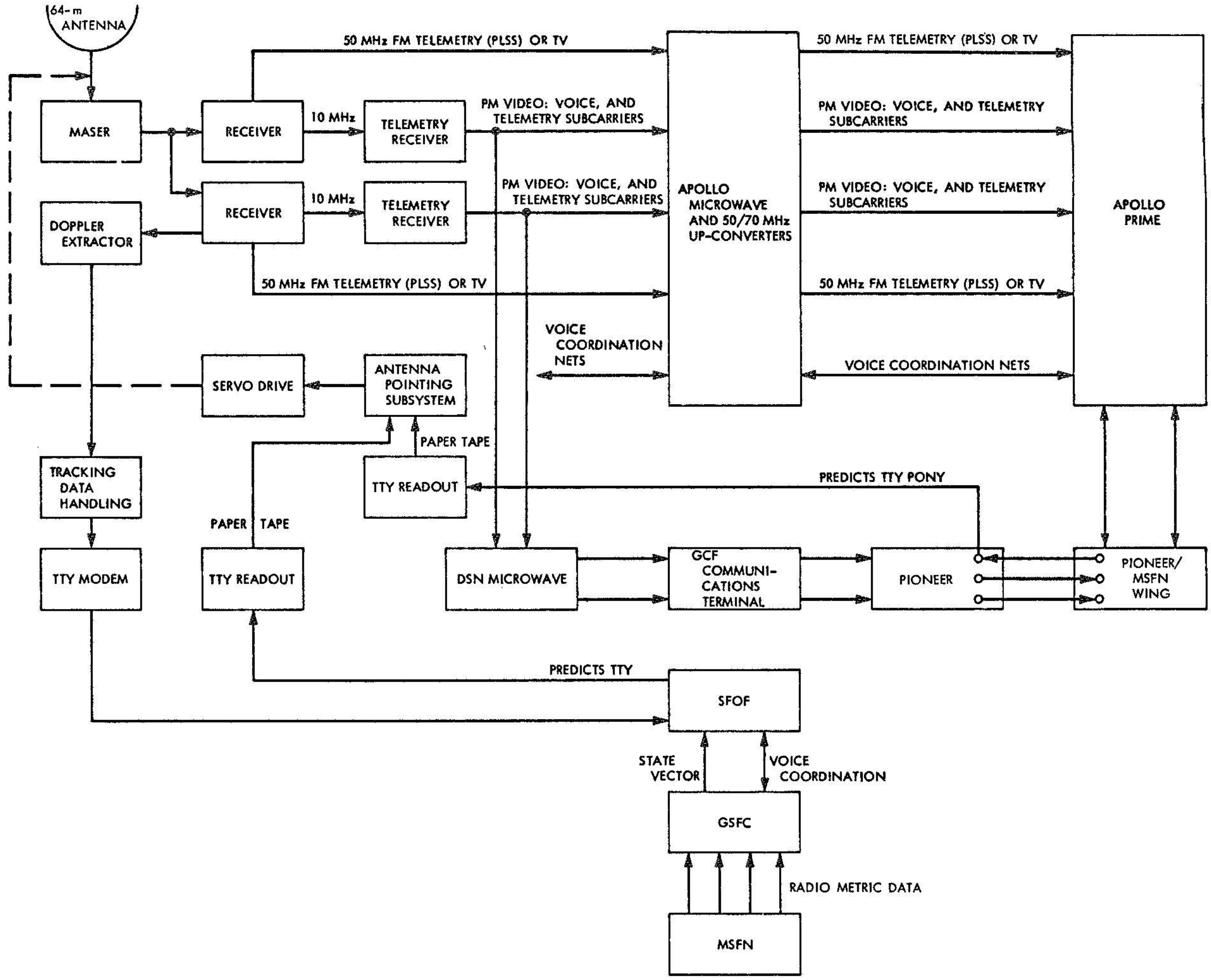


Fig. 17. MSFN/Apollo network interface configuration for Mars station

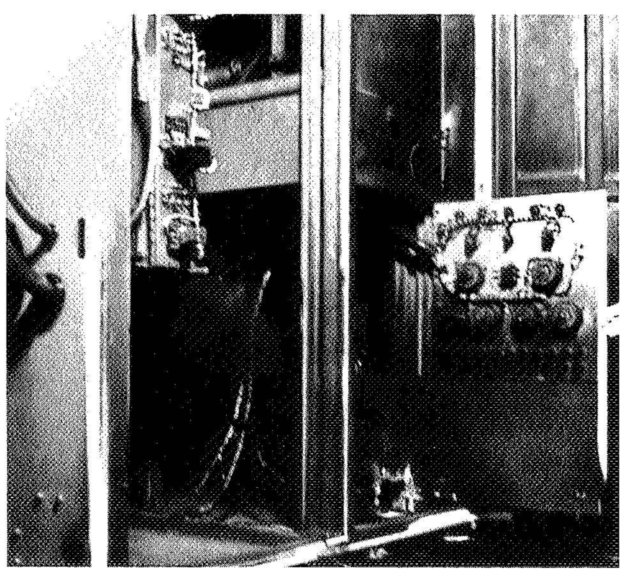


Fig. 18. General view of cabinet damage to transmitter No. 2 at Tidbinbilla

A. Mission Description

The Apollo 12 mission was the second manned lunar landing and followed just 4 months after the successful completion of Apollo 11. On November 14, 1969, at 16:22 GMT, Apollo 12 was launched from Pad 39-A at Cape Kennedy with astronauts Charles Conrad, Jr. (spacecraft commander), Richard P. Gordon (CM pilot), and Alan L. Bean (LM pilot) on board. At the time of launch the weather was inclement with a ceiling of approximately 335 m and intermittent showers. At approximately 36 s after launch, and again at approximately 52 s after launch, an electrical discharge caused numerous circuit breakers aboard the spacecraft to trip. Fortunately, however, the guidance system aboard the third-stage S-IVB instrumentation unit was able to maintain control of the launch vehicle while the astronauts reset the circuit breakers aboard the spacecraft to restore normal power system operation. During the subsequent earth-orbital revolutions, the crew realigned the guidance platform and other instrumentation that had been affected by the power outage. However, they were unable to check out the instrumentation aboard the still encapsulated LM until after the translunar injection (TLI), which occurred over the Pacific Ocean some 2 h and 50 min later.

After the S-IVB stage successfully injected the Apollo 12 spacecraft on a trajectory toward the moon, the CSM separated from the booster and docked with the unattended LM, which was still attached to the S-IVB. Extraction of the LM occurred at 04:13 GET. However, unlike the procedure followed on previous missions, the evasive maneuver to prevent contact between the CSM/LM and the S-IVB was performed by an S-IVB auxiliary propulsion system burn rather than a CSM service propulsion system burn. Approximately 2 h after TLI, the S-IVB initiated a LOX dump which placed the S-IVB into a "slingshot" trajectory so that it would pass behind the tracking edge of the moon. The acceleration should have increased substantially due to the lunar gravitational field to place the vehicle into a heliocentric orbit. However, because of navigational unaccuracies, the vehicle did not pass close enough to the moon to gain the necessary velocity and so remained in a highly eccentric earth orbit.

Upon separation from the S-IVB, the combined CSM/LM were on a free-return trajectory that would swing the spacecraft around the moon and return to the earth for a normal reentry without further maneuvers. At 30:53 GET, the CSM/LM executed a minor midcourse correction which, for the first time in Apollo history, placed the spacecrafts in a nonfree-return trajectory. This maneuver was restricted so that in the event of a service propulsion system failure, return to earth would not be beyond the capability of the docked LM descent propulsion system. The new nonfree-return trajectory would bring the CSM/LM closer to the lunar surface to shorten the LM descent burn and to conserve the fuel for additional hovering time during the landing phase. Shortly after separation, the crew entered the LM to check out its onboard systems to verify that the electrical phenomenon that occurred at launch had not disrupted any of the equipment.

At 83 h and 25 min after launch, Apollo 12 burned its service propulsion system engine to successfully insert the joined spacecraft into lunar orbit. After two lunar orbits, the engine was burned again to circularize the orbit, and early in orbit 13 the LM, carrying astronauts Conrad and Bean, separated from the CM. The actual LM descent phase occurred during lunar orbit 14. The descent trajectory of the LM was so accurate that the vehicle landed near the rim of the crater that contains Surveyor III, Apollo 12's targeted landing area. After 4.5 h of preparation, astronauts Conrad and Bean emerged from the landed LM to deploy the scientific instruments on the surface of the moon and to collect samples of lunar soil. The traverse paths are shown in Fig. 19. After an excursion of 3 h and 56 min, the astronauts then returned to the LM for rest and replenishment of their life-support system. After a 12.5-h rest period, the astronauts reemerged from the LM to make their longest traverse on the moon, including a visit to the Surveyor III spacecraft which had landed on the moon 31 months earlier (see Fig. 20). Using hand-tools, the astronauts detached the Surveyor III TV camera, pieces of the spacecraft wiring harness, the scoop from the surface sampler, and pieces of aluminum tubing for return to earth and analysis by the scientific community. The astronauts also collected additional lunar samples, including a deep-core sample, on their second excursion onto the lunar surface that lasted a total of 3 h and 50 min. Once inside the LM, the astronauts spent 6 h and 41 min in preparation for takeoff from the lunar surface, which occurred at 142 h into the mission.

The ascent stage of the LM was successfully launched from the lunar surface; some 3 h and 32 min after takeoff, it made a rendezvous with the orbiting CSM, which was now in orbit 32 of the moon. Astronauts Conrad and Bean transferred the lunar samples and Surveyor parts from the LM into the CM and secured the ascent stage of the LM for separation and its ultimate powered descent two orbits later into the lunar surface, which was intentionally done to calibrate the seismometer instrument they had left near the landing site. The three crewmen remained in lunar orbit for another 27 h to take additional landmark sightings for future Apollo missions; then, at the end of orbit 45 of the moon, the CSM burned its service propulsion engine for a successful return flight to earth.

The injection towards earth was so precise that only one small midcourse correction was required. Apollo 12 reentered the earth's atmosphere on November 25 and landed in the Pacific Ocean approximately 3.630 km from the carrier USS Hornet. The landing site was 2767 km southwest of Hawaii. The astronauts were recovered from the spacecraft by helicopter and landed aboard the Hornet, 1 h and 10 min after splashdown, to complete mankind's second successful mission to the surface of the moon. For a complete sequence of events for Apollo 12 refer to Table 21.

B. Requirements for DSN Support of Apollo 12

The Spacecraft Monitoring Station was required to support previous Apollo missions up through Apollo 11, covering both premission testing and launch activities. This requirement was removed after the successful Apollo 11 mission and did not officially participate in the Apollo 12 mission. Unofficial participation is discussed in Sect. V-C, below.

As on previous Apollo lunar missions, Pioneer, Tidbinbilla, and Robledo stations were committed to support Apollo 12 under direct MSFN/MSC control starting at launch minus 2 weeks through to the end of the mission.

The MSFN again required the support of DSN's 64-m antenna at Mars station on every view period from translunar injection through transearth injection, lunar orbit coverage to be horizon-to-horizon, and translunar coverage to start at horizon rise and continue until the end of the spacecraft TV transmissions (Table 22). The DSN scheduled all horizon-to-horizon passes since the TV schedule is often changed in real time. The DSN was not able to commit formally to the first pass after translunar injection for two reasons:

(1) The pass began less than 15 min after the translunar injection burn, making it difficult to obtain and process the necessary pointing angle predicts in time for horizon rise.

(2) The angular tracking rates when the spacecraft is still near the earth exceed those normally experienced at the Mars station.

In the past Mars received DSN predicts from the SFOF and the MSFN predicts from Houston. The MSFN/Houston predicts would arrive first at the Pioneer Apollo Wing in X-Y coordinates, converted to HA-DEC coordinates, transmitted to the Goldstone Apollo Prime station and then via two TTY "pony" circuits to Mars where they were converted into a drive tape. To simplify the MSFN predict situation, the DSN prepared an R&D program using an SDS-920 computer at Mars which would allow the station to receive the X-Y predicts directly from MSFN/Houston, convert to HA-DEC, and produce the necessary antenna drive tape.

As with previous Apollo missions, MSFN required time synchronization between the participating Apollo stations at the Goldstone complex. Time synchronization measurements using the Goldstone Standard Laboratory portable cesium clock are shown in Tables 23 and 24.

As part of a continuing study of lunar potential anomalies (MASCONS), a requirement was placed on the DSN which called for the use of the 64-m antenna at Mars to provide precision doppler and signal strength recordings during the LM descent phase to the lunar surface.

C. DSN Mission Support

1. DSN Premission Activities.

a. DSN/MSFN Wing Stations. The Pioneer, Tidbinbilla, and Robledo stations were placed on mission status at 00:01 GMT on November 3, 1969, and from that time until splashdown the stations were under MSFN control. Prior to November 3, each wing station conducted extensive maintenance and a long pretrack countdown to ensure the integrity of the equipment common to the DSN and MSFN.

b. Mars. During previous Apollo missions, it had been considered necessary to conduct an Operational Readiness Test (ORT) with all stations and the Space Flight Operations Facility (SFOF). However, during the DSN Apollo 12 premission planning, it was felt that the most optimum test that could be conducted at Mars was a Configuration Verification Test which would include bit error rate, data verification, operational data tests, etc. The Configuration Verification Test was a significant improvement over the premission activities conducted on prior missions. The test included all elements depicted in Fig. 21.

2. Apollo 12 Mission Activities.

a. DSN/MSFN Wing Stations. Pioneer, Tidbinbilla, and Robledo successfully supported the earth-orbital, lunar-transfer, lunar-orbital, and earth-return phases of the mission (see Tables 25 to 28), with only the following minor anomalies noted:

(1) Pioneer. Transmitter tripoffs continued to plague the Pioneer station. One fault occurred when the station was transmitting, and caused an uplink loss of transmission for 58 s. Other faults occurred during the premission calibrations.

(2) Tidbinbilla. The only problem noted at Tidbinbilla was a compressor motor burnout in the air-conditioning unit in the antenna Declination Axis Room at 01:35 GMT on November 20. No operational impact to the mission was felt; a second compressor was able to handle the air-conditioning load since the weather at the time was cool.

(3) Robledo. One transmitter failure was experienced at 17:40 GMT on November 15, while the station was transmitting to the spacecraft. The apparent cause was a malfunctioning relay which caused a high-voltage rectifier interlock trip.

(4) Spacecraft Monitoring Station. Although Spacecraft Monitoring Station participation in the Apollo 12 mission was not required, the opportunity was utilized by the station as a training exercise to demonstrate Flight/Ground Interface unique capabilities. Computerized Compatibility Test Programs were employed to measure the CSM (2287.5 MHz) carrier and the first-order sidebands (telemetry and voice). No anomalies were observed within the spectrum.

To increase station-effectiveness during Apollo missions, station personnel utilized the FR-1400 recorders to record the 51.2 kilobit telemetry data. A block diagram of the configuration employed is depicted in Fig. 22. Fourteen reels of tape were used to record all CSM data from S-band rf turn-on through post-launch loss-of-lock (Table 29). Tape speed was 30 ips using FSM modules in the FR-1400 recorders. On December 2, 1969, the first and last tapes were played back through the PCM system at the MILA/MSFN station and were validated as being of excellent quality.

(5) Mars. Seven passes were tracked by the Mars station, all of which were complete horizon-to-horizon coverage except the last one, when Mars was officially released from further Apollo 12 activities at 06:25 GMT on November 21. These passes included all mission phases from just after translunar injection through lunar-orbit insertion, descent, landing, lunar-surface activities, and postrendezvous lunar-orbit coverage. See Table 30 for detailed tracking support data.

As mentioned earlier, the first pass, which began approximately 10 min after the translunar injection burn, was not a formal requirement. The pass was intended to be a "training pass," and no station predicts were available until 30 min after spacecraft rise. This delay in station predicts was unusual in that there are three sources available to the Mars station.

(a) Houston state vectors. Houston is the prime source for state vectors. These are received at the SFOF in X-Y coordinates and converted to HA-DEC for transmission to the Mars station. For Apollo 12, Houston transmitted 3 sets of state vectors to the SFOF. One set was received before launch but was not used because a more accurate vector was expected just prior to launch. A second state vector, labeled Post TLI, was received after the launch but turned out to be a parking orbit vector for the time of TLI. The third state vector arrived time tagged 1857 Z. The computers in the SFOF were ready for SDA at 1911 Z and the PREDIX run started in Mode 2 at 1919 Z. The run, however, was interrupted twice by the string going from mode 2 into mode 3 at the times listed below:

Mode 2	Mode 3
1919 Z	192253 Z
192316 Z	192341 Z
192514 Z	

The run was completed at 19:25:36 Z, but produced no TTY output due to the interruptions. A second run was made from 19:26 Z to 19:27 Z and was successful in producing a TTY output. Predict transmission to Mars station started at approximately 19:40 Z and was completed at approximately 19:48 Z.

(b) GSFC state vector. GSFC is the backup source for state vectors in the event something should happen to Houston. For Apollo 12, however, the computer at GSFC which produces the GSFC state vectors was "down" and therefore not available.

(c) Houston 29-point acquisition message. The Houston 29-point acquisition message is a backup for their state vector; however, instead of being converted to HA-DEC coordinates at the SFOF, the message is routed directly to the Mars station where it is converted to a drive tape. For Apollo 12, the 29-point acquisition message was received on time but could not be converted because of incorrect format. The computer program had been written and checked out with GSFC 29-point acquisition messages which always have 4 digits in each of the X and Y angle fields even if leading zeros are needed. The Houston message, however, arrived with the leading zeros omitted and the computer rejected the points. The program was altered in real time via a telephone call to the programmer, and processing of the Houston 29-point acquisition message began. Using manual angles supplied via telephone by the MSFN Wing at Pioneer, Mars acquired Apollo 12 at 1925 Z. The first use of predicts was at approximately 1950 Z with an antenna drive tape prepared from the Houston 29-point acquisition message. SFOF predicts prepared from the Houston state vector were in use by 2040 Z.

During this first training pass, the unique capabilities of Mars proved to be invaluable. Apollo Mission Control in Houston altered the plan to activate the LM at approximately 7.5 h into the mission instead of the previously planned time of 64 h into the mission to confirm that none of its systems had been affected by the electrical discharge that occurred just after launch. However, the LM and the third-stage S-IVB booster transmit on the same S-band frequency and, at this point in the mission, these vehicles had not separated very widely. Thus, when the LM signal was activated, two interfering signals were seen simultaneously by the 26-m antenna stations, with no usable data being obtainable. Mars, however, which has a beamwidth of 0.14 deg (compared to 0.33 deg for the 26-m antennas), was able to point at the LM while having the S-IVB out of the main beam. In this way, Mars was the only ground station able to obtain usable LM telemetry data during this early LM checkout.

The unique capabilities of the Mars station were again used to advantage when CSM signal level drops of 10 to 12 dB were experienced. These drops occurred on several occasions, with the drops being either step changes or gradual over a period of up to 2 min. During these anomalies, there was never any degradation of data from Mars. The problem is suspected to be the spacecraft's antenna striplines associated with the high-gain antenna, especially when used in the narrow beam (highest gain) mode.

No operational problems occurred at Mars for the remainder of the mission. The relatively high signal levels received from typical Apollo missions are unusual for this station (which usually tracks unmanned planetary spacecraft beyond the range of 26-m antennas). The LM signal was very strong when the steerable antenna was aligned toward earth, being at a level of -83 dBmW for several hours.

(6) Cebreros. Although not officially required for Apollo support, the Cebreros station, near Madrid, Spain, tracked the LM ascent stage from its deorbit burn until its crash onto the moon's surface. This effort by the Cebreros station was a part of a continuing JPL study regarding MASCONs, lunar ephemeris, lunar radius, etc. Although the track lasted only from 21:33 GMT until LM crash at 22:17:17 GMT on November 20, several hours were spent in preparation, and the radio metric data were of excellent quality.

(7) SFOF Participation. The SFOF areas and equipment involved in the Apollo 12 operations included the Operations Area, the Flight Path Analysis Area, the displays, and the Mode II 7044-7094 computers. These areas and functions were staffed during all Goldstone view periods, and at other times as required to support special activities such as the generation of additional predict information for Mars. Aside from the difficulty in producing predicts for the first pass at Mars, there were no problems in the SFOF.

(8) GCF Participation. The DSN Ground Communications Facility (GCF) provided voice and teletype circuits as required to support the operations mentioned above. In addition, JPL acts as West Coast Switching Center for the NASA Communications Network and handles many non-DSN circuits in support of Apollo. There were no communications problems that constrained the DSN support of Apollo 12, and the communications support was flawless.

Table 21. Sequence of events, Apollo 12

Event	GET
Range zero - 16:22:00 GMT, Nov. 14, 1969	
Lift-off	00:00:00.7
S-IC outboard engine cutoff	00:02:41.7
S-IC/S-II separation	00:02:42.4
S-II engine ignition (command)	00:02:44.2
Launch escape tower jettison	00:03:21.6
S-II engine cutoff	00:09:12.4
S-IVB engine ignition (command)	00:09:15.6
S-IVB engine cutoff	00:11:33.9
Translunar injection maneuver	02:47:23
S-IVB/command and service module separation	03:18:05
Translunar docking	03:26:53
Spacecraft ejection	04:13:01
S-IVB separation maneuver	04:26:41
First midcourse correction	30:52:44
Lunar orbit insertion	83:25:23
Lunar orbit circularization	87:48:48
Undocking	107:54:02
First separation maneuver	108:24:37
Descent orbit insertion	109:23:40
Powered descent initiation	110:20:38
Lunar landing	110:32:36
First extravehicular egress	115:10:35
First extravehicular ingress	119:06:38
First lunar orbit plane change	119:47:13
Second extravehicular egress	131:32:45
Second extravehicular ingress	135:22:00
Lunar lift-off	142:03:48
Coelliptic sequence initiation	143:01:51
Constant differential height maneuver	144:00:03
Terminal phase initiation	144:36:26
Lunar orbit docking	145:36:20
Ascent stage jettison	147:59:32
Second separation maneuver	148:04:31

Table 21 (contd)

Event	GET
Ascent stage deorbit maneuver	149:28:15
Ascent stage impact	149:55:16
Second lunar orbit plane change	159:04:46
Transearth injection maneuver	172:27:17
Second midcourse correction	188:27:16
Third midcourse correction	241:22:00
Command module/service module separation	244:07:20
Entry interface	244:22:19
Landing	244:36:25

Table 22. Planned TV schedule for Apollo 12

Day	Date (GMT)	GMT	GET	Duration	Activity/Subject	Vehicle	Station
Fri	14 Nov	19:47	0325	1 hr 05 min	Transposition and docking	CSM	GDS
Sat	15 Nov	22:47	30:25	35 min	Interior of spacecraft at MCC-2	CSM	GDS
Mon	17 Nov	07:52	63:30	50 min	Earth, spacecraft interior, and intervehicular transfer	CSM	GDS/ HSK
Tues	18 Nov	01:52	81:30	20 min	Pre LOI-2	CSM	GDS
Tues	18 Nov	04:22	84:00	30 min	Lunar surface	CSM	GDS
Wed	19 Nov	04:12	107:50	40 min	Undocking and formation flying	CSM	GDS
Wed	19 Nov	11:02	114:40	3 hr 30 min	Lunar surface activities	LM	Parks
Thu	20 Nov	05:42	133:20	4 hr 55 min	Lunar surface activities	LM	GDS
Thu	20 Nov	17:37	145:15	30 min	Docking	CSM	MAD
Fri	21 Nov	21:17	172:55	20 min	Post-TEI-Lunar surface	CSM	MAD
Sun	23 Nov	23:37	223:15	30 min	Moon, Earth and spacecraft interior	CSM	GDS

Table 23. Portable clock measurements

Date (1969)	Microseconds of Lead (+) or Lag (-) Time Relative to NBS Clock 8			
	Apollo Prime Station		Apollo Wing Station	
	Clock A	Clock B	Clock A	Clock B
13 Nov	+0.7 (1818)	+0.7 (1819)	+9.3 (1645)	+0.2 (1647)
14 Nov	+0.9 (1630	+0.9 (1632)	+0.4 (1532)	+0.3 (1534)
16 Nov	Clocks Reset to NBS 8		+0.6 (1828)	+0.5 (1829)
17 Nov	+0.6 (1754)	0 (1755)	+0.6 (1647)	+0.5 (1648)
19 Nov	+0.3 (2239)	+0.2 (2240)	+0.7 (2256)	-1.4 (2258)*
20 Nov	+0.4 (1823)	+0.3 (1824)	+0.2 (1733)	+0.2 (1735)**
24 Nov	+0.5 (1720	+0.4 (1722)	-3.8 (1658)	-3.1 (1659)
26 Nov	+0.6 (1737)	+0.5 (1738)	-3.9 (1719)	-3.2 (1720)

NOTE: Values in parentheses give time of day of the measurement in GMT.

TTY Reports:

*DSIF portable clock maintained on standby status at Apollo Wing station from 2300Z 19 Nov 1969 to 0610Z 20 Nov 1969 during tracking data noise tests per ISI No. 47.

**Time synchronization of Apollo Wing clocks had been lost during night and reset to the DSIF tick using delay figure of 116.5 microseconds. Reset prior to arrival of portable clock. DSIF delay measured at 1800Z 20 Nov from Reference Standards Lab to Apollo Wing via Mars and Apollo prime as 116.3 microseconds.

Table 24. Microwave link via Mars station measurements

Date (1969)	Delay in Microseconds	
	Apollo Prime Clock A	Apollo Wing Clock A
13 November	90.9	116.3
16 November	90.9	116.3

Table 25. Pioneer tracking report, Apollo 12

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
15 November	Earth orbits 1 and 2	Unknown	Three-way	TXR switched to nonstandard configuration as requested by wing M & O supervisor.
	translunar Pass 1	Unknown	Two-way	
16 November	Translunar Pass 2	Unknown	Three-way	TXR 1 and 2 tripped off simultaneously while in standby condition; no effect on mission support.
17 November	Translunar Pass 3	Unknown	Two-way	During countdown, TXR 1 tripped off while radiating 2 kw from both TXR's at collimation tower; no effect on mission support.
18 November	Translunar Pass 4 and lunar orbits 1, 2, and 3	Unknown	Three-way	TXR 1 tripped off during countdown; no effect on mission support
19 November	Lunar orbits 10 through 14 and LM landing	Unknown	Two-way	None
20 November	Lunar stay Pass 2	Unknown	Two-way	None
21 November	Lunar orbits 35 through 40	Unknown	Three-way	None
22 November	Transearth Coast Pass 1	Unknown	Three-way	None
23 November	Transearth Coast 2	22/2353Z to 23/0222Z	Three-way	
		23/0222Z to 23/0822Z	Two-way	TXR 2 tripped off; uplink lost for 58 seconds.
		23/0822Z to 23/1153Z	Three-way	
24 November	Transearth Coast 3	24/0015Z to 24/0750Z	Three-way	
		24/0750Z to 24/1152Z	Two-way	None
		24/1152Z to 24/1233Z	Three-way	

Table 26. Tidbinbilla tracking report, Apollo 12

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
15 November	Translunar Coast 1	Unreported	Three-way	None
16 November	Translunar Coast 2	Unreported	Two-way and three-way	None

Table 26 (contd)

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
17 November	Translunar Coast 3	Unreported	Two-way and three-way	None
18 November	Lunar orbits 1 through 6	Unreported	Two-way and three-way	None
19 November	Lunar orbits 13 and 14	Unreported	Three-way	None
	Lunar surface operations	Unreported	Two-way and three-way	None
20 November	Lunar surface operations	Unreported	Two-way and three-way	None
	Ascent operations	Unreported	Two-way	None
	Lunar orbit 31	Unreported	Three-way	
21 November	Lunar orbits 39 through 43	Unreported	Three-way	None
22 November	Transearth Coast 1	Unreported	Three-way	None
23 November	Transearth Coast 2	Unreported	Three-way	None
24 November	Transearth Coast 3	Unreported	Three-way	None

Table 27. Robledo tracking report, Apollo 12

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
15 November	Translunar Coast 1	Unreported	Three-way	None
16 November	Translunar Coast 2	16/1333Z to 16/1352Z	Three-way	During two-way track, TXR 1 tripped off. Interlock was reset and two-way operations resumed.
		16/1352Z to 16/0022Z	Two-way	
		16/0022Z to 16/0038Z	Three-way	
17 November	Translunar Coast 3	17/1402Z to 18/0043Z	Three-way	None
18 November	Pass 4	18/1414Z to 18/1452Z	Three-way	

Table 27 (contd)

Date 1969	Pass or Orbit	Tracking Time	Tracking Mode	Anomalies Affecting Support
18 November (contd)		18/1452Z to 19/2322Z	Two-way	None
		18/2322Z to 18/0040Z	Three-way	
19 November	Pass 5	Unreported	Three-way	None
20 November	Pass 6	Unreported	Two-way and three-way	None
21 November	Lunar orbits 31 through 35	Unreported	Two-way and three-way	None
22 November	Lunar orbits 43 through 45	Unreported	Three-way	None
23 November	Transearth Coast 1	Unreported	Unreported	None
24 November	Transearth Coast 2	Unreported	Three-way	None

Table 28. Wing site spacecraft view periods

Pioneer	Tidbinbilla	Robledo
14/1751 - 14/1756	14/1722 - 14/1728	14/1939 - 15/0022
14/1917 - 15/0822	15/0259 - 15/1444	15/1315 - 16/0107
15/2057 - 16/0842	16/0312 - 16/1517	16/1343 - 17/0113
16/2116 - 17/0847	17/0314 - 17/1531	17/1355 - 18/0111
17/2126 - 18/0854	18/0309 - 18/1533	18/1422 - 19/0125
18/2215 - 19/0918	19/0410 - 19/1612	19/1432 - 20/0302
19/2212 - 20/1056	20/0557 - 20/1639	20/1538 - 21/0427
20/2239 - 21/1210	21/0622 - 21/1629	21/1518 - 22/0511
21/2307 - 22/1232	22/0700 - 22/1707	22/1531 - 23/0515
22/2316 - 23/1240	23/0708 - 23/1732	23/1551 - 24/0529
23/2342 - 24/1308	24/0739 - 24/2046	24/1824 - 24/1859

Table 29. Launch operations recorded by spacecraft monitoring station

14 November 1969	Event
GET 0158 Z	CSM S-band RF on. Frequency was 23.307315 MHz at station Receiver VCO.
GET 0201 Z	Frequency changed to 23.307292 MHz at level of -68 DBM. This frequency is the 2-way coherent link frequency.
GET 1200 Z	All spectrum plots of carrier and sidebands completed
GET 1622 Z	Lift-off
GET 162241 Z	Receiver out-of-lock (Lightning struck spacecraft)
GET 162253 Z	Receiver in-lock
GET 162428 Z	Receiver out-of-lock. Contact was never recovered due to intense weather conditions and lack of adequate antenna pointing information.

Table 30. Mars station tracking support data log

GMT	Event
Pass 1: 14/15 November 1969, Day 318/319	
1925	S/C in view. No predicts on station at this time. Acquired manually with pointing information received from Pioneer.
1940	Received 29-point acquisition message. Message not in correct format for conversion. Computer program being modified on station.
1948	First JPL predict set received complete.
1950	Signal level -81.5 dbm on CSM/PM.
2016	S/C video signal off.
2348	A comparison between the 29-point acquisition message and JPL predicts indicates a difference of 0.3 degrees. Error appears to be in the 29-point message making these predicts unusable.
2356	Antenna driven in sidereal mode due to JPL predicts running out. No new predict yet received. Twenty-nine point message also unusable.
2400	Signal level -97.0 dbm from the LM/PM.
0010	Receiving LM downlink due only to narrow antenna beamwidth. 26-m antenna cannot discriminate between the CSM and LM when separated; both use some downlink frequency.
0026	JPL predicts received and antenna drive tape available.
0151	Twenty-nine point messages being received from GGDS over comm pony circuit. Last CSM 29-point message shows agreement with JPL predicts.
0200	S/C signal -104 dbm from the CSM/PM. Angle offsets are -0.020 degrees in both HA and DEC.
0700	Angle offsets still -0.020 degrees in HA and DEC.
075343	Antenna at prelimits and EOT. Signal level -109 dbm from the CSM/PM.

Table 30 (contd)

Pass 2: 15/16 November 1969, Day 319/320	
212740	S/C acquired at signal level of -109 dbm on CSM/PM. Angle offsets; HA -0.015 degrees and -0.025 degrees in DEC. S/C signal level on CSM/PM -109 dbm and varying.
2237	Prepared for receipt of video data.
2239	Video data started.
2400	Signal strength -109 dbm on CSM. Angle offsets; DEC -0.015 degrees, HA -0.025 degrees.
0030	CSM signal strength -113 dbm.
0100	Angle offsets; DEC -0.010 degrees, HA zero. CSM signal strength -114 dbm.
0400	Angle offsets; DEC +0.030 degrees, HA +0.030 degrees. CSM signal strength -107 dbm.
0600	Angles offset; DEC +0.08 degrees, HA +0.070 degrees.
060745	RCVR 9 LOS for 5 seconds. RCVR 10 did not loose lock.
062150	RCVR 9 LOS for 2 minutes.
0700	Angle offset; DEC +0.080 degrees, HA +0.070 degrees. Signal strength -113 dbm on CSM.
081421	Antenna at prelimits and EOT. Signal level -113 dbm on CSM.
Pass 3: 16/17 November 1969, Day 320/321	
214550	AOS at -110 dbm using 29-point acquisition message drive tape. The 29-point message does not appear to have atmosphere refraction correction. Station using manually applied bias which is continuously being updated.
2206	LOS on all RCVR's. S/C switching to high gain antenna.
221355	AOS at -116 dbm signal level.
2220	Started using JPL predicts as 29-point message drive required such continuous updating that operator error might result.
2225	Angle offsets zero.
2227	Signal strength -90 dbm.
2400	Angle offsets zero. Signal strength -110 dbm.
0142	Reconfigured RCVR 10 to receive CSM/FM.
0200	Angle offset; DEC +0.010 degrees, HA -0.010 degrees.
0500	Angle offset; DEC +0.020 degrees, HA -0.000 degrees.
053320	RCVR 9 O/O/L. S/C aligning position.
053430	RCVR 9 in lock. Signal strength -110 dbm.
0700	Signal level -89 dbm on S/C high gain antenna. Angle offset; DEC +0.020 degrees, HA -0.000 degrees. Station ready for TV sequence.
071417	AOS for TV sequence.
0810	TV transmission complete. Signal strength remained constant during TV period.
081835	Antenna at prelimits and EOT. Signal level -112 dbm.

Table 30 (contd)

GMT	Event
Pass 4: 17/18 November 1969, Day 321/322	
215526	AOS at -112 dbm.
2300	Signal strength -112 dbm. No antenna angle offsets required.
0134	S/C on high gain antenna signal level at -89 dbm. TV scheduled transmission canceled due to dirty S/C window.
0300	Signal level -89 dbm on CSM.
033347	LOS. S/C moon occultation. Signal level at -114 dbm prior to LOS.
040612	AOS at -91 dbm on CSM.
042100	TV FM signal started. PM signal level -89 dbm.
045528	TV sequence ended. PM signal level -89 dbm.
053047	LOS. S/C moon occultation. Signal level at -89 dbm prior to LOS.
061437	AOS on exit occultation. PM CSM signal -88 dbm.
071300	S/C to low gain antenna. Signal at -118 dbm from CSM/PM.
073914	LOS. S/C moon occultation. End of pass. Signal level at -108 dbm at occultation.
Pass 5: 18/19 November 1969, Day 322/323	
221200	AOS at -91 dbm on CSM/PM and FM.
2300	Signal level -90 dbm on CSM. Angle offsets; DEC +0.005 degrees, HA +0.005 degrees.
232344	LOS during S/C occultation. Signal level -91 prior to LOS.
002710	AOS on LM at -119 dbm.
0050	S/C on high gain at signal level of -94 dbm.
012205	LOS from S/C occultation. Signal level prior to LOS was -120 dbm on LM/PM.
020822	AOS of LM/PM at -94 dbm.
021048	AOS of LM/FM.
025216	S/C antenna mode change on LM. Signal level -110 dbm.
031400	Antenna change. Signal now -94 dbm.
032033	LOS due to occultation. Signal level at LOS -94 dbm.
040650	AOS of LM/PM at -94 dbm.

Table 30 (contd)

GMT	Event
Pass 5: 18/19 November 1969, Day 322/323 (cont'd)	
040900	TV sequence started. LM/PM signal level -93 dbm.
042200	TV FM downlink signal level fluctuating. Steerable antenna on CSM believed to be reason. Fluctuations lasted 7 minutes.
045105	TV FM off. Lost part of TV sequence on CSM omni-antenna. Picture snowy but discernible.
050000	LM/PM signal -93 dbm.
051900	LOS due to occultation. LOS signal -113 dbm.
060620	AOS on LM at -94 dbm. TDH to 10-second data.
061800	LM/PM signal -95 dbm.
062300	TDH to 1- and 10-second sample rate. TDH format 07.
064239	PDI
065437	LM touchdown on moon. Signal level at -93 dbm and remained throughout descent.
065645	TDH off. 1-second data taken during entire descent.
070000	LM signal -93 dbm and constant.
0717	LM signal -94 dbm.
080205	LM signal -95 dbm.
094035	Antenna at prelimits. Signal level -95 dbm prior to LOS. End of pass.
Pass 6: 19/20 November 1969, Day 323/324	
224229	AOS of CSM at -123 dbm. Using manual track as only predicts available for LM. Twenty-nine point message requested from Houston and is being reformatted.
2300	CSM signal strength -119 dbm. JPL predicts are being run for CSM.
230410	LOS on CSM. Station will track LM.
232620	AOS of LM at -95 dbm.
0000	CSM/PM on omni-antenna with signal at -114 dbm.
0100	CSM/PM now -118 dbm.
010234	LOS of CSM due to occultation.
010257	AOS of LM/PM at -96 dbm.

Table 30 (contd)

GMT	Event
	Pass 6: 19/20 November 1969, Day 323/324 (cont'd)
014600	Switching from LM/PM to CSM/PM.
014852	AOS of CSM/PM at -115 dbm. Omni-antenna used.
020000	CSM/PM signal at -116 dbm.
030101	LOS of CSM due to occultation. Signal at -115 dbm at LOS.
030122	AOS of LM/PM at -83 dbm.
032138	TV FM on to check camera.
032705	TV FM off. Camera still bad.
040000	LM/PM signal at -83 dbm. Using portable S-Band antenna.
103500	Antenna to brake at prelimits.
104400	LOS of LM/PM. Signal at -127 dbm at LOS. End of pass.
	Pass 7: 20/21 November 1969, Day 324/325
002350	AOS on CSM/PM at -114 dbm.
002520	AOS on CSM/FM.
004000	LOS of FM and AOS of PM at -115 dbm.
004337	LOS due to occultation.
013000	AOS of CSM/PM at -117 dbm.
013250	AOS of CSM/FM.
013736	Data dump complete and FM off.
020000	CSM/PM at -113 dbm.
023700	LOS of CSM/PM due to occultation. Signal at -118 dbm at LOS.
032823	AOS of CSM/PM at exit occultation. Signal at -116 dbm.
033342	AOS of CSM/FM.
0400	CSM/PM acquired at signal level of -113 dbm.
044030	LOS due to occultation.
052656	AOS at exit occultation on CSM/PM at -116 dbm.
052903	AOS of FM carrier.
053411	FM carrier off. Receiving PM carrier at -113 dbm.
054500	S/C on high gain antenna. Signal at -97 dbm.
055200	LOS at -109 dbm. End of pass.

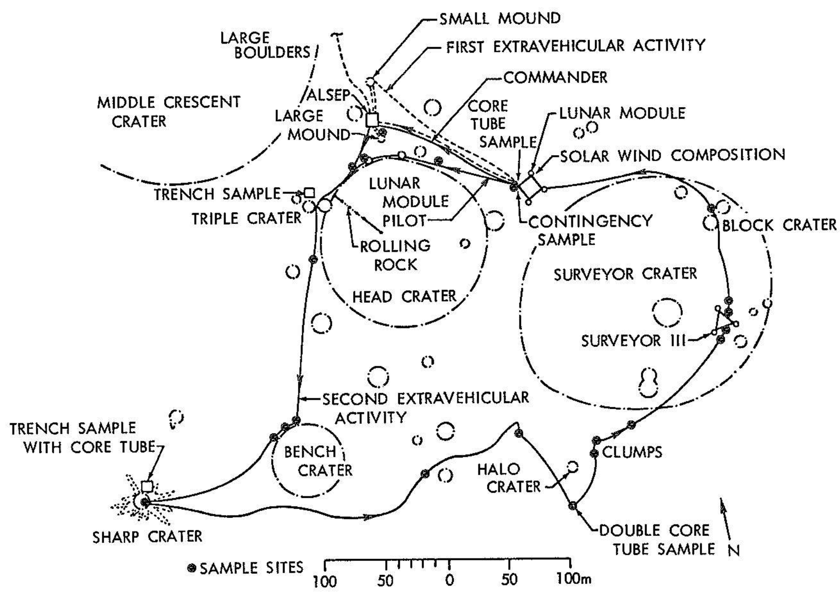


Fig. 19. Traverse map

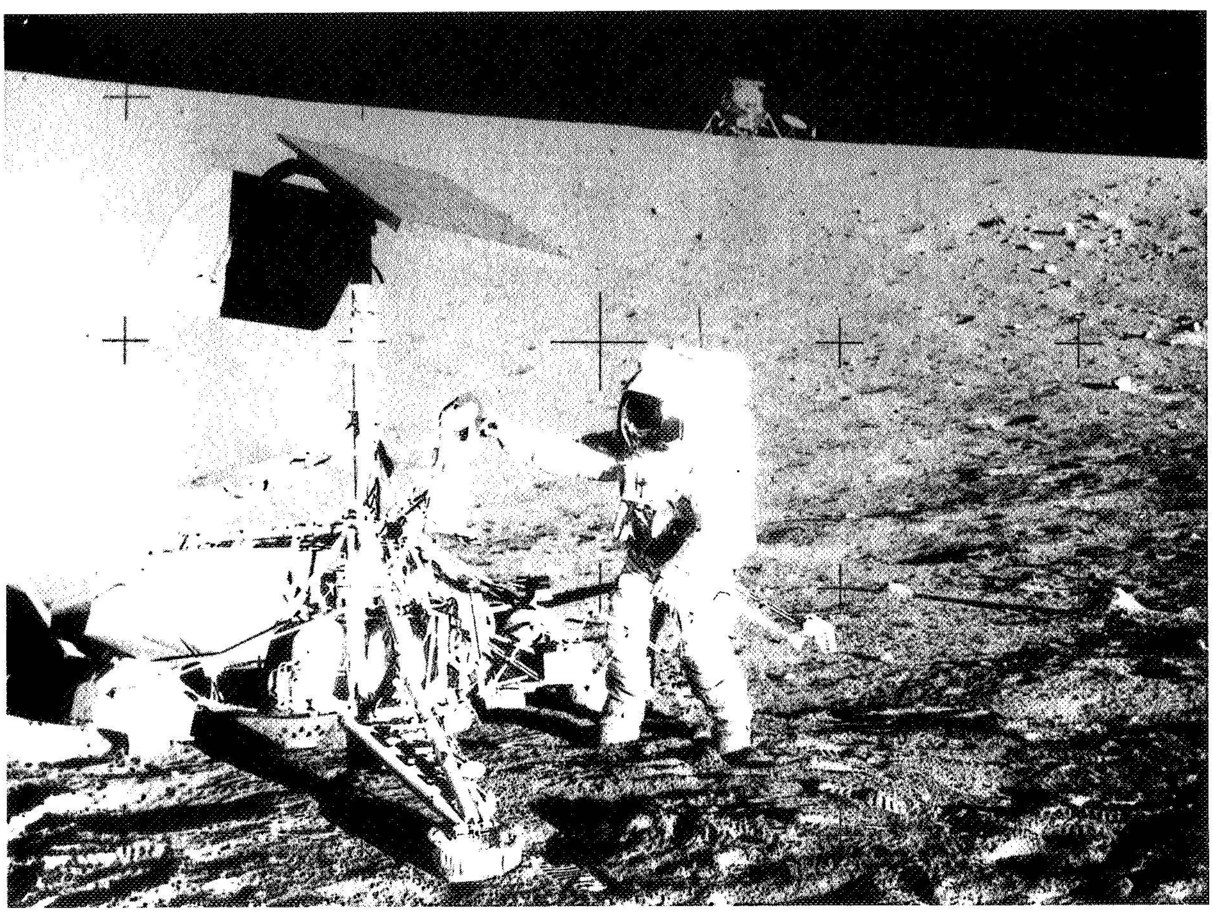


Fig. 20. Apollo astronauts' lunar excursion to Surveyor III site

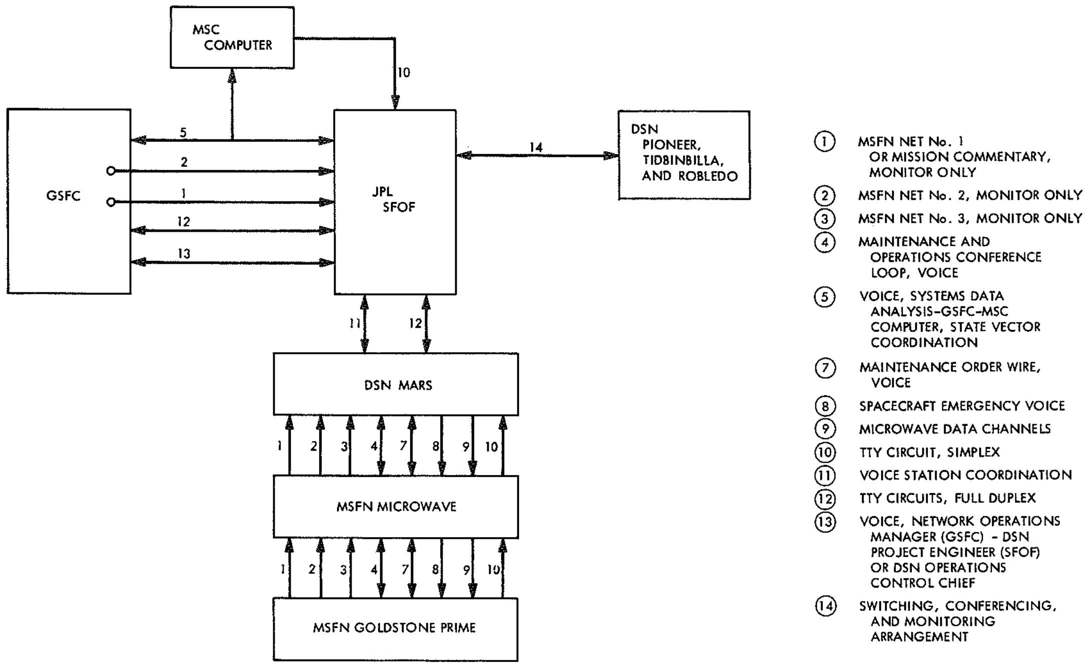


Fig. 21. Goldstone communications requirements for Apollo 12

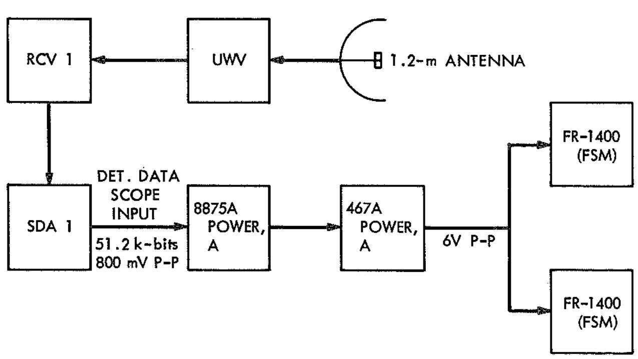


Fig. 22. Block diagram of 51.2 kilobit telemetry data recording configuration

A. Mission Description

The Apollo 13 Mission, with astronauts James A. Lovell, Jr. (spacecraft commander), Thomas K. Mattingly, III (CM pilot), and Fred W. Haise, Jr. (LM pilot), was planned as the fifth mission to the moon and the third lunar landing. Approximately 56-h after launch, the mission had to be aborted because of an explosion in bay 4 of the service module which resulted in an abrupt loss of cryogenic oxygen and electrical power. Although the mission goal of landing in the Fra Mauro uplands was unsuccessful as planned, a lunar flyby and several scientific experiments were completed before the crew successfully splashed down in the south Pacific Ocean.

Apollo 13 was launched on April 11, 1970, at 19:13 GMT (0:00 GET) from Pad 39A at Cape Kennedy. An early shutdown of the S-II stage altered the earth parking orbit such that subsequent staging and translunar injection (TLI) times occurred later than originally planned but well within the nominal flight plan.

At 02:35:46 GET, midway through the second earth parking orbit revolution, the S-IVB was restarted and a 5-min, 57-s TLI burn placed Apollo 13 on a translunar trajectory. Following TLI, the CSM separated from the S-IVB, pitched 180 deg and docked with the LM. CSM/LM ejection from the S-IVB occurred at 04:18:01 GET.

For the first time in Apollo history, the discarded S-IVB was directed toward an impact on the moon to generate seismic waves for the seismometer package left on the moon during the Apollo 12 mission. Lunar impact occurred some 78 h after launch at 01:09:39 GMT on April 15 at lunar coordinates 2.4°S, 27.9°W, 119 km from the Apollo 12 seismometer. The impact velocity was 99,974 cm/s, creating an impulse equivalent to 10 tons of TNT. These data compare with the crash of the Apollo 12 LM, which was 68 km from the seismometer with an equivalent energy of one ton of TNT. The seismic waves recorded were of similar character, but the S-IVB impact waves were 20 to 30 times larger and lasted four times longer (approximately 4 h).

The accuracy of the translunar injection maneuver eliminated the need for midcourse correction 1, which had been planned for 11:41 GET (Ground Elapsed Time, or time after launch). The spacecraft at this point was on a "free-return" trajectory; i.e., should all propulsion be lost, the spacecraft would swing around the moon and return to a normal reentry into the earth's atmosphere. At 30:41 GET, midcourse correction 2 altered the spacecraft's free-return trajectory to a "hybrid" trajectory that would enable a saving of fuel for the lunar landing sequence. However, with a hybrid trajectory, loss of all propulsion would doom the spacecraft to miss the earth and enter a perpetual solar orbit.

The mission continued nominally until 55:00 GET, when the crew entered the LM to check the pressure of the supercritical helium following premission indications of an anomalous heat-leak rate. After being satisfied that no problem existed, the crew was reentering the CM when a loud "bang" was heard. The sound did not cause immediate anxiety because one of the LM systems often makes this same noise. However, warning signals soon indicated problems in the SM power subsystem, the first indication being at 55:54:53 GET (03:07:53 GMT on April 14). An apparent oxygen tank explosion forced the crew to shut down first one fuel cell, and then all three fuel cells, which left the CM with no electrical power and no oxygen. The crew then returned to the LM, powered up its systems, and prepared to use it as an emergency lifeboat for the remainder of the mission. From its complete shutdown at 58:40 GET until the reentry phase, the CM was used for nothing but cold (276.5°K) sleeping quarters.

The unthinkable had happened -- the entire capability of the SM, with all its many redundant systems, had been lost. All mission objectives except return to earth were abandoned. A quick analysis showed that the LM consumables (water, power, and oxygen) were barely adequate for the return trip. The critical problem was the hybrid trajectory and the lack of the normal service propulsion system of the SM. Accordingly, a burn of the LM descent engine at 61:29:43 GET successfully returned the spacecraft to a free-return trajectory.

The remainder of the mission consisted mainly of minimizing activity to reduce electrical power usage. Several additional orbit changes were conducted. About 2 h after passing behind the moon, a midcourse correction speeded up the spacecraft to decrease its transit time to earth by 10 h and enable the use of the original recovery area. Unfortunately, a small out-of-plane component created a trajectory that would have caused the spacecraft to enter the atmosphere improperly. This error was trimmed out by a small motor burn of 457 cm/s at 105:18:28 GET. The final orbit correction was conducted at 137:39:52 GET, only 5 h before entering the earth's atmosphere, and changed the entry flight-path angle. Shortly after this maneuver, the SM was jettisoned and photographs taken of the damage. The crew reentered the CM, powered up its systems (using the reentry batteries), and jettisoned the LM just one hour before landing. Entry, splashdown, and recovery were all normal except for the deletion of all quarantine measures. The sequence of events for the Apollo 13 mission are given in Table 31 and the mission profile is shown in Fig. 23. The astronauts arrived aboard the USS Iwo Jima 44 min after splashdown, thus ending Apollo's first aborted lunar mission.

B. Apollo Interface Team

Between Apollo Missions 12 and 13, DSN management decided that the level of DSN support for Apollo no longer warranted the services of a DSN Manager. Accordingly, the position of DSN Manager for Apollo was abolished with most of the DSN Manager duties being assumed by the DSN Project Engineer (Fig. 24). Another "first" for Apollo 13 was the formal transfer of the Apollo support capability from the Interface Team to the Mission-Independent Operations Organization. Unfortunately, the predict generation capability was not transferred. In the areas that were transferred, however, no operational problems were noted. The Operations Organization and its advisory interfaces with the Interface Team are shown in Fig. 25.

C. Requirements for DSN Support of Apollo 13

As with previous Apollo missions, the Pioneer, Tidbinbilla, and Robledo stations were committed to support Apollo 13 under direct MSFN/MSC control starting at launch minus 2 weeks (March 31, 1970) through the end of the mission.

On previous missions, the Mars station supported the Apollo mission exclusively for 6 or 7 days. With Apollo 13, this was not possible since the Mariner Mars 1969 Extended-Operations Mission was in its prime scientific phase and required Mars support. A sharing schedule (Fig. 26) was developed by DSN Scheduling in an attempt to satisfy the critical requirements of both missions. This schedule was accepted by all parties.

A special effort was made to cover all planned TV broadcasts (Table 32) but, due to the explosion, all TV was discontinued after the fourth showing which began at 55 GET instead of 58 GET.

The MSFN required time synchronization between the various stations at Goldstone (Mars, Pioneer/MSFN Wing, and Apollo Prime). The time synchronization was supplied in the same manner as on previous missions by transporting a Goldstone Standards Laboratory cesium clock to the various sites several times throughout the mission. The results of these measurements are shown in Tables 33 and 34. A supplementary 1-pulse/s time tick accurate to 5 μs was made available at the MSFN microwave interface at Mars. An additional request was received for the portable clock to be stationed within the Pioneer/MSFN Wing for a 30-h period during lunar operations. The MSFN planned to conduct a series of experiments with a new hydrogen maser frequency standard and was concerned over a possible loss of absolute time reference. The DSN planned the support, and the necessary overtime was authorized. However, with the aborted mission, the plans were cancelled.

As part of a continuing study of lunar potential anomalies (MASCONs), Mars was required to provide precision doppler recordings of the CSM during several low lunar orbits, and of the LM during the descent phase. Signal strength recordings were also required during the LM descent. Additionally, MSFN stated a desire to have precision LM doppler data from Cebreros on low lunar orbits 34 and 35. During these orbits, the LM would be viewable only from Madrid DSCC, as the Madrid Apollo Prime and Wing sites were not equipped with doppler resolvers. Since Cebreros is not a normal Apollo support station, this coverage was planned, based on no interference to other missions and no additional resources required.

D. DSN Mission Support

1. Premission Activities.

a. DSN/MSFN Wing Stations. The Pioneer, Tidbinbilla, and Robledo stations were placed on mission status at 00:01 GMT on March 31, 1970, and from that time until splashdown, the stations were under MSFN control. Prior to March 31, each wing site conducted extensive maintenance and a long pretrack countdown to ensure the integrity of the equipment common to the DSN and MSFN.

b. Mars. Two tests were conducted at the Mars station prior to the Apollo 13 mission. The first test was a 12-h internal Configuration Verification Test on March 26. In the second test, Mars linked up with the Goldstone Prime station for a 24-h data-flow test including bit error-rate checking. During this second test, the SFOF predict transmission procedure was tested by sending center-of-the-moon predicts to Mars. As the results of the predicts exercise were doubtful, an additional test was conducted on April 7, during which the premission nominal predicts were successfully transmitted.

c. Tidbinbilla. Due to construction, begun in November 1969, of a new 64-m deep space communications antenna near the Tidbinbilla station, the microwave link between this station and the MSFN Apollo Prime station would be obstructed by large mobile cranes and a 1218-m erection tower by the time of the Apollo 13 launch in April 1970. After investigating various solutions, it was decided to relocate the microwave tower at Tidbinbilla. The task was begun in mid-January and completed and back in operation on February 23, 1970. Tests indicated an overall improvement averaging 3 dB per channel due to an improved rf signal path to the MSFN Apollo Prime station.

2. Apollo 13 Mission Activities.

a. DSN/MSFN Wing Stations. The Pioneer, Tidbinbilla, and Robledo stations successfully supported the earth-orbital, translunar, and trans-earth phases of the mission. The tracking reports are summarized in Tables 35 through 37 and the station viewperiods are given in Table 38. The following anomalies were noted:

(1) Pioneer. During the week prior to launch, the MSFN reported Pioneer "red can support" due to apparent shifts of the rf boresight. The shifts were on the order of 0.060 deg, but were only observable at temperature extremes of night vs day. The DSN has no specifications for boresight shift, and the MSFN specification of 0.018 deg is felt by some to be unrealistic. Several tests were run following the first report of the problem at 17:29 GMT on April 2, and a star track was conducted to calibrate the shifts. Armed with these calibrations, the MSFN declared Pioneer green at 23:21 GMT on April 9, two days before launch. A second premission problem at Pioneer was the failure of maser 2, but it was returned to operational status before launch. During the first translunar pass, a circuit breaker tripped on the ac regulator for maser 1. A switch was made to maser 2 with a loss of 2 min of data.

(2) Tidbinbilla. The only problem occurring at Tidbinbilla was the failure of transmitter power amplifier 4 during a pretrack System Readiness Test at 02:40 GMT on April 14. A fan motor bearing failed in the heat exchanger and was repaired by 04:28 GMT.

(3) Robledo. About 5 h before launch, a large water leak occurred on the pump of heat exchanger 2, causing 2 min of a test to be lost. The pump was replaced, but a defective mechanical seal caused a small leak to develop 1 day later during a tracking period. The uplink was not lost, however, and the problem was corrected after the uplink was taken over by another tracking station.

b. Mars. Six passes were tracked (see Table 39) with the planned schedule shown in Fig. 26 being altered in only two cases. On the third pass (April 14), MSFN requested Mars to be on track at 01:00 GMT instead of 04:00 to cover the LM familiarization TV broadcast and telemetry. The end of the Mariner track was changed from 23:00 GMT to 21:30 and the post-calibration was shortened to 0.5 h for ranging only. Toward the end of the LM familiarization, the SM explosion occurred, which resulted in Mars being requested to track horizon-to-horizon for the remainder of the mission. Since the fifth and sixth passes (April 16 and 17) were already scheduled horizon-to-horizon, the only schedule change required was to drop the Mariner track on April 14 in order to track Apollo from horizon rise on the fourth pass (late April 14).

No problems occurred at Mars affecting Apollo support. One problem did occur at JPL: at the end of the fourth pass, it was erroneously determined that the existing predicts would be valid for the fifth pass. Upon acquisition during the fifth pass, Mars reported large offsets of 0.300 deg in both axes. These offsets were caused by the "speedup" burn 18 h earlier, which altered the trajectory enough to require new predicts. As mentioned before, predicts generation will be transferred to the Mission-Independent Operations Organization for future Apollo missions and this problem should not reoccur.

As in past missions, Mars was able to demonstrate its unique capabilities. After the abort, the spacecraft conserved power by transmitting with low power through the omniantenna (the high-gain antenna is electrically steered). During many portions of the mission, Mars was the only station to receive a solid downlink. When the station acquired the spacecraft and took over the function of downlink from a 26-m antenna station, the reduction in background noise on the astronaut's voice was immediately noticed. In addition, when the S-IVB signal interfered with the LM signal (the two craft use the same frequency causing the same problem on every mission), Mars again separated the two, spatially, using the station's narrow beamwidth.

c. Cebreros. When the mission was aborted, the special support planned for Cebreros was cancelled.

d. SFOF Participation. The SFOF areas and equipment involved in the Apollo 13 operations included the Operations Area, the Network Analysis Area, the displays, and the Mode IV 7044-7094 computers. These areas and functions were staffed during all Mars passes and at other times to support special activities. Strict access control was activated in the Operations Area during the reentry and splashdown phase. The reduction of unnecessary personnel was very effective. Aside from the difficulty with predicts for the Mars fifth pass, there were no problems in the SFOF.

e. GCF Participation. The DSN GCF provided voice and teletype circuits similar to those for Apollo 12 (Fig. 21) as required to support the operations mentioned above. In addition, JPL acts as the West Coast Switching Center for the NASA Communications Network and handles many non-DSN circuits in support of Apollo. There were no communications problems that constrained the DSN support of Apollo 13.

Table 31. Apollo 13 sequence of events

Event	GMT	GET
Launch	April 11, 19:13:00.56	0:00:00
Translunar injection	April 11, 21:48:36	02:35:46
Midcourse maneuver 2 (to "hybrid" trajectory)	April 13, 01:53:50	30:40:50
Begin Lunar Module Checkout	April 14, 02:13:00	55:00:00
Service module explosion	April 14, 03:07:53	55:54:53
Lunar Module signal on	April 14, 05:10	57:57
All Command/Service Module fuel cells off	April 14, 05:11	57:58
Command/Service Module completely off	April 14, 05:53	58:40
Maneuver (to "free return" trajectory)	April 14, 08:42:43	61:29:43
Lunar occultation	April 15, 00:22	77:09
End lunar occultation	April 15, 00:46	77:33
S-IVB impact	April 15, 01:09:39	77:56:39
Maneuver ("speedup")	April 15, 02:40:39	79:27:39
Maneuver (trim)	April 16, 04:31:28	105:18:28
Maneuver (trim)	April 17, 12:52:52	137:39:52
Jettison Service Module	April 17, 13:14:48	138:01:48
Jettison Lunar Module	April 17, 16:43:00	141:30:00
Enter atmosphere	April 17, 17:53:46	142:40:46
Splashdown	April 17, 18:07:41	142:54:41

Table 32. Apollo 13 premission TV schedule

Day	Date (GMT)	GMT	GET	Duration	Activity/Subject		Station
Saturday	11 April	20:48	1:35	0:07	Earth	CSM	SMS
Saturday	11 April	22:28	3:15	1:08	Transposition and docking	CSM	GDS
Monday	13 April	01:28	30:15	0:30	Interior of spacecraft and MCC-2	CSM	GDS
Tuesday	14 April	05:13	58:00	0:30	Intervehicular transfer and spacecraft	CSM	GDS
Wednesday	15 April	19:03	95:50	0:15	Frau Mauro	CSM	MAD
Thursday	16 April	07:23	108:10	3:52	Lunar surface activities	LM	GDS/HSK
Friday	17 April	03:03	127:50	6:35	Lunar surface activities	LM	GDS
Friday	17 April	15:38	140:25	0:22	Docking	CSM	MAD
Saturday	18 April	17:23	166:10	0:40	Lunar surface	CSM	MAD
Saturday	18 April	19:13	168:00	0:15	Post-TEI/lunar	CSM	MAD
Tuesday	21 April	00:58	221:45	0:15	Earth and spacecraft interior	CSM	GDS

Table 33. Portable clock measurements

Date (April 1970)	Microseconds of Lead (+) or Lag (-) Time Relative to NBS Clock 8				
	Apollo Prime Station		Apollo Wing Station		Measurements to Compare NBS Clock 8 with Apollo Wing Clock NP3A
	Clock A	Clock B	Clock A	Clock B	
10	-0.5 (2044)	-0.4 (2043)	-0.1 (2145)	-0.1 (2147)	-0.2 (2149)
13	-0.7 (1654)	-0.7 (1656)	-0.2 (1714)	-0.1 (1716)	-0.5 (1718)
16	-0.1 (1712)	-0.2 (1814)	-0.1 (1743)	-0.1 (1745)	-0.1 (1750)
17	-0.2 (1656)	-0.3 (1658)	-0.1 (1719)	-0.1 (1721)	-0.1 (1723)
NOTE: Values in parentheses are time of day in GMT.					

Table 34. Microwave link delays

Date (1969)	Delay in Microseconds	
	Apollo Prime Clock A	Apollo Wing Clock A
13 November	90.9	116.3
16 November	90.9	116.3

Table 35. Pioneer tracking report, Apollo 13

Date 1970	Pass or Orbit	Tracking Times (GMT)	Tracking Mode	Anomalies
11/12 April (Days 101/102)	Earth Orbit & Translunar coast	Not Reported	Not Reported	Circuit breaker on ac power supply for active maser tripped. Lost data for approximately 2 minutes.
12/13 April (Days 102/103)	Translunar pass	Not Reported	Not Reported	None
13/14 April (Days 103/104)	Translunar coast	Not Reported	Not Reported	None
14/15 April (Days 104/105)	Translunar & transearth coast	Not Reported	Not Reported	None
15/16 April (Days 105/106)	Transearth coast	Not Reported	Not Reported	None
16/17 April (Days 106/107)	Transearth coast	Not Reported	Not Reported	None

Table 36. Tidbinbilla tracking report, Apollo 13

Date 1970	Pass or Orbit	Tracking Times (GMT)	Tracking Mode	Anomalies
11 April (Day 101)	Earth orbit	Not Reported	Three-way with CSM/IU	None
12 April (Day 102)	Translunar coast	Not Reported	Two-way & three-way with IU Three-way with CSM	None
13 April (Day 103)	Translunar coast	Not Reported	Two-way & three-way with IU	None
14 April (Day 104)	Translunar & transearth coast	Not Reported	Three-way with CSM Two-way & three-way with LM	Transmitter No. 2 (MSFN) fan on heat exchanger failed during SRT. No effect on mission support.
15 April (Day 105)	Transearth coast	Not Reported	Two-way & three-way with LM	None
16 April (Day 106)	Transearth coast	Not reported	Two-way & three-way with LM	None
17 April (Day 107)	Transearth coast	Not reported	Two-way & three-way with LM Three-way with CSM	None

Table 37. Robledo tracking report, Apollo 13

Date 1970	Pass or Orbit	Tracking Times (GMT)	Tracking Mode	Anomalies
11 April (Day 101)	No view this period			
12/13 April (Days 102/103)	Translunar coast	121527-122801 122801-211301 211301-015755	Three-way Two-way Three-way	Water leak on mechanical seal of heat exchanger No. 2 pump. No effect on mission support.
14/15 April (Days 104/105)	Translunar & transearth coast	130550-131904 131904-004806 004806-020851	Three-way Two-way Three-way	None
14/15 April (Days 104/105)	Translunar coast	125125-131301 131301-211301 211301-222453 222453-020301 020301-021205	Three-way Two-way Three-way Two-way Three-way	None
15/16 April (Days 105/106)	Transearth coast	130405-011220 011220-011947	Three-way with LM Two-way with CSM	None
15/16 April (Days 105/106) (continued)		011947-020610	Three-way with LM	
16/17 April (Days 106/107)	Transearth coast	132049-151939 151939-231301 231301-021814	Three-way Two-way Three-way	None

Table 38. Apollo 13 wing view periods (GMT)

Parameters	Pioneer	Tidbinbilla	Robledo
Earth Orbit	11/20:40-11/20:46	11/20:12-11/20:20	
Translunar Cruise	11/22:07-12/09:28 12/19:45-13/09:53 13/20:07-14/10:03 14/20:15-	12/04:08-12/13:18 13/04:31-13/14:03 14/04:34-14/14:18	11/23:12-12/00:53 12/11:43-13/02:38 13/12:18-14/02:43 14/12:30-
Lunar Orbit	-15/10:13 15/20:59-16/10:43 16/21:55-17/10:53 17/23:28-18/11:28	15/05:21-15/13:58 16/04:23-16/15:15 17/05:46-17/16:43 18/05:51-18/17:43	-15/02:28 15/12:56-16/03:13 16/14:02-17/03:01 17/15:36-18/03:53 18/16:04-
Transearth Cruise	18/23:37-19/11:33 19/23:23-20/11:33 21/00:18-21/11:33	19/06:03-19/17:48 20/06:03-20/18:03 21/06:14-21/19:59	-19/04:03 19/16:13-20/03:53 20/16:38-21/03:53

Table 39. Mars tracking support data

GMT	Events
	Pass 1: 12 April 1970, Day 102
030720	S/C acquired on CSM/PM. Downlink signal level -98 dbm. Twenty-nine point acquisition message used to acquire with offsets +0.125 degrees in HA and +0.040 degrees in DEC.
032800	Predict Set 001 for CSM being transmitted.
040000	Downlink -100 dbm. Twenty-nine point acquisition message predict +0.120 degrees in HA and +0.040 degrees in DEC.
050000	Using Predict Set 001, offsets are +0.033 degrees in HA and -0.012 degrees in DEC. Signal level -99 dbm.
060000	Predict Set 001 now +0.022 degrees in HA and +0.002 degrees in DEC. Signal level -99 dbm.
070000	Signal level -103 dbm. Offsets from Predict Set 001, +0.038 degrees in HA and +0.001 degrees in DEC.
080000	Signal level -106 dbm. Offsets from Predict Set 001, +0.006 degrees in DEC and +0.002 degrees in HA.
085330	S/C signal level -113 dbm. Antenna at prelimits. EOT.

Table 39 (contd)

GMT	Events
Pass 2: 13 April 1970, Day 103	
002910	S/C acquisition at signal level of -119 dbm. Offsets from Predict Set 002, zero in both HA and DEC.
010000	Signal level -88 dbm on CSM/PM. Offsets from Predict Set 002, +0.004 degrees in HA and zero in DEC.
012000	TV synchronization signal being received.
012620	TV picture being received. Signal level -93 dbm on FM.
015400	MCC-2 initiated.
020000	Signal level -88 dbm on CSM/PM. Offsets zero in both axes.
021523	TV signal terminated.
030000	Signal level -88 dbm on CSM/PM. Offsets still zero in both axes.
040000	Signal level -108 dbm on CSM/PM. Offsets zero.
050000	Signal level -109 dbm on CSM/PM. Offsets zero.
060000	Signal level -109 dbm on CSM/PM. Offsets zero.
070000	Signal level -122 dbm on CSM/PM. Offsets zero.
080000	Signal level -112 dbm on CSM/PM. Offsets zero.
090000	Signal level -119 dbm on CSM/PM. Offsets zero.
092848	Antenna at prelimits. Signal level -114.5 dbm. EOT.
Pass 3: 14 April 1970, Day 104	
003610	S/C acquisition at -112 dbm on CSM/PM. Predict Set 003 on station.
010000	Receiver 10 tuned to LM/PM frequency best locked to S-IVB/IU signal at -131 dbm. S-IVB is in antenna beamwidth when antenna is pointed at CSM/LM.
015000	Station reconfigured to Receiver 10 on CSM/FM receiving weak TV picture. Receiver 9 on LM/PM (IU).
020000	Receiver 9 on IU. Receiver 10 receiving TV, carrier only.
020800	Receiver 9 to CSM/PM at signal of -124 dbm.
022730	TV signal on at signal level of -83 dbm. S/C using high gain antenna.
025954	TV signal off.
030000	Signal level -90 dbm on CSM/PM. Offsets from Predict Set 003, +0.004 degrees in both axes.
030810	Signal level -109 dbm on CSM/PM.
032600	Signal level -115 dbm on CSM/PM. Apparent fuel cell problem reported.
040000	Signal level -114 dbm on CSM/PM. Predict offsets -0.004 degrees in HA and +0.006 degrees in DEC. CSM on fuel cell 2, bus A only. CSM is partially powered down. Problem appears to be venting from fuel cell. Roll and pitch rates occurring in S/C.
041000	S/C problem appears to be loss of 0_2 in fuel cell 3. Fuel cell 3 being shut down.
043000	Fuel cell 1 being shut down; 0_2 venting in SPS main supply.
050000	Signal level -112 dbm on CSM/PM. LM being powered up.
015010	AOS of LM at signal level of -114 dbm.

Table 39 (contd)

GMT	Events
Pass 3: 14 April 1970, Day 104 (cont'd)	
051700	CSM on battery power. Voice circuit to backup mode. Signal -130 dbm on CSM/PM.
055200	CSM dead with LOS on CSM/PM.
060000	Signal level -119 dbm on LM/PM.
072320	LOS on LM/PM with IU interference.
072840	AOS on LM/PM at -116 dbm.
080000	Signal level -113 dbm on LM/PM.
090000	Signal level -116 dbm on LM/PM.
093543	Antenna at prelimits with signal at -116 dbm. EOT.
Pass 4: 14/15 April 1970, Days 104/105	
204510	S/C AOS at -129 dbm on LM/PM. Predict Set 004 on station.
210000	Signal level -129 dbm with both receivers on LM.
213200	Signal level -120 dbm. LM/PM data at high bit rate.
221000	Signal level -134 dbm. LM/PM data at low bit rate.
230000	Signal level -127 dbm with LM/PM back to high bit rate data.
240000	Signal level -127 dbm with LM/PM still at high bit rate data.
002135	LOS of LM/PM.
004029	AOS of LM/PM at signal level of -136 dbm.
010000	Signal level -139 dbm on LM/PM.
020000	Signal level -118 dbm on LM/PM.
024039	TEI. MCC-1 initiated.
030000	Signal level -115 dbm on LM/PM.
040000	Signal level -129 dbm on LM/PM.
050000	Signal level -128 dbm on LM/PM.
060000	Signal level -130 dbm on LM/PM.
070000	Signal level -130 dbm on LM/PM.
080000	Signal level -130 dbm on LM/PM.
090000	Signal level -136 dbm on LM/PM.
093145	Antenna at prelimits. Signal level at -134 dbm. EOT.

Table 39 (contd)

GMT	Events
	Pass 5: 15/16 April 1970, Days 105/106
205100	AOS at signal level of -128 dbm on LM/PM. Predict Set 004 on station for acquisition off by +0.0300 degrees in both HA and DEC. Used offset predict data obtained from Apollo Wing to acquire S/C.
205800	Predict Set 005 being sent to Mars.
211000	Using 29-point acquisition message for antenna drive. Offsets zero in both HA and DEC.
221400	Signal level -126 dbm.
231400	Signal level -110 dbm. S/C using high power transmitter.
000000	Signal level -112 dbm.
010815	AOS on CSM/PM. Signal at -113 dbm after short period.
011552	CSM powered down.
012004	Configured Receiver 10 to LM/PM downlink. Signal at -114 dbm.
020000	Signal varying 20 to 30 dbm.
020900	Signal still varying about -114 dbm.
030000	Signal level at -107 with P/A on.
040000	Signal level at 107 dbm with P/A on.
043200	Course correction burn.
050000	Signal level -123 dbm.
060000	Signal level -127 dbm.
070000	Signal level -125 dbm.
080000	Signal level -125 dbm.
082900	Signal level -111 dbm with S/C transmitter on high power.
083500	Signal level -126 dbm with transmitter on low power.
090000	Signal level -123 dbm.
093415	Antenna at prelimits at signal level of -125 dbm. EOT.
	Pass 6: 16/17 April 1970, Days 106/107
211213	AOS at -121 dbm on LM/PM.
220000	Signal level -117 dbm on LM/PM.

Table 39 (contd)

GMT	Events
Pass 6: 16/17 April 1970, Days 106/107 (cont'd)	
221847	AOS of CSM at -113 dbm.
222513	LOS on CSM.
230000	Signal level -123 dbm on LM/PM.
000000	Signal level -119 dbm and varying every 22 minutes on S/C rolls.
010000	Signal level -121 dbm.
020000	Signal level -110 dbm.
030000	Signal level -110 dbm.
040000	Signal level -107 dbm.
050000	Signal level -115 dbm.
060000	Signal level -112 dbm.
070000	Signal level -115 dbm.
080000	Signal level -106 dbm.
090000	Signal level -106 dbm.
095000	Signal level -106 dbm with antenna at prelimits. EOT and station released from Apollo 13 support.

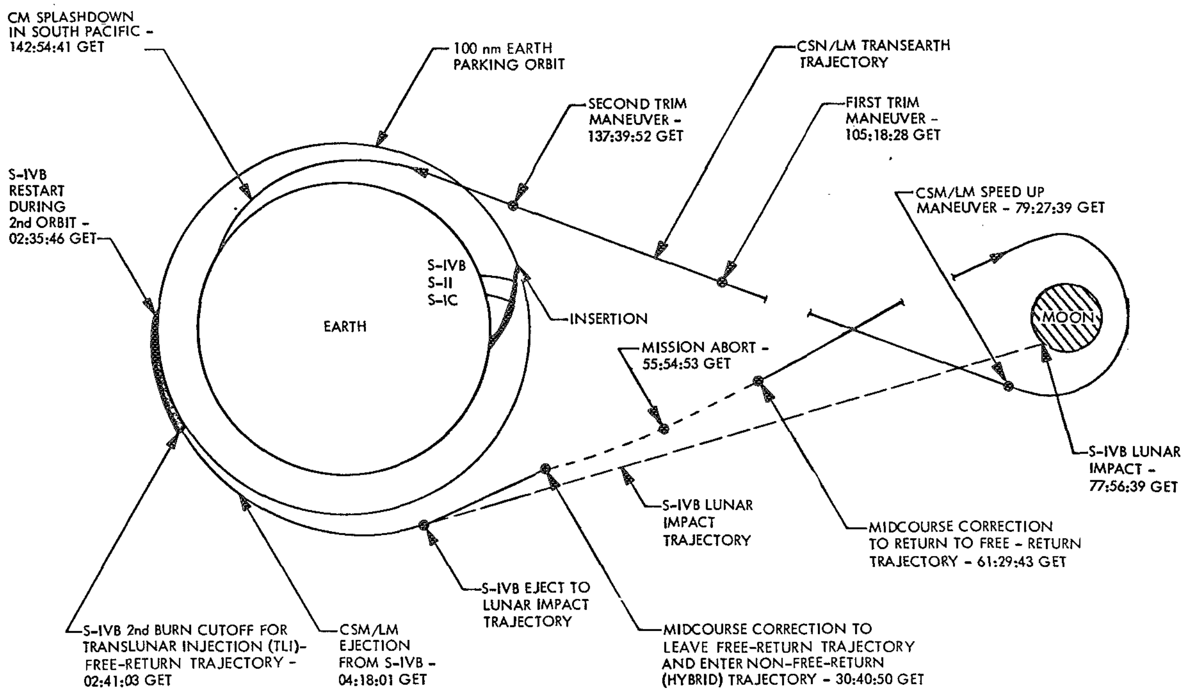


Fig. 23. Mission profile for Apollo 13 mission

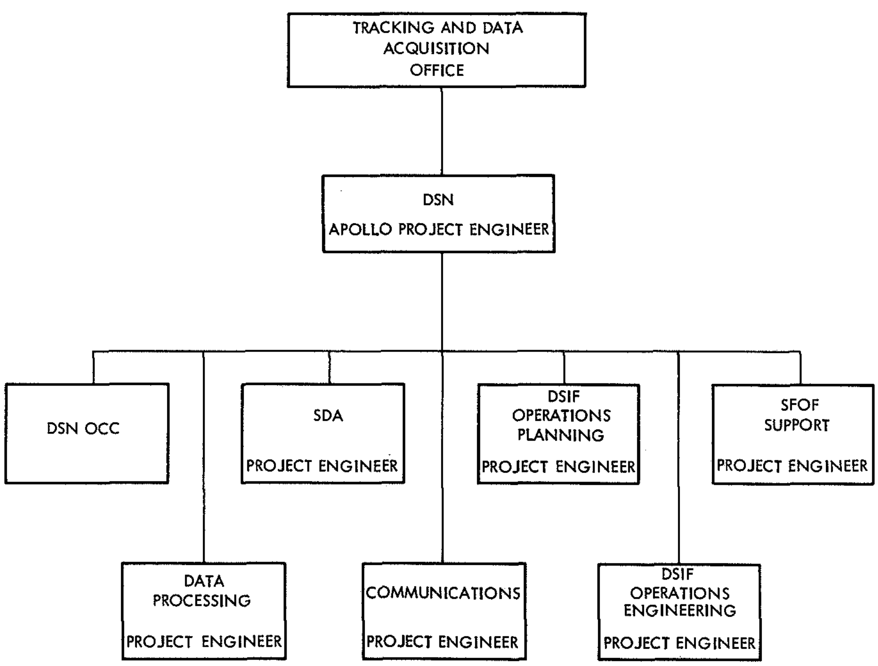


Fig. 24. Apollo 13 interface planning team

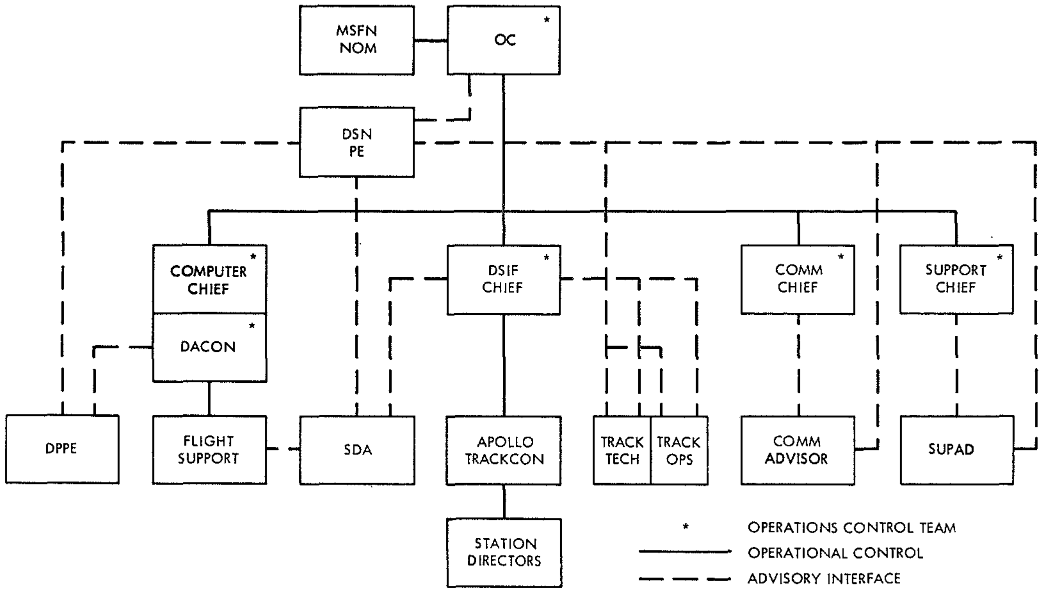


Fig. 25. DSN operations organization for Apollo 13

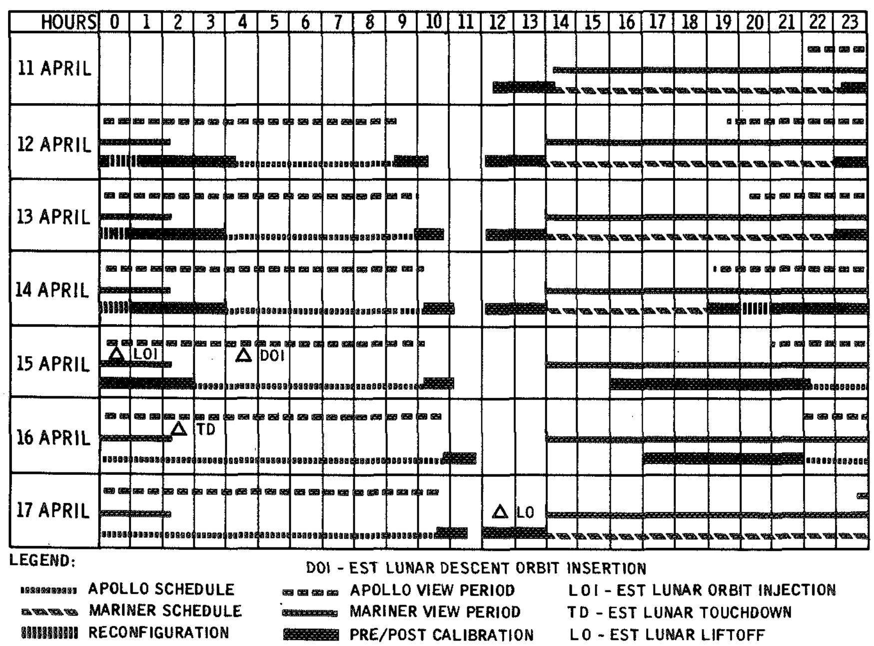


Fig. 26. Mars station planned tracking schedule for Apollo 13

A. Introduction

In the period of time between the abortive Apollo 13 mission (April, 1970) and the end of calendar year 1970, there were a number of developments which affect DSN support of Apollo. This Section will describe these various developments and future plans.

B. Bistatic Radar Experiment

On April 14, 1969, Stanford University submitted a formal proposal to NASA to conduct a "Downlink Bistatic Radar Study of the Moon" using the Mars station. The specific goals of this experiment are:

(1) To determine the Brewster angle of the lunar crust at S-band

(2) To measure the spectral properties of bistatic radar echoes from low altitude orbit

(3) To gain operational experience with Apollo systems and operations as an aid in the design of future bistatic radar experiments

If successfully completed, the proposed experiment will provide fundamental new scientific information on the upper few centimeters of the lunar crust through a short wavelength determination of the Brewster angle of the lunar surface, and will provide engineering data necessary for optimizing the design of future bistatic radar experiments from low lunar orbits (approximately, 100-km altitude). Furthermore, the results will provide a lunar S-band, bistatic radar calibration which will have considerable utility in the interpretation of similar experiments conducted in the future at the planets.

It was proposed that the downlink CSM S-band signal would be directed toward the lunar surface. At the Mars station, the reflected signal (and a portion of the direct signal) would be received in two polarizations simultaneously using the Polarization Diversity S-band (PDS) cone. The outputs of the two receiver chains would be recorded on FR-1400 recorders.

A meeting was held at JPL on May 8, 1970, to discuss the feasibility of the proposed experiment. In attendance were representatives of MSC, GSFC, NASA Headquarters, North American Rockwell, Stanford University, and the DSN, DSIF, and GCF. The potential problem areas were identified and a number of action items were assigned. Shortly afterward, a support requirement was issued at MSC (May 19, 1970). DSN support was planned to begin with Apollo 14 to be launched January 31, 1971.

The final details on the configuration at the Mars station were discussed at another meeting at JPL on November 9, 1970, with approximately the same representation as the May 8 meeting.

Several installation and test periods are required. Three test periods have been completed:

(1) December 21/16:00-24:00: cable installation and station familiarization.

(2) December 22/22:00-02:01: cable installation and station familiarization.

(3) December 23/02:01-06:00: track of Pioneer 6 spacecraft using its rf carrier as a test signal for the bistatic equipment.

Tests 2 and 3 (above) are planned to be repeated on approximately January 8, 1971, and January 29, 1971. With Apollo 14 launch scheduled for January 31, 1971, the actual experiment would take place on February 6, 1971, while the CSM is in lunar orbit and the LM is on the lunar surface.

C. Goldstone Timing Synchronization

The time-synchronization agreement reached before Apollo 11 (see Section IV) was amended on June 9, 1970. The new agreement, which will be valid for all future Apollo missions, is as follows: A one-pulse/s tick is distributed via DSN microwave to Mars. The pulse originates from Goldstone Standards Laboratory, arrives at the sites with known offsets, and is accurate to better than 5 μs. This signal is made available to the MSFN at the MSFN microwave interface at Mars. The portable cesium clock will be used only to calibrate the microwave delays when changes have occurred to the microwave system. Routine support of the portable clock will be discontinued. In the case of a bona fide timing emergency, the portable cesium clock will be available with a delay of 2 h during the normal working day and 48 h otherwise.

D. Modification of MSFN Wing Site Control Rooms

In order to accommodate MSFN use of the 26-m antennas at Pioneer, Tidbinbilla, and Robledo for the Apollo Project, a separate MSFN control room was built at each dual site location. During MSFN tests and tracking periods, control of the antenna and other common equipment (masers, servo, microwave, power amplifier, etc.) had to be switched from the DSN control to MSFN control. The DSN is now in the process of constructing two new 64-m antennas near Tidbinbilla and Robledo. Rather than build control rooms for these new stations, a considerable cost could be saved by using the original DSN control rooms for the new 64-m antennas and using the MSFN control room for all 26-m antenna operations. Agreement was reached with GSFC in late 1970 on a control room layout with a mixture of DSN and MSFN equipment and one operations team. Although the requirement was only for Tidbinbilla and Robledo, Pioneer station will also be reconfigured to maintain network uniformity.

The modifications have already started at Pioneer and the station will be in an interim configuration for Apollo 14. Modifications at Tidbinbilla and Robledo will begin after Apollo 14, and the work at all sites will be completed before Apollo 15 (presently scheduled for July 26, 1971).

E. Intermodulation Products Problem

The MSFN has a requirement for the Wing sites to be able to transmit two simultaneous uplink carriers. It was noticed as early as Apollo 8 that the use of two uplinks would occasionally cause a degradation of the received downlink signal, apparently due to intermodulation products. The problem is of an intermittent nature and has never been observed at Robledo. At Tidbinbilla the downlink FM threshold has on occasion been degraded by about 8 to 20 dB, and Pioneer has observed a 2 dB degradation. Based upon this information the following precautionary notice is included in the MSFN Operations Procedures:

> "Wing Stations (GDSX, HSKX, and MADX). Dual uplinking may produce intermodulation products, causing signal degradation. It is, therefore, an undesirable operational configuration, but is permitted if essential for mission operations."

As of December, 1970, no solution has been found. In search of a substitute capability, the DSN is testing a method of transmitting two switched carriers using a single Klystron amplifier with a single microwave system by employing a high-speed switch and pulse-driver circuitry, which will allow a finite guard time between carriers to avoid any interference between them. The switching is accomplished in the 66 MHz exciter circuitry at a switch rate of 500 kHz.

F. Uplink of 20 kW

Original plans for the operation of the Wing stations were for simultaneous 10-kW radiated uplink signals. This was accomplished using two 20-kW transmitters fed into a combiner which introduced a 3-dB loss. Thus, 10-kW of power from each transmitter was radiated from the antenna. The other 10-kW from each transmitter (20-kW) which was lost in the combiner was dissipated in a 20-kW water load.

With the precautionary restriction to a single uplink, there was no longer a need for the combiner and its accompanying 3-dB loss, and a nonstandard configuration was entered at some Wing sites which bypassed the combiner, allowing a single 20-kW radiated power uplink. Unfortunately, since this was not a standard configuration, the combiner water load interlock was not disabled; that is, any failure in the water load would shut down the transmitter, even though the water load was not in use. No changes could be authorized because the radiation of a single 20-kW uplink had never been requested or committed.

On June 12, 1970, GSFC levied an official requirement upon the DSN for the 20-kW capability. An Engineering Change Order (ECO) was issued to defeat the water-load interlock when in the 20-kW configuration. The modifications were completed in November 1970. Certain operational limitations remain:

(1) There exists no backup 20-kW capability since the installed microwave switching gear allows only one transmitter (the DSN transmitter) to be switched around the combiner.

(2) All uplinks must be turned off before any microwave switching can occur.

G. SPU Cone at Pioneer Station

In order to enhance reception of Pioneer spacecraft signals, an S-band Polarized Ultracone (SPU) was installed at the Pioneer station in mid-July, 1970. Since the cone does not have a monopulse feed, which is necessary for auto-tracking, the original S-band Cassegrain Monopulse (SCM) cone was required to be replaced before Apollo mission activity or approximately six weeks before Apollo launch. Accordingly, the SCM cone was back in operation at Pioneer in early December 1970.

H. Wing Site Support of ALSEP

Apollo lunar-surface experiments package (ALSEP) communications are usually accomplished using the 9-m antennas of the MSFN. In September, 1969, the DSN received a requirement for the Wing sites to track ALSEP during the Active Seismic Experiment on ALSEP No. 4 during the Apollo 14 mission period. During this new experiment, the ALSEP transmits at 10.6 k-bits/s, a higher rate than past ALSEPs and beyond the capability of the 9-m antenna stations. The experiment, dubbed the "thumper" because of a series of small charges which are actuated by the astronauts to generate artificial seismic waves, is presently scheduled to occur during the lunar-surface operations phase of Apollo 14.

I. Apollo Lunar Communications Relay Unit (LCRU)

In December, 1969, the DSN received a request from GSFC for cost and schedule impact for implementing reception capability on 2250.5 MHz at all Wing sites and Mars. This new frequency was to be used by the LCRU, a hand-carried S-band system which would relay the astronauts VHF communications directly to earth during EVA periods when the LM is beyond VHF range. The new frequency proved to be very difficult to implement and was later changed to 2265.5 MHz. This new frequency can be received without modification at Mars using the broadband R&D maser. At the Wing sites, it is necessary to retune one of the two masers (leaving one maser configured for normal LM/CSM communications). The retuned maser will have some degradation in gain and system temperature. With the retuned maser, no backup is available except on the 2272.5 MHz downlink (where the maser passbands will overlap) except that either maser can be retuned to the other's frequency in approximately 30 min. The first LCRU is planned for Apollo 15, presently scheduled for July 26, 1971.

APPENDIX

GLOSSARY OF APOLLO TERMS

ALSEP	Apollo lunar-surface experiments package
ARIA	Apollo range instrumented aircraft
ASE	Active seismic experiment (on ALSEP)
BIOMED	Biomedical data
CADFISS	Computation and data flow integrated subsystem test
CCGE	Cold cathode gauge experiment (on ALSEP)
CDH	Constant delta height (maneuver during rendezvous)
CDR	Commander
CM	Command module
CMP	Command module pilot
CPLEE	Charged particle lunar-environment experiment (on ALSEP)
CSI	Coelliptic sequence initiation (maneuver during rendezvous)
CSM	Command and service module
DOI	Descent orbit insertion
DPS	Descent propulsion system
DSCC	Deep space communication complex
EI	Entry interface (earth reentry); engineering instruction
EMU	Extravehicular mobility unit
EO	Earth orbit
EPO	Earth parking orbit
EVA	Extravehicular activity
EVCS	Extravehicular communication system
GDS	Goldstone, MSFN station
GDSX	Goldstone, DSN/MSFN Wing station (Pioneer)
GET	Ground elapsed time
GSFC	Goddard Space Flight Center, Greenbelt, Maryland
HFE	Heat flow experiment (on ALSEP)
HGA	High-gain antenna
HSK	Honeysuckle Creek, Australia, MSFN station
HSKX	Honeysuckle Creek, DSN/MSFN Wing station (Tidbinbilla)
IU	Instrumentation unit (part of S-IVB)
IVT	Intravehicular transfer
LM	Lunar module
LMP	Lunar module pilot
LO	Lunar orbit
LOI	Lunar orbit insertion
LOPC	Lunar orbit plane change
LPO	Lunar parking orbit
LS	Lunar stay
MAD	Madrid, MSFN station
MCC	Mission Control Center, Houston, Texas; midcourse correction
MILA	Merrit Island, Florida, MSFN station
MOCR	Mission Operations Control Room (at MSC)
MSC	Manned Spacecraft Center, Houston, Texas
MSFN	Manned Space Flight Network
MSFNOC	Manned Space Flight Network Operations Center (GSFC)
NOD	Network operations directive (GSFC)
NST	Network Support Team (GSFC)

PC	Plane change
PCA	Point of closest approach
PDI	Powered descent initiation
PI	Project Investigator
PLSS	Portable life support system
PSE	Passive seismic experiment (on ALSEP)
PTC	Passive thermal control (barbeque mode)
RCS	Reaction control system
RTC	Real-time command
RTG	Radioisotope thermoelectric generator
S-IC	Saturn booster (first stage)
S-II	Saturn booster (second stage)
S-IVB	Saturn IV booster (third stage - fixed to IU)
SCM	Site configuration message
SDDS	Signal data demodulator system
SLV	Saturn launch vehicle
SMS	Spacecraft Monitoring Station
SPS	Service propulsion system
TEC	Trans-earth coast
TEI	Trans-earth injection
TIC	Telemetry instrumentation coordinator
TLC	Translunar coast
TLI	Translunar injection
TPF	Terminal phase final (part of rendezvous)
TPI	Terminal phase initiation (part of rendezvous)
TV	Television (from CSM or LM)

BIBLIOGRAPHY*

Anderson, J. D., Determination of the Masses of the Moon and Venus and the Astronomical Unit from Radio Tracking Data of the Mariner II Spacecraft, Technical Report 32-816, July 1, 1967.

Berman, A. L., ABTRAJ-on-Site Tracking Prediction Program for Planetary Spacecraft, Technical Memorandum 33-391, Aug. 15, 1968.

Berman, A. L., Tracking System Data Analysis Report: Ranger VII Final Report, Technical Report 32-719, June 1, 1965.

Cain, D. L., and Hamilton, T. W., Determination of Tracking Station Locations by Doppler and Range Measurements to an Earth Satellite, Technical Report 32-534, Feb. 1, 1964.

Efron, L., Solloway, C. B., Proceedings of the Conference on Scientific Applications of Radio and Radar Tracking in the Space Program, Technical Report 32-1475, July 1970.

Flanagan, F. M., Goodwin, P. S., Renzetti, N. A., Deep Space Network Support of the Manned Space Flight Network for Apollo: 1962-1968, Volume I, Technical Memorandum 33-452, July 1970.

Gordon, H. J., et al., The Mariner VI and VII Flight Paths and Their Determination from Tracking Data, Technical Memorandum 33-469, December 1, 1970.

Hamilton, T. W., et al., The Ranger IV Flight Path and Its Determination from Tracking Data, Technical Report 32-345, Sept. 15, 1962.

Labrum, R. G., Wong, S. K., and Reynolds, G. W., The Surveyor V, VI, and VII Flight Paths and Their Determination from Tracking Data, Technical Report 32-1302, Dec. 1, 1968.

Lorell, J., and Sjogren, W. L., Lunar Orbiter Data Analysis, Technical Report 32-1220, Nov. 15, 1967.

Lorell, J., Lunar Orbiter Gravity Analysis, Technical Report 32-1387, June 15, 1969.

McNeal, C. E., Ranger V Tracking Systems Data Analysis Final Report, Technical Report 32-702, Apr. 15, 1965.

Melbourne, W. G., et al., Constants and Related Information for Astrodynamical Calculations, Technical Report 32-1306, July 15, 1968.

Miller, L., The Atlas Centaur VI Flight Path and Its Determination from Tracking Data, Technical Report 32-911, Apr. 15, 1966.

Mulholland, J. D., and Sjogren, W. L., Lunar Orbiter Ranging Data: Initial Results, Technical Report 32-1087, Jan. 6, 1967.

*All of the documents listed herein are publications of the Jet Propulsion Laboratory, Pasadena, Calif.

Mulholland, J. Derral, Proceedings of the Symposium on Observation, Analysis, and Space Research Applications of the Lunar Motion, Technical Report 32-1386, April 1969.

Muller, P. M., and Sjogren, W. L., Consistency of Lunar Orbiter Residuals with Trajectory and Local Gravity Effects, Technical Report 32-1307, Sept. 1, 1968.

Muller, P. M., and Sjogren, W. L., MASCONS: Lunar Mass Concentrations, Technical Report 32-1339, Aug. 16, 1968.

Null, G. W., Gordon H. J., and Tito, D. A., Mariner IV Flight Path and Its Determination from Tracking Data, Technical Report 32-1108, Aug. 1, 1967.

O'Neil, W. J., et al., The Surveyor III and Surveyor IV Flight Paths and Their Determination from Tracking Data, Technical Report 32-1292, Aug. 15, 1968.

Pease, G. E., et al., The Mariner V Flight Path and Its Determination from Tracking Data, Technical Report 32-1363, Feb. 1969.

Renzetti, N. A., Tracking and Data Acquisition for Ranger Missions 1-5, Technical Memorandum 33-174, July 1, 1964.

Renzetti, N. A., Tracking and Data Acquisition for Ranger Missions 6-9, Technical Memorandum 33-275, Sept. 1966.

Renzetti, N. A., Tracking and Data Acquisition Report: Mariner Mars 1964 Mission: Volume I. Near-Earth-Trajectory Phase, Technical Memorandum 33-239, Jan. 1, 1965.

Renzetti, N. A., Tracking and Data Acquisition Report: Mariner Mars 1964 Mission: Vol II. Cruise to Post-Encounter Phase, Technical Memorandum 33-239, Oct. 1, 1967.

Renzetti, N. A., Tracking and Data Acquisition Report: Mariner Mars 1964 Mission: Volume III. Extended Mission, Technical Memorandum 33-239, Dec. 1, 1968.

Renzetti, N. A., Tracking and Data Acquisition Support for the Mariner Venus 1962 Mission, Technical Memorandum 33-212, July 1, 1965.

Renzetti, N. A., Tracking and Data System Report for Mariner Venus 1967: Volume I. Planning Phase through Midcourse, Technical Memorandum 33-385, Oct. 1969.

Renzetti, N. A., Tracking and Data System Report for Mariner Venus 1967: Volume II. Midcourse through End of Mission, Technical Memorandum 33-385, Oct. 1969.

Renzetti, N. A., Tracking and Data System Support for the Pioneer Project: Prelaunch to End of Nominal Mission: Vol I. Pioneer VI; Volume II. Pioneer VII; Volume III. Pioneer VIII, Technical Memorandum 33-426 (in publication).

Renzetti, N. A., Tracking and Data System Support for Surveyor: Volume I. Missions I and II; Volume II. Missions III and IV; Volume III. Mission V; Volume IV. Mission VI; Volume V. Mission VII, Technical Memorandum 33-301, 1969.

Sjogren, W. L., et al., Physical Constants as Determined from Radio Tracking of the Ranger Lunar Probes, Technical Report 32-1057, Dec. 30, 1966.

Sjogren, W. L., Proceedings of the JPL Seminar on Uncertainties in the Lunar Ephemeris, Technical Report 32-1247, May 1, 1968.

Sjogren, W. L., The Ranger III Flight Path and Its Determination from Tracking Data, Technical Report 32-563, Sept. 15, 1965.

Sjogren, W. L., et al., The Ranger V Flight Path and Its Determination from Tracking Data, Technical Report 32-562, Dec. 6, 1963.

Sjogren, W. L., et al., The Ranger VI Flight Path and Its Determination from Tracking Data, Technical Report 32-605, Dec. 15, 1964.

Stelzried, C. T., A Faraday Rotation Measurement of a 13-cm Signal in the Solar Corona, Technical Report 32-1401, July 15, 1970.

Thornton, Jr., J. H., The Surveyor I and II Flight Paths and Their Determination from Tracking Data, Technical Report 32-1285, August 1, 1968.

Vegos, C. J., et al., The Ranger VIII Flight Path and Its Determination from Tracking Data, Technical Report 32-766 (in publication).

Vegos, C. J., et al., The Ranger IX Flight Path and Its Determination from Tracking Data, Technical Report 32-767, Nov. 1, 1968.

Winn, F. B., Post Landing Tracking Data Analysis, Surveyor VII Mission Report: Part II. Science Results, Technical Report 32-1264, Mar. 15, 1968.

Winn, F. B., Post Lunar Touchdown Tracking Data Analysis, Surveyor Project Report: Part II. Science Results, Technical Report 32-1265, June 15, 1968.

Winn, F. B., Selenographic Location of Surveyor VI, Surveyor VI Mission Report: Part II. Science Results, Technical Report 32-1262, Jan. 10, 1968.

Wollenhaupt, W. R., et al., Ranger VII Flight Path and Its Determination from Tracking Data, Technical Report 32-694, Dec. 15, 1964.

NASA — JPL — Coml., L.A., Calif.