Apollo Mission Support

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The support provided by the DSN to the Spaceflight Tracking and Data Network during the Apollo 16 mission is described. Support was provided by three 26-m- (85-ft-) antenna deep space stations, the 64-m- (210-ft-) antenna Mars Deep Space Station (DSS 14), the Ground Communications Facility, and the Space Flight Operations Facility. Pre-mission and mission activities of the DSN are discussed, and the mission is described.

I. Introduction

The DSN support provided to the Spaceflight Tracking and Data Network (STDN, previously termed the Manned Space Flight Network) has been described in Refs. 1–3 and in earlier issues of the JPL Space Programs Summary, Vol. II series. This article describes the support provided for the *Apollo 16 (AS-511)* mission, the fifth manned lunar landing and the second of the new "J" type missions devoted almost exclusively to scientific objectives.

II. 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 deg. Translunar injection (TLI) over the Pacific Ocean occurred midway through the second revolution in the Earth parking orbit with a 5-min, 46-sec 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-sec 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 sec, for a velocity change of 854 m/sec (2802 ft/sec), put the spacecraft into a 316- × 108-km (170.3- × 58.1-nmi) orbit. Two orbits later, a descent orbit insertion (DOI) burn lowered the spacecraft to a 107.5- × 20.2-km (58.5- × 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 hr 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 hr after docking and for the CSM to conduct orbital science experiments for another 47 hr. 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 hr. 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 yr, crashed on the Moon on May 29, 1972, only 35 days after release.

The LM was jettisoned 5 hr 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 deg/sec. 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°44'S and 156°12'W in the Pacific Ocean, approximately 300 km southeast of Christmas Island.

Table 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 min, 48 sec at 16:30 GMT on April 21; then, the clock was advanced 24 hr, 34 min, 12 sec 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.

III. Requirements for DSN Support

A. 26-m-Antenna Stations

As was done with previous *Apollo* missions, DSSs 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 (see Ref. 5).

B. 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.

C. 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.

Some results from the same experiment for *Apollo 14* are given in Ref. 4. 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.

D. 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.

E. 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 (see Table 3).

IV. DSN Pre-mission Preparations and Testing

A. 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 (Ref. 5) 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 deg, 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 1 wk 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.

DSSs 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.

B. DSS 14

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

V. DSN Operations During Mission

A. 26-m-Antenna Stations

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

B. DSS 14

Seven *Apollo* passes were tracked, as shown in Table 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 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.

C. 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.

D. 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 offline 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.

References

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4. Sjogren, W. L., et al., "S-Band Transponder Experiment," in *The Apollo 14 Preliminary Science Report*, NASA Document SP-272. National Aeronautics and Space Administration, Washington, D.C., 1971.

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Table 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 1 (contd)

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

Table 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

Table 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	↓