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

1971-1972

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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 third and final volume in a series and reports the support of the network for 1971 and 1972. It covers the Apollo missions 14 through 17.

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

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ABSTRACT

This report summarizes the Deep Space Network (DSN) activities in support of Project Apollo during the period of 1971 and 1972. Beginning with the Apollo 14 mission and concluding with the Apollo 17 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)) used in meeting the radio-metric and telemetry demands of the missions are documented.

SECTION I
INTRODUCTION

A. GENERAL.

Volume I of this series discussed the development of the Apollo project, the unified S-band communication system, the dual DSN and MSFN deep space communication stations which permitted the DSN to 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.

Volume II covered the DSN support provided during Apollo Missions 9 through 13.

B. SCOPE.

This report, Volume III, summarizes and provides a historical account of the operational support activities provided to the MSFN by the JPL DSN in support of Apollo Missions 14 through 17.

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.

Figure 1-1 illustrates the location of the Apollo lunar landing sites. The locations of the DSN deep space communications stations which provided operational support for the Apollo missions are shown in Figure 1-2.

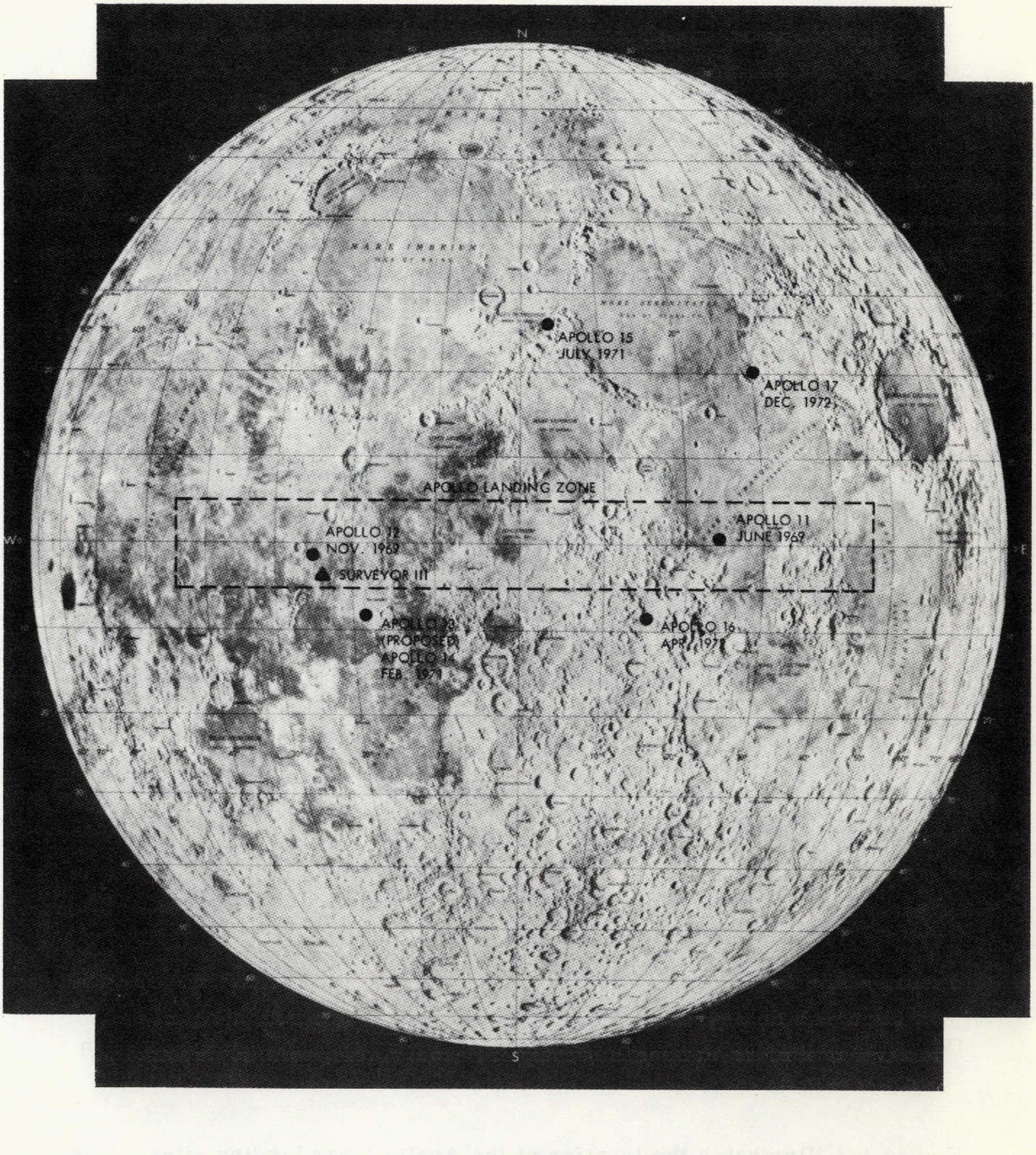

Figure 1-1. Apollo Lunar Landing Sites

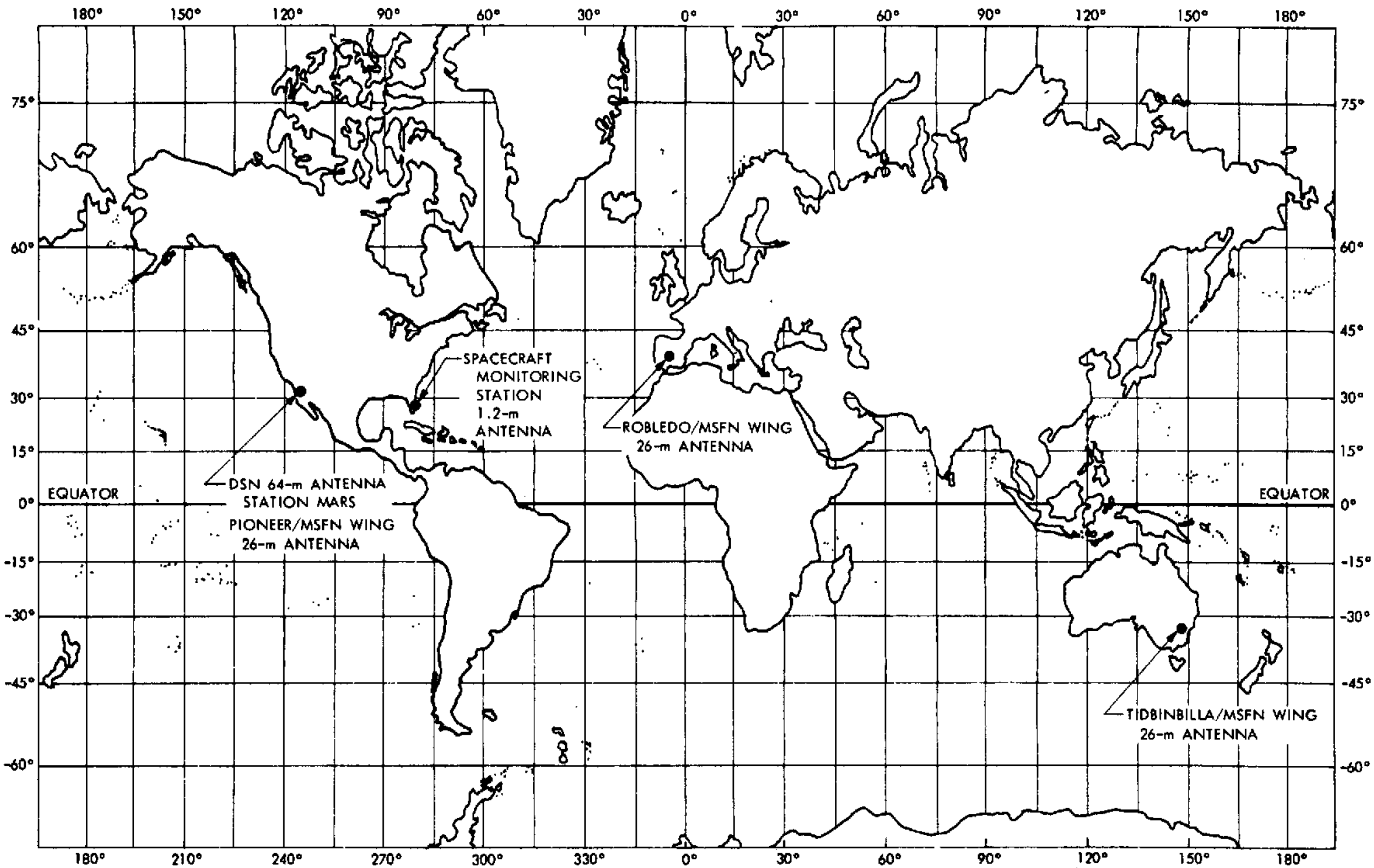

Figure 1-2. Location of DSN Stations used for Apollo Support

SECTION II
THE APOLLO 14 MISSION

A. MISSION DESCRIPTION.

Apollo 14 was the seventh manned Apollo mission flown above the three-stage Saturn V launch vehicle and carried astronauts Alan B. Shepard, Jr. (Commander), Stuart Allen Roosa (Command Module Pilot), and Edgar Dean Mitchell (Lunar Module Pilot). The mission goal was to land in the Fra Mauro uplands, the same goal that the abortive Apollo 13 mission was unable to achieve. The Apollo 14 mission successfully accomplished its objectives in spite of a large number of minor problems, which are mentioned in the following discussion.

Launch from Cape Kennedy Pad 39A occurred at 21:03:02.9 GMT on January 31, 1971, at a launch azimuth of 75.56 degrees. The launch had originally been scheduled for a 20:23 GMT launch, but a launch hold of some 40 minutes was required due to the new weather restrictions developed after the lightning strikes of Apollo 12. This was the first time a manned Apollo mission was not launched on time. Injection into translunar trajectory occurred midway through the second revolution in the Earth parking orbit with a 5-minute 49-second burn of the S-IVB-stage engine.

Following translunar injection (TLI), the Command/Service Module (CSM) separated from the booster and attempted to dock with the unattended Lunar Module (LM). For the first time on Apollo, this docking procedure was unsuccessful, with the capture latches of the docking probe failing to seize the Lunar Module drogue. Without a successful docking there would be no lunar landing, although the crew was in no danger. The docking had to be accomplished within several hours before the S-IVB attitude-control system became inoperative and the S-IVB and Lunar Module started to tumble. Under direction from Mission Control Center in Houston, the astronauts made five additional docking attempts in various configurations. On the sixth attempt, docking was successful.

After docking, the probe was removed from the Command Module/Lunar Module tunnel for examination. No abnormal behavior or contamination could be detected, and the mission was given the "go-ahead" for lunar landing. After separation from the spacecraft, the S-IVB (the launch vehicle third stage) was directed toward a crash on the Moon as a calibration of the seismometer left there during the Apollo 12 mission. The impact occurred at 07:40:55 GMT on February 4, 1971, at lunar coordinates 8° 03' S, 26° 03' W, approximately 174 km southwest of the seismometer which showed vibrations for some 2 hours.

Midcourse correction 1 was deleted due to the accuracy of the translunar injection maneuver. Midcourse correction 2 was executed at 03:39 GMT on February 2, 1971, removing the spacecraft from its "free-return" trajectory to save fuel for the lunar landing sequence. The remainder of the translunar cruise was nominal except for an observed dip from 37.0 to 36.7 V in one of the Lunar Module ascent stage batteries. This dip, first noticed during the Lunar Module checkout at 10:56 GMT on February 3, caused some concern and a test was executed at 02:38 GMT, February 4, which confirmed that the battery would properly support a load.

Other minor problems during translunar coast included difficulty in maintaining correct pointing of the spacecraft high-gain antenna and a high rate of pressure decrease during a cabin leak check. The latter problem was caused by a urine vent valve being accidently left open. Midcourse correction 3 was deleted but a small midcourse correction 4 was executed at 02:01 GMT, February 4, with the burn lasting less than 1 second.

A successful lunar orbit insertion (LOI) burn put the spacecraft in a 315- by 110-km (169.6- by 58.9-nmi) elliptical orbit. Two orbits later a descent orbit insertion (DOI) burn changed these dimensions to 110 by 17.2 km (59.0 by 9.3 nmi). During lunar orbit, additional pointing problems with the high-gain Command/Service Module antenna were experienced.

During lunar orbit 12, the Command/Service Module and Lunar Module separated with astronauts Shepard and Mitchell in the Lunar Module preparing for descent to the lunar surface on orbit 14. Difficulty was experienced maintaining lock on the Lunar Module high-gain antenna, but behavior was normal on the next orbit. An abort pushbutton sent erroneous inputs to the Lunar Module guidance computer on four occasions. The button may have been defective or contaminated since tapping on the switch panel cleared up the problem. The computer was reprogrammed to ignore these abort inputs.

During the descent phase, the landing radar came on in the "near" mode (1066.8 m (3500 ft) maximum) instead of the "far" mode. This problem was first noticed when the radar failed to acquire lock when passing through 9.15 km (30,000 ft). The radar was turned off and on, and lock was acquired.

The landing was normal and was within 20 m of the intended landing site. After more than 5 hours of preparation, the two astronauts began their first excursion during which surface samples were collected; the ALSEP and TV camera were deployed, and the "thumper" was activated. The "thumper" is a hand-held rod which taps the lunar surface as a small explosive charge within it is detonated. This device proved to be especially unreliable, and the astronaut was able to detonate only 13 of the 21 charges. Due to this problem and several others including difficulty unfolding the S-band erectable antenna, a twisted urine tube in the Commander's suit, a broken wrist cable in the Lunar Module Pilot's suit, and an EVA (extra-vehicular activity) radio problem, the astronauts fell behind their planned timeline and were unable to complete all assigned tasks.

During the ensuing rest period, an S-band bistatic radar experiment was conducted between the orbiting Command/Service Module and DSS 14. This experiment is discussed below. Also during the rest period, the Lunar Module astronauts conducted a pressure check of the space suits to confirm that an abnormally high leak rate on the Lunar Module Pilot's suit had not increased to the danger level. All was in order and the astronauts began the second excursion 2 hours and 28 minutes ahead of schedule. This excursion was to take the astronauts 1000 m to the edge of Rim crater. Although this goal was not quite reached, many rock samples of new and different types were collected.

Lunar liftoff, rendezvous, and docking were normal with none of the problems of the earlier docking. Following transfer of the lunar samples to the Command/Service Module, the LM was jettisoned and directed toward a crash on the Moon near the ALSEP seismometer. One orbit later, on orbit number 35, the crew executed the trans-Earth injection burn to start the return trip to Earth.

Apollo 14 landed at approximately 172 degrees W, 27 degrees S, midway between Samoa and New Zealand.

Table 2-1 shows the mission event times and Table 2-2 gives the television coverage. Care must be exercised when using ground elapsed time (GET), which on previous missions recorded the time from launch. With Apollo 14's launch slip (the first on Apollo), the clock carries a different meaning. In order to make the sun angles upon lunar landing identical to the premission plans, the translunar trajectory was made 40 minutes faster than planned. The GET clock was then set forward 40 minutes and 3 seconds at 03:38:03 GMT on February 3. A new clock, actual elapsed time (AET), records the time from launch, and the GET clock is merely a convenient reference time which corresponds very closely to the planned mission timeline.

B. REQUIREMENTS FOR DSN SUPPORT OF APOLLO 14.

1. DSN/MSFN Wing Stations.

As was done during previous Apollo lunar missions, DSS 11, 42, and 61 were committed to support Apollo 14 under direct MSFN/MSC control starting at launch minus 2 weeks through the end of the mission.

2. DSS 14.

The Mars station, DSS 14, was required to receive voice, telemetry, biomedical, and TV and relay the data to the Goldstone Prime MSFN station (GDS). Specific requirements existed for lunar landing, EVA television, and LM crash. Coverage was also desired for television during translunar coast.

Table 2-1. Apollo 14 Sequence of Major Events

Event	Ground elapsed time, h:min:s	Actual elapsed time, h:min:s	Greenwich Mean Time, h:min:s
Launch	00:00:00	00:00:00	Jan 31/21:03:03
TLI ignition	02:28:30	02:28:30	Jan 31/23:31:33
TLI cutoff	02:34:19	02:34:19	Jan 31/23:37:22
First midcourse (TLI + 9 h)	Deleted		
Second midcourse (to hybrid) (TLI + 28 h)	30:36:07	30:36:07	Feb 02/03:39:10
Begin bistatic frequency measurement	52:20:00	52:20:00	Feb 03/01:23:03
End bistatic frequency measurement	52:25:00	52:25:00	Feb 03/01:28:03
Change ground elapsed time	55:15:03	54:35:00	Feb 03/03:38:03
Begin LM inspection	60:59:00	60:18:57	Feb 03/09:22:00
Third midcourse (LOI − 22 h)	Deleted		
Fourth midcourse (LOI − 5 h)	77:38:13	76:58:10	Feb 04/02:01:13
Second LM inspection (30 min)	78:14:58	77:34:55	Feb 04/02:37:58
CSM first occultation	82:23:03	81:43:00	Feb 04/06:46:03
Lunar orbit insertion	82:36:43	81:56:40	Feb 04/06:59:43
S-IVB impact	83:17:55	82:37:52	Feb 04/07:40:55
Descent orbit insertion	86:50:55	86:10:52	Feb 04/11:13:55
Undock	104:28:03	103:48:00	Feb 05/04:51:03
CSM circularization	105:46:48	105:06:45	Feb 05/06:09:48
Powered descent initiation	108:42:01	108:01:58	Feb 05/09:05:01
Touchdown	108:55:14	108:15:11	Feb 05/09:18:14
Begin EVA-1	114:20:00	113:39:57	Feb 05/14:43:00
ALSEP activated	117:05:00	116:24:57	Feb 05/17:28:00
ALSEP high-bit rate on	117:36:00	116:55:57	Feb 05/17:59:00
ALSEP high-bit rate off	118:14:00	117:33:57	Feb 05/18:37:00
End EVA-1	119:04:00	118:23:57	Feb 05/19:27:00
Begin bistatic radar	130:05:00	129:24:57	Feb 06/06:28:00
End bistatic radar	131:04:00	130:23:57	Feb 06/07:27:00
Begin EVA-2	131:48:14	131:08:11	Feb 06/08:11:14
End EVA-2	136:19:00	135:38:57	Feb 06/12:42:00
LM ascent	142:25:43	141:45:40	Feb 06/18:48:43
CSM/LM docking	144:12:00	143:31:57	Feb 06/20:35:00
LM separation	146:25:00	145:44:57	Feb 06/22:48:00
LM deorbit burn	147:54:00	147:13:57	Feb 07/00:17:00
LM crash	148:22:25	147:42:23	Feb 07/00:45:25
Trans-Earth injection	149:16:04	148:36:01	Feb 07/01:39:04
Fifth midcourse	166:14:00	165:33:57	Feb 07/18:37:00
Splashdown	216:42:01	216:01:58	Feb 09/21:05:01

Table 2-2. Apollo 14 Television

GMT, h:min	GET, h:min	AET, h:min	Duration, h:min	Subject	Vehicle	Station[a]
Feb 1/00:07	03:04	03:04	01:55	Transportation and docking	CSM	GDS
Feb 1/08:09	11:06	11:06	01:06	Inspection of docking probe	CSM	GDS
Feb 3/09:04	60:41	60:01	00:41	Interior of spacecraft	CSM	HSK
Feb 5/14:56	114:33	113:53	06:30	EVA-1	LM	HSK/MAD
Feb 6/07:34	131:11	130:31	05:20	EVA-2	LM	GDS/HSK
Feb 6/20:12	143:49	143:09	00:09	Rendezvous	CSM	MAD
Feb 6/20:27	144:04	143:24	00:10	Docking	CSM	MAD
Feb 8/01:21	171:58	171:18	00:51	Inflight demonstrations	CSM	GDS
Feb 8/23:31	195:08	194:28	00:25	Press briefing	CSM	GDS

[a]GDS = Goldstone MSFN station
HSK = Honeysuckle MSFN station, Australia
MAD = Madrid MSFN station, Spain

3. Precision Doppler Data.

As part of a continuing study of lunar potential anomalies (mascons), DSS 14 was required to provide precision doppler recordings of the Command/Service Module during several low lunar orbits and of the Lunar Module during the descent phase and later during the crash. An additional internal DSN requirement was levied for more doppler data during all low Command/Service Module orbits and several adjoining high orbits in support of a JPL study of mascons (with the same principal investigator as the one who originated the formal requirement). As one can see from the timeline (Figure 2-1), one pass from DSS 62 was necessary to provide almost complete coverage of this requirement. A related requirement was for high-speed strip-chart recordings of DSS 14 received signal level during orbit 3 of the Command/Service Module, descent and touchdown of the Lunar Module, and the crash of the Lunar Module.

4. Bistatic Radar Experiment.

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

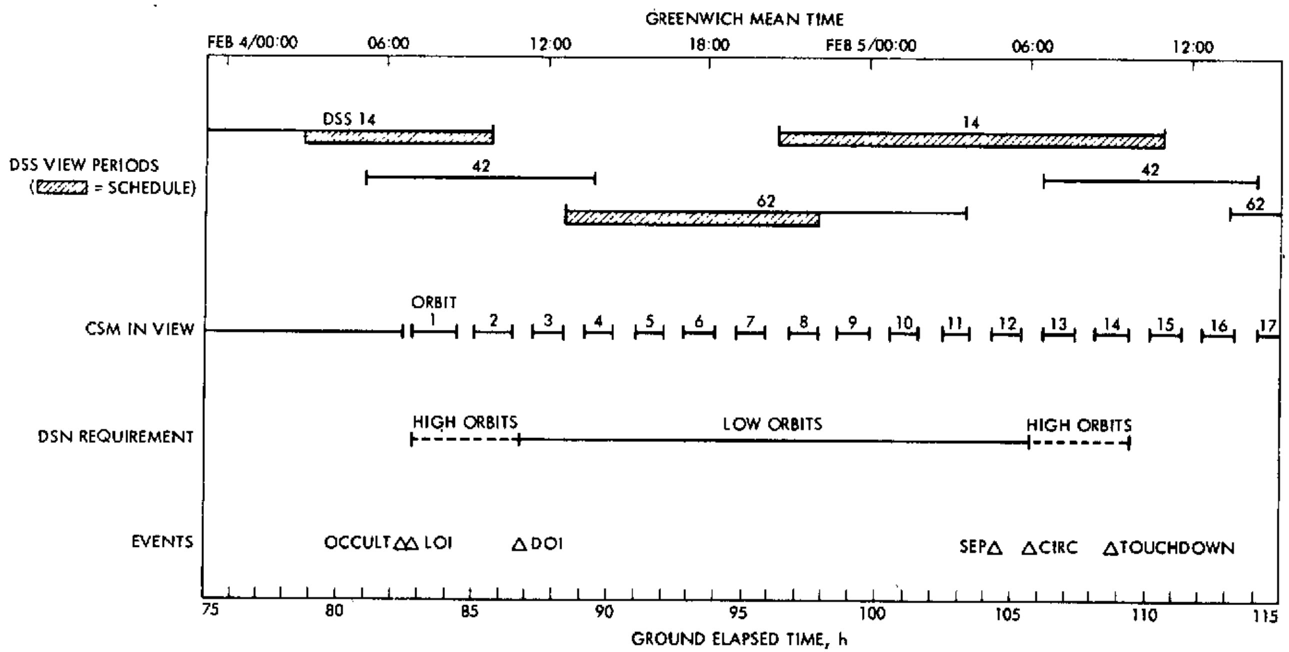

Figure 2-1. DSN Internal Mascon Study Requirement

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

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

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

The experiment should reveal 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 should provide engineering data necessary for optimizing the design of future bistatic radar experiments from low lunar orbits (approximately 100-km altitude). Furthermore, the results should provide a lunar S-band, bistatic radar calibration which would 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 DSS 14 the reflected signal (and a portion of the direct signal) would be received in two polarizations simultaneously using the polarization diversity S-band cone. The outputs of the two receiver chains would be recorded on FR 1400 recorders.

5. Goldstone Timing Synchronization.

An obsolete time sync agreement in effect since Apollo 11, which provided for routine measurements with a DSIF portable cesium clock at all Goldstone/Apollo support sites, was amended on June 9, 1970. The new agreement, which will be valid for all future Apollo missions, is as follows:

> A one pulse-per-second tick is distributed via DSN microwave to DSS 14. The pulse originates in the DSIF 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 DSS 14. The portable cesium clock will be used only to calibrate the microwave delays when changes have occurred to the microwave system. Routine support with 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 hours during the normal working day and 48 hours otherwise. Following any clock trip a TWX giving the results with respect to the National Bureau of Standards and the expected National Bureau of Standards-U.S. Naval Observatory offset will be sent out to interested parties.

6. Twenty-Kilowatt Uplink.

Original plans for the operation of the Wing stations were for two 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, which was lost in the combiner, was dissipated in a 20-kW water load. When transmitting a single uplink, there was no longer a need for the combiner and its accompanying 3-dB loss, and a non-standard 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 was issued to disable the water load interlock when in the 20-kW configuration. The modifications were completed in November 1970. Certain operational limitations remain:

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

7. <u>Wing Site Support of ALSEP</u>.

ALSEP communications are usually accomplished using the 9-m (30-ft) 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 kbits/s, a higher rate than past ALSEPs and beyond the capability of the 9-m (30-ft) stations. The experiment is dubbed the "thumper" because of a series of small charges which are actuated by the astronauts to generate artificial seismic waves.

C. APOLLO INTERFACE TEAM.

Between Apollos 13 and 14, the DSIF was reorganized to eliminate the separate positions of Operations Engineering, Operations Planning, and System Data Analysis (SDA) for Apollo. Instead the DSIF planning efforts are represented by a single DSIF Operations Project Engineer for Apollo, and some of the operations functions, such as predict generation, have been assumed by the DSN mission independent operations organization.

D. PREMISSION PREPARATIONS AND TESTING.

1. <u>DSN/MSFN Wing Stations</u>.

DSS 11, 42, and 61 were placed under configuration control for the Apollo 14 mission as of 00:01 GMT on January 17, 1971, and subsequently placed on mission status by the MSFN as of 00:01 GMT on January 21, 1971. Prior to January 21, each Wing site conducted extensive maintenance and testing of the equipment common to the DSN and MSFN. The new requirement for Wing support of the ALSEP indicated a need for ALSEP premission testing. The downlink tests pose no problem, but the ALSEP uplink frequency (2119 MHz) is at the extreme end of the normally used band (MSFN: 2100-2110 MHz; DSN: 2110-2118 MHz). Some tuning of the klystron power amplifier is therefore needed. Unfortunately, the klystrons may be retuned only a finite number of times before the cavity adjustment screws will bind up, requiring costly and time-consuming repair. In order to maintain these klystrons in good condition for the mission, the DSN limited the MSFN to one ALSEP uplink test at each Wing site. These tests, conducted on January 11 and 12, failed at all three Wing sites due to identical intersite microwave problems unrelated to the klystrons. It is unfortunate that the results of the first test were not applied to the second and third site. Nevertheless, the MSFN requested additional testing and, after management discussions, one additional test at each site (January 23 and 24) was allowed. Later investigation may show that this testing is related to the transmitter problems experienced during the mission.

2. DSS 14.

In addition to the bistatic experiment tests and the predict tests mentioned below, DSS 14 conducted three tests before the Apollo 14 mission (see Table 2-3). The first was an officially required participation in Day 5 of the MSFN network readiness test. DSS 14's participation turned out to be nothing more than a data transmission test between the DSS 14 communications center and the Goldstone MSFN station. The second test was an internal DSIF configuration verification test on January 19. The third test was an extensive data flow test with a spacecraft simulator used at DSS 14 to generate data which were fed through the entire system ending at the Goldstone MSFN station. Due to delays the test required more than the allotted 24 hours on January 21, and the television and Lunar Module tests were rescheduled on January 27. Configuration control was imposed on DSS 14 to January 17.

3. Bistatic Experiment Preparations.

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). The final details on the configuration at DSS 14 were discussed at another meeting at JPL on November 9, 1970 with approximately the same representation as the May 8 meeting.

Table 2-3. DSS 14 Tests

Date	Time, h:min	Test	Comments
12/21/70	16:00–24:00	Bistatic cable installation	
12/22/70	22:00–02:01	Bistatic equipment checkout	
12/23/70	02:01–06:00	Bistatic track of *Pioneer VI*	Receivers 3 and 4 not yet installed; no 152.4 cm/s (60 ips) narrow-band frequency modulation FR 1400 modules
01/08/71		Day 5 of network readiness test	Data transmission test
01/08/71	22:30–05:30	Bistatic test	During Pioneer VI track; used *Pioneer VI* signal; FR 1400 not available
01/19/71		Configuration verification test	
01/21/71	14:20–14:20	Data flow test (24 h)	
01/27/71	14:18–22:17	Data flow test	TV and LM tests
01/28/71	20:00–07:10	Bistatic final calibration	

A number of installation periods and tests were conducted from late December 1970 until launch on January 31. These tests are included in Table 2-3.

4. DSN Predicts.

Predict data for DSS 14 is generated in two ways. The prime method uses state vectors supplied by Houston MSC or Goddard Space Flight Center, and generates DSN predicts in the SFOF computers. The backup system involves a 29-point acquisition message generated at MSC, transmitted directly via TTY to DSS 14, and converted at DSS 14 from X-Y to HA-DEC coordinates with an atmosphere refraction correction added if necessary.

In November 1970 the DSIF served notice that it would not allow further use of the 29-point conversion program because the software had never been properly certified or documented, even though it had been successfully used on several Apollo flights. To make matters worse, the SFOF IBM 7094/7044 computer system was about to be removed to make way for a second IBM 360/75, and it was uncertain if the predict software for the 360 would be ready for Apollo.

Several compromises were necessary. The 7044 was removed, but the 7094 was merely moved to a new location in the SFOF. The 7094, however, lacked a high-speed printer (used for checking the predicts), adequate tape drives (to lessen the required tape changes), and a 7044 to transmit the predicts.

The missing 7044 was overcome by the procedure shown in Figure 2-2. A state vector received in the SFOF was input to the 7094. The output tape was then carried to the PDP-7 computer in the Media Conversion Center of the SFOF where the predicts were transferred to TTY punched paper tape. This tape was taken to a tape reader in the Communications Center, where a TTY header was added, and the data was transmitted. A test of this system on January 18 was successful except for a bad TTY punch in the Media Conversion Center. The test was repeated on January 19 with complete success. In an effort to obtain clearance to use the 29-point conversion program, a number of tests were conducted starting in December 1970. The last tests on January 12 and 22 resulted in acceptance on an emergency backup, best-effort basis only.

E. APOLLO 14 OPERATIONS.

1. DSN/MSFN Wing Stations.

DSS 11, 42, and 61 successfully supported all phases of the Apollo 14 mission. The problems experienced are noted in Table 2-4. The many transmitter problems are being investigated at this time.

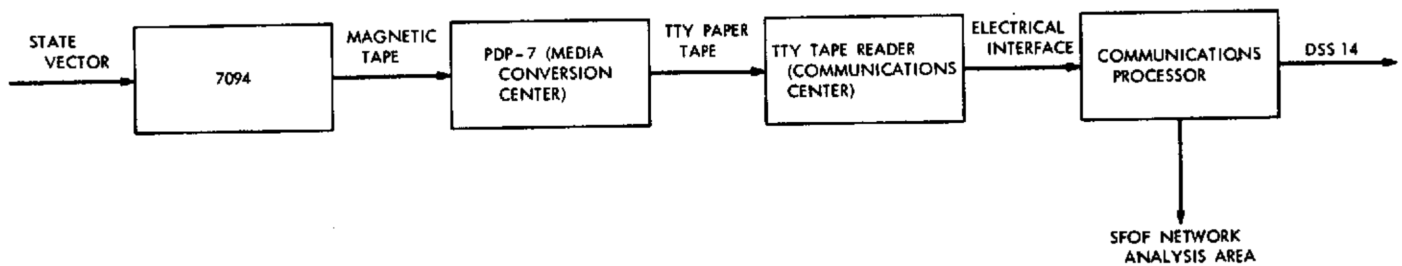

Figure 2-2. DSN Predict Generation for Apollo 14

Table 2-4. Wing Station Tracking

DSS	GMT, h:min	Problem
11	Jan 31/22:31–22:34	None
	Jan 31/23:53–07:35	PA 4 (power amplifier) high-voltage rectifier interlock; no apparent reason. PA 3 arc detector trip; no apparent reason
	Feb 01/20:43–08:42	None
	Feb 02/21:10–09:02	Maser 1 exhaust valve frozen; will replace maser
	Feb 03/21:17–08:54	PA 3 arc detector trip at 22:24; switch to PA 4 after 19 seconds
	Feb 04/21:13–10:05	PA 4 high-voltage ac overcurrent trip; no apparent reason
	Feb 05/21:53–10:54	None
	Feb 07/00:01–11:21	None
	Feb 07/23:37–11:32	None
	Feb 08/23:30–12:06	PA 4 high-voltage ac overcurrent trip; no apparent reason; PA was in standby
42	Feb 01/04:45–12:25	Both klystron power supplies tripped on beam overvoltage; transmitters were not radiating
	Feb 02/05:31–13:18	None
	Feb 03/05:41–13:41	None
	Feb 04/05:42–13:57	None
	Feb 05/06:37–14:45	None
	Feb 06/07:33–15:47	None
	Feb 07/08:02–16:11	None
	Feb 08/08:06–16:29	None
	Feb 09/08:24–16:41	None
	Feb 09/17:08–18:48	None (ALSEP track)
	Feb 09/20:35–20:49	None
61	Feb 01/11:58–02:00	None
	Feb 02/12:33–02:17	None
	Feb 03/12:45–02:26	None
	Feb 04/13:32–03:07	None
	Feb 05/13:50–04:05	PA 2 excessive reflected power trip during pretrack; retuned klystron
	Feb 06/14:43–04:51	None
	Feb 07/15:10–04:54	None
	Feb 08/15:28–04:58	None
	Feb 09/17:56–19:25	None

2. DSS 14.

Seven passes were tracked as shown in Table 2-5. The only schedule change occurred on February 4 when DSS 14 was requested to be on track earlier than the scheduled 03:00 GMT in order to observe the second Lunar Module checkout. This second checkout was to investigate the Lunar Module battery problem, and it was thought that low power levels might have resulted in a degraded telemetry signal. Accordingly, DSS 14 was tracking at 00:43 GMT on February 4. DSS 14 experienced no problems that had any effect on Apollo 14 support.

3. DSS 62.

DSS 62 tracked the Command/Service Module as planned on February 4 from 13:32:18 to 22:12:47 GMT. The required doppler data was successfully taken and sent to JPL.

4. Predict Operations.

It is apparent that the extraordinary care given to predict generation problem before the mission paid off, because no problems were experienced during the mission (unusual for Apollo). The personnel were eagerly cooperative, and it is felt that this spirit is responsible for maintaining and operating the system with so many known weak points.

Table 2-5. DSS 14 Tracking

Date, Feb 1971	GMT, h:min:s
1	01:13:50–06:30:00
2	00:30:52–06:30:00
2	22:59:00–04:30:00
4	00:43:00–09:55:00
4	21:07:15–10:57:40
5	21:42:34–11:51:40
6	22:40:00–06:00:00

The 29-point acquisition messages were also used on occasion at DSS 14. Several comparisons were made between the two types of predicts with no significant discrepancies except for the Lunar Module powered descent. This difference was anticipated since the 7094 predict program cannot model a long duration burn with a changing force vector. Thus, the 29-point message was much more accurate and was used for powered descent.

5. SFOF Participation.

The SFOF areas and equipment used for Apollo 14 included the Operations Area, the Network Analysis Area, the displays, the relocated 7094, and the Media Conversion Center. The SFOF support is limited to predict generation and some off-line monitoring. As mentioned above, the support was excellent.

F. GCF PARTICIPATION.

The DSN 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. The only known GCF problem was a bad set of communications processor log tapes covering parts of the precision doppler data collection. These data were later recovered from the tracking data tapes mailed from DSS 14 and DSS 62.

SECTION III
THE APOLLO 15 MISSION

A. MISSION DESCRIPTION.

Apollo 15, the eighth manned Apollo mission flown above the three-stage Saturn V launch vehicle, carried astronauts David R. Scott (Commander), Alfred M. Worden (Command Module Pilot), and James B. Irwin (Lunar Module Pilot). The mission goal was exploration of the canyon-link Hadley Rille and the Apennine foothills. A second goal was the collection of scientific data while in an extended lunar orbit phase.

Launch from Cape Kennedy Pad 39A occurred at 13:34:00.79 GMT on July 26, 1971, at a launch azimuth of 80.088 degrees. Injection into translunar trajectory over the Pacific Ocean occurred midway through the second revolution in Earth parking orbit with a 5-minute 47-second burn of the S-IVB stage engine. Translunar injection (TLI) put the spacecraft on a direct trajectory toward the Moon, making Apollo 15 the first mission to abandon entirely the "free-return" trajectory which requires no propulsion to return to Earth. This direct trajectory conserves fuel for the critical landing sequence.

Following TLI the Command Service Module (CSM) separated from the booster, docked with the unattended Lunar Module (LM), and extracted the LM from the S-IVB. The S-IVB was directed by ground command toward a crash on the Moon as an additional calibration of the seismometers left there by the Apollo 12 and 14 missions. The impact occurred at 20:58:41.75 GMT on July 29 at lunar coordinates 1.0°S and 11.87°W, about 185 km (100 nmi) from the Apollo 14 landing site.

Midcourse Correction 1 was deleted due to the accuracy of the TLI maneuver. During the translunar cruise a short was noted in the CSM Service Propulsion System thrust indicator circuit. This short would have caused problems during maneuvers, and a set of workaround procedures were developed.

Midcourse Correction 2 was not needed, but was scheduled as a test of these new procedures. Midcourse Correction 3 was deleted, and Midcourse Correction 4 was a short 0.92-second burn.

Other anomalies occurring during translunar cruise were a broken cover glass on the LM range/range rate meter (no impact), a chlorinator valve leak (tightened), and one strong voltage dip on the spacecraft ac and dc power busses. The latter problem occurred only two seconds after loss of uplink caused by a DSS 11 transmitter tripoff, prompting some concern that the two events were related. Later investigation showed that a CSM circuit breaker feeding some lighted pushbuttons on the spacecraft computer console had tripped. A short large enough to trip the circuit breaker would also have caused the voltage dips. The circuit breaker was never reset.

Shortly before entering lunar orbit, the astronauts blew off a door covering the Scientific Instruments Module (SIM) of the Service Module (see Figure 3-1). The SIM bay, a first for Apollo 15, carries scientific instruments for observation of the Moon from lunar orbit. The instruments include a gamma ray spectrometer, an alpha particle spectrometer, a mass spectrometer, a laser altimeter, a 7.62-cm (3-in.) mapping camera, and a 60.96-cm (24-in.) panoramic camera.

A successful lunar orbit insertion (LOI) burn of 400.7 seconds put the spacecraft into a 315- by 108-km (170- by 58-nmi) orbit. Two orbits later a descent orbit insertion (DOI) burn lowered the spacecraft to a 109- by 17.1-km (58.5- by 9.2-nmi) orbit. A DOI trim maneuver later raised this perilune to 17.8 km (9.6 nmi).

During lunar orbit 12 the CSM and LM separated with astronauts Scott and Irwin in the LM preparing for descent to the lunar surface on orbit 14. The undocking was delayed approximately 26 minutes due to a poor connection on the umbilical wire to the CSM docking probe. Shortly after undocking the CSM maneuvered into a near-circular orbit 121 by 102 km (65.2 by 54.8 nmi).

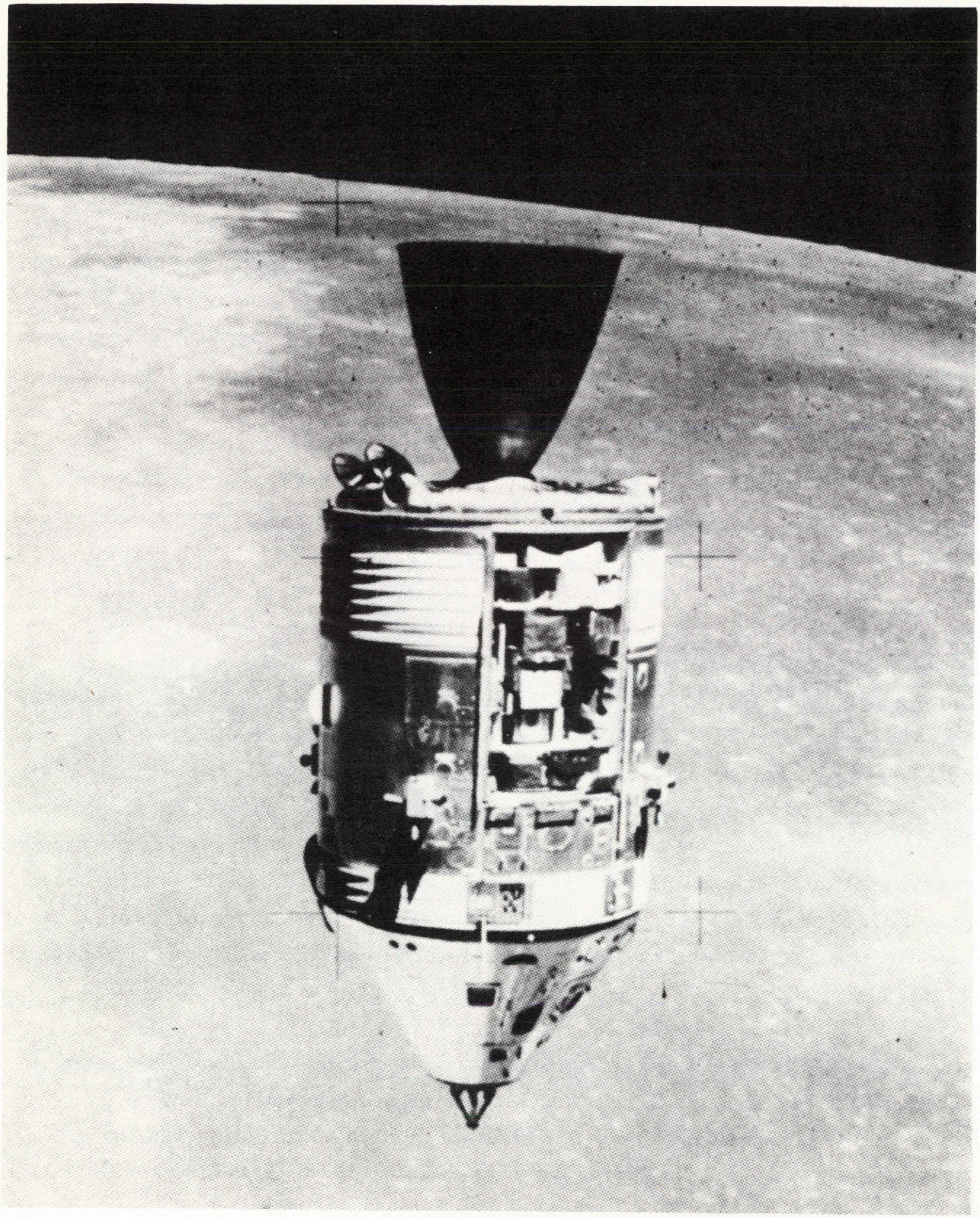

Figure 3-1. Scientific Instrument Module Bay of Service Module

The approach to landing was steeper (25 degrees) than any Moon lander before, providing extra clearance from the 3.66-km (12,000 ft) Apennine peaks. The LM made a normal landing about 121.92 m (400 ft) northeast of the target. The actual landed location is 26.0835°N and 3.665°E. Soon after landing the astronauts conducted a standup extravehicular activity (SEVA), which involved depressurizing the cabin, opening the top (docking) hatch, and making a photographic and visual survey of the landing site from the top hatch. This activity was partly to acquire visual reference points for subsequent navigation chores. A sleep period followed, during which one of the two bistatic radar experiments was conducted with the orbiting CSM.

During the first extravehicular activity (EVA) period the astronauts deployed the lunar rover (Figure 3-2), used for the first time on Apollo 15. Although the front steering was inoperative, the rear steering was sufficient, and the crew drove to several small craters where scientific exploration, surface sampling, and photographic documentation were completed. Observers on Earth were able to watch the activities at each stopping point, thanks to the new Lunar Communications Relay Unit (LCRU) (Figure 3-3). On previous missions the astronauts' VHF transmissions were relayed to Earth by the LM, but with the rover the men would travel beyond VHF range from the LM. Hence, the LCRU was designed as a portable S-band/VHF transceiver, normally resting on the rover, to keep the astronauts in contact with mission control. In addition to voice and telemetry on the downlink, the video output of the LM camera could be transmitted. The uplink carried capcom voice plus television commands (pan, tilt, zoom). A special assembly on the rover provided a mounting platform for the LM TV camera and actuated the camera according to the received commands.

At the end of EVA number 1, the crew deployed the Apollo Lunar Surface Experiments Package (ALSEP), which contains a seismometer and several fields and particles experiments. The crew then re-entered the LM for an eating and sleeping period during which the second bistatic radar experiment was conducted with the CSM.

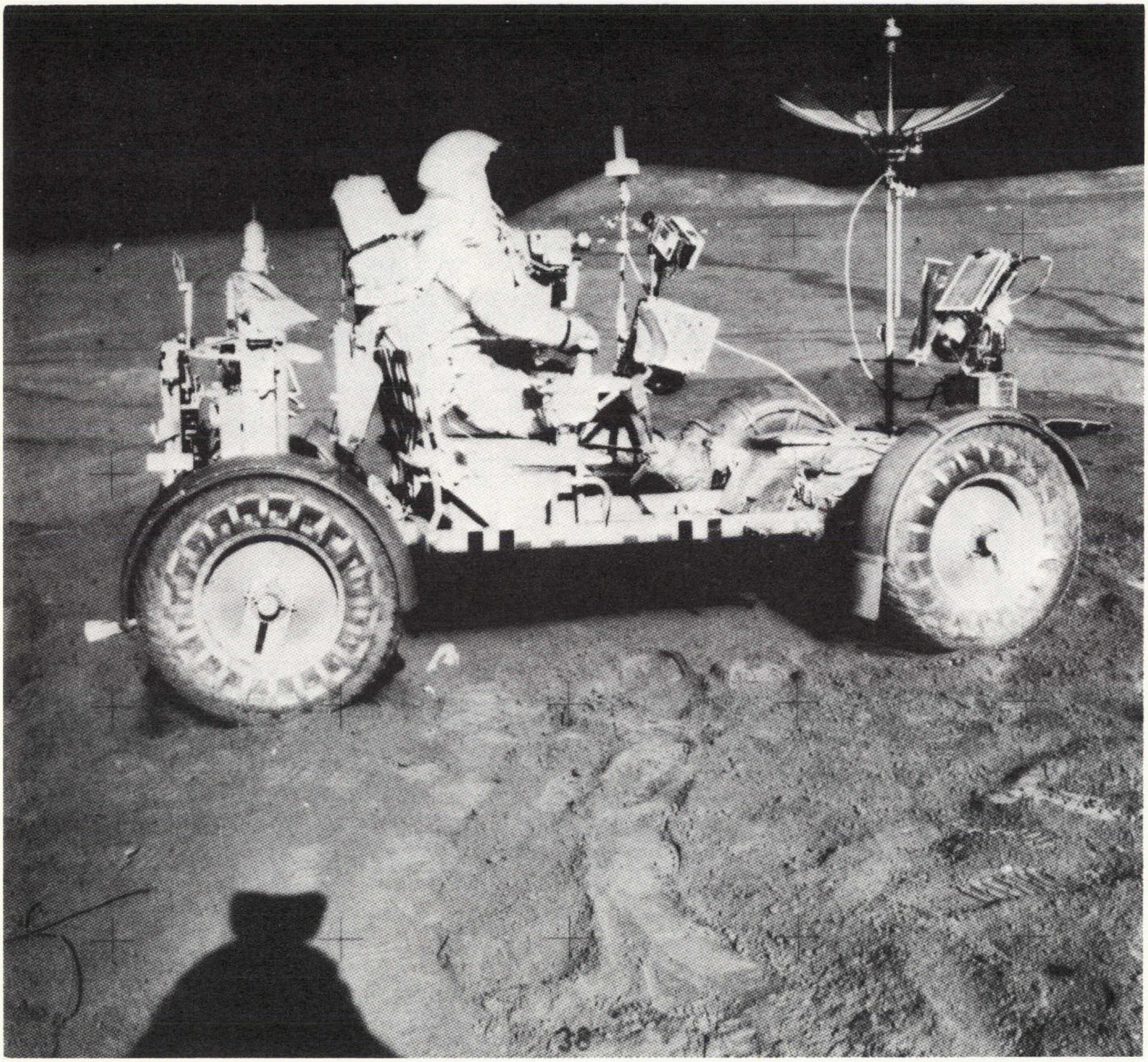

Figure 3-2. Apollo 15 Lunar Rover

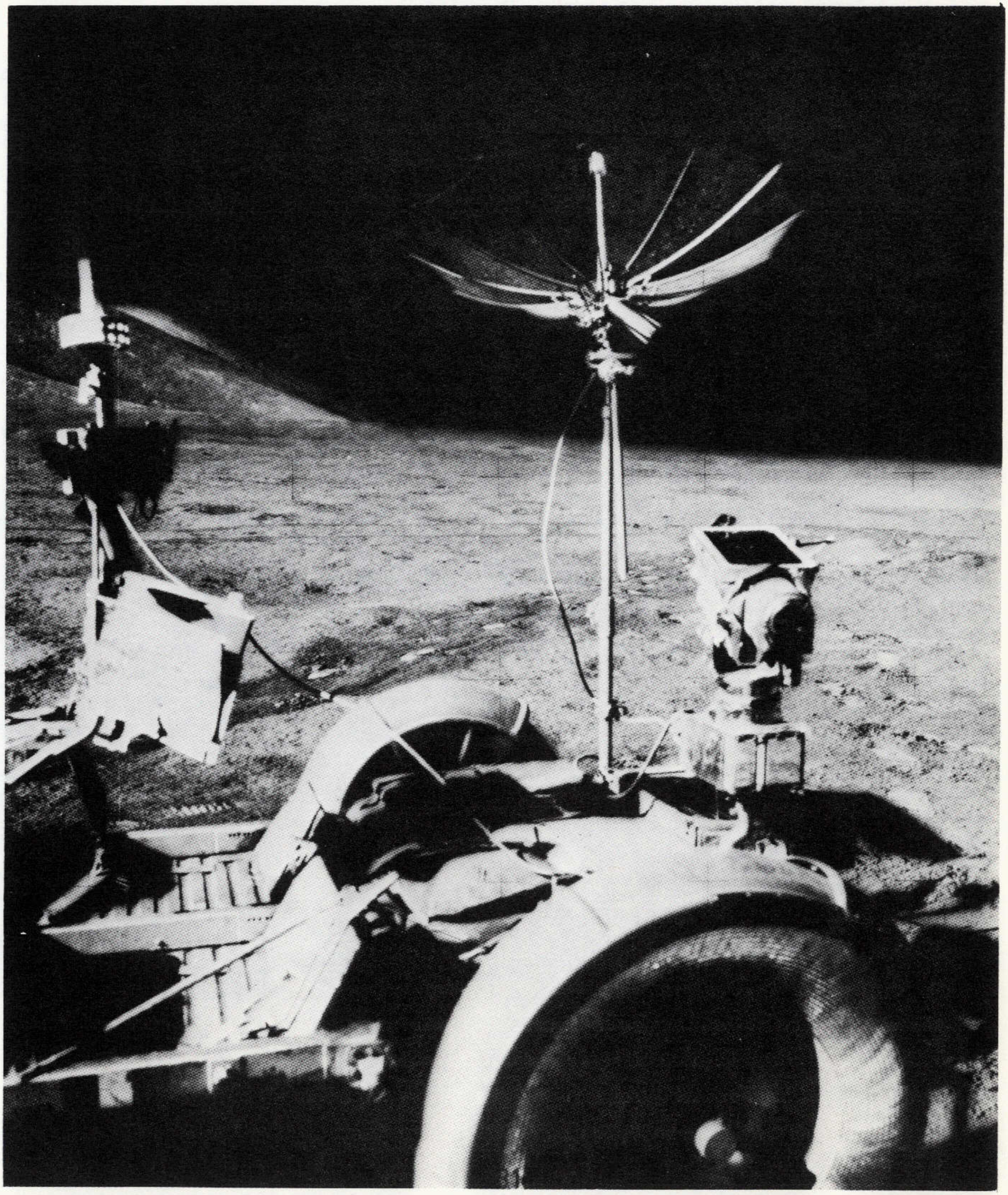

Figure 3-3. View of Lunar Rover Showing Ground Commanded Television Camera, Lunar Communications Relay Unit, and High- and Low-Gain Antennas

At the start of the second EVA, the steering problem in the rover was cleared by resetting a circuit breaker. It was with a fully functioning rover that the astronauts drove to another series of craters for sample collection and scientific investigation, and returned to complete the deployment of the ALSEP package.

After a third eating and sleeping period, the crew made their third and last lunar excursion. This time the route took them along Hadley Rille for some spectacular vistas and a chance to collect samples from what is believed to be lunar bedrock. The total distance traveled during all three EVAs was 28 km, and the rover was driven at a maximum speed of 12 km/h. A total of 83 kg (183 lb) of Moon rock was collected and nearly 3.2 km (2 mi) of film was exposed.

It was less than four hours after the third EVA when the Lunar Module blasted off the lunar surface to rejoin the orbiting CSM. The liftoff was witnessed on Earth via the LCRU and its associated TV camera. Rendezvous and docking were normal and all lunar samples were transferred to the CSM. During a pressure check prior to LM jettison, a leak was detected in the LM/CSM tunnel. Removal and inspection of the hatch disclosed no reason for the leak, and on reinstallation the leak was gone. The pressure check was continued for over an hour, and the LM was finally jettisoned on revolution 52, one orbit later than planned. The LM was maneuvered to a crash on the Moon for another calibration of the three seismometers. Crash occurred at coordinates 26.36197°N and 0.25345°E, 92.6 km (50 nmi) from the Apollo 15 site.

The CSM remained in lunar orbit almost two days longer conducting orbital science experiments with emphasis on the SIM bay experiments. This extended lunar orbit stay is another Apollo "first" in keeping with the science goals of the "J" type mission. The film packages from the SIM bay cameras were retrieved by the Command Module Pilot who took a "spacewalk" during transearth cruise. Shortly before transearth injection, the crew released a Particle and Field Subsatellite (P&FS) into an orbit of 139 by 100 km (75.1 by 57.3 nmi) at an inclination of 151.3 degrees. The subsatellite has a coherent S-band transponder for lunar mass concentration (mascon) studies at JPL.[1]

[1]W. L. Sjogren, principal investigator

The accuracy of transearth injection (TEI) was such that only one short midcourse burn was required shortly before Earth atmosphere entry. Apollo 15 landed at approximately $26^{\circ}4'$N and 158° 4.5'W some 480 km (300 mi) north of Hawaii.

Table 3-1 shows the mission event times and Table 3-2 gives a summary of television coverage.

B. REQUIREMENTS FOR DSN SUPPORT OF APOLLO 15.

1. DSN 26-m Antenna Stations.

As was done with previous Apollo lunar missions, DSS 11, 42, and 61 were committed to support Apollo 15 under direct MSFN/MSC control. The responsibilities at these stations have changed, however.

Previously, the stations had two control rooms or "wings," one MSFN and one DSN, and a set of common equipment, including antenna, servo, microwave, masers, and power amplifiers, with a complicated switch to select the control room to be connected to the common equipment. To avoid needless construction, the DSN wing was designated to be the control room for the new 64-m antennas now being built adjoining DSS 42 and 61. All equipment to operate the 26-m antenna in either DSN or MSFN mode was moved into what had been called the MSFN wing, and the DSN, with MSFN concurrence, assumed responsibility for maintenance and operations of the entire station. DSS 11 was similarly configured to maintain network standardization.

In order to support the increased DSN responsibilities at these stations, the DSIF insisted on a dedicated voice line to each station during its tracking period. The line was for use only if the station had a problem and needed immediate assistance from the SFOF. No routine traffic was to appear on this line. In addition, the existing voice line from the DSN Operations Chief to the MSFN Operations Chief was extended at each end to allow the DSIF Operations Advisor to talk directly to the MSFN Network Support Team.

Table 3-1. Apollo 15 Sequence of Major Events

Event	Ground elapsed time, h:min:s	Greenwich Mean Time, h:min:s
Launch	00:00:00	Jul 26/13:34:01
TLI ignition	02:49:48	Jul 26/16:23:49
TLI cutoff	02:55:35	Jul 26/16:29:36
First midcourse (TLI + 9 h)	Deleted	
Second midcourse (TLI + 27 h)	28:40:00	Jul 27/18:14:01
Third midcourse (LOI − 22 h)	Deleted	
Begin bistatic frequency measurement	60:36:00	Jul 29/02:10:01
End bistatic frequency measurement	60:43:00	Jul 29/02:17:01
Fourth midcourse (LOI − 5 h)	73:31:14	Jul 29/15:05:15
SIM door jettison	74:06:14	Jul 29/15:40:15
LOI	78:31:46	Jul 29/20:05:47
S-IVB impact	79:24:41	Jul 29/20:58:42
DOI	82:39:48	Jul 30/00:13:49
DOI trim	95:56:43	Jul 30/13:30:44
Undock	100:13:30	Jul 30/17:47:31
CSM circularization	101:38:50	Jul 30/19:12:51
Powered descent initiation	104:30:09	Jul 30/22:04:10
Touchdown	104:42:29	Jul 30/22:16:30
Begin SEVA	106:42:00	Jul 31/00:16:01
End SEVA	107:16:00	Jul 31/00:50:01
Bistatic radar begin (Rev 17)	110:02:45	Jul 31/03:36:46
Bistatic radar end	111:15:21	Jul 31/04:49:22
Begin EVA 1	119:39:40	Jul 31/13:13:41
ALSEP transmitter activated	125:03:00	Jul 31/18:37:01
End EVA 1	126:14:00	Jul 31/19:48:01
Bistatic radar begin (Rev 28)	131:42:37	Aug 01/01:16:38
Bistatic radar end	132:54:40	Aug 01/02:28:41
Begin EVA 2	142:14:17	Aug 01/11:48:18
End EVA 2	149:27:09	Aug 01/19:01:10
Begin EVA 3	163:18:00	Aug 02/08:52:01
CSM plane change	165:12:50	Aug 02/10:46:51
End EVA 3	168:08:00	Aug 02/13:42:01
LM ascent	171:37:22	Aug 02/17:11:23
CSM/LM docking	173:36:00	Aug 02/19:10:01
LM jettison	179:30:00	Aug 03/01:04:01
LM separation	179:50:00	Aug 03/01:24:01
LM deorbit burn	181:04:19	Aug 03/02:38:20
LM crash	181:29:35	Aug 03/03:03:36
CSM shaping burn	221:20:47	Aug 04/18:54:48
P&FS deploy	222:39:36	Aug 04/20:13:37
P&FS signal received	222:55:00	Aug 04/20:29:01
TEI	223:48:45	Aug 04/21:22:46
Fifth midcourse (TEI + 15 h)	Deleted	
Begin CSM EVA	241:56:58	Aug 05/15:30:59
End CSM EVA	242:36:15	Aug 05/16:10:16
Sixth midcourse (Entry − 22 h)	Deleted	
Seventh midcourse (Entry − 3 h)	291:58:00	Aug 07/17:32:01
Splashdown	295:11:53	Aug 07/20:45:54

Table 3-2. Apollo 15 Television

GMT, h:min	GET, h:min	Duration, h:min	Subject	Vehicle	Station
Jul 26/17:01	03:27	00:08	Transposition and docking	CSM	GDS
Jul 28/00:29	34:55	00:51	Interior and transfer to LM	CSM	GDS
Jul 30/12:28	94:54	00:15	Landing site	CSM	MAD
Jul 31/13:34[a]	120:00[a]	06:00[b]	EVA-1	LM/LCRU	HSK/MAD
Aug 01/11:54[a]	142:20[a]	06:30[b]	EVA-2	LCRU	PKS/HSK/MAD
Aug 02/09:04[a]	163:30[a]	04:30[b]	EVA-3	LCRU	PKS/HSK/MAD
Aug 02/17:04	171:30	00:15	LM liftoff	LCRU	PKS/HSK/MAD
Aug 02/19:00	173:26	00:13	Rendezvous and docking	CSM	MAD
Aug 04/08:57	211:23	00:07	Surface TV	LCRU	MARS
Aug 05/15:24	241:50	01:00	Transearth EVA	CSM	HSK
Aug 06/19:56	270:22	00:52	Press conference and eclipse	CSM	MAD

[a]Approximate times.

[b]Intermittent coverage.

A new requirement on the 26-m stations was for the reception of the LCRU downlink at 2265.5 MHz, lower in frequency than any previously received Apollo signals. The uplink was on the same frequency as the LM uplink. The P&FS was also to be tracked, but this presented no problem since the uplink and downlink frequencies are the same as the LM.

In view of past problems with transmitter tripoffs, the DSN was required to modify its battleshort function at DSS 11, 42, and 61. The modification left only one interlock, the arc detector, in operation. No other personnel safety or equipment interlocks will function when the battleshort is engaged. The battleshort is used during brief, mission-critical events, such as LM touchdown, when loss of uplink is very undesirable. In the event of a false interlock, there would be no interruption of the uplink. If the interlock is genuine, however, the power amplifier or its power supply would probably be destroyed and be unavailable for the remainder of the mission. Without the battleshort, interlock tripoffs are usually cleared rapidly, losing only a few seconds of uplink lock. Thus, an agonizing tradeoff must be made over use of the battleshort.

2. DSS 14.

The Mars station, DSS 14, was required to receive voice, telemetry, biomedical, and TV, and relay the data to the Goldstone Prime MSFN station (GDS). Specific requirements existed for low lunar orbits, touchdown, EVA television, and LM crash. Coverage was also desired for television during translunar coast.

3. Precision Doppler Data.

As part of a continuing study of lunar potential anomalies (mascons), DSS 14 was required to provide precision high-speed doppler recordings of the CSM and LM during low lunar orbits and of the LM during the descent phase and later during the crash. In cooperation with the principal experimenter for this JPL study, a set of internal DSN requirements was developed to make use of the high-resolution doppler data available from DSN stations equipped with doppler resolvers. Four passes at DSS 51 were scheduled for this purpose. DSS 51 was made available by tracking Mariner Mars 1971 from DSS 62. This was fortunate because the Moon was at a low declination, and DSS 51 had long view periods. Additionally, the desired doppler was recorded at DSS 14 during the passes that had previously been scheduled for official Apollo support.

A related Apollo requirement was for high-speed strip-chart recordings of DSS 14 received signal level during orbit 3 of the CSM and the crash of the LM.

4. Bistatic Radar Experiment.

DSS 14 was required to conduct another bistatic radar experiment as had been done during Apollo 14. The requirements had been expanded to encompass two orbits, 17 and 28, in place of the one orbit on Apollo 14. The experiment consists of receiving the CSM downlink signal, which has been reflected from the lunar surface, at DSS 14 in two orthogonal polarizations simultaneously. From the recorded signal characteristics deductions can be made as to the nature of the lunar soil.

5. ALSEP Support.

The ALSEP transmissions are usually supported by the 9-m (30-ft) antennas of the MSFN. DSN support was requested during Apollo 14 because the ALSEP on that mission occasionally transmitted at a high bit rate (10.6 kilobits per second) and the 26-m stations provided the necessary signal-to-noise ratio. During testing for that mission, it was found that the ALSEP uplink frequency of 2119 MHz was so far removed from the normal DSN and Apollo uplink frequencies as to require retuning of the klystron tubes in the ground transmitters. This retuning significantly increases the chances for internal klystron failure and caused some concern. Accordingly, before Apollo 15 (whose ALSEP had no high bit rate), the DSN voiced its concern to the MSFN. After consultation with NASA Headquarters, it was decided that the DSN would continue with ALSEP uplink testing and operations regardless of the mission risks.

6. LCRU.

Shortly before the mission the Apollo Project requested short tracks of the LCRU from DSS 14 on August 4, 5, 7, and 8. The plan was to conduct television surveys of the landing site after the astronauts had departed. The LCRU batteries were expected to last approximately one week. Since this activity is not intimately related to manned flight support, a ruling was requested from NASA Headquarters on the relationship between the LCRU after LM liftoff and the other unmanned mission support of the DSN. The approval was received and the requested tracking was scheduled by cancelling some DSS 14 support of other projects.

C. PREMISSION PREPARATIONS AND TESTING.

1. DSN 26-m Antenna Stations.

Although the requirement to support LCRU transmissions has been known for some time, final testing of the support capability took place in early 1971 and continued until shortly before launch. The concern centered around reception of the LCRU frequency of 2265.5 MHz, below the normal Apollo band. Wideband masers had been installed at DSS 42 and LCRU reception there proved to be no problem. DSS 11 and 61 had not yet received the new masers, and the bandwidth of the old maser was not sufficient to cover both Apollo and the LCRU. The final procedure developed through this testing was to tune one maser at each site to the lower half of the band and the other maser to the upper half. There was no redundancy in this configuration as retuning required 60 minutes. In addition, the output of only one maser at a time could be selected, though this selection could be changed rapidly. A similar configuration was used at DSS 14 where the masers are different but have a similar bandwidth problem. As the LCRU link is marginal from a signal strength standpoint and is critically affected by a steep gain slope, several tests were necessary to demonstrate compatibility. Before Apollo 16, the new wideband masers will be installed at DSS 11, 14, and 61.

Soon after the DSS 11 reconfiguration was completed in early June 1971, power amplifier (PA) number 3 began to experience interlock tripoffs. Repeated testing and extensive component replacement (even replacement of the entire power supply) failed to improve the reliability. During the two weeks before launch, DSS 11 was reported "Red" due to the intermittent faults. This unreliability continued through the mission period.

DSS 11, 42, and 61 were placed under configuration control for the Apollo 15 mission as of 00:01 GMT on July 16, 1971, and were placed on mission status by the MSFN as of 00:01 GMT on July 15, 1971. On previous missions, scheduling control of these stations reverted to the MSFN during the mission status period. In view of the increased DSN responsibilities at these stations for Apollo 15 and beyond, the DSN planned to retain scheduling control, and the DSN/MSFN Operating Interface Procedures document reflected this plan. The MSFN, based on alleged verbal agreements, assumed that scheduling would be done by the MSFN as in the past. Accordingly, on July 15, the stations began to receive conflicting scheduling messages from both the DSN and MSFN. After several days of negotiation, MSFN scheduling was assigned control as a temporary expedient. It was later decided that on Apollo 16 these stations must be scheduled by the DSN.

2. DSS 14.

DSS 14 conducted the normal premission tests including installation and tests of the bistatic radar experiment equipment as shown in Table 3-3. No scheduling problems were experienced with DSS 14 as scheduling control for the station has always been retained by the DSN.

3. DSN Predicts.

Antenna pointing information for DSS 11, 42, and 61 comes directly from Houston in the form of a 29-point acquisition message. This message also serves DSS 14 but has been considered a backup to SFOF-generated predicts. On Apollo 15 the 29-point message was declared the prime source of predicts for DSS 14. The SFOF continued to supply predicts, but as a backup source only. Both predict systems were tested before the mission. The 29-point system worked perfectly, but the SFOF had some minor software problems. The predicts are generated by entering a Houston-supplied state vector into the 1108 computer where the Double Precision Trajectory Program outputs a probe ephemeris tape. The tape is carried to the IBM 360/75 for processing by the predicts program. The predicts are transmitted directly by the 360. Unfortunately, both computers are undergoing a series of software updates, and with each update the interface compatibility can break down. Only a few days before launch the trajectory program in the 1108 was modified and it was necessary to add a small reformatting program to the 360 to make the data from the probe ephemeris tape compatible with the predicts program. With this last-minute modification the predicts procedure was tested and declared "Green" for launch.

D. APOLLO 15 OPERATIONS.

1. DSN 26-m Antenna Stations.

DSS 11, 42, and 61 successfully supported all phases of the Apollo 15 mission. The problems experienced are noted in Table 3-4. As can be seen, the problems with DSS 11 transmitter number 3 continued. Three tripoffs of this transmitter were experienced during actual uplinking to the spacecraft. After the third tripoff, mission control in Houston finally acquiesced to DSN pleas (which began before launch) and declared DSS 11 transmitter number 4 as prime. After that decision there were no further uplink losses at DSS 11.

During the first pass at Goldstone shortly after TLI, the spacecraft view angles were beyond the antenna gimbal limits at the Goldstone Prime MSFN stations. Therefore, DSS 11 was required to transmit simultaneously on separate frequencies to the CSM and the instrument unit of the S-IVB booster. Although this capability has existed for the entire Apollo program, this is the first time that the capability has actually been used at a DSN station.

The 26-m stations tracked ALSEP several times but were never called upon to transmit the ALSEP uplink signal.

Table 3-3. DSS 14 Tests

Date, 1971	GMT, h:min	Test
Jul 07	14:00–22:00	Bistatic cable installation
Jul 14		Configuration verification test
Jul 18	01:00–01:00	DSS 14/GDS prime data flow test
Jul 22	09:00–13:00	Bistatic countdown
Jul 22	13:00–20:00	Bistatic test

Table 3-4. Apollo 15 Tracking

DSS	GMT, h:min	Problems
11	Jul 26/16:35–05:38	None.
	Jul 27/19:55–02:50	PA 3 fault at 23:21. One way for 48 s due to erroneous instructions from Prime. Released from track early for troubleshooting.
	Jul 28/20:17–05:50	PA 3 fault at 03:26. Uplink lost for 14 s. High-voltage power supply from DSS 14 installed after pass.
	Jul 29/20:22–05:39	PA 3 fault at 03:21. Uplink lost for 20 s.
	Jul 30/21:39–06:45	PA 3 fault at 02:42 (was in standby).
	Jul 31/22:22–06:19	None.
	Aug 01/23:31–07:55	None.
	Aug 03/00:30–08:44	PA 3 fault at 12:30 on Aug 2 (station inactive).
	Aug 04/02:06–09:10	PA 3 fault at 03:30 (was in standby).
	Aug 05/02:02–10:17	Glitches on HA error voltages. No impact because station autotracking. Problem not repeatable.
	Aug 06/02:21–09:59	None.
	Aug 07/03:04–09:59	PA 3 fault at 04:36. Wrong TLM bandwidth while tracking subsatellite.
14	Jul 27/02:17–05:14	None.
	Jul 28/01:24–05:35	None.
	Jul 28/23:02–05:40	None.
	Jul 29/20:29–05:39	None.
	Jul 30/21:39–06:19	None.

Table 3-4. Apollo 15 Tracking (cont'd)

DSS	GMT, h:min	Problems
14 (contd)	Jul 31/22:29–06:19	Antenna pointing 0.2 deg off boresight for first 10 min of lunar revolution 28.
	Aug 03/00:30–03:35	Failed to switch to high doppler sample rate until 16 min after LM jettison.
	Aug 04/08:51–09:40	None (LCRU track).
	Aug 05/04:00–06:30	None (LCRU search).
42	Jul 27/01:00–13:00	None.
	Jul 28/01:08–13:31	None.
	Jul 29/01:22–13:41	None.
	Jul 30/01:18–14:23	None.
	Jul 31/01:54–14:41	None.
	Aug 01/03:14–16:16	None.
	Aug 02/03:18–17:14	None.
	Aug 03/04:26–17:28	None.
	Aug 04/06:02–19:06	None.
	Aug 05/05:29–19:14	Heat exchanger problem on standby PA.
	Aug 06/05:50–19:25	None.
	Aug 07/06:11–20:26	None.
51	Jul 30/10:17–22:18	Failed to take required doppler data for four of six lunar orbits.
	Jul 31/11:30–22:34	None.
	Aug 03/13:20–01:16	None.
	Aug 04/14:18–21:04	None.
61	Jul 26/09:32–21:19	Bad ranging readouts on System 3; replaced faulty cord.
	Jul 27/12:21–21:56	None.
	Jul 28/12:51–22:06	None.
	Jul 29/13:01–21:55	None.
	Jul 30/14:04–22:38	None.
	Jul 31/15:26–22:33	Pretrack ranging problem; repaired before track.
	Aug 01/15:53–23:43	None.
	Aug 02/16:53–23:45	Wrong character in Tracking Data Processor header.
	Aug 03/18:16–01:21	None.
	Aug 04/18:34–02:22	None.
	Aug 05/18:58–02:23	None.
	Aug 06/19:28–02:30	None.

2. DSS 14.

Seven Apollo passes were tracked as shown in Table 3-4. The station also tracked the LCRU twice. The station had originally been scheduled for four LCRU tracks, but after failure of the LCRU at the end of the first pass and a futile attempt at revival on the second pass, DSS 14 was released from further support.

DSS 14 supported the bistatic radar experiment as planned. The experiment was somewhat degraded during lunar revolution 17 because the spacecraft had been pitched the wrong direction, making the radiation toward the lunar surface elliptical rather than circular. Revolution 28 efforts produced good data, and was not noticeably degraded by the operator error which resulted in a brief mispointing of the antenna.

DSS 14 failed to switch to high doppler sampling rate upon LM jettison as required. LM jettison occurred at a nonstandard time, and 16 minutes passed before the station was advised of the event. A verbal mark will be requested from the MSFN if future missions have event-related requirements such as this.

3. DSS 51.

DSS 51 tracked Apollo on four days as shown in Table 3-4. Apparently the station was not familiar with the Apollo requirements and took doppler samples at a one-minute rate instead of a one-second rate during part of the first pass. Unfortunately, the one-second samples were of high priority, since the spacecraft was in a very low lunar orbit at the time. The remainder of the doppler data on pass number 1 and subsequent passes was successfully recorded as required.

4. Predict Operations.

The 29-point acquisition message, which was the prime source of predicts for DSS 14, was used with no problems. The messages occasionally arrived later than desired, but the station was never completely without predicts.

In the SFOF, eight sets of predicts were generated during the mission and transmitted to DSS 14. One set of preflight nominal landing site predicts was generated and transmitted before the mission to DSS 14 and 51. No problems occurred in supplying the scheduled stations with predicts.

5. GCF Participation.

The DSN GCF provided voice, teletype, and high-speed data circuits to support the DSN Apollo operations. 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 known GCF anomalies and GCF support was considered excellent. The voice lines that were scheduled to each 26-m station were used only once.

6. SFOF Participation.

The SFOF areas and equipment used for Apollo 15 included the Operations Area, the Network Analysis Area, the Mariner Mars 1971 computer terminal area, the Univac 1108, and IBM 360/75 computers. The SFOF support is limited to predict generation, tracking data reception, and some off-line monitoring. The only SFOF problems were in the software area. In addition to the predict software problems, the 360 computer was unable to receive Apollo tracking data when tracking data from Mariner Mars 1971 was also being received. Therefore, the Apollo data had to be manually recalled from the GCF Communications Processor during inactive periods of Mariner Mars 1971. Other than these software problems, SFOF support was excellent.

SECTION IV
THE APOLLO 16 MISSION

A. MISSION DESCRIPTION.

Apollo 16, the ninth manned Apollo spacecraft flown above the three-stage Saturn V launch vehicle, carried astronauts John Young (Commander), Charles Duke (Lunar Module Pilot), and Ken Mattingly (Command Module Pilot). The mission goal was exploration of the Descartes highland region of the Moon. A secondary goal was to collect scientific data while in an extended lunar-orbit phase.

Launch from Cape Kennedy Pad 39A occurred at 17:54:00.65 GMT on April 16, 1972, at a launch azimuth of 72.03 degrees. Translunar injection (TLI) over the Pacific Ocean occurred midway through the second revolution in the Earth parking orbit with a 5-minute, 46-second burn of the S-IVB stage engine. Following TLI, the Command Service Module (CSM) separated from the booster, docked with the unattended Lunar Module (LM), and extracted the LM from the S-IVB. The S-IVB was directed by ground command to crash on the Moon as an additional calibration of the seismometers left there by the Apollo 12, 14, and 15 missions. Unfortunately, an abnormal venting of helium gas from a stuck regulator caused trajectory disturbances, and the radio system on the S-IVB quit abruptly at 21:03:58 GMT on April 17, preventing an accurate determination of the crash location. The best estimate is that the crash occurred at 21:01:04 GMT on April 19 at lunar coordinates 1.83°N and 23.3°W, approximately 280 km northeast of the targeted location.

Midcourse correction 1 was deleted due to the accuracy of the TLI maneuver. Midcourse correction 2 was a short 2.1-second burn of the Service Propulsion System (SPS) for a 3.81-m/sec (12.5 ft/sec) velocity change, which lowered the upcoming perilune from 216 km (117 nmi) to 133 km (71.7 nmi), within 0.5 km of the planned height. Midcourse corrections 3 and 4 were not required. During translunar cruise, the astronauts entered the LM twice to activate its radio system, allowing telemetry reception on Earth. The crew also worked at solving several minor problems, including an intermittent monitor on the television camera, a leaking water chlorinator, and a suspected gimbal lock on the Inertial Measurement Unit. The latter problem was resolved as being a false warning indication caused by an electrical transient.

Shortly before entering lunar orbit, the astronauts jettisoned a door covering the Scientific Instruments Module (SIM) of the Service Module. The SIM bay carries scientific instruments for observation of the Moon from lunar orbit. The instruments include a gamma ray spectrometer developed at JPL, an X-ray spectrometer, an alpha particle spectrometer, a mass spectrometer, a laser altimeter, a mapping camera, and a panoramic camera.

A successful lunar orbit insertion (LOI) burn of 374.3 seconds, for a velocity change of 854 m/sec (2802 ft/sec), put the spacecraft into a 316- x 108-km (170.3- x 58.1-nmi) orbit. Two orbits later, a descent orbit insertion (DOI) burn lowered the spacecraft to a 107.5- x 20.2-km (58.5- x 10.9-nmi) orbit.

During lunar orbit 12, the CSM and LM separated, with astronauts Young and Duke in the LM preparing for descent to the lunar surface on orbit 13. When communication was re-established at the beginning of orbit 13, it was learned that the CSM had not executed a circularization burn that should have been completed while behind the Moon. During the checkout for the burn, a rate feedback signal was absent, and the engine gimbal position indicator showed yaw oscillations. Preparations for LM landing were immediately halted, and the two spacecraft went into formation flight, prepared to dock and use the LM as a "lifeboat," as on Apollo 13, should the malfunction be serious and the backup system also become inoperative. Considerable resources were quickly gathered on the ground to study and simulate the problem. Within several hours, a decision was made to continue the mission and to use the backup SPS gimbal system for all SPS burns. The decision was based on the finding that, if the backup system were lost, the oscillating engine gimbal would still allow a desired maneuver to be safely, albeit crudely, executed. The delay, however, caused considerable modification to the rest of the mission.

The landing was planned for orbit 16, and this time the CSM came from behind the Moon in the proper circular orbit. The descent phase was normal, except that the LM high-gain steerable antenna, a perennial trouble source, was malfunctioning, and the LM was forced to transmit using its omni-antenna. The low signal levels caused data dropouts at all stations except DSS 14, the 64-m-antenna station of the DSN. Landing took place at 8°54'S and 15°30'E, only 262 m northwest of the planned site.

The original flight plan anticipated extravehicular activity (EVA) shortly after landing, but, because of the delayed landing, a sleep period was scheduled before the EVA. During the first EVA period, the astronauts deployed the lunar rover. As on Apollo 15, there were initially some problems with the rover; in this case, the rear steering was inoperative, but it later corrected itself. The astronauts set up the Apollo Lunar Surface Experiments Package (ALSEP), which contained a seismometer and several fields-and-particles experiments. Unfortunately, the commander tripped over the cable leading to an experiment designed to measure the flow of heat from the interior of the Moon. The cable was so severely damaged that repair was impractical, and the experiment was lost. The ALSEP transmitter was activated, and stations with 9-m (30-ft) antennas were reporting steady signal levels of -139 dBm. The crew also made one traverse using the rover.

After a sleep period, the crew began the second EVA, which consisted of several traverses primarily for geological exploration. Adjustments were also made to the ALSEP instruments. The rover navigation system experienced a partial failure, but it was not considered necessary for normal range traverses.

After another sleep period, the crew conducted a third EVA, which was of shorter duration than the others. In addition to the geological exploration traverses, a "grand prix" exercise was conducted, with the rover operating at high speeds and making sharp turns to evaluate rover capabilities and the effect of the lunar soil upon maneuverability. At the end of the third EVA, the rover had traveled a total of 27.1 km, and the astronauts had collected approximately 97 kg (213 lb) of rocks.

Some 4 hours after the third EVA, the LM blasted off the lunar surface to rejoin the orbiting CSM. The liftoff was observed on Earth via the television camera on the rover. Rendezvous and docking were normal, except that television coverage was deleted. Television transmission requires the CSM to maintain a high S-band radiated power level, and the LM radiated power level was low due to the unusable high-gain antenna. Earlier in the mission, the strong CSM signal had interfered with the weak LM signal when received at DSS 14, and the television coverage was cancelled to insure high-quality LM data reception.

The original flight plan called for the LM to be jettisoned 4 hours after docking and for the CSM to conduct orbital science experiments for another 47 hours. Because of lingering concern for the SPS engine, the LM was retained until shortly before trans-Earth injection (TEI), and the duration of the orbital operations was reduced to approximately 22 hours. These changes caused the bistatic radar experiment to be reduced from two orbits (numbers 26 and 66) to one orbit (number 40). The planners also cancelled a CSM orbit-shaping burn that was necessary for the Particles-and-Fields Subsatellite (P&FS) to be released into a long-lifetime orbit. The P&FS, which had a planned lifetime of more than 1 year, crashed on the Moon on May 29, 1972, only 35 days after release.

The LM was jettisoned 5 hours before TEI. Unfortunately, an attitude-control switch had been left in the wrong position, and the LM began to tumble at a rate of 3 degrees/second. Without attitude control, it was impossible to conduct the de-orbit burn for the planned lunar impact and the calibration of the ALSEP seismometers. Therefore, the LM remains in a lunar orbit that will eventually (early 1973) degrade, resulting in an unobserved lunar impact. The transmitter on the LM ceased due to battery depletion at 13:05:40 GMT on April 25 during lunar orbit 70.

The TEI maneuver, despite concerns over the SPS engine, was highly accurate, and midcourse correction 5 was a short burn for only a 1.04-m/sec (3.4 ft/sec) velocity change. An EVA was conducted during trans-Earth cruise to retrieve exposed film and other scientific materials from the SIM bay.

Apollo 16 landed at $0^{\circ}44'$S and $156^{\circ}12'$W in the Pacific Ocean, approximately 300 km southeast of Christmas Island.

Table 4-1 shows the mission event times. The term "ground elapsed time" (GET) is actually a misnomer since the GET clocks were readjusted twice during the mission: First, the GET clock was advanced 11 minutes, 48 seconds at 16:30 GMT on April 21; then, the clock was advanced 24 hours, 34 minutes, 12 seconds at 04:08:01 GMT on April 25. These changes caused the GET of the mission events to correspond to the GET indicated in the flight plan, in spite of the delays caused by the SPS problems.

B. REQUIREMENTS FOR DSN SUPPORT.

1. 26-m Antenna Stations.

As was done with previous Apollo missions, DSS 11, 42, and 61 were committed to support Apollo 16 under direct STDN/MSC (Manned Spacecraft Center) control. Their responsibilities included two-way tracking of the CSM, LM, S-IVB, and Lunar Communications Relay Unit (LCRU), which transmits on a frequency of 2265.5 MHz and receives on the LM uplink frequency. The P&FS was also to be tracked, but was not to be activated until after LM impact, since the uplink and downlink frequencies for the two vehicles are identical.

Unlike previous Apollo missions, scheduling authority for the 26-m-antenna stations was retained by the DSN for the entire Apollo 16 mission. This change was necessary because the DSN had assumed complete maintenance and operations responsibility for these 26-m-antenna stations.

2. DSS 14.

The Mars station (DSS 14) was required to receive voice, telemetry, biomedical, and television data and to relay the data to the Goldstone prime STDN station (GDS). Specific requirements existed for low lunar orbit, touchdown, EVA television, and LM crash. Coverage was also desired for television during translunar coast.

Table 4-1. Apollo 16 Sequence of Major Events

Event	Ground elapsed time, hr:min:sec	Actual elapsed time, hr:min:sec	Date/Greenwich mean time, hr:min:sec
Launch	00:00:00	00:00:00	April 16/17:54:01
TLI ignition	02:33:34	02:33:34	April 16/20:27:35
TLI cutoff	02:39:20	02:39:20	April 16/20:33:21
First midcourse (deleted)	—	—	—
Second midcourse	30:39:00	30:39:00	April 18/00:33:01
LM comm test	33:00:00	33:00:00	April 18/02:54:01
Third midcourse (deleted)	—	—	—
LM comm test	53:31:00	53:31:00	April 18/23:25:01
Bistatic frequency check	57:19:39	57:19:39	April 19/03:13:40
Fourth midcourse (deleted)	—	—	—
SIM door jettison	69:59:00	69:59:00	April 19/15:53:01
LOI	74:28:27	74:28:27	April 19/20:22:28
S-IVB impact	75:07:03	75:07:03	April 19/21:01:04
DOI	78:33:44	78:33:44	April 20/00:27:45
Separation	96:13:31	96:13:31	April 20/18:07:32
Second separation	102:30:00	102:30:00	April 21/00:24:01
Power descent initiation	104:17:25	104:17:25	April 21/02:11:26
Touchdown	104:29:35	104:29:35	April 21/02:23:36
Begin EVA 1	119:05:48	118:54:00	April 21/16:48:01
End EVA 1	126:16:48	126:05:00	April 21/23:59:01
Begin EVA 2	142:51:15	142:39:27	April 22/16:33:28
End EVA 2	150:14:41	150:02:53	April 22/23:56:54
Bistatic radar begin (orbit 40)	151:28:21	151:16:33	April 23/01:10:34
Bistatic radar end	152:41:15	152:29:27	April 23/02:23:28
Begin EVA 3	165:43:11	165:31:23	April 23/15:25:24
CSM orbit change	169:28:48	169:17:00	April 23/19:11:01
End EVA 3	171:23:29	171:11:41	April 23/21:05:42
LM ascent	175:43:35	175:31:47	April 24/01:25:48
Docking	177:51:48	177:40:00	April 24/03:34:01
LM jettison	195:12:00	190:00:12	April 24/20:54:13
Lunar orbit plane change (deleted)	—	—	—
P&FS launch	196:13:55	196:02:07	April 24/21:56:08
TEI	200:33:20	200:21:32	April 25/02:15:33

Table 4-1. Apollo 16 Sequence of Major Events (cont'd)

Event	Ground elapsed time, hr:min:sec	Actual elapsed time, hr:min:sec	Date/Greenwich mean time, hr:min:sec
LM battery depletion	235:57:39	211:11:39	April 25/13:05:40
Fifth midcourse	239:21:02	214:35:02	April 25/16:29:03
P&FS commanded on	241:16:30	216:30:30	April 25/18:24:31
CSM EVA	243:35:00	218:49:00	April 25/20:43:01
Sixth midcourse (deleted)	—	—	—
Seventh midcourse	287:22:00	262:36:00	April 27/16:30:01
Splashdown	290:37:06	265:51:06	April 27/19:45:07

3. Precision Doppler Data.

As part of a continuing study (based at JPL) of potential lunar anomalies (mascons), DSS 14 was required to provide precision high-speed doppler recordings of the CSM and LM during low lunar orbits and of the LM during the descent phase and later during the crash. The unexpected events during the mission modified this requirement: First, the extra time spent in low lunar orbit while the SPS engine problem was being studied provided considerable extra mascon data; second, the lack of an LM crash relieved DSS 14 of the coverage requirement. A related Apollo requirement was for high-speed strip-chart recordings of DSS 14 received signal strength during orbit 3 of the CSM and the crash of the LM.

4. Bistatic Radar Experiment.

DSS 14 was required to conduct another bistatic radar experiment as had been done on Apollos 14 and 15. The experiment was originally scheduled for CSM orbits 26 and 66, but after the SPS problems the experiment was rescheduled to the single orbit 40. The experiment consists of receiving the CSM downlink signal, which has been reflected from the lunar surface, at DSS 14 in two orthogonal polarizations simultaneously. From the recorded signal characteristics, deductions can be made as to the nature of the lunar soil.

5. LCRU.

A very late requirement was imposed for additional DSS 14 tracking of the LCRU after LM liftoff. The requirement, received on April 18 (during translunar cruise), was for 10 short daily passes from April 25 through May 4 to receive television signals from the LCRU until its batteries were depleted. Due to the unmanned, non-Apollo nature of the requirement and its severe impact on DSS 14 tracking of unmanned spacecraft and radioscience objects, the conflict was submitted to NASA Headquarters for resolution. The DSN was subsequently instructed to schedule the LCRU tracking, regardless of the impact on other activities. The LCRU was tracked daily until it ceased to operate on April 30.

C. DSN PRE-MISSION PREPARATIONS AND TESTING.

1. 26-m Antenna Stations.

Because of power amplifier interlock tripoffs on past missions, the DSN undertook a reliability study shortly after the Apollo 15 mission. This study resulted in a mechanical redesign of the transmitter power supply. This modification was made at each 26-m-antenna station before the Apollo 16 mission. In addition, a particularly troublesome power amplifier at DSS 11 was completely replaced with a new unit direct from the manufacturer.

Between the Apollo 15 and 16 missions, the method of processing pointing data at the stations was changed. Previously, the 29-point acquisition message from the Goddard Space Flight Center (GSFC) or the Manned Spacecraft Center (MSC) was entered into an STDN Univac 1218 computer, where it was reformatted for inputting to the Antenna Position Programmer (APP). After the Apollo 15 mission, the Univac 1218 computer was removed, and a program was written for the existing DSN Antenna Pointing System (APS) computer to assume the reformatting function. The program was written using a specification from GSFC, the DSN's official Apollo contact, and the program operated perfectly when tested with GSFC.

Shortly before the mission, testing began with MSC, and the program developed serious problems. An investigation quickly revealed that MSC does not transmit 29-point acquisition messages formatted according to the GSFC specification; when an angle in the message is less than 10 degrees, GSFC fills the unused digit position with a zero, whereas MSC fills the position with a teletype space. MSC claimed that they would be unable to meet the specification with the launch less than one week away.

During a worldwide conference call, DSS 61 operations personnel mentioned that they had discovered that changes in only two computer words of the on-site program would enable the program to accept either format. The modifications were studied by the programmer at JPL and hastily tested at both DSS 61 and DSS 42. The changes were found to be sound, and the modified program was used during the mission. It is anticipated that the program will be rewritten before the Apollo 17 mission to improve the input formatting and also to remove several operator inconveniences discovered during testing.

DSS 11, 42, and 61 were placed under configuration control for the Apollo 16 mission on April 4, 1972. They were placed on mission status by the STDN on April 3.

2. DSS 14.

DSS 14 conducted normal pre-mission activities, including installation and tests of the bistatic radar equipment, as shown in Table 4-2.

Table 4-2. DSS 14 Tests

Date/GMT, hr:min	Test
April 4/18:00–22:00	Countdown for bistatic test
April 4/22:00–24:00	Bistatic signal flow test
April 5/00:00–05:00	Bistatic final checkout
April 7	CVT/OVT
April 9, 10/06:16–05:25	Data flow test with GDS

D. DSN OPERATIONS DURING MISSION.

1. 26-m Antenna Stations.

DSS 11, 42, and 61 successfully supported all phases of the Apollo 16 mission. The problems experienced are noted in Table 4-3. As can be seen, there were no power amplifier overcurrent or arc detector tripoffs.

2. DSS 14.

Seven Apollo passes were tracked, as shown in Table 4-3. The station also tracked six LCRU passes. The station had originally been scheduled for ten LCRU tracks, but, on April 30, the signal could not be acquired, indicating a dead LCRU battery.

DSS 14 experienced a pointing problem on the first pass, beginning shortly after TLI. The spacecraft rose rapidly in the west, crossed the station meridian at a high elevation, reversed its apparent motion, and again set in the west. At the moment that the spacecraft crossed the station meridian going from west to east, the Antenna Pointing System (APS) malfunctioned. At first it was thought to be a predict problem, but post-mission study may show that the APS correctly interpolates forward from an hour angle of 359 to 0, but not in reverse. This is a unique problem because it is the first known spacecraft track at DSS 14 to cross the meridian in a reverse direction.

A significant problem occurred on April 19 and 20. With the CSM and LM both in the main beam of the DSS 14 antenna and the CSM and LM signal levels at -92 and -115, respectively, the LM signal received interference that caused an increased telemetry bit error rate. When the CSM signal was reduced, the bit error rate returned to normal. Assuming that a maser overload was at fault, DSS 14 switched masers and then retuned the backup maser. In so doing, gain on the backup maser was lost, and the station switched back to the prime maser. The immediate impact of the problem was to restrict the allowable CSM signal level whenever it was in the vicinity of the LM. Therefore, it was necessary to cancel the planned television coverage of the CSM-LM docking

Table 4-3. Apollo 16 Tracking

Date/GMT, hr:min	Problems
DSS 11	
April 16/20:44–06:47	PA3 beam voltage not controllable remotely
April 17/19:14–07:11	Defective iso-amp in system 3 ranging
April 18/19:31–07:23	None
April 19/19:18–07:48	None
April 20/20:12–08:43	None
April 21/21:30–08:30	PA3 and PA4 failed during pretrack tests. Caused by low flow through combiner. Flow increased
April 22/22:09–10:11	Pretrack ranging problem. Replaced relay
April 23/23:06–09:53	None
April 25/00:36–10:46	Defective exciter turning potentiometer on system 3
April 26/00:00–10:44	None
April 27/00:18–10:19	None
DSS 14	
April 16/23:09–03:03	APS problems near zenith
April 17/23:11–07:56	None
April 19/18:46–07:48	Distortion of LM signal when using Mod 3 maser. Switched to PDS maser at 00:30Z. 35 min gap in predicts
April 20/20:04–08:58	Distortion of LM signal when using either maser. Tuning of backup maser caused loss of gain. Confusion over too many predict sets (one set for each mission contingency)
April 21/20:58–09:29	None
April 22/21:59–09:56	TDH doppler counter hung up 03:02–09:56Z
April 23/22:57–05:15	None
April 25/05:33–05:50	None (LCRU track)
April 26/06:25–06:46	
April 27/06:10–06:54	
April 28/06:24–06:45	
April 29/07:26–07:59	None (LCRU track)
April 30/06:38–08:00	No LCRU signal received
DSS 42	
April 17/03:18–11:19	None
April 18/03:45–12:10	
April 19/03:58–12:25	
April 20/04:52–13:09	
April 21/04:39–14:04	
April 22/05:25–14:26	
April 23/05:29–16:03	
April 24/05:51–16:56	
April 25/06:01–17:14	
April 26/05:59–17:23	
April 27/05:51–18:28	
DSS 61	
April 17/10:31–21:04	None
April 18/11:05–00:40	
April 19/11:17–00:17	
April 20/12:28–00:59	
April 21/13:36–00:42	
April 22/13:57–02:07	
April 23/15:00–02:06	
April 24/16:42–03:05	
April 25/16:54–02:34	
April 26/16:35–02:27	

maneuvers. This interference was not experienced on past missions because the LM usually transmits a high signal level using its high-gain steerable antenna.

DSS 14 supported the bistatic radar experiment successfully. The experiment was reduced from two lunar orbits to one orbit (number 40) because of the other mission problems.

3. GCF Participation.

The GCF provided voice, teletype, and high-speed data circuits to support the DSN Apollo operations. 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 known GCF anomalies, and GCF support was considered excellent.

4. SFOF Participation.

The SFOF areas and equipment used for the Apollo 16 mission included the Operations Area, the Network Analysis Area, the Mariner computer terminal area, and the Univac 1108 and IBM 360/75 computers. The SFOF support was limited to predict generation and some off-line monitoring. In contrast to previous Apollo missions, no problems were experienced with predict generation. Fourteen Probe Ephemeris Tapes were generated on the Univac 1108, and sixteen predict sets were generated for DSS 14 on the IBM 360/75. The SFOF support was excellent.

SECTION V
THE APOLLO 17 MISSION

A. MISSION DESCRIPTION.

Apollo 17, the tenth manned Apollo spacecraft flown above the three-stage Saturn V launch vehicle, carried astronauts Eugene A. Cernan, Commander (CDR), Ronald E. Evans, Command Module Pilot (CMP), and Harrison H. Schmitt, a geologist by profession, Lunar Module Pilot (LMP). The mission goal was exploration of the area around the Taurus Mountains and Littrow Crater with the aim of filling in gaps in current knowledge of the moon and its history.

Launch from Cape Kennedy Pad 39A occurred at 5:33:00.83 GMT on December 7, 1972, at launch azimuth of 92.0 degrees. A countdown hold of 2 hours 40 minutes was required when the launch auto-sequencer failed to pressurize a third stage LOX tank, and then failed to recognize that the launch controllers had manually pressurized the tank after observing the discrepancy. The sequencer was reprogrammed to overlook the one countdown step, and the countdown proceeded normally. This was the first Apollo program launch hold for technical reasons (Apollo 14 was held for weather). The launch was the first Apollo launch to occur at night. The geometry of the Sun and moon constrain a launch to one or two days in any month to allow acceptable Sun lighting angles at the landing site during touchdown. During December, the geometry was such that a daylight launch would have required the spacecraft to spend many hours in the shadow of the Earth, causing an unacceptable amount of spacecraft cooling. The trajectory of the night launch avoided this long duration in the shadow.

Due to the unusual launch time, translunar injection (TLI) occurred over the Atlantic Ocean in the beginning of the third revolution in Earth parking orbit (the customary TLI occurs over the Pacific Ocean in the second orbit). A 5-minute 46-second burn of the S-IVB engine placed the spacecraft on a translunar trajectory. Following TLI, the Command Service Module (CSM) separated from the booster and docked with the unattended Lunar Module (LM). During docking, three of the docking latches did not lock. The crew manually recocked and fired two of the problem latches and they seized properly, completing an adequate docking. The CSM extracted the LM from the S-IVB, and the S-IVB was directed by ground command to crash on the moon in a seismic experiment involving the seismometers left there by the Apollo 12, 14, 15, and 16 missions. The S-IVB impacted the moon at 20:32:43 GMT on December 10 at lunar coordinates 4° 12' S, 12° 18' W, approximately 160 km northwest of the planned site.

Midcourse correction 1 was deleted due to the accuracy of the TLI maneuvers. Midcourse correction 2 was a short 1.7 second burn of the Service Propulsion System (SPS) for a velocity change of 3.0 m/s (9.9 ft/s) and a trim of 0.2 m/s (0.7 ft/s) with the Reaction Control System (RCS). Midcourse corrections 3 and 4 were not required.

At 22:33 GMT on December 9, the ground elapsed time (GET) clocks were advanced from 65:00 GET to 67:40 GET to compensate for the 2-hours 40-minute delay in the launch. This time clock change, together with a faster translunar trajectory, timed to speed up moon arrival by 2 hours 40 minutes, put the mission back onto the original GMT/GET schedule. After this change, all mission events occurred within minutes of the premission plan. Table 5-1 reflects both the GET times and the actual elapsed times (AET) of each event.

Several minor problems occurred during translunar cruise. Several erroneous master alarms were observed in the spacecraft. The master alarm system warns the astronauts when some measurement in the spacecraft is found to be reaching an unusual value, but the master alarm was sounding without reason. The alarm was by-passed during sleep periods to avoid unnecessarily waking the astronauts. On December 9, mission control found it impossible to wake the astronauts, and they overslept more than an hour. As usual, only one astronaut (the CMP) was sleeping with his headset on, and the the headset inadvertently fell off, leaving the crew out of contact with mission control. In such a circumstance, Houston normally sends a master alarm command to the spacecraft, setting off the warning signals. Since the master

Table 5-1. Apollo 17 Sequence of Major Events

Event	GET, h:min:s	AET, h:min:s	Date/GMT, h:min:s
Launch	0:00:00	0:00:00	12– 7/05:33:01
Insertion	0:11:47	0:11:47	12– 7/05:44:48
TLI ignition	3:12:35	3:12:35	12– 7/08:45:36
TLI cutoff	3:18:21	3:18:21	12– 7/08:51:22
Transposition/ docking	3:43:00	3:43:00	12– 7/09:16:01
CSM/LM eject	4:45:00	4:45:00	12– 7/10:18:01
S4B evasive maneuver[a]	5:30:00	5:30:00	12– 7/11:03:01
S4B first midcourse[a]	6:36:00	6:36:00	12– 7/12:09:01
First midcourse (deleted)			
Second midcourse	35:29:59	35:29:59	12– 8/17:03:00
LM communication test begin	41:16:00	41:16:00	12– 8/22:49:01
LM communication test end	41:59:00	41:59:00	12– 8/23:32:01
LM communication test begin	60:12:00	60:12:00	12– 9/17:45:01
LM communication test end	60:26:00	60:26:00	12– 9/17:59:01
Third midcourse (deleted)			
Fourth midcourse (deleted)			
SIM door jettison	84:12:00	81:32:00	12–10/15:05:01
CSM first occultation	88:43:22	86:03:22	12–10/19:36:23
LOI	88:54:21	86:14:21	12–10/19:47:22
S4B impact	89:39:42	86:59:42	12–10/20:32:43
DOI	93:11:00	90:31:00	12–11/00:04:01
Separation	110:27:55	107:47:55	12–11/17:20:56
CSM circularization	111:57:28	109:17:28	12–11/18:50:29
DOI-2	112:02:41	109:22:41	12–11/18:55:42
PDI	112:49:53	110:09:53	12–11/19:42:54
Touchdown	113:01:58	110:21:58	12–11/19:54:59
EVA 1 begin	117:01:36	114:21:36	12–11/23:54:37
ALSEP activated	120:00:31	117:20:31	12–12/02:53:32
EVA 1 end	124:13:47	121:33:47	12–12/07:06:48
EVA 2 begin	140:34:49	137:54:49	12–12/23:27:50
EVA 2 end	148:12:10	145:32:10	12–13/07:05:11
EVA 3 begin	163:32:35	160:52:35	12–13/22:25:36
EVA 3 end	170:48:06	168:08:06	12–14/05:41:07
Lunar orbit plane change	182:33:53	179:53:53	12–14/17:26:54
LM ascent	188:01:36	185:21:36	12–14/22:54:37
CSM/LM docking	190:17:03	187:37:03	12–15/01:10:04
LM jettison	193:58:35	191:18:35	12–15/04:51:36
LM deorbit	195:38:13	192:58:13	12–15/06:31:14
LM crash	195:57:18	193:17:18	12–15/06:50:19
TEI	236:42:08	234:02:08	12–16/23:35:09
Fifth midcourse (deleted)			
CSM EVA begin	257:34:24	254:54:24	12–17/20:27:25
CSM EVA end	258:41:42	256:01:42	12–17/21:34:43
Sixth midcourse (deleted)			
Seventh midcourse[a]	301:18:00	298:38:00	12–19/16:11:01
CM/SM separation	304:03:48	301:23:48	12–19/18:56:49
Entry interface	304:18:41	301:38:41	12–19/19:11:42
Splashdown	304:31:58	301:51:58	12–19/19:24:59

[a]Time approximate.

alarm was disabled, the crew could not be reached, causing some concern at mission control: without a master alarm, the crew might have slept through a spacecraft emergency. Other problems included a pressure oscillation in a hydrogen tank and several losses of communication; a 3-minute dropout at 60:55 GET caused by a ground problem at the Ascension STDN site; a 9-minute dropout at 86:08 GET caused by a maser failure at the Madrid STDN site, and a 4-minute delay in acquisition due to an antenna pointing problem at the Goldstone STDN site during the first lunar revolution, resulting in a rapid handover to DSS 11.

Shortly before entering lunar orbit, the astronauts jettisoned a door covering the Scientific Instruments Module (SIM) of the Service Module. The SIM bay carries scientific instruments for observation of the moon from lunar orbit.

A successful lunar orbit insertion (LOI) burn of 6 minutes, 33 seconds, for a velocity change of 911.32 m/s (2989.9 ft/s), put the spacecraft into a 315.4 x 97.2 km (170.3 x 52.5 nmi) orbit. Two orbits later, a descent orbit insertion (DOI) burn of 22 seconds for a velocity change of 60.41 m/s (198.2 ft/s) lowered the orbit to 109.5 x 27.6 km (59.1 x 14.9 nmi).

During lunar orbit 12, the CSM and LM separated, with astronauts Cernan and Schmitt in the LM preparing for descent to the lunar surface on orbit 13. A LM-only descent orbit burn (DOI-2) at 18:55:42 on December 11 placed the LM into a 110.4 x 11.5 km (59.6 x 6.2 nmi) orbit. Landing occurred at 19:54:59 GMT on December 11 at lunar coordinates 20° 9' 50.5" N and 30° 46' 19.3" E, approximately 369 meters east of the planned landing site. After a short eating period, the astronauts began extra-vehicular activity 1 (EVA1), during which they deployed the lunar rover, set up the Apollo Lunar Surface Experiments Package (ALSEP) and activated the ALSEP transmitters. The ALSEP signals were received at Goldstone at 2:53:32 GMT on December 12, at a signal level of -133 dBm on a 26-m-diameter antenna. Several 9-m (30-ft) stations later reported signal fluctuations of ±1 dB with a period of approximately 45 seconds and an average level of -137 dBm. Shortly after deployment of the rover, the CDR inadvertently knocked the right rear fender extension off.

A temporary fix was attempted using tape, but the extension fell off again during the one short traverse of the first extravehicular activity (EVA1), resulting in the astronauts and rover being covered with considerable dust. The EVA ended after 7 hours 12 minutes.

After a sleep period, the crew began the second EVA. Prior to starting the traverse, the crew replaced the rover fender extension with a set of four plastic maps taped together and held in position with a clamp from a portable utility lamp in the LM. The fix worked perfectly and alleviated the dust problem. The crew visited four sites, obtaining photographs and samples and deploying three explosive charges to be detonated by timers after liftoff as part of seismic studies. During this traverse, the LMP noticed an orange-colored material that may provide evidence of recent volcanic activity on the moon and could be the youngest lunar material ever brought back to Earth. EVA2 lasted 7 hours 38 minute's, the longest EVA of the Apollo program.

Following another sleep period, EVA3 was begun. Five sites were visited and one explosive charge was deployed. The LMP attempted unsuccessfully to repair the Lunar Surface Gravimeter (part of ALSEP), which had not been working since deployment. The third EVA was 7 hours 16 minutes long. At the end of this EVA, the crew had explored the surface for a total of 22 hours 6 minutes and had driven the rover 32.0 km (19.9 mi) at speeds up to 17.8 kph (11.1 mph), all three figures setting records for the Apollo program. Other records broken were the amount of rocks and soil collected: 117 kg (258 lb) and the time spent on the moon: 74 hours 59 minutes. Approximately 2120 photographs were taken during the EVAs.

Following EVA 3 and an 8-hour sleep period, the LM blasted off the lunar surface to rejoin the orbiting CSM. The liftoff was observed on Earth via the television camera on the rover. This camera continued to provide television views of the moon until its temperature control unit failed at 08:13 GMT on December 16. It had been expected to last until battery depletion on approximately December 25. Rendezvous and docking were also televised, the first use of the CSM television camera on Apollo 17. The crew transferred the samples and exposed film to the CSM, then jettisoned the LM for its deorbit and subsequent crash on the moon. The crash occurred at 6:50:19 on December 15 at 19° 54' N and 30° 30' E. The event was observed by the seismometers from Apollos 12, 14, 15, and 16, and by the four geophones of the Apollo 17 ALSEP.

The CSM remained in lunar orbit for another 40 hours conducting orbital science. On this flight, however, there was no Particle and Fields Subsatellite, as its space was given over to a lunar sounder experiment. Also there was not enough time in the mission plan for a Bistatic Radar Experiment. Trans-Earth injection (TEI) was initiated at 23:35:09 GMT on December 16 with an SPS burn of 144.9 s for a velocity change of 928.51 m/s (3046.3 ft/s). The TEI maneuver was very accurate, and midcourse corrections 5 and 6 were not needed. The CMP conducted an EVA on December 17 to retrieve exposed film and other scientific materials from the SIM bay. Apollo 17 landed at 19:24:59 GMT December 19 at 17° 52' S and 166° 8' W, approximately 630 km (340 nmi) southeast of Pago Pago.

B. REQUIREMENTS FOR DSN SUPPORT.

1. DSN 26-m Antenna Stations.

As was done with previous Apollo missions, DSS 11 , 42, and 61 were committed to support Apollo 17 under direct STDN/Manned Spacecraft Center (MSC) control. Their responsibilities included two-way tracking of the CSM, LM, S-IVB, and the rover's Lunar Communications Relay Unit (LCRU), which transmits on a frequency of 2265.5 MHz and receives on the LM uplink frequency. Scheduling authority for these stations was retained by the DSN for the entire mission, since the DSN has complete maintenance and operations responsibilities.

2. DSS 14.

The Mars station, DSS 14, was required to receive voice, telemetry, biomedical, and television data and to relay the data to the Goldstone prime STDN station (GDS). No uplink was required. DSS 14 was also required to receive 15-minutes television transmissions from the LCRU approximately once each day from LM liftoff through December 25. Contrary to previous missions, there were no requirements for Bistatic Radar reception or for precision doppler recording at DSS 14.

Several months before launch, NASA questioned the DSN as to whether DSS 43, the 64-m-diameter antenna station under construction in Australia, could be committed for Apollo use to avoid the need for the Parkes, Australia, 64-m-diameter radio-astronomy antenna. Since the operational date of DSS 43 was not until mid-1973, committed support was impossible. Nevertheless, the station did track on an uncommitted basis as backup to Parkes, and the acquired data were used.

C. DSN PREMISSION PREPARATIONS AND TESTING.

1. DSN 26-m Antenna Stations.

A light level of testing was conducted continuously from Apollo 16 to Apollo 17. As the testing pace increased in late November 1972, a few problems surfaced. DSS 11 experienced a transmitter tripoff due to a primary ac overcurrent sensing. Because of several similar problems in the past at DSS 11, considerable attention was focused upon the problem, which turned out to be nothing more than a chafed high-voltage cable. DSS 11 was found to have a doppler problem on December 6 during an STDN test. The problem was traced to a modified doppler detector that had been installed at STDN request. With the original detector returned to service, the problem disappeared. DSS 11 also experienced a pump failure on heat exchanger No. 2, and the pump was replaced. DSS 11, 42, and 61 were placed on mission status by the STDN on December 1.

2. DSS 14.

DSS 14 conducted the normal premission tests as shown in Table 5-2. In addition, since DSS 14 experienced overloading during Apollo 16 when trying to receive a weak LM signal in the presence of a strong CSM television

Table 5-2. DSS 14 Tests

Date	Test
Nov. 8, 1972	Support constraint testing
Nov. 15, 1972	Configuration verification test
Dec. 1, 1972	Apollo 17 OVT
Dec. 2, 1972	24-h interface test with GDS

signal, a 20-dB attenuator was added after the Mod III maser. This configuration was then tested, even though the Mod III maser was only to be used as backup to the polarization diversity S-band (PDS) maser.

D. DSN OPERATIONS DURING MISSION.

1. 26-m Antenna Stations.

DSS 11, 42, and 61 successfully supported all phases of the Apollo 17 mission. The problems experienced are noted in Table 5-3.

2. DSS 14.

Nine Apollo passes were tracked, as shown in Table 5-3. The station had originally been scheduled for short LCRU tracks through December 25, but, as mentioned earlier, the LCRU ceased to operate on December 16.

DSS 14 experienced a pointing problem on the first pass. The antenna was pointed manually from 18:40 to 19:09 GMT because the station was unable to process the 29-point acquisition message. The problem was apparently caused by a bad punch point at the start of the acquisition message tape. Normal tracking was again interrupted at 20:57 due to a bad sample on the drive tape. A new drive tape was prepared from the same acquisition message, and normal tracking operations resumed at 21:26 GMT.

Table 5-3. Apollo 17 Tracking

Date/GMT, h:min	Problems
DSS 11	
Dec 7/18:31 – 03:47	100-channel event recorder inoperative 23:52 – 01:57
Dec 8/18:40 – 04:20	None
Dec 9/18:45 – 04:42	None
Dec 10/18:42 – 05:11	Declination angle DATEX jumping intermittently 00:42 – 01:20. No data loss
Dec 11/19:26 – 06:12	None
Dec 12/19:43 – 06:10	None
Dec 13/20:33 – 07:52	None
Dec 14/20:49 – 08:48	None
Dec 15/21:15 – 09:19	None
Dec 16/22:04 – 10:03	None
Dec 17/22:26 – 10:13	None
Dec 18/22:36 – 10:23	Antenna drives off in both axes (06:31 – 06:40) due to bad interpolation on predict
DSS 14	
Dec 7/19:04 – 03:25	Problem with 29-point acquisition message 18:40 – 19:09 and 20:57 – 21:26. Cut new tape from same message. Antenna stowed 22:35 – 23:35 due to high winds
Dec 9/18:53 – 03:00	Backup Mod III maser red 9/1500 – 10/0200
Dec 10/18:52 – 03:27	Lost 20 min of 1-s doppler data due to punch being on 60-s rate
Dec 11/19:29 – 05:37	None
Dec 12/19:43 – 06:36	None
Dec 13/20:11 – 07:43	None
Dec 14/20:41 – 08:49	None
Dec 15/21:17 – 03:28	None
Dec 16/22:39 – 04:30	None

Date/GMT, h:min	Problems
DSS 42	
Dec 7/23:09 – 11:53	None
Dec 8/23:39 – 12:03	None
Dec 9/23:53 – 12:05	None
Dec 11/00:27 – 12:21	None
Dec 12/01:22 – 12:50	None
Dec 13/01:57 – 13:22	None
Dec 14/03:05 – 13:56	None
Dec 15/04:26 – 14:26	None
Dec 16/06:10 – 15:09	None
Dec 17/06:18 – 15:17	None
Dec 18/06:34 – 15:02	None
Dec 19/07:22 – 13:54	None
DSS 61	
Dec 7/10:43 – 19:06	None
Dec 8/11:24 – 20:18	None
Dec 9/11:28 – 20:35	None
Dec 10/11:26 – 20:33	None
Dec 11/11:52 – 21:37	None
Dec 12/11:54 – 22:22	None
Dec 13/12:56 – 23:52	None
Dec 14/12:48 – 00:59	None
Dec 15/13:22 – 01:30	None
Dec 16/14:06 – 03:09	None
Dec 17/14:13 – 03:16	None
Dec 18/13:59 – 03:31	None
Dec 19/16:38 – 19:23	None

Beginning at 17:00 on December 8, problems were experienced with the Mod III maser. The maser was out of service three times until it was reliably back in service at 16:30 on December 10. Since the Mod III maser is only used for backup on Apollo, its problems did not affect Apollo support.

3. Ground Communications Facility Participation.

The Ground Communications Facility (GCF) provided voice, teletype, and high-speed data circuits to support the DSN Apollo operations. In addition, JPL acts as the West Coast switching center for the NASA Communications Network and handles many non-DSN circuits, including video channels, in support of Apollo. There were no known GCF anomalies.

4. Mission Control and Computing Center Participation.

The Mission Control and Computing Center (MCCC) areas and equipment used for the Apollo 17 mission included the Operations Area, the Network Analysis Area, the Mariner computer terminal area, and the Univac 1108 and 360/75 computers. The MCCC support was limited to backup predict generation for DSS 14 (and DSS 43), and some off-line monitoring the operations area.

APPENDIX A

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)

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