

407 pages

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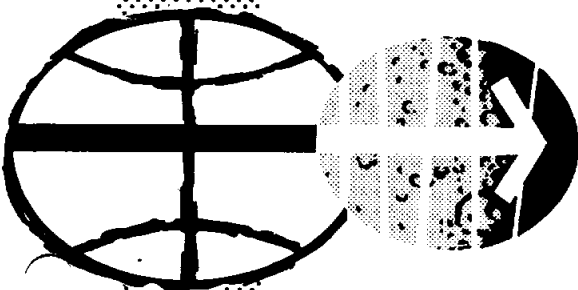


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 16 MISSION REPORT

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MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

AUGUST 1972

APOLLO SPACECRAFT FLIGHT HISTORY

<u>Mission</u>	<u>Mission report number</u>	<u>Spacecraft</u>	<u>Description</u>	<u>Launch date</u>	<u>Launch site</u>
PA-1	Postlaunch memorandum	BP-6	First pad abort	Nov. 7, 1963	White Sands Missile Range, N. Mex.
A-001	MSC-A-R-64-1	BP-12	Transonic abort	May 13, 1964	White Sands Missile Range, N. Mex.
AS-101	MSC-A-R-64-2	BP-13	Nominal launch and exit environment	May 28, 1964	Cape Kennedy, Fla.
AS-102	MSC-A-R-64-3	BP-15	Nominal launch and exit environment	Sept. 18, 1964	Cape Kennedy, Fla.
A-002	MSC-A-R-65-1	BP-23	Maximum dynamic pressure abort	Dec. 8, 1964	White Sands Missile Range, N. Mex.
AS-103	MFR-SAT-FE-66-4 (MSFC)	BP-16	Micrometeoroid experiment	Feb. 16, 1965	Cape Kennedy, Fla.
A-003	MSC-A-R-65-2	BP-22	Low-altitude abort (planned high-altitude abort)	May 19, 1965	White Sands Missile Range, N. Mex.
AS-104	Not published	BP-26	Micrometeoroid experiment and service module reaction control system launch environment	May 25, 1965	Cape Kennedy, Fla.
PA-2	MSC-A-R-65-3	BP-23A	Second pad abort	June 29, 1965	White Sands Missile Range, N. Mex.
AS-105	Not published	BP-9A	Micrometeoroid experiment and service module reaction control system launch environment	July 30, 1965	Cape Kennedy, Fla.
A-004	MSC-A-R-66-3	SC-002	Power-on tumbling boundary abort	Jan. 20, 1966	White Sands Missile Range, N. Mex.
AS-201	MSC-A-R-66-4	SC-009	Supercircular entry with high heat rate	Feb. 26, 1966	Cape Kennedy, Fla.
AS-202	MSC-A-R-66-5	SC-011	Supercircular entry with high heat load	Aug. 25, 1966	Cape Kennedy, Fla.

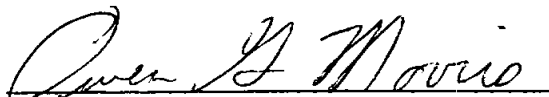
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APOLLO 16 MISSION REPORT

PREPARED BY

Mission Evaluation Team

APPROVED BY

A handwritten signature in cursive script, reading "Owen G. Morris", is written over a horizontal line.

Owen G. Morris  
Manager, Apollo Spacecraft Program

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS  
August 1972



Apollo 16 lift-off.

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## 1.0 SUMMARY

The Apollo 16 space vehicle was launched from the Kennedy Space Center (Launch Complex 39A) at 12:54:00 p.m. e.s.t. (17:54:00 G.m.t.) on April 16, 1972. The crew for this mission were Captain John W. Young, Commander; Lt. Commander Thomas K. Mattingly II, Command Module Pilot; and Lt. Colonel Charles M. Duke, Jr., Lunar Module Pilot.

The spacecraft/S-IVB combination was inserted into an earth parking orbit for spacecraft systems checkout and preparation for translunar injection. Following the translunar injection maneuver, the command and service modules were separated from the S-IVB for lunar module docking and ejection. One midcourse correction was required during the translunar phase to achieve the desired lunar orbit insertion maneuver conditions. The S-IVB impact point was not accurate because a leak in the auxiliary propulsion system produced an unpredictable thrust and also prevented the final targeting maneuver from being performed.

During translunar coast, a significant command and service module systems problem was encountered in that an indication of inertial measurement unit gimbal lock was received by the spacecraft computer when no gimbal lock condition existed. Subsequently, a software program was used to inhibit the computer from responding to such indications during critical operations. Activities during translunar coast included a cislunar navigation exercise, ultraviolet photography of the earth and moon, a fluid electrophoresis demonstration, and investigation of the visual light flash phenomenon that has been experienced on previous flights. The docked spacecraft were inserted into a lunar orbit of 170 by 58 miles following a service propulsion firing of 374.9 seconds.

Preparations for lunar descent proceeded on schedule; however, while activating the lunar module systems, the S-band steerable antenna was not movable in the yaw plane. As a result, the two omnidirectional antennas were used for most of the remaining lunar operations. The powered descent to the lunar surface was delayed approximately 5 3/4 hours because of oscillations detected in a secondary yaw gimbal actuator on the service propulsion system engine during systems checks for the circularization maneuver. A command-and-service-module-active rendezvous was performed to place the vehicles in close proximity while the problem was being evaluated. Tests and analyses showed that the redundant system was still usable and safe, had it been required. Therefore, the vehicles were separated again and the mission continued on a revised timeline.

The lunar module was landed approximately 276 meters northwest of the planned landing site at about 104 1/2 hours. About 100 seconds of hover time remained at touchdown. The landing coordinates were 8 degrees 59 minutes 29 seconds south latitude and 15 degrees 30 minutes 52 seconds east

longitude based on the Lunar Topographic Photomap of Descartes, First Edition, January 1972.

The first extravehicular activity was initiated at 119 hours after an 8-hour rest period. Television coverage of surface activity was delayed until the lunar roving vehicle systems were activated because the steerable antenna on the lunar module could not be used. The lunar surface experiments packages were deployed, but accidental breakage of the electronics cable rendered the heat flow experiment inoperable. After completing their activities at the experiments site, the crew drove the lunar roving vehicle west to Flag Crater where they performed the planned tasks. The inbound traverse route was just slightly south of the outbound route, and the next stop was Spook Crater. The crew then returned, via the experiment station, to the lunar module at which time they deployed the solar wind composition experiment. The duration of the extravehicular activity was approximately 7 hours 11 minutes and the distance traveled by the lunar roving vehicle was approximately 4.2 kilometers.

The second extravehicular traverse was south-southeast to a mare sampling area near the Cinco Craters on Stone Mountain. The crew then drove in a northwesterly direction, making stops near Stubby and Wreck Craters. The last leg of the traverse was north to the experiments station and the lunar module. The duration of the second extravehicular activity was approximately 7 hours 23 minutes and the distance traveled by the lunar roving vehicle was 11.1 kilometers.

Four stations were deleted from the third extravehicular traverse because of time limitations. The first stop was North Ray Crater and "House Rock", on the rim of North Ray Crater, was sampled. The crew then drove southeast to "Shadow Rock". The return route to the lunar module nearly retraced the outbound route. The duration of the third extravehicular activity was approximately 5 hours 40 minutes and the distance traveled by the lunar roving vehicle was 11.4 kilometers.

The lunar surface activities lasted 20 hours and 14 minutes and about 95 kilograms of samples were collected. The total distance traveled in the lunar roving vehicle was 26.7 kilometers. The crew remained on the lunar surface approximately 71 hours.

While the lunar module crew was on the surface, the Command Module Pilot was obtaining photographs, measuring physical properties of the moon and deep space, and making visual observations. Essentially the same complement of instruments was used to gather data as was used on the Apollo 15 mission; however, different areas of the lunar surface were flown over, and more comprehensive deep space measurements were made, providing scientific data that can be used to validate findings from Apollo 15 as well as add to the total store of knowledge of the moon and its atmosphere, the solar system, and galactic space.

Lunar ascent was initiated at 175 1/2 hours and was followed by a normal rendezvous and docking. Attitude control of the lunar module was lost at jettison; consequently, a deorbit maneuver was not possible. The estimated orbital life of the lunar module is about 1 year.

The particles and fields subsatellite was launched into lunar orbit and normal systems operation was noted. However, the spacecraft orbital shaping maneuver was not performed prior to ejection and the subsatellite was placed in a non-optimum orbit that resulted in a much shorter life-time than the planned year. Loss of all subsatellite tracking and telemetry data on the 425th revolution (May 29, 1972) indicated that the subsatellite had impacted the lunar surface.

The mass spectrometer deployment boom stalled during a retract cycle and was, therefore, jettisoned prior to transearth injection. The second plane change maneuver and some orbital science photography were deleted so that transearth injection could be performed about 24 hours earlier than originally planned.

Activities during the transearth coast phase of the mission included photography for a Skylab contamination study, and completion of the visual light flash phenomenon investigation which had been partially accomplished during translunar coast. A 1-hour and 23-minute transearth extravehicular activity was conducted by the Command Module Pilot to retrieve the film cassettes from the scientific instrument module cameras, visually inspect the equipment, and expose a microbial response experiment to the space environment. Two midcourse corrections were made on the return flight to achieve the desired entry interface conditions.

Entry and landing were normal. The command module was viewed on television while on the drogue parachutes and continuous coverage was provided through crew recovery. The spacecraft landed at 0 degrees 42 minutes 0 seconds south latitude and 156 degrees 12 minutes 48 seconds west longitude, as determined by the onboard computer. Total time for the Apollo 16 mission was 265 hours, 51 minutes, and 5 seconds.

## 2.0 INTRODUCTION

The Apollo 16 mission was the second in the science-oriented J series of missions, and the vehicle configuration and science payload were similar to those of Apollo 15. The differences are described in Appendix A. A major objective of the mission was to investigate the lunar surface in the Descartes highlands area because it was considered to be representative of much of the moon's surface, and an area of this type had not been previously visited. A detailed assessment of the degree to which this and other mission objectives were accomplished is given in section 12.0.

This report primarily provides information on the operational and engineering aspects of the mission. Preliminary scientific results and launch vehicle performance are reported in references 1 and 2, respectively. A complete analysis of all applicable data is not possible within the time frame of the preparation of this report. Therefore, report supplements will be published as necessary. Appendix E lists the reports and gives their status, either published or in preparation.

Customary units of measurement are used in those sections of the report pertaining to spacecraft systems and trajectories. The International System of Units (IS) is used in sections pertaining to science activities. Unless otherwise specified, time is expressed as elapsed time from range zero (established as the integral second before lift-off), and does not reflect the two time updates shown in table 3-I. Mileage is given in nautical miles and weight is referenced to earth gravity.

### 3.0 TRAJECTORY

The trajectory profile of this mission was similar to that of Apollo 15. The major differences, aside from the trajectory differences necessary to reach another landing site, were the elimination of the command and service module orbit-shaping maneuver and a plane change maneuver, and the inability to deorbit the lunar module ascent stage. The sequence and definition of events for the Apollo 16 mission are shown in tables 3-I and 3-II. Tables 3-III and 3-IV contain the listing and definition of trajectory parameters, and table 3-V contains a summary of the maneuvers.

#### 3.1 LAUNCH AND TRANSLUNAR TRAJECTORIES

The launch trajectory is given in reference 3. The translunar injection was normal and ejection of the command and service module/lunar module from the S-IVB stage after the translunar injection firing were normal. One translunar midcourse correction was required.

#### 3.2 S-IVB STAGE

The S-IVB stage evasive maneuver and first lunar impact maneuver were performed. However, as a result of an auxiliary propulsion system leakage problem, the second lunar impact maneuver was cancelled. Therefore, the impact point of the S-IVB on the lunar surface was inaccurate. Further, tracking was lost at about 29 hours and this prevented an accurate determination of the impact point and time. Two determinations of the impact point have been made - one on the basis of tracking data and the other from lunar surface seismic data. The point determined from the seismic data was 1.3 degrees north latitude and 23.8 degrees west longitude; whereas, the point determined from tracking data was 2.1 degrees north latitude and 22.1 degrees west longitude. The final impact point will be published by the Marshall Space Flight Center after review of existing data.

#### 3.3 LUNAR ORBIT

##### 3.3.1 Orbital Phase

The lunar orbit insertion maneuver placed the spacecraft into an orbit having a 170-mile apocynthion and a 58-mile pericynthion. Four hours later, a descent orbit insertion maneuver was performed which lowered the

TABLE 3-I.- SEQUENCE OF EVENTS

<u>Events</u> <sup>a</sup>	<u>Elapsed time</u> <u>Hr:min:sec</u>
Lift-off (Range zero = 17:54:00 G.m.t., April 16, 1972)	00:00:00.6
Earth orbit insertion	00:11:56
Translunar injection maneuver	02:33:37
S-IVB/command and service module separation	03:04:59
Translunar docking	03:21:53
Spacecraft ejection	03:59:15
First midcourse correction	30:39:01
Scientific instrument module door jettison	69:59:01
Lunar orbit insertion	74:28:28
S-IVB lunar impact	75:08:04
Descent orbit insertion	78:33:45
Lunar module undocking and separation	96:14:00
Circularization maneuver	103:21:43
Powered descent initiation	104:17:25
Lunar landing	104:29:35
Mission Control Center time update (+00:11:48)	118:06:31
Start first extravehicular activity	118:53:38
Apollo lunar surface experiment package first data	121:44:00
End first extravehicular activity	126:04:40
Start second extravehicular activity	142:39:35
End second extravehicular activity	150:02:44
Start third extravehicular activity	165:31:28
Plane change	169:05:52
End third extravehicular activity	171:11:31
Lunar ascent	175:31:48
Vernier adjustment maneuver	175:42:18
Terminal phase initiation	176:26:05
Terminal phase finalization	177:08:42
Docking	177:41:18
Lunar module jettison	195:00:12
Separation maneuver	195:03:13
Mass spectrometer experiment and boom jettison	195:23:12
Subsatellite launch	196:02:09
Transearth injection	200:21:33
Mission Control Center time update (+24:46:00)	202:18:12
Second midcourse correction	214:35:03
Start transearth extravehicular activity	218:39:46
End transearth extravehicular activity	220:03:28
Third midcourse correction	262:37:21
Command module/service module separation	265:22:33
Entry interface (400 000 feet)	265:37:31
Begin blackout	265:37:47
End blackout	265:41:01
Forward heat shield jettison	265:45:25
Drogue deployment	265:45:26
Main parachute deployment	265:46:16
Landing	265:51:05

<sup>a</sup>See Table 3-II for identification of events shown in this table.

TABLE 3-II.- DEFINITION OF EVENTS

<u>Event</u>	<u>Definition</u>
Range zero	Final integral second before lift-off
Lift-off	Time of instrumentation unit umbilical disconnect as indicated by launch vehicle telemetry
Earth orbit insertion	S-IVB engine cutoff time plus 10 seconds as indicated by launch vehicle telemetry
Translunar injection maneuver	Start tank discharge valve opening, allowing fuel to be pumped to the S-IVB engine
S-IVB/command module separation, translunar docking, spacecraft ejection, scientific instrument module door jettison, lunar module undocking and separation, docking, lunar module jettison, and subsatellite launch	The time of the event based on analysis of spacecraft rate and accelerometer data
First midcourse correction, lunar orbit insertion, descent orbit insertion, circularization maneuver, powered descent initiation, plane change, lunar ascent, and transearth injection	The time the spacecraft computer commanded the engine on as indicated in the computer word telemetry data
Second and third midcourse corrections	Engine ignition as indicated by the appropriate engine bilevel telemetry measurement or other telemetry data
S-IVB lunar impact	The time determined from Apollo lunar surface experiment package seismic data.
Lunar landing	The time of first contact of lunar module footpads with the lunar surface as derived from spacecraft rate data
Beginning of extravehicular activity	The time cabin pressure reaches 3 psia during depressurization as indicated by telemetry data
End of extravehicular activity	The time cabin pressure reaches 3 psia during repressurization as indicated by telemetry data
Apollo lunar surface experiment package first data	The receipt of first data considered valid from the Apollo lunar surface experiments package telemetry
Terminal phase initiation	The time of start of the terminal phase initiation maneuver during the rendezvous sequence as calculated by the computer
Terminal phase finalization	The time during the rendezvous sequence when the first braking maneuver is performed as calculated by the computer
Command module/service module separation	The time of separation by command module/service module separation relays via the telemetry system
Entry interface	The time the command module reaches 400 000 feet geodetic altitude as indicated by the best estimate of trajectory
Begin blackout	The time of S-band communication loss due to air ionization during entry
End blackout	The time of aquisition of S-band communications following blackout
Forward heat shield jettison, drogue deployment, and main parachute deployment	The time of deployment as indicated by the relay actuations via the telemetry system
Earth landing	The time the spacecraft was visually observed to touch the water
Time update	The Mission Control Center time was updated twice during the mission to conform to the time in the onboard flight plan. NOTE: These time updates are not reflected in this report.



TABLE 3-III.- TRAJECTORY PARAMETERS<sup>a</sup>

Event	Reference body	Time hr:min:sec	Latitude deg:min	Longitude deg:min	Altitude n. mi.	Space-fixed velocity ft/sec	Space-fixed flight-path angle, deg	Space-fixed heading angle, deg E of N
Translunar phase								
Translunar injection	Earth	02:39:28	11:59 S	162:29 E	171.0	35 565.7	7.47	59.5
Command and service module/lunar module ejection from S-IVB	Earth	03:59:15	32:38 N	111:13 W	12 492.7	16 533.5	61.07	88.39
First midcourse correction	Earth	30:39:01	25:13 N	106:29 W	119 343.8	4 511.8	76.86	111.56
Ignition	Earth	30:39:03	25:13 N	106:30 W	119 345.3	4 508.1	76.72	111.50
Cutoff								
Scientific instrument module door jettison	Moon	69:59:01	02:45 S	54:56 W	11 135.4	3 896.5	-79.85	-82.39
Lunar orbit phase								
Lunar orbit insertion	Moon	74:28:28	08:09 N	166:38 W	93.9	8 105.4	-9.51	-89.95
Ignition	Moon	74:34:43	07:07 N	169:19 E	75.3	5 399.2	2.22	-95.5
Cutoff								
Descent orbit insertion	Moon	78:33:45	08:35 N	136:01 E	58.5	5 486.3	-0.40	-87.16
Ignition	Moon	78:34:09	08:37 N	137:16 W	58.4	5 281.9	0.10	-87.31
Cutoff								
Command and service module/lunar module separation	Moon	96:13:31	02:22 N	121:55 E	33.8	5 417.2	-1.43	-98.83
Command and service module circularization	Moon	103:21:43	08:53 N	151:59 W	59.2	5 277.8	-0.06	-87.75
Ignition	Moon	103:21:48	08:54 N	151:57 W	59.1	5 348.7	0.42	-87.75
Cutoff								
Powered descent initiation	Moon	104:17:25	08:40 S	32:44 E	10.5	5 548.8	-0.07	-93.04
Command and service module plane change	Moon	169:05:52	05:36 N	108:50 E	58.6	5 349.8	0.26	-97.57
Ignition	Moon	169:05:59	05:34 N	108:30 E	58.6	5 349.9	0.28	-98.93
Cutoff								
Ascent insertion	Moon	175:38:56	09:46 S	05:26 E	9.9	5 523.3	0.34	-93.88
Vernier adjustment	Moon	175:42:18	10:20 S	05:50 W	11.2	5 515.2	0.59	-91.89
Terminal phase initiation	Moon	176:26:05	06:53 N	147:22 W	40.2	5 351.6	-0.00	-82.07
Docking	Moon	177:41:18	10:32 S	55:39 W	65.6	5 313.7	-0.04	-90.33
Lunar module jettison	Moon	195:00:12	01:08 N	70:28 E	59.2	5 347.9	0.39	-100.50
Subsatellite launch	Moon	196:02:09	00:01 S	115:59 W	58.4	5 349.4	-0.41	-79.43
Transearth injection	Moon	200:21:33	09:43 N	175:16 E	52.2	5 383.6	-0.15	-85.80
Ignition	Moon	200:24:15	10:58 N	164:21 E	59.7	8 663.0	5.12	-82.37
Cutoff								
Translunar coast								
Second midcourse correction	Earth	214:35:03	03:46 S	74:32 E	183 668.0	3 806.8	-75.08	165.08
Ignition	Earth	214:35:25	03:46 S	74:30 E	183 664.8	3 807.9	-80.35	164.99
Cutoff								
Third midcourse correction	Earth	262:37:21	29:38 S	82:11 E	25 312.9	12 256.5	-69.02	157.11
Ignition	Earth	262:37:27	29:38 S	82:10 E	25 305.2	12 258.3	-69.02	157.10
Cutoff								
Entry and landing phases								
Entry interface	Earth	265:37:31	19:52 S	162:08 W	65.8	36 196.1	-6.55	21.08
Landing	Earth	265:51:05	00:42 S	156:13 W	—	—	—	—

<sup>a</sup>See Table 3-IV for trajectory parameter definitions.

TABLE 3-IV.- DEFINITION OF TRAJECTORY AND ORBITAL PARAMETERS

<u>Trajectory parameters</u>	<u>Definition</u>
Geodetic latitude	The spherical coordinate measured along a meridian on the earth from the equator to the point directly beneath the spacecraft, deg:min
Selenographic latitude	The definition is the same as that of the geodetic latitude except that the reference body is the moon rather than the earth, deg:min
Longitude	The spherical coordinate, as measured in the equatorial plane, between the plane of the reference body's prime meridian and the plane of the spacecraft meridian, deg
Altitude	The distance measured between the spacecraft and the reference radius of the earth along a line from the center of the earth to the spacecraft. When the reference body is the moon, it is the distance measured from the spacecraft along the local vertical to the surface of a sphere having a radius equal to the distance from the center of the moon to the landing site, ft or miles
Space-fixed velocity	Magnitude of the inertial velocity vector referenced to the body-centered, inertial reference coordinate system, ft/sec
Space-fixed flight-path angle	Flight-path angle measured positive upward from the body-centered local horizontal plane to the inertial velocity vector, deg
Space-fixed heading angle	Angle of the projection of the inertial velocity vector onto the body-centered local horizontal plane, measured positive eastward from north, deg
Apogee	The point of maximum orbital altitude of the spacecraft above the center of the earth, miles
Perigee	The point of minimum orbital altitude of the spacecraft above the center of the earth, miles
Apocynthion	The point of maximum orbital altitude above the moon as measured from the radius of the lunar landing site, miles
Pericynthion	The point of minimum orbital altitude above the moon as measured from the radius of the lunar landing site, miles
Period	Time required for spacecraft to complete 360 degrees of orbit rotation, min
Inclination	The true angle between the spacecraft orbit plane and the reference body's equatorial plane, deg
Longitude of the ascending node	The longitude at which the orbit plane crosses the reference body's equatorial plane going from the Southern to the Northern Hemisphere, deg

TABLE 3-V.- MANEUVER SUMMARY

## (a) Translunar

Maneuver	System	Ignition time, hr:min:sec	Firing time, sec	Velocity change, ft/sec	Resultant perilune conditions				
					Altitude, miles	Velocity, ft/sec	Latitude, deg:min	Longitude, deg:min	Arrival time, hr:min:sec
Translunar injection	S-IVB	2:33:37	341.9	10 389.6	146.7	7941.1	7:48 N	178:06 E	74:32:22
First midcourse correction	Service propulsion	30:39:01	2.0	12.5	71.7	8180.0	7:47 N	176:47 E	74:32:07

## (b) Lunar orbit

Maneuver	System	Ignition time, hr:min:sec	Firing time, sec	Velocity change, ft/sec	Resultant orbit	
					Apocynthion, miles	Pericyynthion, miles
Lunar orbit insertion	Service propulsion	74:28:28	374.9	2802.0	170.3	58.1
Descent orbit insertion	Service propulsion	78:33:45	24.4	209.5	58.5	10.9
Circularization	Service propulsion	103:21:43	4.7	81.6	68.0	53.1
Powered descent initiation	Descent propulsion	104:17:25	734.0	6703.0	---	---
Lunar orbit plane change	Service propulsion	169:05:52	7.1	124.0	64.6	55.0
Ascent	Ascent propulsion	175:31:48	427.7	6054.2	40.2	7.9
Terminal phase initiation	Ascent propulsion	176:26:05	2.5	78.0	64.2	40.1

## (c) Transearth

Event	System	Ignition time, hr:min:sec	Firing time, sec	Velocity change, ft/sec	Resultant entry interface condition				
					Flight-path angle, deg	Velocity, ft/sec	Latitude, deg:min	Longitude, deg:min	Arrival time, hr:min:sec
Transearth injection	Service propulsion	200:21:33	162.3	3370.9	-7.44	36 196.9	21:30 S	162:43 W	265:36:52
Second midcourse correction	Reaction control	214:35:03	8.0	3.4	-6.5	36 196.4	19:48 S	162:05 W	265:47:34
Third midcourse correction	Reaction control	262:37:21	3.2	1.4	-6.48	36 196.2	19:44 S	162:06 W	265:47:32

apocynthion to 58 miles and the pericynthion to 11 miles. After lunar module separation and while preparing the command and service module for the lunar orbit circularization maneuver, a service propulsion system control problem was detected (section 14.1.10) which caused a 5 3/4-hour delay in the circularization maneuver and the lunar module descent.

## 3.3.2 Descent

At powered descent initiation, the lunar module was at an altitude of 66 500 feet and the target was 3.56 miles out of the orbital plane.

A landing site update of 800 feet downrange was entered into the onboard computer about 2 minutes after powered descent initiation. Landing occurred 12 minutes and 10 seconds after engine ignition at 8 degrees 59 minutes 29 seconds south latitude and 15 degrees 30 minutes 52 seconds east longitude as shown on the NASA Lunar Topographic Photomap of Descartes, First Edition, January, 1972 (fig. 3-1). This point is 270 meters (886 ft) north and 60 meters (197 ft) west of the prelaunch target point.

### 3.3.3 Ascent and Rendezvous

The lunar module ascent stage lifted off from the lunar surface at 175:31:48 and was inserted into a 40-mile by 8-mile lunar orbit about 7 minutes later. Insertion was approximately 33 000 feet further downrange than desired, and a vernier adjustment maneuver of 10 ft/sec was necessary to change the orbit to the desired conditions. The required rendezvous maneuvers were performed and the lunar module was docked with the command and service module about 2 hours and 10 minutes after lunar lift-off.

### 3.3.4 Lunar Module Deorbit Maneuver

It was planned to deorbit the lunar module ascent stage to impact the lunar surface at a predetermined target point. However, immediately after the lunar module was jettisoned, attitude control of the lunar module was lost (see sec. 14.2.6). As a result, the ascent stage remained in lunar orbit with an expected orbital lifetime of about one year.

### 3.3.5 Orbit-Shaping Maneuver and Subsatellite Launch

An orbit-shaping maneuver was to have been accomplished in order to position the command and service module properly for launching the particles and fields subsatellite into an orbit that would provide a minimum lifetime of one year. However, because of the service propulsion system control problem mentioned previously, the maneuver was cancelled. As a result, the subsatellite was launched into an orbit that provided a lifetime considerably less than planned.

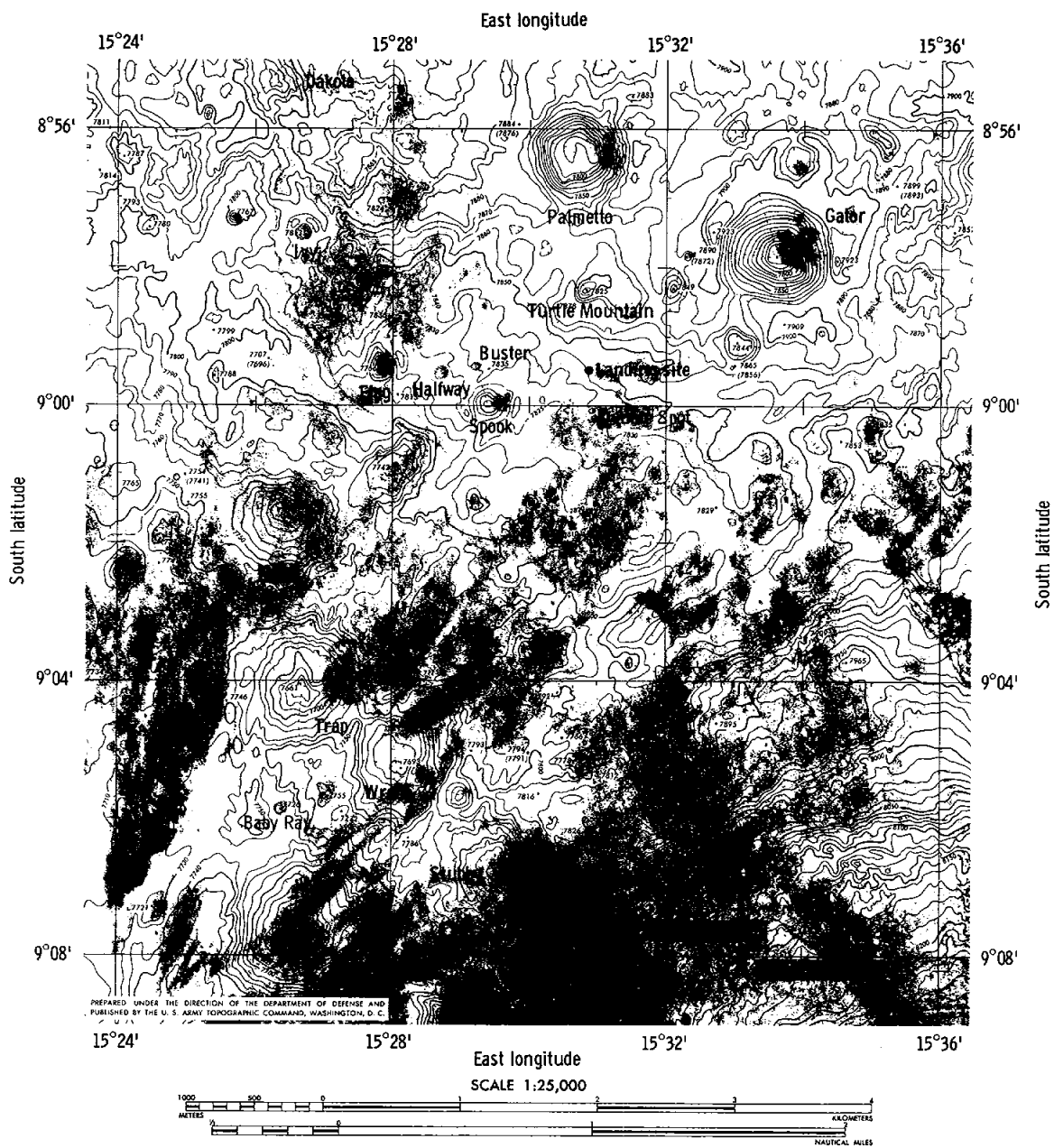


Figure 3-1.-- Lunar module landing site on photomap of Descartes.

### 3.4 TRANSEARTH AND ENTRY TRAJECTORY

The transearth injection maneuver was performed after 64 revolutions. Two midcourse corrections were made during transearth flight to achieve the desired entry interface conditions. The command and service modules were separated 15 minutes prior to entry interface. Entry was nominal with the command module landing about 3 miles from the target point. The landing coordinates, determined from the spacecraft computer, were 0 degree 42 minutes 0 seconds south latitude and 156 degrees 12 minutes 48 seconds west longitude.

## 4.0 LUNAR SURFACE SCIENCE

The experiments which comprised the Apollo lunar surface experiments package for this mission consisted of a passive seismometer, an active seismometer, a lunar surface magnetometer, and a heat flow experiment. Other lunar surface experiments consisted of a portable magnetometer experiment, a far ultraviolet camera/spectroscope experiment, a cosmic ray detector experiment, a solar wind composition experiment, geological investigation, and a soil mechanics experiment. Descriptions of the experiment equipment or references to other documents in which descriptions may be found are contained in appendix A. A comprehensive discussion of the preliminary scientific results of the mission are contained in reference 1.

### 4.1 SUMMARY OF LUNAR SURFACE ACTIVITIES

The Commander landed the lunar module on an undulating cratered surface about 270 meters north and 60 meters west of the preplanned target point. It was landed on the west side of a 5-meter-deep crater and with the minus-Y footpad adjacent to a 50-centimeter block, one of many blocks of varying sizes that dot the landscape. Figure 4-1 shows the proximity of the lunar module to the edge of the crater.

The topographic characteristics of the Descartes highlands landing site provided the opportunity for exploration and sampling of a kind of terrain never before visited on the lunar surface. During the approximately 71 hours on the surface, the crew completed three periods of extravehicular activity. The events of each of the three periods are summarized in table 4-1 and the routes traversed are shown in figure 4-2. The arrangement of the experiment equipment is shown in figure 4-3. More detailed descriptions of the lunar surface activities are given in sections 4.11 and 9.8.

### 4.2 APOLLO LUNAR SURFACE EXPERIMENTS PACKAGE CENTRAL STATION

The site selected for emplacement of the Apollo lunar surface experiments package was approximately 95 meters southwest of the lunar module. As shown in figure 4-4, the deployment site is highly cratered and rock strewn but this was unavoidable because this is the general character of the terrain. While the Lunar Module Pilot was carrying the experiments package to the deployment site, subpackage 2 fell off the carry bar. The subpackage became detached because the latch pin had not locked. Lunar dirt in the subpackage socket had prevented the flanged end of the carry

TABLE 4-I.- LUNAR SURFACE EXTRAVEHICULAR ACTIVITY EVENTS

Elapsed time, hr:min:sec	Event
First Extravehicular Activity	
118:53:38	Lunar module cabin depressurized.
119:25:29	Lunar roving vehicle offloaded.
119:32:44	Lunar roving vehicle deployed.
119:54:01	Far ultraviolet camera/spectroscope deployed.
120:05:40	Television activated.
120:21:35	Apollo lunar surface experiments package off-
	loaded.
122:55:23	Apollo lunar surface experiments package deployed,
	deep core sample gathered, and lunar roving ve-
	hicle configured for traverse.
122:58:02	Departed for station 1.
123:23:54	Arrived at station 1. Performed radial sampling,
	gathered rake and documented samples, and per-
	formed panoramic and stereographic photography.
124:14:32	Departed for station 2.
124:21:10	Arrived at station 2. Performed a lunar portable
	magnetometer measurement, gathered samples and
	performed panoramic and 500-mm photography.
124:48:07	Departed for Apollo lunar surface experiments
	package site (station 3/10).
124:54:14	Arrived at station 3/10. Performed "Grand Prix"
	with lunar roving vehicle, retrieved core sam-
	ple, and armed the active seismic experiment
	mortar package.
125:05:08	Departed for lunar module.
125:05:09	Arrived at lunar module. Deployed solar wind
	composition experiment, gathered samples, per-
	formed photography, and commenced with extra-
	vehicular activities closeout.
125:07:00	Solar wind composition experiment deployed.
126:04:40	Lunar module cabin repressurized.
Second Extravehicular Activity	
142:39:35	Lunar module cabin depressurized.
142:49:29	Prepared lunar roving vehicle for traverse.
143:31:40	Departed for station 4.



TABLE 4-I.- LUNAR SURFACE EXTRAVEHICULAR ACTIVITY EVENTS

Elapsed time, hr:min:sec	Event
144:07:26	Arrived at station 4. Performed penetrometer measurements, gathered samples, obtained a double core tube sample, gathered a soil trench sample, and performed 500-mm and panoramic photography.
145:05:16	Departed for station 5.
145:10:05	Arrived at station 5. Gathered samples, performed lunar portable magnetometer measurement, and performed panoramic photography.
145:58:40	Departed for station 6.
146:06:37	Arrived at station 6. Gathered samples and performed panoramic photography.
146:29:18	Departed for station 8 (station 7 deleted).
146:40:19	Arrived at station 8. Gathered samples, obtained a double core tube sample, and performed panoramic photography.
147:48:15	Departed for station 9.
147:53:12	Arrived at station 9. Gathered samples, obtained single core tube sample, and performed panoramic photography.
148:29:45	Departed for station 10.
148:54:16	Arrived at station 10. Gathered samples, performed penetrometer measurements, obtained a double core tube sample, and performed panoramic photography.
149:21:17	Departed for lunar module.
149:23:24	Arrived at lunar module and began extravehicular activity closeout.
150:02:44	Lunar module cabin repressurized.
Third Extravehicular Activity	
165:31:28	Lunar module cabin depressurized.
165:43:29	Prepared lunar roving vehicle for traverse.
166:09:13	Departed for station 11.
166:44:50	Arrived at station 11. Gathered samples, performed 500-mm and panoramic photography.
168:09:46	Departed for station 13.
168:17:39	Arrived at station 13. Gathered samples, performed lunar portable magnetometer measurement and performed panoramic photography.

TABLE 4-I.- LUNAR SURFACE EXTRAVEHICULAR ACTIVITY EVENTS (Concluded)

Elapsed time, hr:min:sec	Event
168:46:33	Departed for station 10 prime.
169:15:38	Arrived at station 10 prime. Gathered samples, obtained a double core tube sample, and performed 500-mm and panoramic photography.
169:01:48	Drove lunar roving vehicle to lunar module. Gathered samples and commenced extravehicular activity closeout.
170:12:00	Solar wind composition experiment retrieved.
170:23:06	Departed for lunar roving vehicle final parking area.
170:27:09	Arrived at final parking area. Performed two lunar portable magnetometer measurements, gathered samples, and continued with extravehicular activity closeout.
171:01:42	Retrieved film from far ultraviolet camera/spectroscope.
171:11:31	Lunar module cabin repressurized.

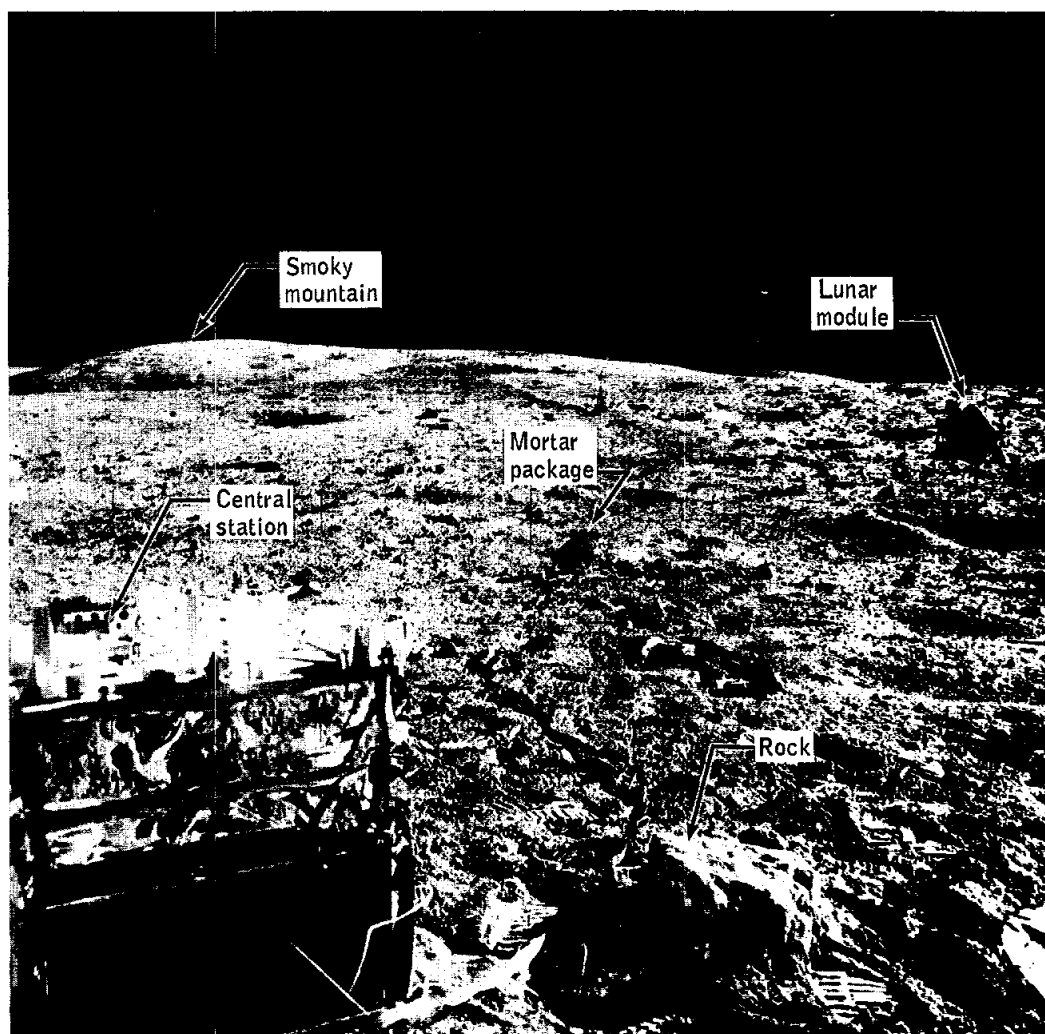


Figure 4-4.- Apollo lunar surface experiments package central station

bar from sliding all the way into place so that the pin could lock. As a result, the package was free to rotate and vertical oscillations caused the detachment. The Lunar Module Pilot knocked the dirt out of the socket and re-attached the package. Dropping of the package caused no operational degradation.

Initial data were received in the Mission Control Center at 1938 G.m.t. on April 21 and the received signal strength ( $-139 \pm 2$  dBm) was in the range of values measured on other packages operating on the moon. Within 68 minutes of emplacement of the central station, all instruments were turned on and their operational checkout showed normal performance except the heat flow experiment which was inoperative because of a broken cable, as discussed in section 4.6. The radioisotope thermoelectric power source is providing 70.4 watts, approximately 15 watts higher than the basic system requirement. The solid-state timer has generated all scheduled 18-hour pulses which provide a backup means of initiating certain functional changes.

The temperature of the central station electronics, as indicated by sensors on the thermal plate, has varied from a maximum of  $42.8^{\circ}$  C during lunar day to a minimum of  $2.8^{\circ}$  C during lunar night.

### 4.3 PASSIVE SEISMIC EXPERIMENT

The passive seismic experiment (S-031) was deployed as planned. All elements of the experiment have functioned normally with the exception of the thermal control system. Two days after activation, the temperature increased markedly beyond the controller set point and eventually exceeded the range of the sensor,  $61.4^{\circ}$  C. The temperature stabilized at night to  $52.2^{\circ}$  C. Photographs of the instrument show the shroud skirt to be raised at several places (fig. 4-5); further, dust was inadvertently kicked onto the skirt after the photographs were taken. These factors are believed to be responsible for the abnormal temperatures. The temperatures are not expected to affect instrument life or seismic data, but will degrade the tidal data.

Seismic signals were detected from surface activities by the crew and movements of the lunar roving vehicle at all points along the traverses (maximum range of 4.4 km). Abrupt changes in the signals detected from the rover appear to be correlated in some cases with the blockiness of the terrain being traversed. Other changes remain to be explained.

Seismic signals from the S-IVB impact, which preceded deployment of the Apollo 16 station, were recorded at all three seismic stations (Apollo stations 12, 14, and 15) (fig. 4-6). The first detectable signals arrived at station 12 in approximately 30 seconds, at station 14 in approximately 46 seconds, and at station 15 in approximately 148 seconds. The loss of normal S-IVB tracking data (see sec. 13.3) prevented accurate determination of the time and location of the impact. This uncertainty will greatly reduce the lunar structural interpretation based upon these data. As

data from the four stations will expand the knowledge of the lunar structure much beyond that previously possible.

Three grenades were fired on May 23 from the active seismic experiment mortar package (see sec. 4.4). The largest and the one having the longest range tilted the passive seismic experiment sensor 3 arc seconds southward. This tilt is within the capability of the passive seismic experiment leveling system and the experiment was re-leveled. The two smaller grenades showed no effect.

#### 4.4 ACTIVE SEISMIC EXPERIMENT

The active seismic experiment (S-033) mortar package was deployed about 17 meters northeast of the central station with the geophone line extending 90 meters northwest of the mortar package (fig. 4-4). The central station was commanded to high-bit-rate mode at 19:54:30 G.m.t. on April 21 to record the active seismic experiment/thumper mode of operation. Thumping operations began about 7 minutes later at geophone 3 (furthest from the central station) and proceeded at 4.5-meter intervals (except between positions 11 and 12 and positions 18 and 19 which are 9-meter intervals) toward geophone 1 (nearest to the central station). The final thumper charge was fired about 14 minutes after the first firing. The central station was commanded to normal bit rate at 20:16:32 G.m.t. The thumper was fired at the 19 scheduled cable positions. Two attempts were needed to fire the thumper at position 2 because the thumper was not armed for the necessary 5 seconds prior to firing. Seismic signals were recorded at all three geophones for all 19 thumper firings. A calibration pulse was sent after the last thumper firing verifying that all three geophones were still operational.

Minor difficulty was experienced in the deployment of the mortar package pallet when one of the four stakes that support the mortar package could not be deployed. This anomaly is discussed in section 14.4.2. The mortar package was leveled and armed to fire four grenades on command to distances of 150, 300, 900, and 1500 meters. Near the close of the third extravehicular activity, the mortar package roll angle sensor reading was off scale (see sec. 14.4.3); however, a television panorama taken near the close of the third extravehicular activity verified that the mortar package was properly positioned and aligned.

The central station was commanded to high bit rate at 0106 G.m.t. on April 24 to record the impulse produced by the lunar module ascent. A strong seismic signal was recorded by the geophone array. The central station is scheduled for periodic operation in the high-bit-rate mode for listening to detect natural seismic signals and to verify experiment operational capability.

On May 23, the Apollo lunar surface experiment package was commanded to high bit rate between 0520 and 0644 G.m.t. for the active seismic experiment/mortar mode of operation. Three of the four high-explosive grenades in the mortar package were successfully launched. Grenade 2 (1024 grams) was launched a distance of 900 meters; grenade 4 (695 grams) was launched a distance of 150 meters; and grenade 3 (775 grams) was launched a distance of 300 meters; in the sequence given. Grenade 1 (1261 grams and planned to be launched a distance of 1500 meters) was not launched because the mortar package pitch angle sensor went off-scale high after firing grenade 3. (See section 14.4.12 for a discussion of this anomaly.) The off-scale indication makes the pitch position of the launch assembly uncertain. Seismic signals were noted by all three geophones for each grenade launched. The data from the mortar firings combined with the data from the thumper mode of operation indicates that the regolith has a depth of about 12 meters in the Descartes area.

#### 4.5 LUNAR SURFACE MAGNETOMETER EXPERIMENT

The lunar surface magnetometer (S-034) was successfully deployed approximately 15 meters west of the central station (fig. 4-7). The experiment was initially commanded on during the first extravehicular activity. All operations of the experiment have been normal. A one-time site survey was successfully completed on April 28. The remanent magnetic field measured at the lunar surface magnetometer site is  $230 \pm 15$  gammas. The instrument is also continuously measuring magnetic fields induced in the lunar interior by changing solar magnetic fields.

#### 4.6 HEAT FLOW EXPERIMENT

Deployment of the heat flow experiment (S-037) was initiated on schedule. The experiment instrument package was moved to the selected site and the electronics cable was connected to the central station. A hole was drilled to the depth of the first bore stem section in 51 seconds at an average penetration rate of 2.3 centimeters per second. The second bore stem section was added and the hole drilled to the depth of the two sections in 39 seconds at an average rate of 1.8 centimeters per second. Upon adding the final section, the hole was drilled to the planned depth in 54 seconds at a rate of 1.3 centimeters per second. Total penetration was approximately 250 centimeters. The lunar surface wrench was used successfully to restrain the bore stems during power head removal.

Heat flow probe number 1 was inserted into bore hole number 1 to the full depth and both radiation shields were properly emplaced. While the Commander was working near the central station, he became entangled in the



Figure 4-7.- Lunar surface magnetometer experiment and Commander performing active seismic experiment.

heat flow experiment electronics cable and broke it loose at the connector to the central station. Further deployment was abandoned and the experiment is inoperable. The details of this failure are given in section 14.4.1.

#### 4.7 LUNAR PORTABLE MAGNETOMETER EXPERIMENT

The deployment and operation of the lunar portable magnetometer experiment (S-198) was normal in all respects; leveling, orientation, positioning, switching, and cable winding operations were accomplished without difficulty. The instrument was operated at four different sites. Digital readings relayed over the voice link indicated total magnetic field magnitudes of  $180 \pm 15$  gammas at station 2,  $125 \pm 15$  gammas at station 5,  $310 \pm 15$  gammas at station 13, and  $120 \pm 15$  gammas at the lunar roving vehicle final parking site. After completion of the first measurement at the final site, a lunar rock sample was placed on top of the magnetometer sensor block, and a second field measurement was made to study the magnetization of the sample.

#### 4.8 FAR ULTRAVIOLET CAMERA/SPECTROSCOPE EXPERIMENT

The far ultraviolet camera/spectroscope (S-201) was deployed approximately 2 meters southwest of the down-sun footpad of the lunar module with the camera in the shade and the battery in sunlight (fig. 4-8). Because of the landing delay and the consequently high sun angle, it was necessary to move the camera into the shade during the second and third extravehicular activities. Difficulty was experienced in adjustment of the azimuth ring. The condition degraded with each adjustment. Section 4.4.9 contains a discussion of this anomaly.

The camera was turned on at the beginning of the first extravehicular activity and operated until closeout of the third extravehicular activity for a span of approximately 51 hours. The film was retrieved for postflight analysis. The camera was pointed at 11 targets by the crew as planned. No data were recorded for the eleventh target because the camera had run out of film, as expected.

Imagery of the earth in the 1216-angstrom wavelength of hydrogen (Lyman-alpha) revealed that the geocorona is nearly spherical and extends out more than 10 earth radii (fig. 4-9). Imagery of the earth's atmosphere in the 1230- to 1550-angstrom range showed two auroral belts - one on either side of the magnetic equator and inclined about 15 degrees to the equator (fig. 4-10). Spectroscopic data without the lithium fluoride (LiF) transmission optics shows the 584-angstrom line of helium in the solar wind plasma. The photographs and spectra contain a great deal of astrophysical detail.





Figure 4-8.- Far ultraviolet camera/spectroscope experiment.

#### 4.9 COSMIC RAY DETECTOR EXPERIMENT

The panel array of the cosmic ray detector experiment (S-152) was exposed in its initial configuration upon jettisoning of the spacecraft-launch vehicle adapter panels. The hidden surface of panel 4 was partly exposed by the Commander early in the first extravehicular activity (fig. 4-11). The planned area of exposure for detecting particles at the lunar surface could not be obtained because the experiment mechanism jammed as described in section 14.4.4. The detector panel array was retrieved at

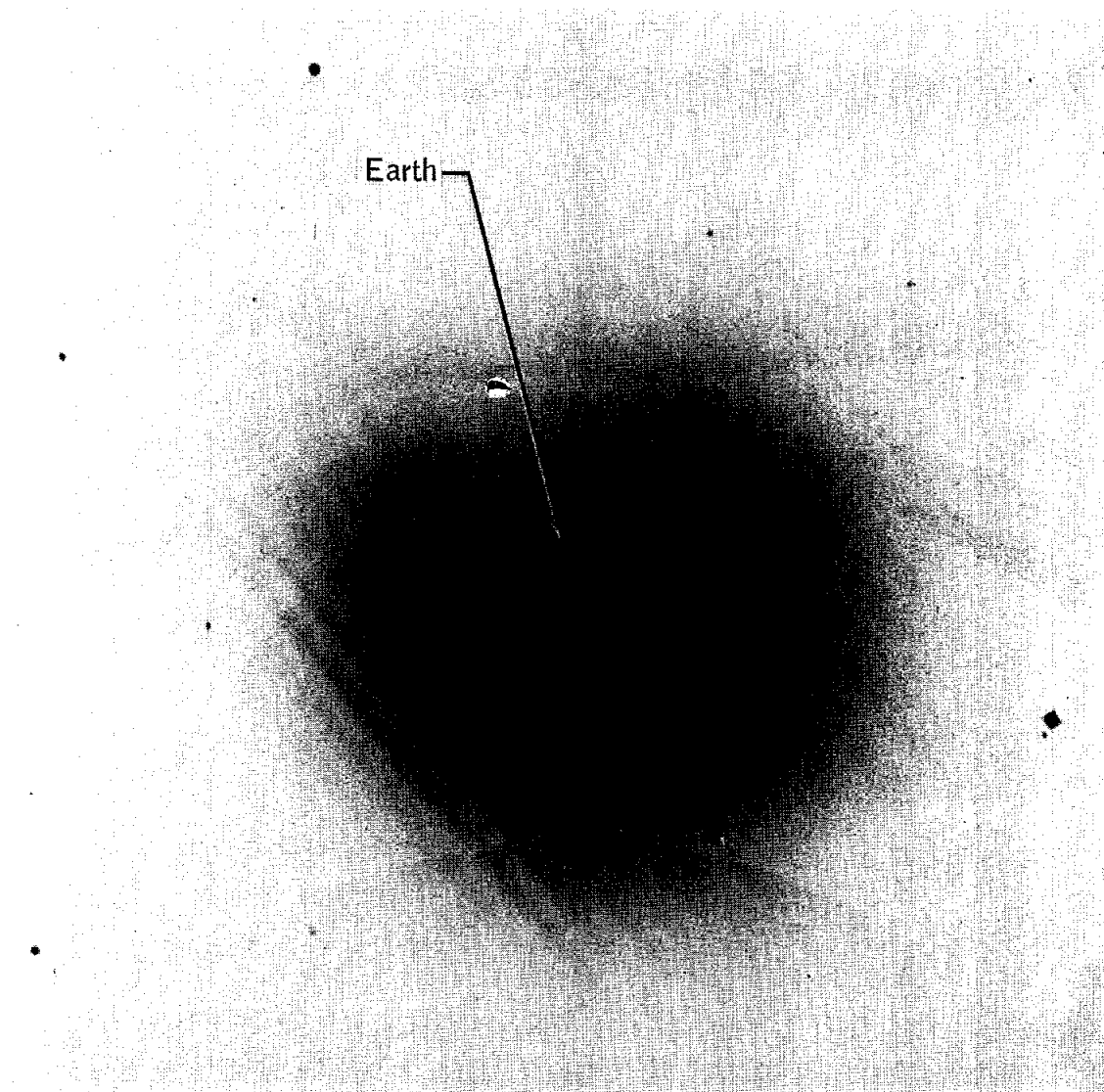


Figure 4-9.- Lyman-alpha imagery of hydrogen cloud surrounding earth.

the end of the third extravehicular activity, folded in the proper configuration for transearth coast data collection, and returned for analysis. It was difficult to separate the panel assembly from the main frame at the end of the third extravehicular activity because of thermal expansion of the Teflon slides.

The plastic in all panels of the experiment was degraded by heating above the design limit of  $54^{\circ}\text{C}$ , at which temperature degradation begins. The high temperature was most likely caused by a film accumulating on the thermal control surface, in addition to lunar dust. Analysis of the film has not been completed.

Analysis of the data received on the lunar surface and during trans-lunar and transearth coast will be degraded because of the minor solar flare which occurred during translunar flight. This flare blanketed the detector panels with low energy tracks which interfere with the analysis of the higher energy tracks received during the previously discussed periods. Also, the resolution will be reduced because of the high temperature which the experiment hardware experienced on the lunar surface.

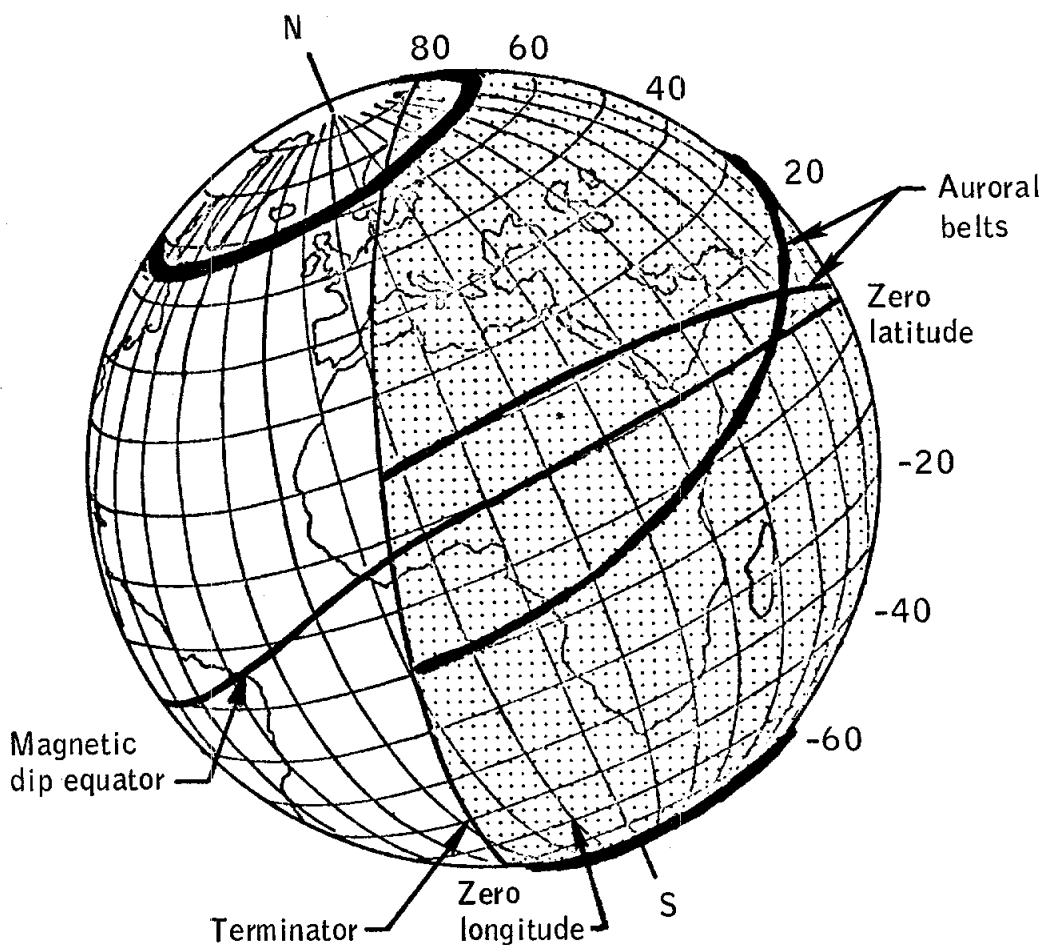


Figure 4-10.- Newly discovered auroral belts.

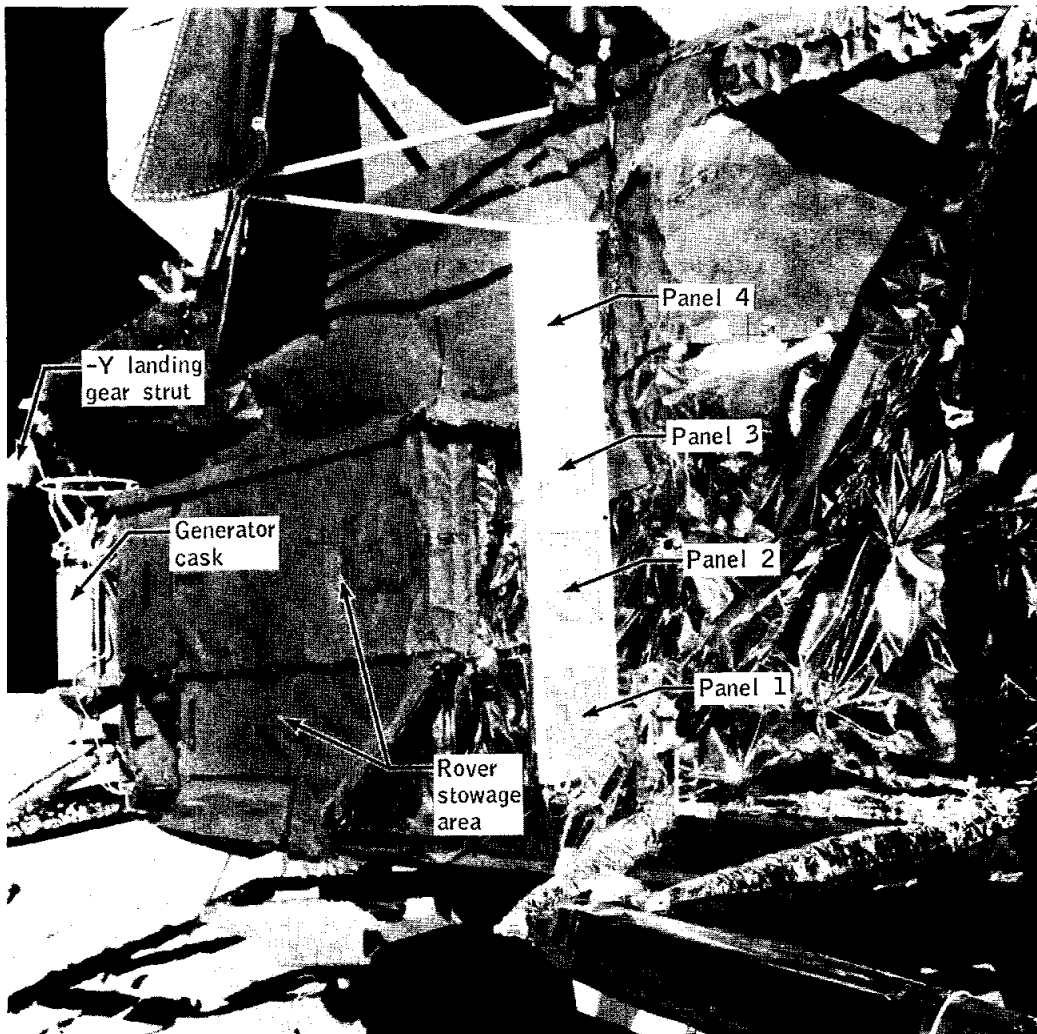


Figure 4-11.- Cosmic ray detector experiment.

As a result of the incomplete exposure of panel 4, the portion of the experiment designed to measure neutron flux was degraded, as were those designed to measure solar wind gas, and search for radon ( $\text{Rn}^{222}$ ) and argon ( $\text{Ar}^{40}$ ).

The plastics should be suitable for a study of solar wind particles. In addition, both solar and galactic cosmic ray tracks have been observed in the plastics and some of the glasses of the panels. The plastics that were pre-irradiated with neon ( $\text{Ne}^{20}$ ) showed annealing effects from overheating, but neutrons from the fuel cask will be measurable.

#### 4.10 SOLAR WIND COMPOSITION EXPERIMENT

The solar wind composition experiment (S-080) for this mission differed from those of previous missions in that pieces of platinum foil were attached to the specially prepared aluminum foil used to entrap noble gas particles. This was done to determine whether or not the platinum foil pieces could be cleaned with fluoridic acid to remove lunar-dust contamination without destroying rare gas isotopes of solar wind origin up to the mass of krypton.

The experiment was deployed about 18 meters northwest of the lunar module at the end of the first extravehicular activity period and retrieved near the end of the third extravehicular period. The total foil exposure time was 45 hours and 5 minutes, some 3 hours longer than that of any previous mission.

#### 4.11 LUNAR GEOLOGY

##### 4.11.1 Sample Collection

Areas visited and sampled for the lunar geology investigation (S-059) during the extravehicular activities included the northwest flank of Stone Mountain (Descartes Mountains), Flag and Spook Craters west of the lunar module landing site on the Cayley Plains, North Ray Crater, and South Ray Crater ejecta on the plains between the lunar module and Stone Mountain. The sampling stations and traverses are shown in figure 4-2.

On the first traverse, the tasks at stations 1 and 2 were performed as planned except for sampling the rim of Spook Crater. A 2.6-meter deep core sample was obtained at the Apollo lunar surface experiments package site.

Station 7 was deleted from the second extravehicular activity to allow more time for sampling in the lunar module/Apollo lunar surface experiments package area. Double cores were collected at stations 4, 8, and 10. Documented and rake/soil samples were collected at all traverse stops except for station 9 which was devoted to obtaining undisturbed surface material with the lunar surface samplers, sampling the top and bottom of a large boulder, and sampling the soil beneath the boulder after it was overturned.

The third extravehicular activity, limited to 5 hours, permitted only North Ray Crater to be studied. Stops were made at stations 11 and 13, and documented and rake/soil samples were collected. The preplanned stations 14 (flank of Smoky Mountain), 15, 16, and 17 (Cayley formation and Palmetto Crater) were deleted. At station 13, a soil sample that had probably been in permanent shadow was obtained from the base of a large overhang on a 2-meter-high boulder (fig. 4-12). Additional sampling at the lunar module/experiments site included: a second double core (originally assigned to station 14), two rake/soil samples across a probable ray contact, seven bags of documented rock samples, and three large rocks.

#### 4.11.2 Summary of Geology

Samples were collected that are typical of the Cayley Plains in the landing area from station 1 (Flag and Plum Craters) and station 2 (Buster Crater) as well as some samples from the lunar module/Apollo lunar surface

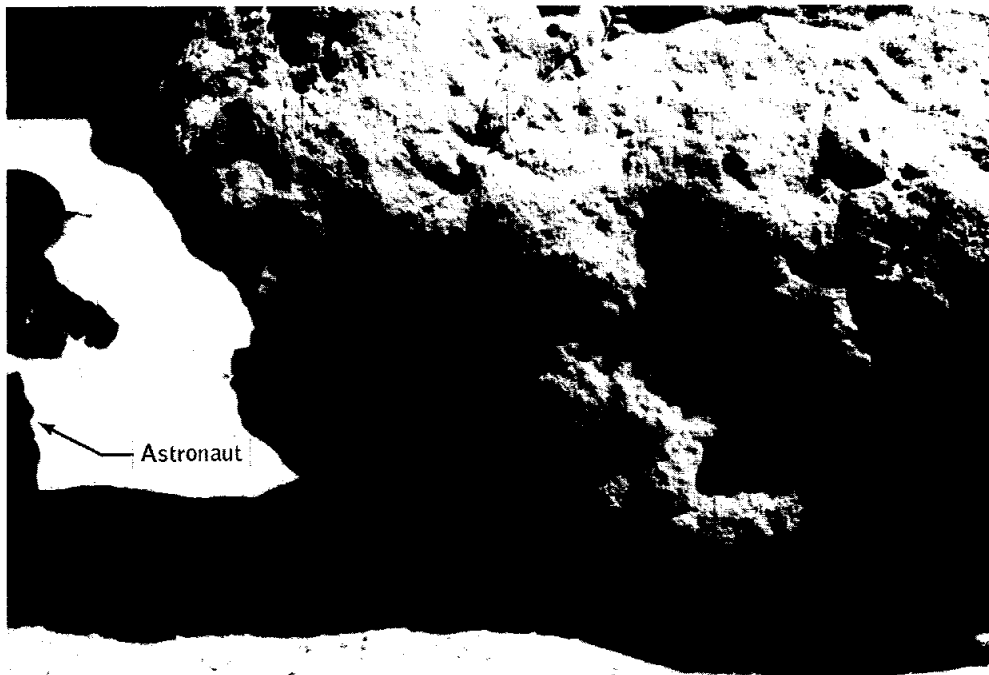


Figure 4-12.- "Shadow Rock".

experiments package site (station 3/10); South Ray Crater ejecta was collected at stations 4, 8, 9, and station 3/10; North Ray Crater ejecta were collected at stations 11 and 13. Descartes materials were collected from the flank of Stone Mountain at stations 4, 5, and 6.

The Cayley formation appears to consist of light- and dark-colored breccias, possibly in interstratified layers. It does not consist, at least in this area, of lava flows, as had been widely supposed. The Descartes highland materials of Stone Mountain consist of light-colored breccias and crystalline fragments of, as yet, unknown origin.

No bedrock was sampled by the crew although they tentatively identified bedrock layers in North Ray Crater and in a large crater high on Stone Mountain. Elsewhere, all large craters were heavily mantled with deep regolith that completely masks any possible strata. Boulders of varying sizes were sampled by the crew, the largest being the 20-meter "House Rock" on the rim of North Ray Crater (fig. 4-13).

About 95 kilograms of documented rock and soil samples were obtained. The material collected from widely distributed sampling stations, including samples of ejecta from deep craters, should provide for the study of the Cayley Plains region down to depths of 200 meters.

#### 4.11.3 Equipment

The equipment used during the geology portion of the extravehicular activities performed well with the following exceptions:

- a. One of the retractable tethers (yo-yo's) would not fully retract. Postflight inspection showed that the tether was operating, but that the friction increased during the retraction cycle (see sec. 14.3.7).
- b. The vertical staff of the gnomon was pulled off at station 6. When the gnomon was being unstowed, the leg assembly stayed in the bag and the vertical staff came out by itself (see sec. 14.4.5).
- c. The Velcro hook patch which provides the attachment point for a Velcro wrapping strap on each of the two padded sample bags came off before use (see sec. 14.4.10).
- d. The reseau plate on the Lunar Module Pilot's 70-mm electric data camera was smeared during a magazine change between extravehicular activities 2 and 3.
- e. Sample return container 1 did not seal properly because part of a sample collection bag was caught in the seal area between the knife edge and the indium seal.

f. The sample collection bags fell off the portable life support system mounts (see sec. 14.4.8).

g. The documented sample bag dispensers repeatedly fell off the attachment brackets on the 70-mm camera (see sec. 14.4.6).

h. The screws came loose on one of the documented sample bag dispenser assemblies (see sec. 14.4.7).

i. The lanyard loop came off the penetrometer stowage release pin (see sec. 14.4.11).

#### 4.11.4 Photography

A total of 1774 photographs were taken on the lunar surface with the 70-mm electric data cameras using the 60-mm and 500-mm focal-length lenses, and 4 1/2 magazines of 16-mm lunar surface data acquisition camera film were exposed. At least one 360-degree 60-mm panorama was taken at each station. The first successful use of a polarimetric filter on the lunar surface was an 80-meter stereobase polarimetric panorama of the interior of North Ray Crater.

#### 4.12 SOIL MECHANICS EXPERIMENT

The soil mechanics experiment (S-200) provided a greater amount of qualitative data on the properties of the lunar surface and subsurface soils than has been previously obtained. All parts of the soil mechanics experiment were completed with the exception of the soil mechanics trench at station 10 which was omitted because of time limitations.

Preliminary analysis has indicated that the self-recording penetrometer performed normally with a loss of data for only one of eleven tests. Four cone penetration tests were accomplished at station 4. Five cone penetration tests were performed between the experiments station and the lunar module. Of these, four were on a line between the deep drill core site and the station 10 double-core tube site. Cone penetration depths range between 20 and 75 centimeters. Additionally, two plate-load tests were performed at station 10.

Preliminary analysis of the self-recording penetrometer data has indicated that the soil density and strength characteristics are highly variable, both laterally and vertically. Definite evidence of layering is visible in some of the load-versus-penetration tracks indicated on the penetrometer.



## 5.0 INFLIGHT SCIENCE AND PHOTOGRAPHY

This section contains a discussion of experiments and science-oriented detailed objectives which were performed in lunar orbit, and during translunar and transearth flight. Preliminary scientific findings are not given in detail in the discussion since this information will be included in reference 1, which is in preparation. The experiment equipment was similar to that of the Apollo 15 mission. Appendix A provides information on minor changes from the Apollo 15 configuration.

Experiments located in the scientific instrument module consisted of a gamma-ray spectrometer, an X-ray spectrometer, an alpha-particle spectrometer, a mass spectrometer, and a subsatellite which was the vehicle for three experiments that were to obtain data on particles and fields. The scientific instrument module equipment also included a mapping camera, a panoramic camera, and a laser altimeter.

The other experiments and detailed objectives performed during flight, and which required active crew participation, consisted of: an S-band transponder experiment; a down-link bistatic radar experiment; ultraviolet photography of the earth and moon; photography of the Gegenschein, other astronomical subjects, and the lunar surface; visual observations from lunar orbit; an experiment to determine microbial response to the space environment; investigation of the visual light flash phenomenon; and a demonstration of fluid electrophoresis in space. Experiments that did not require active crew participation consisted of measurement of meteoroid impacts on the spacecraft windows, a biostack experiment to determine the effects of high-energy heavy ions on biological systems, and measurement of bone mineral loss in the crew.

### 5.1 GAMMA-RAY SPECTROMETER EXPERIMENT

Over 80 hours of prime data were obtained in lunar orbit and during transearth coast from the gamma ray spectrometer experiment (S-160). Some planned data measurements were not made in lunar orbit because of the early termination of lunar orbit operations. However, the large amount of data reduced and analyzed indicates that all major objectives were accomplished.

The instrument performed satisfactorily throughout the mission. Gain stability was significantly improved over that of Apollo 15. At initial turn-on, the spectrometer calibration was the nominal preflight value. Thereafter, a small downward gain drift occurred, after which the gain calibration was stable. Energy resolution of the instrument based upon

measurements of the classical monoenergetic line of 0.511 Mev in the spectrum was improved approximately 15 percent over Apollo 15. The extraneous shield event counts that had been noted in preflight calibration were experienced during flight. However, the rate stabilized and was not detrimental to the data. As a result of the problem with the mapping camera deployment mechanism, the mapping camera door remained open during the entire period in which the gamma ray spectrometer was active in lunar orbit. This resulted in some loss in sensitivity due to the increased background radiation contributed by the thorium lens of the mapping camera. The deployment boom failed to fully retract on three occasions but the condition had no effect on the data. Details of the boom failure are noted in section 14.1.9.

Maps prepared from over 50 hours of data confirm earlier conclusions pertaining to the geochemistry of the lunar surface, that the regions of highest radioactivity are the western maria - Oceanus Procellarum and Mare Imbrium. Data obtained during transearth coast indicate that the spacecraft background radiation and the total cosmic gamma-ray spectrum are in essential agreement with Apollo 15 results. Preliminary analysis of data collected from a scan of the supergalactic equator along four planes indicates that galactic gamma rays exhibit anisotropic properties.

## 5.2 X-RAY FLUORESCENCE EXPERIMENT

Over 60 hours of prime data were obtained with the X-ray fluorescence experiment (S-161) and nearly 12 hours were spent with the spectrometer pointed at two celestial X-ray sources, Scorpius X-1 and Cygnus X-1. The flight plan changes had an effect upon the schedule for ground-based astronomical observations; however, some coverage was obtained. The following table gives the times of the observations and indicates the coverage by the ground-based observatories.

Observation	Object	Starting time, G.m.t., April 1972, day:hr:min	Duration of observation, hr:min	Ground-based observatory Coverage
1	Sco X-1	25:03:25	00:40	-
2	Cyg X-1	25:22:55	03:00	-
3	Sco X-1	26:02:15	02:30	<sup>a</sup> Algonquin
4	Sco X-1	26:20:15	03:20	<sup>b</sup> Leyden, <sup>c</sup> Wise
5	Cyg X-1	27:02:45	02:55	-

<sup>a</sup>Algonquin Radio Observatory, Canada

<sup>b</sup>Leyden (optical) Observatory, South Africa

<sup>c</sup>Wise (optical) Observatory, Israel

The overall performance of the instrument was satisfactory. Nominal operation of the four detectors was evidenced by calibration data from the built-in sources. A high count rate in channel 1 of detector 1 was observed, but a similar high count was observed during the Apollo 15 mission. Detectors 2 and 3 incorporate filters to enhance the detection of X-rays from aluminum and magnesium sources, but detector 1 is unfiltered. Detector 4 is part of the solar monitor and does not view the lunar surface. The orientation required to view Cygnus X-1 subjected the spectrometer to an undesirable cold soak and necessitated a special maneuver to alleviate the condition. The maneuver caused the loss of X-ray pointing and may result in some loss of data. The X-ray detectors survived the cold soak condition quite well.

The region of overlap between the Apollo 15 and Apollo 16 coverage shows excellent agreement. The Descartes region shows the high aluminum and low magnesium content that is characteristic of the highlands on the far side. The mare areas to the west of Descartes show a substantial decrease in the ratio of aluminum to silicon.

Data monitored in real time indicate that Scorpius X-1, the brightest object in the X-ray sky, may have been rather active during one of the viewing sessions.

### 5.3 ALPHA-PARTICLE SPECTROMETER

Approximately 70 hours of prime data were collected in lunar orbit with the alpha-particle spectrometer experiment (S-162). Deletion of the second lunar orbit plane change prevented an observation of the highly interesting Alphonsus area.

The spectrometer operated satisfactorily during all scheduled orbital and transearth observations. All ten detectors performed within the expected energy resolution. There were no periods of noisy operation as experienced on Apollo 15. The alpha-particle spectrometer was subjected to the same cold soaks as the X-ray spectrometer and lowered temperatures an undetermined amount below the red-line limit. No detrimental effects on detector performance resulted.

From a preliminary analysis of real-time data, a localized concentration of polonium ( $\text{Po}^{210}$ ) in the general vicinity of Mare Fecunditatus was detected. This is shown in the calculation of polonium count rate versus

lunar latitude. It appears that the increase of polonium is statistically significant.

Deep-space observations to determine non-radon-related background revealed significant solar alpha particle activity. The deep-space counting rates exceeded the lunar rates by a factor of 2 or 3, indicating that a solar alpha-particle background will have to be considered in the analysis of the data.

#### 5.4 MASS SPECTROMETER EXPERIMENT

The mass spectrometer experiment (S-165) instrument operated very well in lunar orbit collecting approximately 84 hours of data, three-fourths of this being in the minus-X direction of flight of the command and service module, the prime data mode, wherein the gas entrance scoop points in the ram direction and scoops up native lunar gases. The remainder was background data taken primarily in the plus-X direction.

Telemetry data about 15 hours prior to lunar module undocking indicated that the plus 12-volt power supply voltage had dropped from 11.9 to 9.4 volts, although the instrument operated nominally. After several oscillations between these values, the voltage stabilized at 12 volts for the remainder of the flight. Postflight analysis showed that the 12-volt sensor had a slow rise time and was sampled before reaching its full value. The power supply itself did not malfunction.

As on Apollo 15, the boom would not fully retract. On the initial occurrence, the boom retracted to within 12 inches of full retraction, sufficient for a safe service propulsion system firing. The number of boom retractions was minimized following this problem. During the final retraction for the transearth injection maneuver, the boom stalled at approximately 2/3 of full extension necessitating jettisoning of the boom and instrument. The transearth coast data were to have been used to supplement analysis of the lunar orbit data. However, Apollo 15 data can be used for this purpose.

The Apollo 16 data resembles that of Apollo 15 on the distribution of gasses in the lunar atmosphere. Preliminary analysis indicates that lunar atmospheric neon is lower than predicted.

#### 5.5 PARTICLES AND FIELDS SUBSATELLITE EXPERIMENTS

The subsatellite was launched on the dark side of the moon about one hour after lunar module jettison during the 62nd revolution (April 24,

21:56:09 G.m.t.). An orbit-shaping maneuver was to have been performed prior to launching of the subsatellite to obtain the desired lifetime of one year. However, the maneuver was not performed because of the decision to limit the use of the service propulsion system to the transearth injection maneuver as a result of the engine gimbal actuator control problem (discussed in section 6.6). Consequently, the planned orbit was not obtained. The initial orbital parameters, as compared to the Apollo 15 parameters, were as follows:

<u>Mission</u>	<u>Perilune, km (mi)</u>	<u>Apolune, km (mi)</u>	<u>Inclination</u>
Apollo 15	105 (55)	144 (76)	-28°
Apollo 16	97 (52)	120 (66)	-11°

It was not possible to activate the subsatellite for about 20 hours after launch because of communications frequency interference resulting from the failure of the lunar module ascent stage to deorbit. At the time of launch, the subsatellite was in the magnetosheath heading toward the magnetopause and geomagnetic tail. The delay in activation had no detrimental effect on the subsatellite systems.

The subsatellite is calculated to have impacted the far side of the moon (110 degrees east longitude) during revolution 425 on May 29, 1972. The last telemetry data were received at 2031 G.m.t., coinciding with loss of signal. The signal should have been reacquired at 2200 G.m.t., but was not.

The physical cause for the short orbital life appears to be the lunar mass concentrations on the front and far sides located relatively near the subsatellite ground track.

#### 5.5.1 Particle Shadows/Boundary Layer

All charged-particle telescopes and electrostatic analyzer detectors operated normally during the lifetime of the particle shadows/boundary layer experiment (S-173) portion of the subsatellite. On two passes, usable data were obtained in the geomagnetic tail of the magnetosphere.

Particle tracing was improved by a better shadow structure than on Apollo 15. This resulted from the telescopes operating at a lower temperature.

#### 5.5.2 Magnetometer

The biaxial fluxgate magnetometer experiment (S-174) performed satisfactorily. Measurements are in agreement with Apollo 15 results that the

lunar magnetic field is more varied on the far side than the near side. However, individual features overflown during the first geomagnetic tail pass are not as clearly defined as those measured on Apollo 15. While in the solar wind, the magnetometer mapped the diamagnetic cavity, examined limb compressions over the terminator, and measured lunar induction fields produced by transients in the interplanetary field. While the size of the magnetic enhancement in the diamagnetic cavity (approximately 1/2 gamma) is similar to that seen on Explorer 35, the limb compression exterior to this cavity is significantly stronger at the low subsatellite altitudes (up to 6 gammas).

### 5.5.3 S-band Transponder

The subsatellite S-band transponder experiment (S-164) system functioned satisfactorily. Better-than-planned coverage was obtained from May 8 through May 16 when the altitude of the subsatellite was between 11 and 20 kilometers. Several orbits just prior to impact are expected to reveal new gravity data, but since the impact was on the far side, much of the extremely low-altitude portion of the trajectory occurred during occultation. Therefore, only that portion of the trajectory near the eastern limb will supply new information. A good gravity profile is expected over Copernicus.

### 5.6 S-BAND TRANSPONDER EXPERIMENT (CSM/LM)

The S-band transponder experiment (S-164) systems on the command and service module and the lunar module performed satisfactorily. Gravitational profile data were obtained while the docked spacecraft were in elliptical orbit and while the command and service module was in circular orbit (except for revolutions 12 through 16 when firing of thrusters during stationkeeping degraded the data). No S-band doppler measurements from the lunar module ascent stage after undocking were obtained because of the inability to control its attitude. Data reduced in real-time were of excellent quality and definite gravity variations were observed. Gravity anomalies in the Ptolemaeus, Descartes, Fecunditatus, and Procellarum regions were identified.

### 5.7 DOWN-LINK BISTATIC RADAR OBSERVATIONS OF THE MOON

Dual S-band/VHF observations were conducted for the down-link bistatic radar observations of the moon experiment (S-170) during revolution 40. Strong direct and reflected S-band signals were received by the Jet Propulsion Laboratory 210-foot dish antenna, and weak VHF reflected signals

were received by the 150-foot dish antenna at Stanford University. Interference was experienced with the VHF signals during one-seventh of the pass from the Apollo test and training satellite (TETR-D satellite 5492 launched September 29, 1971, for testing of NASA tracking stations and training of ground network personnel) transmitter operating on the same frequency. The transmitter could not be commanded off prior to the Apollo 16 mission because of a satellite systems failure.

The VHF-only test was initiated on revolution 42. The other omnidirectional antenna was used to improve signal strength, but this was not successful because of poor antenna orientation and the transmitter was switched back to the original antenna and good signals were received. Data obtained during revolutions 42, 43, and 44 were clear of the interference from the training satellite. The reason for the weak reflections is unknown.

The S-band data appear to be of high quality and most of the scientific goals dependent upon dual S-band and VHF data can be met even though the VHF data on revolution 40 were of poor quality. The VHF data taken on revolutions 42 and 43 have enough similarity that it may be substituted.

## 5.8 SERVICE MODULE ORBITAL PHOTOGRAPHY

### 5.8.1 Panoramic Camera

The panoramic camera was carried on Apollo 16 to obtain high-resolution photography of the lunar surface. The priority of the coverage was the Apollo 16 landing site area both prior to and after the extravehicular activities, areas near the terminators, and other areas of the ground track. The coverage during lunar orbit operations is shown in figure 5-1. In addition to that shown in the figure, some coverage was obtained after transearth injection.

Concurrent with camera activation for revolution 3 photography, an abnormal bus voltage condition was noted. Consequently, the camera was turned off after exposing only four frames, thereby resulting in the loss of coverage between 170 degrees west and 168 degrees east longitude. Analysis showed that the under-voltage condition was caused by the spacecraft configuration, and that camera operation was normal. Rescheduling of subsequent panoramic camera passes recovered a portion of this loss as well as other losses incurred as a consequence of the delay in the circularization maneuver, cancellation of the plane change maneuver, and the one-day-early return to earth.

From the beginning of camera operation, the exposure sensor consistently read lower light levels than were present (sec. 14.5.4). Post-flight analysis of data shows that frames taken over approximately 25 degrees away from the terminator were over-exposed by 1 to 2 f-stops. A development process using a lower gamma compensated for the overexposure in the subsolar area without compromising the resolution of the near-terminator photographs. A section of film, taken after transearth injection, was cut from the roll and processed separately to test the change in the chemical processing. Examination of the main roll after development showed excellent quality photographs. Revolution 47 telemetry data indicated several unusual transients in the lens motor current. This condition persisted for several successive frames. A review of the film disclosed no corresponding degradation in the photography.

A photograph of the Descartes area obtained with the panoramic camera on revolution 28 (fig. 5-1) was used in the preparation of figure 4-2. The lunar module can be identified in the photograph.

### 5.8.2 Mapping Camera System

The mapping camera provided cartographic-quality photographs from which selenodetic data were derived for use in mapping at a scale of 1:250 000. Complete mapping camera coverage was obtained of all areas overflown by the spacecraft in daylight. Simultaneous vertical operation of the mapping camera was performed with the panoramic camera to provide geometric support for photographic reduction. The mapping camera was also operated vertically during revolutions 4, 29, 46, 59, 60, and after transearth injection.

Oblique photography was taken 25 degrees forward of the spacecraft on the 25th revolution, 40 degrees south of the lunar ground track on the 26th and 48th revolutions, and 40 degrees north of the lunar ground track on the 27th and 37th revolutions. Approximately 90 percent of the planned coverage was obtained. Figure 5-2 shows the daylight coverage obtained during lunar orbit. The obtained coverage is less than 5 percent of the lunar surface and about 80 percent of the coverage is new, i.e., not photographed during Apollo 15. The coverage lost because of flight plan changes was along the northeast and southwest edges of the ground track, and 8 degrees of longitude at the western daylight limit. This coverage loss is discussed in the panoramic camera section (5.8.1).

The mapping camera system consists of a mapping (metric) camera and a stellar camera; the function of the stellar camera is to obtain synchronized star field photographs for each frame of metric photography while on the illuminated side of the moon and for each laser altimeter firing on the dark side of the moon. Measurements and computations from these photographs provide an independent determination of attitude. Satisfactory stellar photography was obtained on all mapping camera passes, and



camera operation was normal; however, during the transearth extravehicular activity, the glare shield for the stellar camera was found jammed against the handrail paralleling the scientific instrument module bay. This anomaly is discussed further in section 14.5.2.

The mapping camera deployment mechanism exhibited anomalous performance similar to the Apollo 15 problem. The first extension was normal, but the retract time was excessive by a factor of two. (This anomaly is discussed further in section 14.5.1.) In order to reduce the possibility of total failure of the mechanism, the camera remained in the extended position after the second extension (on revolution 17) until retraction (on revolution 48) for the plane change maneuver. The remaining nine planned deployment cycles were reduced to three - two during lunar orbit, and one between transearth injection and the transearth extravehicular activity. As a result, the mapping camera and laser altimeter were left extended for long periods of time. This presented no apparent problems for these instruments.

Upon opening the cassettes for film development, the film was found to be contaminated with metal chips (see sec. 14.5.7). A scheme was devised using air jets and tacky rollers to clean both the mapping and stellar film before processing. Examination of the developed film shows the image quality of the mapping photography to be excellent. Nine or more frames, however, are overexposed (see sec. 14.5.6). In most cases, this condition occurred when the shutter speed changed from 1250 to 800 rpm.

It is conceivable that some of the metal chips found in the cassette may have been between the emulsion and the reseau plate at the focal plane. This would not seriously degrade the image quality, but may introduce geometric distortions which will adversely affect the measurements on some frames. The photography will satisfy all basic requirements.

### 5.8.3 Laser Altimeter

The functions of the laser altimeter are to provide a distance measure from the spacecraft to the lunar surface in synchronism with each mapping camera exposure, and to provide topographic profiles for correlation with gravity anomalies obtained from tracking data.

Altimeter data were obtained on all mapping camera passes on the illuminated side of the moon. Initial operation was normal but the percentage of valid measurements gradually decreased as the mission progressed because the laser output power decreased. This anomaly is discussed in section 14.5.3. About 65 percent of the observations were valid through revolution 60, but on the last pass (revolution 63), only 10 percent of the measurements were valid. (See section 14.5.5 for a discussion of

this anomaly.) The loss of altitude data on the illuminated side of the moon will have little effect on the interpretation of mapping photography since there is redundancy in determining altitude. However, some interpolation will be required in correlating topographic profiles with gravity anomalies.

Altimeter data on the dark side was not affected as severely because less laser output power is required when ranging against non-illuminated surfaces. Approximately 82 percent of these data was good.

## 5.9 COMMAND MODULE ORBITAL PHOTOGRAPHY

### 5.9.1 Astronomical Photography

Astronomical light sources ranging from the relatively bright solar corona to extremely faint galactic regions were photographed with the 16-mm data acquisition camera (T-1 18-mm lens), the 35-mm camera (f/1.2, 55-mm lens), the 70-mm camera (f/2.8, 80-mm lens), and high-speed film with an American Standards Association speed rating of 2485.

Solar corona photography.- The objective of the photographic observations included two lunar sunrise sequences and two lunar sunset sequences, but revisions to the flight plan caused by the early return to earth would not permit the sunset sequences. Two sequences of the eastern half (sunrise) of the solar corona were obtained, each of which required seven exposures starting 75 seconds prior to sunrise and ending 10 seconds prior to sunrise. Exposures of 10, 4, 1, 1/2, 1/3, 1/30 and 1/60 seconds were made on high-speed recording film using the 70-mm camera with 80-mm lens set at f/2.8. However, the 1-second and 1/2-second exposures were not obtained because of a procedural error. The trigger was released too quickly for the 1-second exposure, so the shutter remained open, and the film was transported for the next exposure. Proper actuation of the trigger for the 1/2-second exposure returned the camera to normal status. The result of the action was an exposure of less than 1 second and another of more than 10 seconds. Neither were usable because the exact durations of the exposures were unknown.

The 16-mm camera was run as a secondary data source. However, the maximum available exposure time of 1/60-second (1 ft/sec) was not long enough for the low light levels present, and no images were observed on the film.

Faint galactic regions.- Two 5-minute exposures to study the outer regions of galaxies were taken, one each adjacent in time to the Gegen-schein/Moulton region sequences. These are among the first attempts to

perform deep-space photography above the earth's airglow. The results will aid in planning the trade-off's between exposure time and smear for Apollo 17. The 5-minute exposures do exhibit greater instability than is ultimately desired. In an effort to reduce the problems associated with long exposures, an intensive effort will be made during the analysis to enhance the already high sensitivity of the f/1.2 aperture-2485 film system.

Ground-based photography.- Ground-based photography in support of the inflight photography was planned for Haleakala Observatory, Maui, Hawaii. Unfavorable cloud conditions prevented photography there. However, good quality supporting photography was obtained in the Mojave Desert during the mission and at Mt. Palomar after the mission.

#### 5.9.2 Command Module Lunar Surface Photography

Color photography with 70-mm camera.- Because of insufficient time, photographs of two of the planned fifteen targets were not taken using the 70-mm camera with the 250-mm lens and color exterior film. Most of the 756 frames obtained are adequate, although over 50 frames show detectable smear, and a few are excessively underexposed.

Black-and-white photography with 70-mm camera.- Two of the scheduled eleven targets for near terminator photography using the 70-mm camera with the 250-mm lens and the very-high-speed black and white film were deleted because of insufficient time. However, a few unscheduled targets were obtained which compensates for the loss. A total of 103 frames was exposed and most are good. Only a few frames are slightly overexposed.

Earthshine photography.- Earthshine photography was scheduled on revolutions 15 and 16 using the 35-mm camera with black-and-white film (2485). Due to the delay in the lunar module landing, the scheduled earthshine photography could not be obtained. The Command Module Pilot did, at his option, take a few earthshine photographs. These very dark exposures were taken much farther west and later in the mission. However, two of the exposures are usable in that features have been identified as being near the crater Riccioli, which is only about 15 degrees east of the earthshine terminator. This is in an area not previously photographed on any Apollo mission. Surface features were readily distinguished by the eyes of the Command Module Pilot at the time the photographs were taken. The shutter speed of 1/8-second was fast for the lighting conditions, but was chosen as a compromise between lighting and smear.

These results indicate that it may be possible to obtain usable earthshine photography on Apollo 17, with more of the earth being illuminated at the time of the lunar landing.

### 5.10 VISUAL OBSERVATIONS FROM LUNAR ORBIT

Visual observations were successfully performed on 9 of the 10 scheduled targets. One target (Goddard area) was deleted because of the flight plan changes and returning to earth one day early.

The visual observation site graphics were adequate and the 10-power binoculars were very useful in the investigations of small scale features. The significant results of the task are the following:

- a. A thorough description of the landing site area was obtained that helped with real-time traverse planning.
- b. Formations which appeared as lava flows were observed coming from a small crater on the western wall of the crater Lobachevsky.
- c. The distribution of small lineaments on the lunar surface were noted.
- d. Numerous lava-like marks were detected along highland hills in Mare Nubium, Mare Cognitum, and Oceanus Procellarum.

### 5.11 ULTRAVIOLET PHOTOGRAPHY - EARTH AND MOON

The ultraviolet photography - earth and moon experiment (S-177) was a continuation of an effort begun on Apollo 15 to record the appearance of the earth and the moon at ultraviolet wavelengths. A 70-mm camera equipped with a 105-mm ultraviolet transmitting lens was used with IIA-0 film to obtain images through the right side window of the command module. The regular glass panes were replaced with annealed-fused silica to prevent blockage of ultraviolet radiation. Plexiglass and cardboard shields were provided to protect the crew. A filter wheel containing four filters permitted the passing of specific ultraviolet bands for photography:

<u>Filter designation</u>	<u>Bandpass, angstrom</u>
UV cutoff	4000
3750	3150 - 3900
3050	2700 - 3300
2650	2550 - 2700

Sixty-six high-quality images were recorded with the three satisfactory filters. (Filter 2650 did not perform satisfactorily.) Two sequences (16 frames) of translunar coast photography of the lunar crescent were

blank because of incorrect pointing of the spacecraft. There is no explanation for the loss of photography. Flight plan changes required deletion of three other sequences - one of lunar maria, and two of the earth seen from lunar orbit.

A preliminary study of the images has led to the following impressions:

1. The contrast between maria and terrae on the moon is not dramatically reduced in the 2700-3300 angstrom band as predicted.

2. As expected, surface detail of earth imagery is greatly reduced when taken through the 3050-angstrom filter. Cloud patterns are clear, but land-sea boundaries are barely discernible near the terrestrial center and disappear completely at the limb.

3. Refraction by ice crystals in cirrus clouds seems to be the likely cause of a flare observed at the limb of the crescent earth. It is invisible at 3050 angstrom and most apparent for wavelengths greater than 4000 angstrom.

#### 5.12 GEGENSCHIEIN FROM LUNAR ORBIT

The photographic observations of the Gegenschein and Moulton regions from lunar orbit experiment (S-178) were performed satisfactorily using the 35-mm camera with the aperture set to f/1.2 and the focus set to infinity.

The desired 10 exposures - half of them 1 minute in duration, and the other half, 3 minutes in duration - were obtained. The pointing was accurate and the quality of photography was good.

The spacecraft stability during the longer exposures was better than 0.3 degree.

Solar radiation caused less degradation of the film than on previous missions. The data reduction plan requires careful isodensitometry of all the observational frames including the vignetting data.

#### 5.13 SKYLAB CONTAMINATION STUDY

The tendency of a contamination cloud to collect around a spacecraft has been of concern to Skylab planners. The objectives of the Skylab

contamination photography were to determine if a cloud of particles exist around the spacecraft, to obtain the dynamics of the cloud through a study of individual particles, and to determine the effects of water dumps on the background brightness.

All lunar orbit photography and the early transearth coast photographs were deleted as an indirect result of the problem encountered with the service propulsion system thrust vector control. The phase function, the dump, and post-dump photographs were obtained. However, because of the one-day-early return, all photographs were plagued by scattered moonlight. It appears that most of the phase function and all the post-dump photographs are unusable. During the phase function photography, moonlight was on the window (command module window 4) opening, but not on the window itself. There was also a considerable amount of light scattered from the window edge and the opening. There are some restricted areas on the photographs where data free of scattered light can be obtained.

Photographs of the residual contamination cloud were taken with the 35-mm camera late in transearth coast and resulted in 16 frames. Shortly afterward, a waste water dump using the auxiliary hatch dump nozzle was performed. Photographs of conditions during this dump have considerably fewer tracks than were anticipated from similar studies of Apollo 15. Photographs of the dump plume show a narrow cone and a varying density distribution in the cone. The post-dump photograph sequence was shortened by 15 minutes because of thermal considerations resulting from changes in attitude. Six frames of 70-mm film were taken through the command module window 3, and approximately 800 frames of 16-mm photographs of the dump and post-dump conditions were taken through command module windows 2 and 4.

#### 5.14 APOLLO WINDOW METEOROID EXPERIMENT

This Apollo window meteoroid experiment (S-176) is passive in that approximately 0.4 square meter of the external surface of the command module side and hatch windows are used for detecting meteoroids having a mass of  $10^{-9}$  grams or less. The windows are made of 99-percent-pure silica glass and are mounted almost flush with the external surface of the heat shield contours.

The windows were returned to the Manned Spacecraft Center and are being scanned at a magnification of 20X (200X magnification for areas of interest) to map all visible defects. Possible meteoroid craters will be identified to determine the meteoroid cratering flux on glass surfaces and to discover possible correlation with lunar rock cratering studies. Table 5-II contains a tabulation of meteoroid impacts from previous missions.

TABLE 5-I.- METEOROID CRATERS AND RELATED INFORMATION

Mission	Window exposure $m^2$ -sec	Number of impacts	Meteoroid flux number/ $m^2$ -sec	95 percent confidence limits number/ $m^2$ -sec	Minimum meteoroid mass g
Apollo 7 (Earth orbital without LM)	$2.21 \times 10^5$	5	$2.26 \times 10^{-5}$	$5.29 \times 10^{-5}$ $7.23 \times 10^{-6}$	$1.31 \times 10^{-10}$
Apollo 8 (lunar orbital without LM)	$1.8 \times 10^5$	1	$1.07 \times 10^{-5}$	$5.96 \times 10^{-5}$ $1.07 \times 10^{-6}$	$7.86 \times 10^{-11}$
Apollo 9 (Earth orbital with LM)	$1.87 \times 10^5$	1	$5.36 \times 10^{-6}$	$3.0 \times 10^{-5}$ $5.36 \times 10^{-7}$	$5.37 \times 10^{-10}$
Apollo 10 (lunar orbital with LM)	$1.99 \times 10^5$	0	--	$1.86 \times 10^{-5}$ --	$7.86 \times 10^{-11}$
Apollo 12 (lunar landing)	$2.43 \times 10^5$	0	--	$1.52 \times 10^{-5}$ --	$7.86 \times 10^{-11}$
Apollo 13 (circumlunar abort with LM)	$1.42 \times 10^5$	1	$1.36 \times 10^{-5}$	$7.6 \times 10^{-5}$ $1.37 \times 10^{-6}$	$5.91 \times 10^{-9}$
Apollo 14 (lunar landing)	$2.35 \times 10^5$	2	$1.64 \times 10^{-5}$	$5.9 \times 10^{-5}$ $1.64 \times 10^{-6}$	$1.64 \times 10^{-11}$
Apollo 15 (lunar landing)	$2.88 \times 10^5$	0	--	$1.28 \times 10^{-5}$	$5.37 \times 10^{-10}$

### 5.15 VISUAL LIGHT FLASH PHENOMENON

Two light flash observation periods were scheduled during Apollo 16 and these were successfully completed. The first test period began at about 49 hours and continued for 66 minutes. The Lunar Module Pilot wore the Apollo light flash moving emulsion detector to provide a direct physical measurement of the cosmic rays that cause the light flashes. The device is worn on the head somewhat like a helmet and contains cosmic-ray-sensitive emulsion plates that surround the eyes. The Commander wore eye shields during this test period. The Command Module Pilot participated in the tests as a recorder. He was to have worn the moving emulsion detector, but, for an unknown reason, he was not observing any light flashes. This is the first crewman since Apollo 11 that has not experienced light flashes. A total of 70 light flash events were reported during the 66-minute period by the Commander and Lunar Module Pilot. The frequency of light flashes reported by the Commander averaged one event every 3.6 minutes and for the Lunar Module Pilot, one event every 1.3 minutes.

During transearth coast, a test using only eyeshields was initiated at about 238 hours and was terminated one hour later. For a 32-minute period of voice reporting, the Commander reported 7 flashes and the Lunar Module Pilot 15 flashes. The Command Module Pilot participated, but did not observe any flashes. The average frequency during this period was one event every 4.5 minutes for the Commander and one every 2.1 minutes for the Lunar Module Pilot. The number and characteristics of the light flash events imprinted on the Apollo light moving emulsion detector will be analyzed and correlated with the visual observations reported by the two crewmen.

### 5.16 MICROBIAL RESPONSE IN SPACE ENVIRONMENT

The microbial response in space environment experiment (M-191) was conducted to quantitatively measure the combined effects of certain space flight environmental parameters on selected microbial organisms and to evaluate alterations in mutation rates and adaptive patterns. The effects of the following space flight parameters were measured:

- a. Changes in oxygen partial pressure
- b. Changes in barometric pressure from sea level to hard vacuum
- c. Changes from 1-g environment to extended weightlessness
- d. Exposure to a known flux of ultraviolet radiation



e. Exposure to galactic radiation.

The exposure of the test microbial systems to ultraviolet and cosmic radiation was accomplished by use of the microbial ecology evaluation device (appendix A). The device was attached to the end of the television camera boom near the end of the transearth extravehicular activity. It was oriented towards the sun and opened for a 10-minute period while the spacecraft was maintained in the preselected attitude.

The dosimetry film was developed after recovery and showed that the experiment system functioned properly. Preliminary analysis shows that good usable data were obtained. The results of the experiment will be published in a separate report (Appendix E).

#### 5.17 BIOSTACK EXPERIMENT

The biostack experiment (M-211) was conducted to determine the biological effects of high-atomic-number high-energy heavy ions on selected biological systems. The information derived from the experiment will be important in assessing the nature and extent of radiation hazards to future long-duration space missions.

The experiment was unique in that it was the first medical experiment designed, developed, fabricated, financed, and analyzed by a foreign government (West Germany). No crew participation was required. The hermetically sealed aluminum canister containing biological systems was stowed in the command module. A description of the experiment apparatus is given in appendix A.

The biostack canister was returned to the principal investigator where it was first opened for postflight analysis. The results of the experiment will be published in a separate report.

#### 5.18 BONE MINERAL MEASUREMENT

The bone mineral measurement experiment (M-078) was again conducted to determine the degree of bone mineral changes in Apollo crewmen that result from exposure to weightlessness. This study employs an X-ray technique that utilizes an iodine isotope monoenergetic beam possessing predictable photon absorption characteristics to assess bone mineral changes.

No significant loss of bone mineral from the central os calcus (heel) occurred in any of the crewmen on this mission. However, during the first 3 days after return to earth, there was a progressive decrease in the os

calcis mineral in the Command Module Pilot. An additional measurement was taken on this crewman 7 days after return to earth and essentially the same value was obtained as on the first day following landing. This indicated that the expected reversal of the trend had occurred. The results obtained were similar to those of Apollo 14, but different from those of Apollo 15 when the crew experienced bone mineral losses during the flight. There is no explanation for the variations in bone mineral loss.

#### 5.19 FLUID ELECTROPHORESIS IN SPACE DEMONSTRATION

Electrophoresis was first demonstrated in space on Apollo 14 when red and blue dyes were separated. Photographs showed that the boundary dividing the dyes was sharper and better defined than on earth. The apparatus also contained samples of hemoglobin and DNA which were not observed to separate. Subsequent examination of the apparatus indicated that these specimens were destroyed by bacteria, probably during the long storage time before the demonstration in space actually took place. As a result of what was learned from Apollo 14, the design and operation of the apparatus was improved for a second demonstration on the Apollo 16 mission.

The Apollo 16 apparatus demonstrated the electrophoresis of large, dense non-biological particles in order to evaluate the potential for separation of biological particles such as living cells. The apparatus contained three separation columns; one column containing a mixture of monodispersed polystyrene latex particles of 0.2- and 0.8-micron diameter and, in the other two columns, particles of each diameter were run separately to provide comparative data. The demonstration apparatus had the same dimensions and comparable weight as the Apollo 14 unit, but several modifications were made to obtain more data. Photographs were taken every 20 seconds during the separation run.

A careful examination of enlarged photographs and color contour densitometer traces shows that the shape of the particle bands and sharpness of the particle fluid boundary at the band front were extremely stable during the first electrophoretic run down the columns. An unexplained particle circulation in a corkscrew pattern was observed in the upper and middle column (but not the lower column) near the end of the run.

Electrophoresis in space was shown to be less subject to the disturbing effects of thermal convection and sedimentation than when conducted under 1-g conditions. However, the behavior of the polystyrene latex particles during electrophoresis in space was different than expected in that more electroosmosis accompanied the electrophoretic migration of particles than was anticipated; i.e., the electroosmotic interaction increased particle velocity in the center of flow and retarded particle velocity near

the wall. Postflight ground tests are being conducted to understand the relationship of these electrokinetic processes. Although the two sizes of polystyrene latex in the same tube did not separate, distinct differences in migrating velocities did occur. A final report will be issued explaining the observations in detail (Appendix E).

## 6.0 COMMAND AND SERVICE MODULE PERFORMANCE

This section contains an evaluation of the command and service module systems performance with emphasis on problems encountered during the mission. The consumables usage is presented in section 6.11.

### 6.1 THERMAL, STRUCTURES AND MECHANICAL SYSTEMS

Command and service module temperatures remained within acceptable limits. Scientific instrument module temperatures were normal for most of the mission. However, the X-ray spectrometer and alpha-particle spectrometer temperatures fell below the minimum established limits during transearth coast because the spacecraft was held in attitudes such that the instruments were shaded for prolonged periods.

Command module accelerometer data indicated that the launch-vehicle-induced oscillations were similar to those measured in previous flights. The amplitude of these oscillations and the structural loads encountered during all phases of the mission were within the design limits of the spacecraft structure.

Separation from the S-IVB was normal and docking transients were less than 0.5 degree per second in all axes. Low-rate disturbances during the rigidizing sequence reflect good alignment (less than 0.5 degree in all axes) of the spacecraft before the probe retract sequence was initiated. Extraction of the lunar module from the S-IVB was normal.

Rate disturbances experienced during the scientific instrument module bay door jettison were less than 0.1 degree per second in all axes and velocity changes to the command and service module were not perceptible.

Command module window contamination, similar to that reported on previous flights, was observed shortly after orbital insertion and remained throughout the mission. A fine mist condensed on the inner surface of the exterior (heat shield) panes of the two side windows (1 and 5) and the hatch window (3). The outer surface of the exterior pane on window 3 was also contaminated. This contamination was described as a residue from a liquid droplet which produced a streak across the window and an additional residue which appeared to have resulted from the evaporation of a liquid droplet. The contamination on the inner surfaces of the heat shield windows is attributed to outgassing of nonmetallic materials in the immediate window area. On window 5, the contamination appeared to terminate along a straight line. Remedial action was initiated to reduce the outgassing

problem on all spacecraft following Apollo 10; however, a small amount of interior contamination was anticipated. The outer surface contamination was most likely caused by a liquid deposit on the window prior to boost protective cover jettisoning.

Docking ring latch no. 10 did not preload during translunar docking. All latches operated properly during undocking and during lunar orbit docking. From postflight inspection and the inflight description of the latch, it was concluded that the latch no. 10 was not properly cocked prior to launch.

Problems similar to those of Apollo 15 were encountered with the retraction of the mass spectrometer boom. The boom retracted past the "safe service propulsion system firing" position on all occasions until prior to transearth injection when it finally stalled beyond the "safe" position, and was therefore jettisoned prior to the transearth injection maneuver (see sec. 14.1.8).

Full retraction of the gamma-ray spectrometer boom was not attained on three of five attempts. The mechanism is similar in design to the mass spectrometer boom. Details of this anomaly are discussed in section 14.1.9.

The earth landing system performance was normal. All three main parachutes were recovered and postflight inspections were made. Numerous pinhole burns were found in the canopy of one parachute and smaller numbers of burn holes were found in the other two parachute canopies (see sec. 14.1.18). Microscopic examination confirmed that the damage was identical to that produced by reaction control system oxidizer on laboratory samples of parachute material and also identical to that shown on enlarged photographs of a recovered Apollo 14 main parachute which sustained oxidizer burns. Postflight inspection of the recovered parachutes revealed that the dome nuts were loose on two of the three fabric riser/steel riser pilot parachute connector links. The cause has been attributed to the use of nuts with nylon inserts which did not provide a positive locking capability. Future spacecraft will be inspected to insure that proper nuts are used and that the installed nuts are secure.

## 6.2 ELECTRICAL POWER AND FUEL CELLS

The electrical power system batteries and fuel cells performed satisfactorily through the mission.

Entry batteries A and B were charged 10 times during flight - battery A, 4 times and battery B, 6 times. Load sharing and voltage delivery were satisfactory during each of the service propulsion system firings, during the service propulsion system troubleshooting procedure, and during entry.

An apparent deviation from previous missions occurred in the pressure indication from the entry battery vent manifold. The pressure was induced by the normal gassing of the batteries, and was relieved by venting the manifold. The maximum pressure was approximately 14 psia. Manifold pressures had followed the cabin pressure on previous missions. Postflight testing verified that the Apollo 16 command module had an unusually good leak-tight manifold system.

An odor (like burned insulation) was noticed during one of the battery charges. Bench tests previously performed on battery chargers had shown that a similar odor could be produced from the chargers.

The fuel cells were activated 61 hours prior to launch. Following cryogenic loading (48 hours prior to launch), fuel cell 2 was placed on main bus A at 25 to 30 amperes. Three and one-half hours prior to lift-off, fuel cells 1 and 3 were placed on main buses A and B, respectively. Load sharing was as expected throughout the flight, with a nominal spread of 2 to 7 amperes. The fuel cells supplied 596 kilowatt hours of energy at an average current of 78 amperes and bus voltage of 28.8 volts.

### 6.3 CRYOGENIC STORAGE

The cryogenic storage system satisfactorily supplied reactants to the fuel cells and metabolic oxygen to the environmental control system throughout the mission. Quantities consumed during the mission showed excellent agreement with preflight predictions.

Hydrogen tank 3 in sector I of the service module experienced a high initial heat leak of 15 to 20 Btu/hr which gradually diminished to a normal value of 4 to 6 Btu/hr by 70 hours elapsed time. Analysis indicates the most likely cause to be degradation and subsequent recovery of the insulating annulus vacuum (see sec. 14.1.5).

### 6.4 COMMUNICATIONS

The command and service module communications equipment functioned satisfactorily except as discussed in the following paragraphs.

On two occasions, the up-data link would not accept commands. Each time the problem was cleared by the crew cycling the up-telemetry switch from "normal" to "off" to "normal" which resets the up-data link logic. A similar problem was experienced on Apollo 9 (see sec. 14.1.6).

At approximately 234 hours, the high-gain antenna would not operate properly in the reacquisition-narrow-beamwidth mode. Normal performance was restored after the crew selected the manual mode momentarily and then returned to the reacquisition mode. This anomaly is discussed in section 14.1.16.

Intermittent operation of a communications carrier headset earphone circuit was experienced during transearth coast. The condition was cleared by flexing the constant wear garment harness near a 21-pin connector (see sec. 14.3.6).

At various times during the mission, the network sites reported that there was high background noise on the crew voice dumped from the data recorder-reproducer. Evaluation revealed that background noise was present, but was not sufficient to impair the voice intelligibility. The noise was of three types: (1) normal RF noise, (2) a 400-hertz tone, and (3) a tone of approximately 3 kilohertz believed to be electromagnetic interference in the spacecraft. The noise was present during other Apollo missions but was higher for Apollo 16. Normal bandpass filtering improved the voice quality.

Video received from all command module telecasts was good. Non-uniformity of the lighting in the cabin caused some degradation. Since the camera's sensitivity adjusts itself to average lighting, the video from all scenes, especially those rapidly changing, is not optimized in accordance with the capability of the camera. Also, focusing is not optimum since the lens is set for distances greater than cabin dimensions. On two occasions, the onboard monitor malfunctioned but had no effect on the video signal to earth (see sec. 14.3.1).

## 6.5 INSTRUMENTATION

The instrumentation system satisfactorily supported the mission with all 501 operational measurements providing usable data. Two measurements deviated from the expected performance. Readings of 0.2 to 1.5 percent (on one occasion, 5.0 percent) were experienced on the oxidizer tank 2 quantity measurement when the service propulsion system was not firing. During such periods, the quantity gage is not electrically energized, and it should read zero. Erratic readings were also observed prior to launch. The most probable cause of the unexpected quantity indication was noise pickup on the transducer electrical wiring.

There was a 15 psia upshift in the service propulsion system oxidizer tank pressure measurement after the spacecraft reached a vacuum environment. The bias was constant throughout the mission and data were obtained

by subtracting 15 psi from the indicated pressure measurement. This anomaly is discussed in greater detail in section 14.1.2.

## 6.6 GUIDANCE, NAVIGATION AND CONTROL

Performance of the guidance, navigation, and the primary and backup control systems was good throughout the flight with the exception of four anomalous conditions. No systems capability was lost; however, item b in the following listing of the four anomalies had a significant impact upon the subsequent mission operations.

a. The computer issued a gimbal lock warning when no gimbal lock condition existed. This is discussed in this section and in greater detail in section 14.1.3.

b. An oscillation was detected in the secondary yaw axis servo system for the service propulsion engine gimbal during pre-ignition checkout for the lunar orbit circularization maneuver. This condition is discussed in this section and in greater detail in section 14.1.10.

c. Uneven drive rates were experienced when positioning the scanning telescope shaft axis. This anomaly is discussed in section 14.1.14.

d. Inertial subsystem warnings and inertial coupling data unit fail indications were received on six occasions during the transearth coast phase of the mission. These anomalous conditions are discussed in section 14.1.4.

The primary guidance system provided good boost trajectory monitoring during launch and the translunar injection maneuver. At earth orbit insertion, the differences between the primary guidance velocity vector and the Saturn guidance velocity vector were minus 5.8, plus 18.0, and minus 7.1 feet per second in the primary guidance X, Y, and Z axes, respectively. The magnitudes of the X and Z errors are typical of previous Apollo missions and represent 1.2- and 0.8-sigma platform errors. The Y-axis velocity error, which is primarily sensitive to gyrocompassing error, reflects a 0.3-sigma (minus 0.0046 deg) azimuth misalignment. The small error is a significant improvement over previous Apollo flights and represents an optimized X-gyro bias drift compensation. This technique was used for the first time on this mission to minimize anticipated gyrocompassing error.



A history of primary guidance error coefficients is presented in table 6-I. The preflight performance values were obtained from system calibrations performed after the inertial measurement unit was installed in the command module. The flight performance values are from platform alignment data and accelerometer bias measurements made during the mission.

Table 6-II is a summary of inertial measurement unit realignments performed during the mission. Table 6-III summarizes significant control parameters during service propulsion system maneuvers and the mid-course correction maneuvers.

The previously mentioned gimbal lock warning indication occurred during translunar coast just after the inertial measurement unit was being realigned. The computer downmoded the inertial subsystem to the coarse align mode which caged the platform to the existing attitude reference. In order to prevent the platform from being caged during time-critical periods of flight, an erasable program was manually loaded into the computer. The program prevented the computer from changing the status of the coarse-align discrete. During non-critical time periods, the program was removed to preserve the coarse-align mode in the event of a true gimbal lock condition.

After a normal undocking and separation maneuver from the lunar module, the circularization maneuver was cancelled because an oscillation was detected in the secondary yaw servo system for the service propulsion system engine gimbal while performing the pre-ignition checklist. Analysis of the flight data by ground personnel indicated that the cause of the problem was an open circuit in the rate feedback loop. A review of existing simulation data indicated that the system was safe to use. The mission proceeded after a delay of three lunar revolutions, which represented the time required for the problem evaluation, trajectory considerations, and preliminary changes to the flight plan. The circularization maneuver was performed successfully on the primary servo system and the secondary system was never required for control of the spacecraft. Revision of the flight plan for all subsequent mission activities was necessary because of this anomaly. Two command and service module service propulsion system maneuvers were ultimately eliminated from the prelaunch plan.

Attitude control data taken during lunar orbital operations was examined by ground support personnel in an effort to minimize reaction control thruster activity during sleep periods and to improve spacecraft pointing accuracy. During the Apollo 15 mission, gravity gradient torques had a tendency to hold the vehicle against one side of the deadband. The state vector integration routines in the computer would interrupt the digital autopilot orbital rate maneuver routines and allow the vehicle to

TABLE 6-I.- COMMAND AND SERVICE MODULE INERTIAL COMPONENT SUMMARY

	Number of samples	Sample standard deviation	Sample mean	Countdown value	Flight load	Inflight performance
Accelerometers						
X - Scale factor error, ppm . . . . .	6	19	-255	-252	-310	--
Bias, cm/sec <sup>2</sup> . . . . .	6	0.07	-0.10	-0.03	-0.04	0.00
Y - Scale factor error, ppm . . . . .	6	32	-1294	-1337	-1330	--
Bias, cm/sec <sup>2</sup> . . . . .	6	0.03	1.15	1.20	1.14	1.13
Z - Scale factor error, ppm . . . . .	6	49	-403	-348	-310	--
Bias, cm/sec <sup>2</sup> . . . . .	6	0.19	-0.23	-0.08	-0.13	-0.36
Gyroscopes						
X - Null bias drift, meru . . . . .	6	0.37	-1.87	-1.8	1.1 <sup>a</sup>	-0.89 ±0.25 (1 sigma)
Accelerometer drift, spin reference axis, meru/g . . . . .	6	0.53	-11.05	-10.6	-11	--
Accelerometer drift, input axis, meru/g . . . . .	6	1.66	8.58	10.1	8	--
Y - Null bias drift, meru . . . . .	6	0.95	-0.15	-0.1	-0.4	-0.09 ±0.22 (1 sigma)
Accelerometer drift, spin reference axis, meru/g . . . . .	6	1.40	-13.53	-13.4	-14	--
Accelerometer drift, input axis, meru/g . . . . .	12	2.46	-6.41	-5.5	-7	--
Z - Null bias drift, meru . . . . .	6	0.66	-1.98	-2.8	-1.7	-1.17 ±0.19 (1 sigma)
Accelerometer drift, spin reference axis, meru/g . . . . .	6	0.29	-5.20	-5.0	-5.0	--
Accelerometer drift, input axis, meru/g . . . . .	6	2.43	14.90	18.3	14	--

<sup>a</sup>Adjusted to minimize lift-off gyrocompassing azimuth error.

TABLE 6-II.- COMMAND AND SERVICE MODULE PLATFORM ALIGNMENT SUMMARY

Time, hr:min	Program option	Star used	Gyro torquing angle, deg			Star angle difference, deg	Gyro drift, meru			Comments
			X	Y	Z		X	Y	Z	
00:38	3	23 Denebola, 30 Menkent	0.040	0.031	0.045	0.00	-	-	-	Launch orientation
06:32	3	30 Menkent, 31 Arctarus	0.188	-0.035	-0.076	0.01	-	-	-	Launch orientation
06:39	1	24 Gienah, 31 Arctarus	-	-	-	0.01	-	-	-	Passive thermal control orientation
11:14	3	42 Peacock, 34 Atria	0.164	-0.022	-0.052	0.00	-2.37	0.32	-0.75	Passive thermal control orientation
29:40	3	27 Alkaid, 31 Arctarus	0.631	-0.063	-0.197	0.01	-2.30	0.23	-0.72	Passive thermal control orientation
29:42	3	23 Denebola, 32 Alphecca	0.000	-0.005	-0.002	0.01	-	-	-	Passive thermal control orientation
39:03	3	Earth, Sun	-0.463	0.861	11.480	0.07	-	-	-	After gimbal dump
39:09	3	06 Acamar, 07 Menkar	-0.010	-0.088	-0.109	-	-	-	-	After gimbal dump
39:13	3	12 Rigel, 21 Alphard	0.015	0.006	-0.004	0.01	-	-	-	Passive thermal control orientation
51:18	3	17 Regor, 22 Regulus	-0.062	0.029	0.000	0.00	0.34	-0.16	0.00	Passive thermal control orientation
68:39	3	06 Acamar, 34 Atria	-0.068	0.004	0.054	0.00	0.61	-0.04	0.49	Passive thermal control orientation
71:23	3	35 Rasalhague, 41 Dabih	-0.032	0.017	0.006	0.00	0.78	0.41	0.15	Passive thermal control orientation
71:28	1	35 Rasalhague, 41 Dabih	0.002	0.000	-0.001	0.00	-	-	-	Lunar orbit insertion orientation
75:51	3	24 Gienah, 33 Antares	-0.044	0.006	0.019	0.01	0.68	-0.09	0.29	Lunar orbit insertion orientation
75:59	1	23 Denebola, 30 Menkent	-0.027	-0.151	0.034	0.01	-	-	-	Landing site orientation
76:01	3	23 Denebola, 30 Menkent	-0.001	0.004	-0.001	0.02	-	-	-	Landing site orientation
77:53	3	30 Menkent, 37 Nunki	0.011	0.015	0.009	0.01	-0.39	-0.53	0.32	Landing site orientation
81:41	3	41 Dabih, 44 Enif	-0.029	0.005	0.012	0.01	0.51	-0.09	0.21	Landing site orientation
93:18	3	35 Rasalhague, 44 Enif	-0.066	0.002	0.050	0.00	0.38	-0.01	0.29	Landing site orientation
102:44	3	42 Peacock, 44 Enif	-0.013	-0.011	0.020	0.00	0.09	0.07	0.14	Landing site orientation
118:38	3	35 Rasalhague, 44 Enif	-0.077	0.006	0.075	0.00	0.32	-0.02	0.31	Landing site orientation
130:30	3	--	-0.054	-0.016	0.067	0.01	0.30	0.09	0.38	Landing site orientation
146:21	3	25 Acrux, 24 Gienah	-0.075	0.004	0.076	0.01	0.31	-0.02	0.32	Landing site orientation
164:35	3	22 Regulus, 24 Gienah	-0.103	-0.001	0.097	-	0.38	0.00	0.35	Landing site orientation
168:06	3	30 Menkent, 37 Nunki	0.000	-0.001	0.000	0.01	0.00	0.02	0.00	Landing site orientation
168:10	1	--	0.087	0.776	0.324	0.00	-	-	-	Plane change orientation
168:12	3	30 Menkent, 37 Nunki	0.010	-0.007	0.003	0.01	-	-	-	Plane change orientation
169:38	1	--	0.108	0.061	0.001	0.01	-	-	-	Lift-off orientation
170:50	3	27 Alkaid, 31 Arctarus	0.005	-0.009	-0.004	-	-	-	-	Lift-off orientation
174:00	3	37 Nunki, 45 Fomalhaut	-0.019	-0.019	0.020	0.01	0.39	0.39	0.42	Lift-off orientation
190:09	3	21 Alphard, 30 Menkent	-0.100	0.002	0.095	-	-0.41	-0.01	0.39	Lift-off orientation
198:12	3	20 Dnoces, 27 Alkaid	-0.032	0.001	0.034	0.00	0.27	0.01	0.28	Lift-off orientation
198:16	1	20 Dnoces, 27 Alkaid	-0.375	-0.485	-0.868	0.00	-	-	-	Transearth injection orientation
201:50	3	3 Navi, 20 Dnoces	-0.009	-0.014	0.047	0.01	0.17	0.26	0.86	Transearth injection orientation
201:56	1	3 Navi, 20 Dnoces	0.811	-1.535	1.172	0.01	-	-	-	Passive thermal control orientation
201:58	3	3 Navi, 20 Dnoces	-0.007	0.006	0.007	0.01	-	-	-	Passive thermal control orientation
213:09	3	15 Sirius, 22 Regulus	-0.040	0.030	0.058	0.00	0.24	-0.18	0.34	Passive thermal control orientation
225:50	3	14 Canopus, 16 Procyon	-0.039	-0.012	0.084	0.01	0.21	0.06	0.44	Passive thermal control orientation
241:18	3	21 Alphard, 26 Spica	-0.035	0.002	0.125	0.01	0.15	-0.01	0.54	Passive thermal control orientation
261:07	3	10 Mirfak, 12 Rigel	-0.103	-0.029	0.141	0.01	0.35	0.10	0.47	Passive thermal control orientation
261:13	1	10 Mirfak, 12 Rigel	0.127	-0.089	-0.436	0.01	-	-	-	Entry orientation
264:05	3	15 Sirius, 21 Alphard	-0.014	-0.014	0.015	0.01	0.33	0.33	0.35	Entry orientation

<sup>a</sup>The numbers used in this column represent the following: 1 - Preferred; 3 - REFSMMAT.

TABLE 6-III.- GUIDANCE AND CONTROL MANEUVER SUMMARY

Parameter	Maneuver							
	<sup>a</sup> First midcourse correction	<sup>a</sup> Lunar orbit insertion	<sup>a</sup> Descent orbit insertion	<sup>a</sup> Lunar orbit circularization	<sup>a</sup> Lunar orbit plane change	<sup>a</sup> Transearth injection	Second midcourse correction	Third midcourse correction
Time								
Ignition, hr:min:sec	30:39:00.66	74:28:27.87	78:33:45.04	103:21:43.08	169:05:52.14	200:21:33.07	214:35:02.8	262:37:20.7
Cutoff, hr:min:sec	30:39:02.67	74:34:42.77	78:34:09.39	103:21:47.74	169:05:59.28	200:24:15.36	214:35:25.4	262:37:27.1
Duration, min:sec	0:02.01	6:14.90	24.35	4.66	7.14	2:42.29	8.0	3.2
<sup>b</sup> Velocity gained, ft/sec (actual/desired)								
X	5.88/6.04	2786.35/2786.63	142.99/143.62	+0.25/-0.43	19.63/19.63	-894.13/-894.11	-0.20/-0.11	0.62/0.66
Y	9.01/9.42	265.06/265.07	141.32/141.85	-70.26/-71.17	-59.37/-59.68	-2466.65/-2467.58	0.78/+0.90	-0.38/-0.50
Z	5.58/5.75	125.67/125.69	58.73/58.93	-39.56/-39.99	107.02/107.71	-2116.06/-2115.36	2.98/+3.30	-1.08/-1.19
<sup>c</sup> Velocity residuals, ft/sec								
X	+0.1	+0.2	+0.9	+0.3	+0.8	+0.2	Not applicable	Not applicable
Y	0.0	-0.1	-0.1	+0.2	-0.4	+1.4	Not applicable	Not applicable
Z	+0.1	0.0	+0.1	0.0	-0.6	0.0	Not applicable	Not applicable
Engine gimbal position, deg								
Initial								
Pitch	+1.22	+1.18	+1.88	+0.53	+0.48	+0.66	Not applicable	Not applicable
Yaw	-0.12	-0.12	-0.63	+1.15	+0.98	+0.90	Not applicable	Not applicable
Maximum excursion								
Pitch	+0.34	+0.35	+0.31	-2.10	-2.13	-1.80	Not applicable	Not applicable
Yaw	-0.51	-0.42	-0.34	+2.04	+2.06	+1.95	Not applicable	Not applicable
Steady-state								
Pitch	Not applicable	+1.13	+1.66	+0.57	+0.44	+0.53	Not applicable	Not applicable
Yaw	Not applicable	-0.04	-0.50	+1.02	+1.11	+1.24	Not applicable	Not applicable
Cutoff								
Pitch	Not applicable	1.87	+1.70	+0.57	+0.48	+0.61	Not applicable	Not applicable
Yaw	Not applicable	-0.71	-0.38	+1.02	+1.11	-0.42	Not applicable	Not applicable
Maximum rate excursion, deg/sec								
Pitch	+0.15	-0.09	-0.14	+1.04	+1.00	+0.90	Not applicable	Not applicable
Yaw	+0.22	+0.14	+0.19	-1.01	-1.00	>+1.00	Not applicable	Not applicable
Roll	-0.26	-0.21	-0.11	-0.73	-1.00	>+1.00	Not applicable	Not applicable

<sup>a</sup> Service propulsion system used for these maneuvers.

<sup>b</sup> Inertial coordinates before trimming.

<sup>c</sup> Body coordinates after trimming.

drift slightly outside the deadband. This resulted in longer than desired thruster firings as well as an unnecessary number of firings. Procedural changes were made for Apollo 16 to reduce the state vector integration routine computation time and to bias the pointing vector such that gravity gradient torques would hold the vehicle against the positive deadband only. Results indicate that the procedural changes halved the number of thruster firings and the pointing accuracy was improved by a factor of two.

The crew reported that the Teflon locking rings did not prevent the optical eyeguards on the scanning telescope from unscrewing in zero g and it was annoying to have to refocus the telescope each time it was used. The cause of both problems was the nonavailability of flight hardware for crew training. Flight hardware has been provided in training simulators.

The entry sequence, beginning with command module/service module separation, was normal through landing. The guidance system controlled the spacecraft attitude and lift vector during entry and guided the vehicle to landing coordinates of 0 degrees 42 minutes 0 seconds south latitude, 156 degrees 12 minutes 48 seconds west longitude, as determined from the spacecraft computer.

## 6.7 PROPULSION

### 6.7.1 Reaction Control Systems

Performance of the service module reaction control system was normal throughout the mission. Planned propellant consumption was exceeded by about 90 pounds because of the unanticipated rendezvous maneuver with the lunar module. Approximately 28 pounds of the propellant deficiency was recovered by subsequent systems management and by the deletion of two planned maneuvers.

No preheating of the command module reaction control system was required prior to activation. Checkout firings and systems performance were satisfactory. Both systems were active during entry. The filters and screens were found to be deformed when the regulators were disassembled during postflight testing (see sec. 14.1.21). The propellant depletion firing and system purge was not performed on this mission. However, a "burp" firing from two engines in each system was initiated at an altitude of about 350 feet to relieve the propellant manifold pressure. As a result, pin-hole burns were detected in the recovered parachutes (see sec. 14.1.18). The propellant isolation valves were in the closed position for these firings.

An explosive failure of a ground support equipment decontamination unit tank occurred during the postflight deactivation of the oxidizer (nitrogen tetroxide) portion of the Apollo 16 command module reaction control system (see sec. 14.1.20).

### 6.7.2 Service Propulsion System

Service propulsion system performance was satisfactory during each of the six maneuvers. Total firing time was 575.35 seconds. For times of ignition and durations of firings, refer to table 6-III.

There were three deviations from expected conditions:

- a. The onboard oxidizer and fuel tank pressure indications were known to be biased plus 8 and minus 7 psi, respectively.
- b. The oxidizer tank pressure indication became 15 psi higher at zero-g than actual on both telemetry and onboard display (see sec. 14.1.2).
- c. The propellant utilization valve was left in the normal position throughout the flight because of an electrical problem in the system noted during prelaunch checkout.

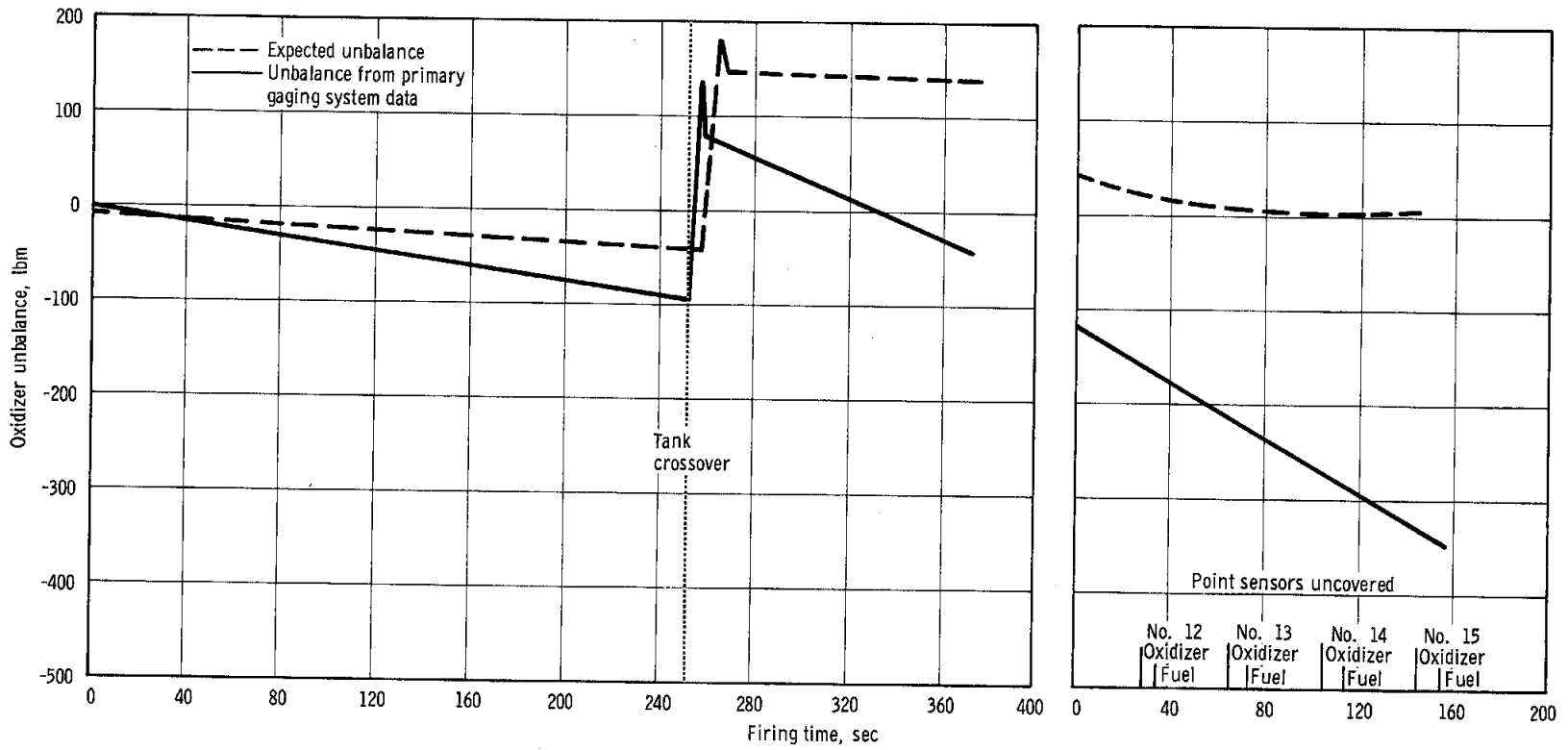
Figure 6-1 shows the propellant unbalance for the lunar orbit insertion and transearth injection firings as indicated by the telemetry data. The auxiliary gaging system was activated for the transearth injection firing; therefore, the figure shows the point sensor uncoverings during firing as indicated by the auxiliary gaging data. The preflight-expected unbalance is also shown in the figure.

## 6.8 ENVIRONMENTAL CONTROL SYSTEM AND CREW STATION EQUIPMENT

### 6.8.1 Environmental Control System

The environmental control system performed satisfactorily. Several anomalies occurred, but none affected the mission significantly.

Shortly after orbital insertion, as the water/glycol reservoir was being isolated, the system valves were inadvertently positioned to completely block the primary coolant loop. The system was supplying no additional heat load in this configuration; therefore, the evaporator started to freeze and the indicated backpressure reached the lower limit of 0.05 psia. The reservoir valves were repositioned, flow was restored, and the evaporator recovered smoothly with no adverse effects.



(a) Lunar orbit insertion maneuver.

(b) Transearth injection maneuver.

Figure 6-1.- Indicated oxidizer propellant unbalance.

After translunar injection, the water/glycol temperature control circuit malfunctioned in the automatic mode. The temperature control valve was positioned manually to maintain acceptable coolant loop temperatures. The mean system temperature was slightly cooler than normal during lunar orbit operations. For a discussion of this anomaly, see section 14.1.1.

The Command Module Pilot reported having to use more than the usual force in performing the third daily water chlorination. Also, some fluid leakage was noted. A detailed discussion of this anomaly is contained in section 14.1.7.

Two of the lithium hydroxide canisters used during solo lunar orbit operations were difficult to remove. One was especially tight and considerable effort was required in the removal. Section 14.1.15 gives further details of this anomaly.

Following cabin depressurization for the transearth extravehicular activity, the water/glycol in the cabin decreased in temperature. The decrease was over an 8-minute period. The primary water/glycol radiator outlet temperature decreased from 30° F to 21° F, the evaporator water/glycol outlet temperature decreased from 45° F to 32° F, and the suit inlet temperature decreased from 48° F to 36.6° F. The water/glycol temperature control valve was then adjusted and the evaporator outlet temperature stabilized at approximately 57° F during the remainder of the extravehicular activity.

A similar but less severe temperature decrease was observed at the beginning of the Apollo 15 mission extravehicular activity. Temperatures decreased and returned to normal about 10 minutes after the cabin had been depressurized. Slight temperature fluctuations have also been observed during depressurized cabin operations in the manned altitude tests. These temperature changes are caused by the freezing of water that had condensed earlier on the water/glycol lines. An evaluation of the Apollo 16 mission cabin environment indicated a higher-than-normal humidity. This would account for an increased amount of condensation and, therefore, greater temperature excursions than were experienced during the chamber runs and the Apollo 15 mission. Based on a 13° F decrease of the evaporator outlet temperature, less than 173 Btu's were removed from the primary coolant loop. This would require the sublimation of approximately 2.6 ounces of water.

The vacuum cleaner failed after becoming clogged with dust. The vacuum cleaner was cleaned postflight and it operated properly. The design of the vacuum cleaner is such that lunar dust can clog the impeller.



The cabin fans began to "moan" shortly after transearth injection and the fans were turned off for the remainder of the mission. In post-flight tests, the fans operated properly. This anomaly is discussed in section 14.1.11.

The residue from approximately 1 teaspoon of water/glycol was discovered on the command module floor during the postflight activities. Traces of water/glycol were also found on the lower front edge of the suit heat exchanger and on the coolant control side of the environmental control unit (see sec. 14.1.19).

### 6.8.2 Crew Station/Equipment

Crew equipment performance was satisfactory. However, the extravehicular mobility unit maintenance kit was swollen to about three times the thickness of a similar kit which was stowed in the lunar module. The cause of this anomaly is discussed in section 14.3.9.

The Command Module Pilot's Y-Y couch strut was difficult to extend and lock during entry preparations. The Command Module Pilot commented that there was no discernable clearance between the strut pad and the command module wall. Postflight inspection indicated a clearance, but did show wear and galling of the strut barrel (see sec. 14.1.17).

## 6.9 CONTROLS AND DISPLAYS

Performance of the controls and displays was normal, with the following two exceptions:

Errors were present in the oxidizer and fuel tank pressure readings and are discussed further in the instrumentation and propulsion sections.

The digital event timer, on panel 1, began to malfunction about halfway through the flight. A similar problem occurred during the Apollo 10 mission. This anomaly is discussed in section 14.1.13.

## 6.10 EXTRAVEHICULAR ACTIVITY EQUIPMENT

The environmental control system and crew equipment performed successfully throughout the transearth extravehicular activity.

The environmental control system suit loop pressure transducers, the Commander's cuff gage, and the Lunar Module Pilot's cuff gage were in disagreement during the time that the cabin was depressurized. See sections 14.1.12 and 14.3.8 for a discussion of these anomalies.

## 6.11 CONSUMABLES

All command and service module consumables remained well within red-line limits.

### 6.11.1 Service Propulsion Propellant

Service propulsion propellant and helium loadings and consumption values are listed in the following table. The loadings were calculated from gaging system readings and measured densities prior to lift-off.

Condition	Propellant, lb		
	Fuel	Oxidizer	Total
Loaded	15 676.2	25 070.3	40 746.5
Consumed	14 491.6	23 635.1	38 126.7
Remaining at end of transearth injection	1184.6	1435.2	2619.8
Usable at end of transearth injection	<sup>a</sup> 699.1	1140.2	1839.3

<sup>a</sup>Based on 1140.2 lb oxidizer and the propellant utilization valve in normal position.

Condition	Helium, lb	
	Storage Bottles	Propellant Tanks
Loaded	86.6	5.4
Consumed	62.6	-
Remaining at end of transearth injection	24.0	68.0

## 6.11.2 Reaction Control System Propellant

Service Module.— The propellant utilization and loading data for the service module reaction control system were as shown in the following table. Consumption was calculated from telemetered helium tank pressure histories and was based on pressure, volume, and temperature relationships.

Condition	Propellant, lb		
	Fuel	Oxidizer	Total
Loaded			
Quad A	110	227	337
Quad B	110	225	335
Quad C	110	226	336
Quad D	110	225	335
Total	440	903	1343
<sup>a</sup> Usable loaded			1252
Consumed			806
Remaining at command module/ service module separation			446

<sup>a</sup>Usable loaded propellant is the amount loaded minus the amount trapped with corrections made for gaging system errors.

## 6.11.4 Water

The water quantities loaded, produced, and expelled during the mission are shown in the following table.

Condition	Quantity, lb
Loaded (at lift-off)	
Potable tank	24.5
Waste tank	35.2
Produced inflight	
Fuel cells	476
Lithium hydroxide	22.7
Metabolic	22.1
Dumped overboard	
Waste tank	394.3
Potable tank	6.7
Skylab contamination experiment	7.8
Urine and flushing	<sup>a</sup> 76.3
Evaporator usage	9.9
Remaining at command module/ service module separation	
Potable tank	36.3
Waste tank	49.2

<sup>a</sup>This is the quantity required to complete the balance. Standard Operations Data Book values based on an average metabolic rate of 467 Btu/hr indicate a urine and feces production of 77.0 lb. It is estimated that less than 4 lb of water was used for flushing. The difference between the Standard Operations Data Book values (plus estimated flushing) and the quantity required to complete the balance is approximately 4.7 lb and is negligible considering the inaccuracy and uncertainty of the data used to obtain this balance.

Command Module.- The loading and utilization of command module reaction control system propellant were as follows. Consumption was calculated from pressure, volume, and temperature relationships.

Condition	Propellant, lb		
	Fuel	Oxidizer	Total
Loaded			
System 1	38.6	78.1	116.7
System 2	38.5	78.2	116.7
Total	77.1	156.3	233.4
<sup>a</sup> Usable loaded			196.6
Consumed prior to loss of signal during entry			
System 1			28
System 2			28
Total			56

<sup>a</sup>Usable loaded propellant is the amount loaded minus the amount trapped.

## 6.11.3 Cryogenics

The total cryogenic hydrogen and oxygen quantities available at lift-off and consumed were as follows. Consumption values were based on quantity data transmitted by telemetry.

Condition	Hydrogen, lb		Oxygen, lb	
	Actual	Planned	Actual	Planned
Available at lift-off				
Tank 1	25.9		318	
Tank 2	25.8		323	
Tank 3	26.7		315	
Total	78.4	78.4	956	956
Consumed				
Tank 1	18.7		188	
Tank 2	18.6		152	
Tank 3	16.7		186	
Total	54.0	57.7	526	561
Remaining at command module/service mod- ule separation				
Tank 1	7.2	5.5	130	119
Tank 2	7.2	6.7	171	171
Tank 3	10.0	8.5	129	105
Total	24.4	20.7	430	395

## 7.0 LUNAR MODULE PERFORMANCE

This section contains an evaluation of lunar module systems performance with emphasis on problems encountered during the mission. The consumables usage is presented in section 7.8.

### 7.1 THERMAL, STRUCTURAL AND MECHANICAL SYSTEMS

Thermal performance was satisfactory. All temperatures remained within acceptable limits; however, the modular equipment stowage area temperatures did not follow the preflight predictions. Analysis and photographs indicate that the thermal blankets were not completely closed. Also, the television and 16-mm camera brackets were not removed. The presence of these brackets along with the lunar communications relay unit ancillary bracket, which may not have been removed, would prevent proper closure of the blankets and cause the temperature increase.

The crew had difficulty in adjusting the modular equipment stowage assembly to the proper height following deployment. This was not a hardware problem; therefore, installation and training procedures will be revised.

Structural loads were within design values based on guidance and control data, acceleration data, onboard pressure measurements, photographs, and crew comments. Little or no gear stroking occurred during the lunar landing as evidenced from approximately 6 inches of clearance between the lunar surface and the undamaged descent engine skirt. The landed attitude was estimated to be 2.3 degrees pitch up and 0.4 degree roll left.

A large number of long, thin, white particles were seen coming from the left side (minus-Y side) of the ascent stage at transposition and docking. Inflight examination and ground analysis verified that the thermal paint on the micrometeoroid shields had flaked and peeled. No adverse temperature effects were experienced from this anomaly, which is discussed in detail in section 14.2.1.

The lunar surface television camera showed loose material on the ascent stage during the lunar lift-off. This material was later identified as four thermal/micrometeoroid shields which were partially torn loose from the base of the aft equipment rack. Temperature control was maintained by the thermal blankets located under the panels. Additional details of this anomaly are given in section 14.2.2.

## 7.2 ELECTRICAL POWER

The performance of the batteries and the electrical power distribution system was satisfactory. The lunar landing delay caused an unplanned energy consumption of 200 ampere hours prior to descent. Because of power load reductions while on the lunar surface, approximately 100 ampere-hours were recovered in the planned-versus-actual electrical power budget. The d-c bus voltage was maintained above 28.2 volts and the maximum observed current was 72 amperes, during powered descent. Because the lunar module did not deorbit, data were obtained until batteries 5 and 6 had dropped to 21.7 and 21.5 volts, respectively.

After final egress from the lunar module, a master alarm was noted on PCM data. Review of the closeout switch position checklist revealed that the inverter select switch was left in the "inverter 2" position, which resulted in the nuisance alarm. The switch should have been left in the "off" position which inhibits the alarm.

## 7.3 COMMUNICATIONS

With the exceptions discussed in the following paragraphs, all functions, including voice, data, and ranging of both the S-band and VHF equipment operated satisfactorily during all phases of the mission.

The steerable antenna would not move in the yaw axis during initial activation. Several unsuccessful activation attempts were made in both the manual slew and auto track modes (see sec. 14.2.3). Except for a short period of time when the vehicle attitude was changed to point the steerable antenna at the earth, all S-band communications were maintained using the omnidirectional antennas. As expected, the voice and data quality were degraded by the resulting low signal strength. During lunar revolutions 12, 13, and 14, variations in signal strength of 10 to 15 dB were experienced while using the forward omnidirectional antenna. An example of this variation is shown in the ground-station-received signal plot in figure 7-1. This condition occurred at both the Madrid and Goldstone ground stations. An analysis of the data indicates that the reduction in signal always occurred within small areas of the antenna pattern. The most probable cause of this is multipath reflections from portions of the vehicle structure such as the rendezvous radar antenna dish. A detailed antenna gain pattern will be plotted of this critical area to better define what can be anticipated for Apollo 17 in the event that the omnidirectional antennas are required.



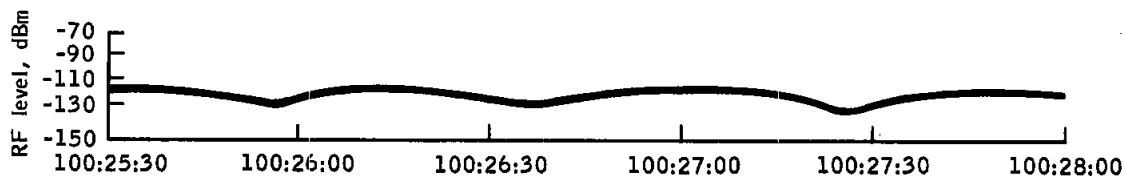


Figure 7-1.- Madrid ground station received signal.

At times during the mission, it was necessary to change the system configuration from "normal voice" to "down voice backup". At the time of switching, the down-link signal strength dropped abruptly for a short period. This was caused by a transient in the S-band transceiver output which caused the power amplifier to recycle. During this time, the system operates in the low-power mode which is reflected in signal strength reduction. This condition was discovered prior to the flight of Apollo 11. No change was warranted due to its random occurrence and the relatively small effect that it has on a mission.

The lunar module crewmen reported voice quality of the VHF B channel was degraded during ranging operation. The ranging switch was left on in the command and service module at all times even when ranging data were not being monitored. This degradation is inherent in the ranging system design.

During the communications check prior to the first extravehicular activity, the microphone audio signal from the Lunar Module Pilot's headset was too weak to operate the voice-operated keying circuitry in his extravehicular communications system. This was attributed to a loose tip on one of the communications carrier headset microphone booms plus orange juice blockage of the other microphone boom. This anomaly is discussed in section 14.3.5.

#### 7.4 RADAR

Landing radar performance was satisfactory. Two successive landing radar self-tests produced erroneous data, but a third self-test, performed approximately 30 minutes later, was normal in all respects. Analysis indicates the two unsuccessful self-tests resulted from lockup to signal returns from the lunar surface rather than the self-test stimulus. During

descent, velocity and range acquisition occurred at a slant range of approximately 48 700 feet. There was no evidence of dropout in signal tracking between acquisition and touchdown.

The rendezvous radar performance during separation and during the rendezvous sequence was normal. The rendezvous radar acquired the command and service module transponder during ascent at a range of approximately 150 miles. Data indicates good correlation between the rendezvous radar and VHF ranging system.

During the platform alignment prior to powered descent, the rendezvous radar antenna drifted into view of the alignment optical telescope. This is normal since, in the unpowered state, the antenna holds its orientation only by inherent frictional resistance, but this is not great enough to resist the inertial loading on the antenna.

## 7.5 GUIDANCE, NAVIGATION, AND CONTROL

The guidance, navigation, and control system performance was normal throughout the manned lunar module activities. The unmanned deorbit maneuver to impact the ascent stage on the lunar surface was not accomplished because of the loss of attitude control capability. This anomaly is discussed in greater detail later in this section and in section 14.2.6.

The primary guidance system was activated at 94 hours 33 minutes; the computer timing was then synchronized to the command module computer, and the platform was aligned to the command module guidance system. A manual update to the state vector in the computer was required because of the S-band steerable antenna problem. A summary of all primary guidance system platform alignments is shown in table 7-I. Table 7-II contains a summary of mission and preflight inertial component histories. The inertial instruments performed well; only one update was required, for an accelerometer bias term.

The abort guidance system was activated following a normal undocking and separation from the command module. A summary of preflight and in-flight performance of the abort guidance system accelerometers and gyros is shown in table 7-III. The first lunar surface calibration indicated that the X-gyro bias drift had shifted from the previous calibration by 1.1 degrees per hour. Although greater than expected, this shift was within acceptable limits.

Following a three-orbit delay, the powered descent was initiated and was normal with two minor exceptions:

TABLE 7-I.- LUNAR MODULE PLATFORM ALIGNMENT SUMMARY

Time hr:min	Type alignment	Alignment mode						Star angle difference, deg	Gyro torquing angle, deg		
		Option <sup>a</sup>	Technique <sup>b</sup>	Detent <sup>c</sup>	Star	Detent <sup>c</sup>	Star		X	Y	Z
96:58	52	3	---	2	26-Spica	2	33-Antares	-0.05	-0.060	0.139	-0.018
102:42	52	1	--	2	26-Spica	2	33-Antares	-0.01	-0.067	0.108	0.050
105:03	57	3	3	3	40-Altair	-	--	-0.01	-0.019	0.038	-0.021
173:49	57	4	3	1	04-Achernar	-	--	0.03	-0.540	0.046	-0.056
174:58	57	3	3	1	04-Achernar	-	--	0.04	-0.019	0.017	-0.012

<sup>a</sup>1 - Preferred; 2 - Nominal; 3 - REFSMMAT; 4 - Landing site.

<sup>b</sup>0 - Stored attitude; 1 - REFSMMAT + g; 2 - Two bodies; 3 - 1 body + g.

<sup>c</sup>1 - Left front; 2 - Center; 3 - Right front; 4 - Right rear; 5 - Rear; 6 - Left rear.

TABLE 7-II.- LUNAR MODULE INERTIAL COMPONENT HISTORY<sup>a</sup>

Parameter	Countdown value	Flight load	Inflight performance		
			Power-up to surface	Surface power-up to lift-off	Lift-off through rendezvous
(a) Accelerometers					
X - Axis					
Scale factor error, ppm . . . . .	-816	-890	-	-	-
Bias, cm/sec <sup>2</sup> . . . . .	1.83	1.84	1.83	1.84	1.81
Y - Axis					
Scale factor error, ppm . . . . .	-403	-400	-	-	-
Bias, cm/sec <sup>2</sup> . . . . .	1.57	1.60	1.62	1.66	1.65
Z - Axis					
Scale factor error, ppm . . . . .	-526	-4.70	-	-	-
Bias, cm/sec <sup>2</sup> . . . . .	1.23	1.16	1.24	1.23	1.25
(b) Gyroscopes					
X - Axis					
Null bias drift, meru . . . . .	0.3	-0.3	0.78	1.15	-
Acceleration drift along spin reference axis, meru/g . . . . .	-0.3	-1.0	-	-	-
Acceleration drift about input axis, meru/g . . . . .	13.1	13.0	-	-	-
Y - Axis					
Null bias drift, meru . . . . .	-0.9	0.6	-1.26	-1.03	-
Acceleration drift along spin reference axis, meru/g . . . . .	-6.7	-4.0	-	-	-
Acceleration drift about input axis, meru/g . . . . .	-6.0	-3.0	-	-	-
Z - Axis					
Null bias drift, meru . . . . .	-2.3	-2.6	0.58	-0.73	-
Acceleration drift along spin reference axis, meru/g . . . . .	3.6	3.0	-	-	-
Acceleration drift about input axis, meru/g . . . . .	17.7	14.0	-	-	-

<sup>a</sup>The pre-countdown samples, means, and standard deviations normally given in this table are not available because the inertial measurement unit was changed in the spacecraft just before lunar module closeout.

TABLE 7-III.- ABORT GUIDANCE SYSTEM CALIBRATION HISTORY

Accelerometers								
Static bias, $\mu\text{g}$	Preflight performance				Inflight performance			
	Number of calibrations	Mean of calibrations	Standard deviation of calibrations	Flight load	System activation	Pre-descent	Post-ascent	
X	21	-.009	0.001	+0.010	+0.008	+0.0072	+0.0066	
Y	21	-0.001	0.0003	-0.001	-0.001	-0.0023	-0.0024	
Z	21	-0.002	0.0002	-0.002	-0.002	-0.0025	-0.0027	

Gyros								
Gyro drift, deg/hr	Preflight performance				Inflight performance			
	Number of calibrations	Means of calibrations	Standard deviation of calibrations	Flight load	System activation	Surface calibration no. 1	Surface calibration no. 2	Post-ascent
X	21	0.03	0.05	-0.10	-0.06	-1.16	-1.13	Varying
Y	21	-0.29	0.02	-0.27	-0.45	-0.52	-0.60	-0.60
Z	21	0.55	0.03	0.59	0.29	0.68	0.64	-0.64

a. An out-of-plane velocity component difference became apparent between the abort and primary guidance systems. This increased to a maximum of 28 feet per second near lunar touchdown.

b. The abort guidance system indicated a roll axis misalignment of 0.47 degree from the primary guidance system following the lunar landing.

These problems are discussed in section 14.2.7.

A time history of altitude during descent and several significant events pertaining to landing radar performance are shown in figure 7-2. Table 7-IV contains the sequence of events during powered descent. The total effect of the landing point redesignations was to move the landing site coordinates 189 meters (620 ft) uprange and 194 meters (635 ft) south. Data became noisy as the lunar module approached the lunar surface and this precluded a detailed analysis of the landing dynamics.

Performance during ascent was normal. Velocity residuals were low and no trim maneuver was required; however, a vernier adjustment maneuver was performed. Table 7-V contains a summary of insertion conditions as indicated by the primary and abort guidance systems and by the powered flight processor (ground computation). Table 7-VI is a summary of rendezvous maneuvers obtained from several sources.

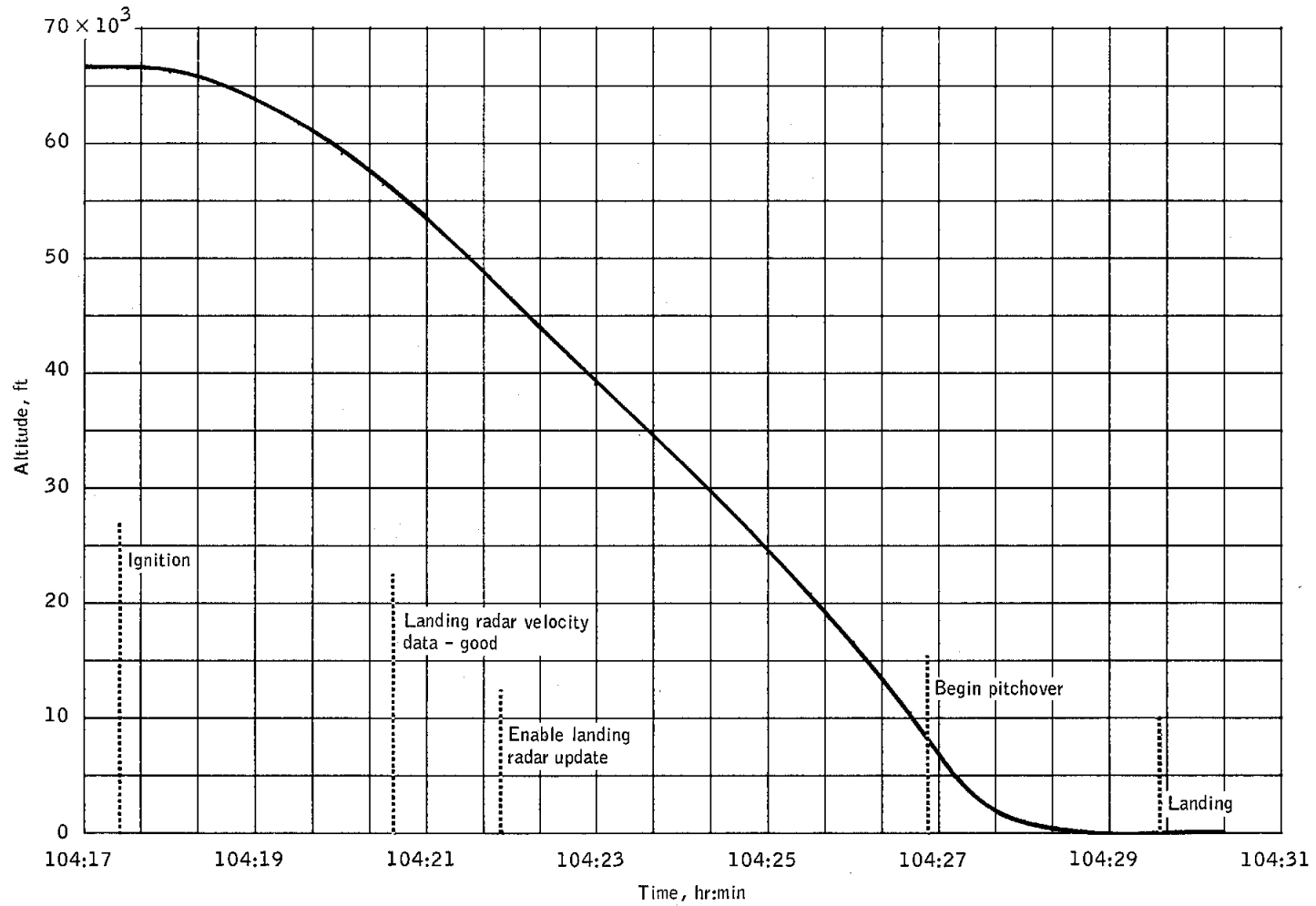


Figure 7-2.- Time history of altitude and landing radar events during descent.

TABLE 7-IV.- SEQUENCE OF EVENTS DURING POWERED DESCENT

Elapsed time, hr:min:sec	Time from ignition, min:sec	Event
104:17:18	-00:07	Ullage on
104:17:25	00:00	Ignition
104:17:53	00:28	Throttle to full-throttle position
104:19:16	01:51	Manual target (landing site) update- Noun 69
104:20:38	03:13	Landing radar velocity data good
104:21:24	03:59	Landing radar range data good
104:21:54	04:29	Enable landing radar updates - Verb 57
104:24:14	06:49	Enter landing point redesignation phase
104:24:54	07:29	Throttle down
104:26:50	09:25	Landing radar antenna to position 2
104:26:52	09:27	Approach phase program selected Program 64, and pitchover
104:27:20	09:55	First landing point redesignation
104:27:32	10:07	Landing radar to low scale
104:28:37	11:12	Select attitude hold mode
104:28:42	11:17	Select landing phase program - Program 66
104:29:35	12:10	Lunar landing (approximate)

TABLE 7-V.- LUNAR ASCENT INSERTION SUMMARY

Source	Altitude, ft	Velocity in inertial coordinates, ft/sec		
		X	Y	Z
Primary guidance system	59 957	-958.82	0.77	5441.84
Abort guidance system	59 665	-959.83	-2.81	5441.77
Powered flight processor	59 750	-959.94	2.19	5442.52

TABLE 7-VI.- RENDEZVOUS SOLUTIONS

Maneuver	Local vertical coordinates	Computed velocity change, ft/sec		
		Command module computer	Lunar module guidance computer	Abort guidance system
Terminal phase initiation	$\Delta V_x$	78.4	78.0	78.3
	$\Delta V_y$	2.4	2.7	2.9
	$\Delta V_z$	-3.8	0.7	-3.7
	Total	78.5	78.0	78.4
First midcourse correction	$\Delta V_x$	-0.2	-0.3	0.0
	$\Delta V_y$	-0.1	-0.1	0.9
	$\Delta V_z$	-0.4	+0.9	0.8
	Total	0.5	1.0	1.2
Second midcourse correction	$\Delta V_x$	0.5	0.5	0.6
	$\Delta V_y$	-0.5	0.2	0.9
	$\Delta V_z$	2.2	0.7	1.0
	Total	2.3	0.9	1.5

After docking, the lunar module was powered-down and the crew returned to the command module overnight. Power was reapplied to the primary guidance and control system the next day, but the 28-volt-dc enabling voltage did not reach the primary preamplifiers. Consequently, the control system could not issue engine firing commands. There was no thruster firing activity following jettison and the deorbit maneuver was not performed.

## 7.6 PROPULSION

### 7.6.1 Reaction Control System

Performance of system B was normal throughout the mission; however, an anomalous condition developed when system A was activated. The regulated outlet pressure increased beyond the specification lockup pressure of the system. This was attributed to regulator leakage. The condition persisted throughout the mission causing intermittent operation of the helium relief valves and overboard venting of the pressurant gas. The leakage of helium through the regulator and subsequent venting overboard was not high enough, however, to require a blowdown operation. To relieve this condition, the ullage volume in system A was increased by



transferring a portion of the propellants to the ascent propulsion tanks. The ullage volume in system A tanks was thereby increased, providing sufficient blowdown capability so that this system could be used as a back-up in case of a malfunction in system B. The problem is discussed further in section 14.2.4.

### 7.6.2 Descent Propulsion System

The descent propulsion system performed well during powered descent with one exception. The gaging system fuel probes indicated a lower-than-expected fuel quantity. This condition existed throughout the firing and is believed to have been caused by a difference in the conductivity of the fuel in the reference conductor and the measuring conductor. Previous testing of these probes has shown similar errors when such differences exist. Total firing time was about 731 seconds. The usable propellant quantity remaining (1128 pounds) would have provided approximately 102 seconds of hover time.

### 7.6.3 Ascent Propulsion System

System performance was satisfactory during the lunar ascent and the terminal phase initiation maneuver. Ascent firing duration was 427.7 seconds. Terminal phase initiation firing duration was estimated to be 2.5 seconds, making the total firing time approximately 430.2 seconds.

Two upward shifts in the engine chamber pressure were recorded during the ascent maneuver, as shown in figure 7-3. A review of all other available engine and acceleration data failed to substantiate the increased chamber pressure indication. The crew did not recall feeling additional acceleration or surges during the maneuver. This anomaly is discussed further in section 14.2.8.

## 7.7 ENVIRONMENTAL CONTROL

The performance of the system was satisfactory. Two anomalies which occurred are discussed in the following paragraphs.

One off-nominal condition was experienced approximately 2 hours after system activation when the suit circuit valves were configured to the cabin mode of operation. The crew reported hearing a chattering noise and experienced pressure pulsations in suit circuit flow. The problem was traced

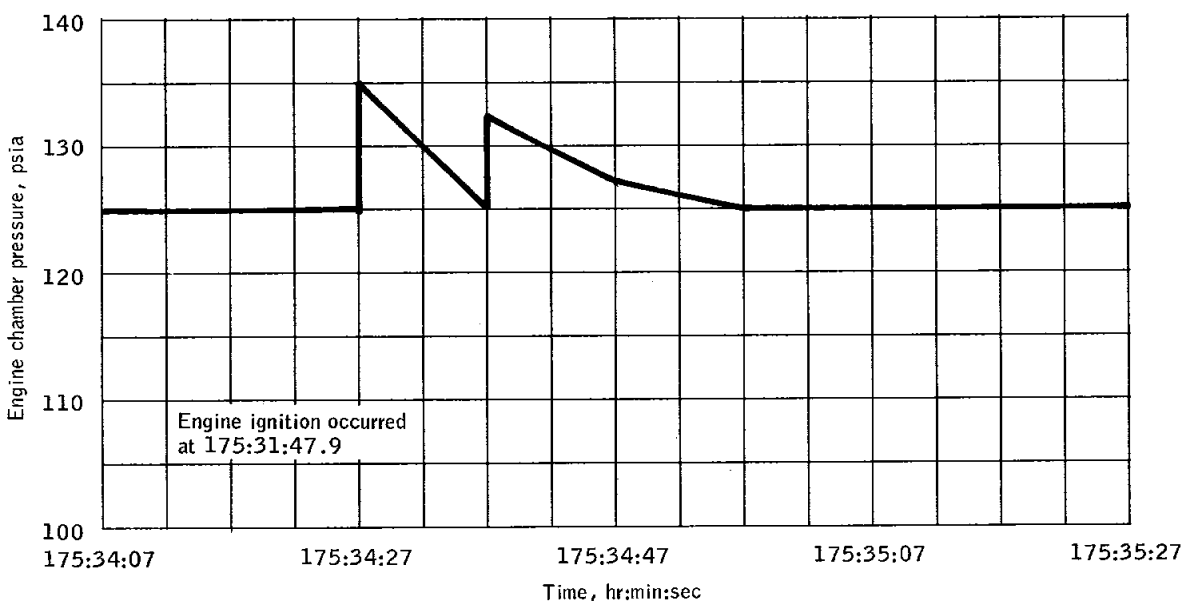


Figure 7-3.- Ascent propulsion system pressure fluctuations.

Figure 7-3.- Ascent propulsion system pressure fluctuations.

to the cabin gas return valve which apparently failed to open in the automatic mode. Manual control was used for the remainder of the mission although the automatic mode was checked subsequently and found to be operable. See section 14.2.5 for further discussion of this anomaly.

Fluctuations in the water/glycol pump differential pressure were noted following the cabin depressurizations for each extravehicular activity. Pressure fluctuations occurred in the same manner after two of four extravehicular activities on Apollo 15. The heat transfer performance of the system was satisfactory. An analysis of this anomaly is given in reference 4.

## 7.8 CONSUMABLES

All lunar module consumables remained well within red-line limits.

## 7.8.1 Descent Propulsion System

Propellant.- The descent propulsion system propellant load quantities shown in the following table were calculated from known volumes and weights of offloaded propellants, temperatures, and densities prior to lift-off.

Condition	Quantity, lb		
	Fuel	Oxidizer	Total
Loaded	7530.4	12 028.9	19 559.3
Consumed	7105.4	11 221.9	18 327.3
Remaining at engine cutoff:			
Total	425	807	1232
Usable	396	732	1128

Supercritical helium.- The quantities of supercritical helium were determined by computations using pressure measurements and the known volume of the tank.

Condition	Quantity, lb	
	Actual	Predicted
Loaded	51.2	51.2
Consumed	41.8	42.7
Remaining at landing	9.4	8.5

## 7.8.2 Ascent Propulsion System

Propellant.- The ascent propulsion system total propellant usage was approximately as predicted. The loadings shown in the following table were determined from measured densities prior to launch and from weights of off-loaded propellants.

Condition	Propellant mass, lb			<sup>a</sup> Predicted quantity,
	Fuel	Oxidizer	Total	
Loaded	2017.8	3224.7	5242.5	5242.5
Transferred from reaction control system	16.0	44.0		
Total on board at lunar lift-off	2033.8	3268.7		
Consumed	1869.8	3011.0	4880.8	4903.6
Remaining at ascent stage jettison	164.0	257.7	421.7	338.9

<sup>a</sup>Propellant required for ascent was reduced by 80.0 lbm to account for reaction control system consumption.

Helium.- The quantities of ascent propulsion system helium were determined by pressure measurements and the known volume of the tank.

Condition	Actual Quantity, lb
Loaded	13.2
Consumed	8.4
Remaining at ascent stage jettison	4.8

## 7.8.3 Reaction Control System Propellant

The reaction control system propellant consumption was calculated from telemetered helium tank pressure histories using the relationships between pressure, volume, and temperature.

Condition	Actual quantity, lb			Predicted quantity, lb
	Fuel	Oxidizer	Total	
Loaded				
System A	107.4	208.2	315.6	
System B	107.4	208.2	315.6	
Total			631.2	631.2
Transferred to ascent propulsion system	16.0	44.0	60.0	
Consumed to:				
Lunar landing			125	142
Docking			212	266
Remaining at ascent stage jettison			359.2	365.2

## 7.8.4 Oxygen

The actual quantities of oxygen loaded and consumed are shown in the following table:

Condition	Actual quantity, lb	Predicted quantity, lb
Loaded (at lift-off)		
Descent stage		
Tank 1	46.7	
Tank 2	46.6	
Ascent stage		
Tank 1	2.4	
Tank 2	2.4	
Total	98.1	
Consumed		
Descent stage		
Tank 1	21.9	25.7
Tank 2	21.5	25.6
Ascent stage		
Tank 1	0	0
Tank 2	0	0
Total	43.4	51.3
Remaining in descent stage at lunar lift-off		
Tank 1	24.8	21.0
Tank 2	25.1	21.0
Remaining at docking (ascent stage)		
Tank 1	2.4	2.4
Tank 2	2.4	2.4
Total	4.8	4.8

## 7.8.5 Water

The actual water quantities loaded and consumed, shown in the following table are based on telemetered data.

Condition	Actual quantity, lb	<sup>a</sup> Predicted quantity, lb
Loaded (at lift-off)		
Descent stage		
Tank 1	193.9	
Tank 2	199.4	
Ascent stage		
Tank 1	42.5	
Tank 2	42.5	
Total	478.3	
Consumed		
Descent stage (lunar lift-off)		
Tank 1	193.9	192.4
Tank 2	199.4	197.9
Ascent stage (docking)		
Tank 1	7.2	7.5
Tank 2	6.9	7.5
Total	407.4	405.3
Remaining in descent stage at lunar lift-off		
Tank 1	<sup>b</sup> 0	1.5
Tank 2	<sup>b</sup> 0	1.5
Remaining in ascent stage at docking		
Tank 1	35.3	35.0
Tank 2	35.6	35.0
Total	70.9	70.0

<sup>a</sup>Adjusted to compensate for the additional 5 hours in lunar orbit prior to descent.

<sup>b</sup>Because of the extended lunar module activity, the descent stage water tanks reached depletion at the same time the crew selected ascent stage consumables.

## 7.8.6 Electrical Power

The total battery energy usage is given in the following table.

Battery	Available power, ampere hours	Power consumed, ampere hours	
		Actual	Predicted
Descent	2025	1746	1646
Ascent	592	<sup>a</sup> 285	285

<sup>a</sup>Batteries 5 and 6 provided a total of 285 ampere hours through crew transfer. The total energy provided by batteries 5 and 6 until data loss was 358.9 and 377.8 ampere hours, respectively.



## 8.0 LUNAR SURFACE EQUIPMENT PERFORMANCE

### 8.1 LUNAR ROVING VEHICLE

The lunar roving vehicle performance was good; however, several system problems occurred. These problems are:

- a. Higher-than-expected battery temperatures
- b. Multiple failures of instrumentation hardware
- c. Loss of rear fender extension
- d. Temporary loss of rear steering.

Procedural errors resulted in the temporary loss of rear drive power and a temporary loss of all navigation displays except heading and speed.

The approximate distances driven during the three extravehicular activities were 4.2, 11.1 and 11.4 kilometers for a total of 26.7 kilometers. Speeds up to 14 kilometers per hour were achieved on the level surface. Slopes estimated to be as steep as 20 degrees were negotiated without difficulty.

The lunar roving vehicle provided electrical power for voice, telemetry, and television communications throughout the first two extravehicular activities, and also provided power for television operations after the third extravehicular activity. A total of 98.2 ampere-hours was consumed from the 242 ampere-hours available in the two batteries.

Several minor problems, which subsequently disappeared, were experienced during the activation of the lunar rover. The rear steering was inoperative, the battery 2 ampere-hours remaining and voltage readings were off-scale low, and both battery temperatures were off-scale low (see sec. 14.6.1 and 14.6.2).

After returning to the lunar module near the end of the first traverse, the Commander performed a lunar roving vehicle evaluation while the Lunar Module Pilot took 16-mm documentary motion pictures.

At the conclusion of the first extravehicular activity, the vehicle was parked with the front of the vehicle pointing towards the north. The battery temperatures were 104° F and 105° F with 108 and 105 ampere-hours remaining. The battery covers were brushed and opened, the radiator surfaces were dusted, and the power-down was completed. The battery covers did not close between the first and second extravehicular activities and temperatures at power-up for the second extravehicular activity were 70° F and 82° F.

On the second traverse, the attitude indicator pitch scale fell off, but the needle was still used to estimate pitch attitudes (see sec. 14.6.4). Incorrect matching of switches caused a loss of rear-wheel drive. Correct switch configuration returned the vehicle operation to normal. The crew noted that the forward wheels tended to dig in when attempting to climb slopes without rear-wheel power. The right rear fender extension was knocked off and, thereafter, dust was thrown up from the right rear wheel and covered the crew, the console, and the communications equipment. Midway through the second extravehicular traverse, the ampere-hour integrator for battery 1 began indicating about four times the normal battery usage. Because of higher-than-desired temperatures on battery 1, a series of procedures were initiated to lower the load. These procedures probably caused the inadvertent removal of drive power from a pair of wheels, thereby losing two odometer inputs and the associated static range, bearing, and distance displays (see sec. 14.6.3). The problem cleared when the normal switch and circuit breaker configuration was restored.

At power-up for the third traverse, the battery covers were closed manually and the lunar communications relay unit was switched to its own power. The lunar roving vehicle battery temperatures were 102° F and 120° F. About 2 hours after power-up, the caution and warning flag was activated because the battery 2 temperature exceeded 125° F. Rear-wheel drive power and steering were switched to battery 1 bus B. Later, the battery 1 temperature indicator went off-scale low, indicating a meter failure. Both batteries were functional at the end of the third extravehicular activity when the lunar roving vehicle was configured to provide power for television. The closeout reading of the battery 2 temperature was 143° F.

## 8.2 LUNAR COMMUNICATIONS RELAY UNIT AND GROUND COMMANDED TELEVISION ASSEMBLY

The lunar communications relay unit and ground commanded television assembly operated for 12 hours 44 minutes during the lunar surface extravehicular activities. The relay unit in conjunction with the television camera was energized by up-link command for lunar module ascent television coverage and for six days of scientific lunar surface observations on a once-per-day basis until April 30, 1972. At that time, the system could not be energized by up-link command. Down-link data from the relay unit on the preceding day showed the expected temperatures, internal voltages, and RF signal strength. Possible causes of the problem include: (1) malfunction of the television control unit up-link decoder due to its pre-launch predicted high temperature condition (above qualification level), and (2) loss of input power because of incorrect circuit breaker configuration on the lunar roving vehicle that would have placed only one of the two batteries on the line.

### 8.3 EXTRAVEHICULAR MOBILITY UNIT

Throughout the three extravehicular activities, the performance of the extravehicular mobility units was satisfactory and the crew were able to perform their functions in an effective manner. Telemetry data were not available until after crew egress from the lunar module because of the steerable antenna malfunction (see sec. 14.2.3), therefore, consumables were computed based on previous experience with these units as well as telemetry data.

The crew had some difficulty in closing the restraint zippers during donning of the suits. The suits are custom fitted and, by necessity, must be tight to achieve good mobility. Particular attention will be given to the self-donning of suits during training and a restraint zipper hook has been provided on Apollo 17 as a donning aid.

The checkout of the portable life support system was normal on each extravehicular activity. Higher-than-predicted heat loads were experienced on the first and third extravehicular activities; however, thermal equilibrium was maintained well within acceptable limits even when the crew operated for a considerable length of time in an area of sun reflection from boulders. The heat was so intense that the crew commented that they could feel it. Primary feedwater supply depletion tones occurred during the first extravehicular activity. A warning tone was received for depletion of the Lunar Module Pilot's auxiliary feedwater supply near the end of the first extravehicular activity when his water supply was depleted.

The purge valve pin on the Commander's suit was accidentally pulled out twice during the first extravehicular activity while ingressing the lunar roving vehicle. Both times, the pin was found and reinserted without any adverse effect. To prevent a recurrence during subsequent traverses, both crewmen rotated their purge valves to prevent the pins from being accidentally removed (see sec. 14.3.10).

During ingress after the second extravehicular activity, the Commander broke the tip off of his antenna. The two crewmen exchanged units to preclude a possible limitation on range. Section 14.3.2 contains a discussion on this anomaly.

After exposure to a dusty lunar environment, the both crewmen's suit wrist-ring disconnects were hard to rotate to the locked and unlocked position. This anomaly is explained in section 14.3.4.

Oxygen, power, and feedwater consumption of the extravehicular mobility units during the three extravehicular periods is shown in table 8-I.

TABLE 8-I.- EXTRAVEHICULAR MOBILITY UNIT CONSUMABLES

Condition	Commander		Lunar Module Pilot	
	Actual	<sup>a</sup> Predicted	Actual	<sup>a</sup> Predicted
First extravehicular activity				
Time, min	431	420	431	420
<sup>b</sup> Oxygen, lb				
Loaded	1.93	1.86	1.93	1.86
Consumed	1.24	1.36	1.51	1.36
Remaining	0.69	0.50	0.42	0.50
Redline limit	0.37		0.37	
<sup>b</sup> Feedwater, lb				
Loaded	12.16	12.16	12.11	12.16
Consumed	9.08	9.04	11.62	9.04
Remaining	3.08	3.12	0.49	3.12
Redline limit	0.87		0.87	
Battery, amp-hr				
Initial charge	25.4	25.4	25.4	25.4
Consumed	20.7	19.4	21.0	19.35
Remaining	4.7	6.0	4.4	6.05
Redline limit	3.28		3.28	
Second extravehicular activity				
Time, min	444	420	444	420
<sup>b</sup> Oxygen, lb				
Loaded	1.81	1.81	1.81	1.81
Consumed	1.22	1.31	1.26	1.31
Remaining	0.59	0.50	0.55	0.50
Redline limit	0.37		0.37	
<sup>b</sup> Feedwater, lb				
Loaded	12.46	12.46	12.41	12.46
Consumed	9.48	9.21	10.28	9.21
Remaining	2.98	3.25	2.13	3.25
Redline limit	0.87		0.87	
Battery, amp-hr				
Initial charge	25.4	25.4	25.4	25.4
Consumed	21.4	19.4	21.0	19.4
Remaining	4.0	6.0	4.4	6.0
Redline limit	3.28		3.28	

NOTE: Refer to following pages for notes a and b.

TABLE 8.1.- EXTRAVEHICULAR MOBILITY UNIT CONSUMABLES - Concluded

Condition	Commander		Lunar Module Pilot	
	Actual	<sup>a</sup> Predicted	Actual	<sup>a</sup> Predicted
Third extravehicular activity				
Time, min	341	420	341	420
<sup>b</sup> Oxygen, lb				
Loaded	1.81	1.81	1.81	1.81
Consumed	1.04	1.34	1.02	1.34
Remaining	0.77	0.47	0.79	0.47
Redline limit	0.37		0.37	
<sup>b</sup> Feedwater, lb				
Loaded	12.46	12.46	12.41	12.46
Consumed	8.21	9.34	8.38	9.34
Remaining	4.25	3.12	4.03	3.12
Redline limit	0.87		0.87	
Battery, amp-hr				
Loaded	25.4	25.4	25.4	25.4
Consumed	16.7	19.4	16.4	
Remaining	8.7	6.0	9.0	
Redline limit	3.28		3.28	

## NOTES

<sup>a</sup>The following values were used in the preflight prediction calculations for both crewmen.

Period	Oxygen leak rate, lb/hr	Heat leak rate, Btu/hr
First extravehicular activity	0.02	0
Second extravehicular activity	0.028	215
Third extravehicular activity	0.035	225

<sup>b</sup>The following values were used for postflight calculations.

Period	Commander		Lunar Module Pilot	
	Oxygen leak rate, lb/hr	Heat leak rate, Btu/hr	Oxygen leak rate, lb/hr	Heat leak rate, Btu/hr
First extravehicular activity	0.019	135	0.013	135
Second extravehicular activity	0.021	220	0.0210	220
Third extravehicular activity	0.020	290	0.0210	290



Apollo 16 flight crew  
Commander John W. Young, Command Module Pilot Thomas K. Mattingly II,  
and Lunar Module Pilot Charles M. Duke, Jr.

## 9.0 PILOT'S REPORT

This section contains a description of the Apollo 16 mission as performed by the crew. Specific mission features and equipment operations which were different than Apollo 15 are covered. Some mission activities were modified because of the delay in performing the circularization maneuver, and the effects of those changes are addressed. The flight plan, as executed, is summarized in figure 9-1 at the end of this section.

### 9.1 TRAINING

The Apollo 16 crew was fortunate in that they had been assigned to J-mission spacecraft from the beginning of their training. From April of 1970, they participated in Apollo 15 spacecraft tests as well as those of their own vehicles. The Commander and Lunar Module Pilot participated in early reviews of the J-mission surface hardware, of the extended-stay lunar module, and of the lunar roving vehicle. The majority of the procedure development time for the Commander and Lunar Module Pilot was spent on lunar surface operations, and 40 percent of the total training of these two crewmen was in lunar surface science.

The Command Module Pilot training can be broken into the following discrete phases:

#### Phase I. Basic Apollo background

- a. Hardware
- b. Software
- c. Mission techniques
- d. Lunar science

#### Phase II. Mission-dependent procedures

- a. Experiment procedures
- b. Flight plan development
- c. Ground track and specific lunar science study

#### Phase III. Pilot proficiency

- a. Flight plan study
- b. Contingency training

- c. Operational techniques
- d. Experiments practice
- e. Personal
  - 1. Physical conditioning
  - 2. Aircraft proficiency

Because of the sophistication and complexity of the Apollo J missions, several years of intensive training are required to properly support the objectives. Phase-I training was essentially completed during the Command Module Pilot's preparation for previous missions. Hardware for the scientific instrument module and the command module extravehicular activity hardware were the only Phase-I training items required during the two years immediately preceding the flight of Apollo 16. The last two months prior to flight should have been devoted to Phase-III proficiency training; however, a 30-day delay in the launch of Apollo 16 was announced in January 1972. The delay occurred after the preliminary flight plan had been issued and resulted in a great deal of Phase-III training being postponed until March.

Visual observations of the lunar surface were emphasized throughout the training, and during the final 12 months, nine aircraft flyovers were made over selected terrestrial features, and many briefing sessions were included. Mission experience indicates that training of this type and intensity is essential to take full advantage of the orbiting observer's vantage point.

Command module experiments were tailored to take advantage of the moon as an occulting disk while executing low-light-level photography of celestial targets. This effort required a considerable amount of the Command Module Pilot's time in developing procedures which were compatible with orbital operations of the command and service module.

The pacing items during the Apollo 16 training period were the development of the flight plan and the experiments checklist.

The increased emphasis on orbital science requires that the Command Module Pilot receive detailed real-time training in flight-plan execution that is analogous to the surface crew's extravehicular activity training. However, unlike lunar module crews undergoing concurrent training, where the lunar module mission simulator and extravehicular activity facilities can be scheduled interchangeably, the command module pilots must use the same trainer for all their activities. This means that verification of a 290-hour flight plan, proficiency training, and network simulation exercises must be accomplished for two crews in one facility. The command and service module mission simulator was used in the evenings for stowage exercises and this proved to be a worthwhile use of the Command Module Pilot's time.



To optimize usage of the command and service module mission simulator, most Command Module Pilot extravehicular activity training was conducted in the Manned Spacecraft Center mockup, while rendezvous training was conducted primarily in the command module procedures simulator.

The Command Module Pilot's training, as reflected in the formal training summary, is somewhat misleading in that the times shown reflect, primarily, time spent in actual training activities and do not include time spent formulating and integrating the orbital timelines. In support of the surface extravehicular activities, the formulation and integration activity is executed by a mission scientist and an extravehicular activity training staff; whereas, the flight planners and the Command Module Pilot must add these tasks to their normal activities.

## 9.2 LAUNCH

In general, the crew workload was easy during launch operations and the crew was 15 to 20 minutes ahead of the launch count.

The Lunar Module Pilot noted prior to launch that the readings on the service propulsion system fuel and oxidizer gages were such that they appeared, in combination, to violate the differential pressure limits of the mission rule for service propulsion system thrusting. Clarification by the ground indicated that the gage readings reflected an instrumentation bias.

The S-IC engine ignition and Saturn V lift-off were positively sensed. Vehicle vibration on the first stage was as reported on previous missions and is probably best characterized as being similar to a freight train bouncing on a loose track. In-suit noise levels at maximum dynamic pressure were similar to the Apollo 10 levels recalled by the Commander. Communications were excellent throughout powered flight. Inboard engine cutoff on the S-IC stage was abrupt and was characterized by approximately four cycles of the S-II stage unloading. At S-IC outboard engine cutoff, the major four-cycle unloading of the S-II stage was again exhibited. S-IC outboard engine cutoff is the most impressive physiological experience of the Saturn-V boost phase. During the first 2 to 3 minutes of S-II engine firing, powered flight was extremely smooth and quiet. After that, a high-frequency vibration or buzz was sensed which abruptly disappeared approximately 9 minutes after lift-off. The vibration was also noted during S-IVB powered flight. Saturn-V guidance and control of all three stages, as monitored from crew onboard displays, was normal.

### 9.3 EARTH ORBITAL FLIGHT

Post-insertion activities were normal and proceeded at a comfortable pace. The sights in earth orbit were spectacular; even on the dark side, where thunderstorms and fires in Africa captured the crew's attention. The earth-orbit timeline provided sufficient time for viewing the earth, for unhurried crew adaptation to zero-g, and coping with hardware problems.

The optics covers were jettisoned in the dark. Jettisoning of the sextant cover could be heard, but there was no audible sound from the scanning telescope cover. There was some initial concern that the scanning telescope cover had not been jettisoned because of a total absence of stars in the field-of-view. (The Command Module Pilot had completed dark adaptation of his right eye.) Eventually, the constellation Scorpio came into the field of view and it became apparent that star patterns and relatively dim stars were going to be quite recognizable. The first clue that the scanning telescope cover was off, however, came when the S-IVB auxiliary propulsion system firings became visible in the scanning telescope. S-IVB auxiliary propulsion system firings could be seen through both the window and the optics at night. Some sensation of spacecraft motion could be felt from flexing of the space vehicle.

Sometime during the initial portions of earth orbit, the ground advised that one of the auxiliary propulsion system packages appeared to have a double helium regulator failure and would be venting through the relief valve. This raised the possibility of helium exhaustion and the necessity of using preplanned procedures for control of the S-IVB attitude (non-thrusting) with the service module reaction control system.

A rough check of the body-mounted attitude gyro/gyro display coupler drift was run and indicated that, with body-mounted attitude gyro 2 supplying rate information, a drift of approximately 6 degrees per hour could be expected in roll with lesser values in pitch and yaw.

The primary coolant loop evaporator outlet temperature exhibited a number of excursions. The crew proceeded to execute environmental control system malfunction procedure number 16 but the results were inconclusive. Ground assistance was requested after translunar injection, since the evaporator was not a mandatory mission item.

## 9.4 TRANSLUNAR INJECTION

Prior to and during the translunar injection firing, Apollo range instrumentation aircraft communications were used very effectively with good volume and intelligibility. All events occurred on time. The trajectory, as monitored by the onboard displays, was normal. An unexpected onboard monitoring surprise was the subjectively greater lag in velocity and altitude computations of the translunar injection initiate/cutoff computer program as compared to the command module simulators. This computer program provides a display of firing time to go during the translunar injection maneuver. Prior to flight, the crew had been advised that this calculation was erroneous until late in the firing because of the changing acceleration. They were, nevertheless, surprised at how much the calculation actually differed from the predicted and actual firing time. The computation converged in the final 60 to 90 seconds of the firing and appeared to be very accurate at shutdown.

During both the launch phase and the translunar injection firing, particles were noticed moving in the direction of the spacecraft, and even passing the spacecraft. They were still in evidence during steady-state thrusting.

The S-IVB exhibited the same high-frequency vibration that had been noted during the earth orbital insertion phase of the S-IVB powered flight. Both the Commander and the Command Module Pilot thought that the vibrations were more pronounced during the final half of the firing and that they increased in amplitude as the powered flight progressed. The increase was enough to cause some concern that the vibration might effect a premature S-IVB shutdown.

## 9.5 TRANSLUNAR FLIGHT

### 9.5.1 Transposition, Docking, and Ejection

The most remarkable feature of the transposition, docking, and ejection sequence was that the command and service module mission simulator reproduces these events perfectly. At the completion of the automatic pitch maneuver, the command and service module was approximately 50 feet from the lunar module and oriented such that the crewman optical alignment sight was superimposed on the docking target. The 4-second closure firing did not provide a positive closure rate so two additional very short firings (less than 1 second) were made to insure closure. The remainder of the approach required two small translations down and to the right, and one attitude correction of approximately 3 degrees in pitch and yaw. The closure rate was about 0.1 ft/sec at contact. There was no sound or spacecraft rate to indicate capture; the only indication was the probe talkback

going to barberpole. The command and service module drifted very slowly, but positively, off in roll, pitch, and yaw alignment following capture. Minus-Y and minus-Z translation thrusters were used to realign the two vehicles prior to probe retraction. The two vehicles were aligned very closely in pitch and yaw prior to probe retraction; whereas, the roll alignment was allowed to remain off several degrees. The probe retraction seemed to be very slow and smooth. The docking latches fired in a slow ripple sequence. The visibility of the docking target is excellent even though the data acquisition camera photographs indicate that the target is immersed in a deep shadow.

Command and service module reaction control system thrusters were not audible as the command and service module separated from the S-IVB, pitched around, and translated toward the lunar module. However, as the two vehicles came within about 10 feet of each other, the sound of the command and service module thrusters impinging on the lunar module became apparent. This same sound was noted any time a command and service module forward firing thruster impinged on the lunar module skin while docked, but was never heard when the two vehicles were separated. Thruster impingement could be seen as an "oil canning" of the thermal covers. After docking, some discoloration of the Inconel foil could be observed on the top of the lunar module. Preparations for lunar module ejection proceeded normally. Docking latch 10 was not fully engaged.

An S-IVB nonpropulsive vent was executed while the vehicles were still attached. This produced very fine streamlines, light-purple in color, around the vehicles. The lines, which could be observed by looking down-sun, appeared to converge at a great distance in an unilluminated spot.

Lunar module ejection was on time and was normal. The maneuver to the S-IVB observation attitude was also normal with the S-IVB appearing in the hatch window on schedule. The S-IVB evasive maneuver was observed visually. There were no visible effluents from the S-IVB and motion could be detected only by observing its relative motion against the background of stars and debris.

The television camera was used throughout transposition and docking, and also to show a most unique view of the earth. The earth was oriented such that it displayed the entire Western Hemisphere from the North Polar region to the Yucatan Peninsula with practically no cloud coverage over the United States (fig. 9-2). While attempting to show the S-IVB evasive maneuver, the television monitor became inoperative. The monitor showed a series of horizontal lines similar to lines observed in the command and service module mission simulator when the grounding circuit was lost (see sec. 14.3.1). Attempts to adjust the monitor controls and reverification of all connections produced no improvement in the monitor display; however, a good picture was still being transmitted. This condition was repeated during the transearth press conference; otherwise, performance was normal.

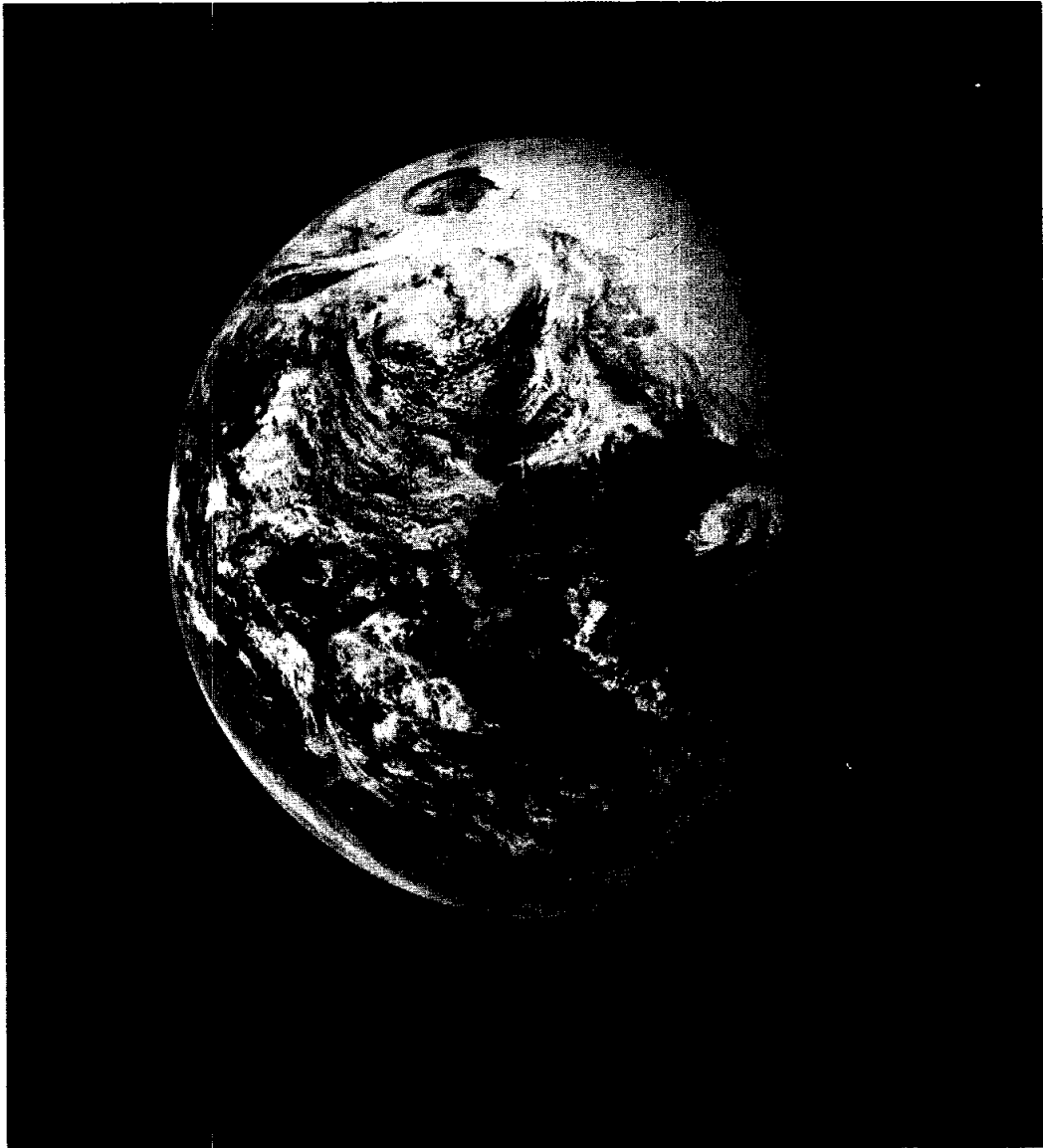


Figure 9-2.- View of the earth during translunar flight.

Immediately following lunar module extraction, Mission Control requested that the primary coolant loop evaporator inlet temperature valve be placed in the manual mode to stop an apparent cycling (sec. 14.1.1). The remainder of the mission was flown with this valve in the manual mode.

### 9.5.2 Translunar Coast Problems

One unexpected sight was the extremely high density of small particulate debris surrounding the S-IVB/lunar module following command and service module separation.

Following docking, it became apparent that the paint was shredding from the lunar module surfaces underneath the docking target in small pieces (generally less than 1-inch long and 1/4-inch wide). It also became apparent that particles were coming from other areas. (For further details see section 14.2.1.) These particles surrounded the spacecraft through undocking in lunar orbit.

At approximately 38 1/4 hours, the Command Module Pilot was using the optics to view several planets. At the completion of this activity, the idling program of the computer was selected. At that time, the command module computer sensed gimbal lock. The command module computer then coarse-aligned the inertial measurement unit and turned on the lower equipment bay primary navigation, guidance and control system warning light and the "NO ATT" light on the display keyboard. The platform was subsequently realigned. The inertial measurement unit orientation was reestablished through sightings on the earth and sun with the computer in option 3 of the inertial measurement unit realignment program. A subsequent realignment, using stars, placed the inertial measurement unit back into a known orientation. Protection against another coarse alignment was provided through the use of erasable computer program EMP 509. This anomaly is discussed further in sec. 14.1.3.

At approximately 46 hours, the uplink telemetry capability was lost (see sec. 14.1.6). Cycling to "command reset" and back to "normal" failed to resolve the problem. Cycling to "off" for 30 seconds and back to "normal" restored normal system operation.

One chlorine ampule broke during the chlorination attempt on the evening of the third day (see sec. 14.1.7). A full buffer ampule was added with no further complications. On several occasions, a small amount of water was taken from the drink gun following chlorination and no unusual tastes were observed.

### 9.5.3 Lunar Module Checkout and Housekeeping

About an hour after informing Houston of the particle problem, the crew was instructed to enter the lunar module for the first time. The crew cleared the tunnel, and entered the lunar module at about 8:17, and powered-up according to the checklist which originally was to have been accomplished at 55 hours. Telemetry indicated that all the systems were

in good shape and that no reaction control system or propulsion leak existed. Powerdown was accomplished within a few minutes and the tunnel was resealed.

The second ingress, which was for housekeeping and communications checkout, was accomplished according to the flight plan at about 33 hours. The lunar module was found to be clean and free of loose particles except for a washer or small screw or two that occasionally floated by and was picked up by the crew. The checklists were adequate.

The third ingress into the lunar module was made at about 55 hours per the checklist. During this entry into the lunar module, the Command Module Pilot made several discrete observations of the malfunctioning docking latch 10. Although the latch was apparently over the lunar module docking ring, it was not in contact with the ring surface. There was a gap of approximately 0.010 inch between the latch and the docking ring. The auxiliary release knob was depressed and it remained in. The left side of the latch appeared normal when compared to the other latches. The cam under the power bungee on the right side of the latch did not appear to be in the same orientation as the other latches. Mission control recommended that the latch be left alone until undocking.

#### 9.5.4 Guidance and Navigation

One set of cislunar midcourse navigation training sightings was taken during the early part of the translunar coast for the dual purpose of providing a measure of the Command Module Pilot's horizon altitude bias and some practice in executing this computer program. Flying the spacecraft-fixed line-of-sight to the substellar point seemed more difficult than the same task in the command and service module mission simulator. The automatic positioning routine placed the line-of-sight very close to the horizon but not on the apparent substellar point. The maximum reticle illumination was too low to allow the lighted portion to be visible against the earth; whereas, it was required against the dark sky background. The only satisfactory technique found for identification of the substellar point was to identify the reticle above the earth and maneuver the spacecraft until the reticle hashmarks touched the earth's horizon simultaneously (fig. 9-3).

There was no problem with the identification of the upper horizon, perhaps because the sightings had to be delayed several hours, allowing the spacecraft/earth separation distance to increase significantly beyond the planned distance. There was only one identifiable horizon on all of the sightings.

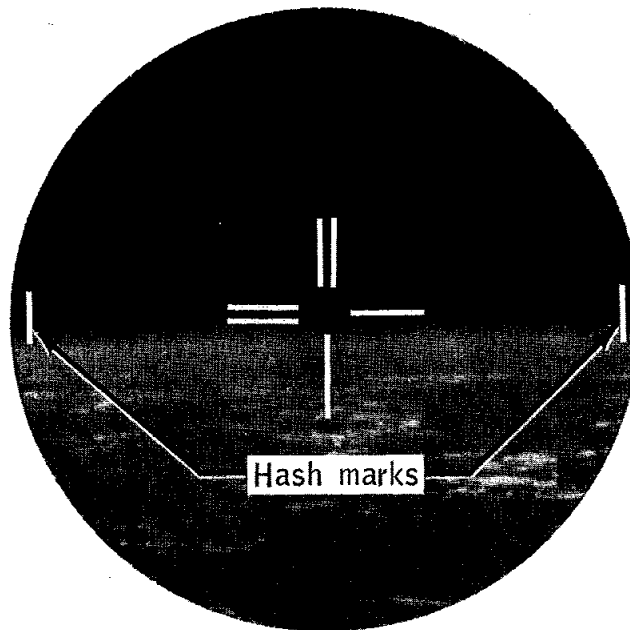


Figure 9-3.- Sighting through sextant for cislunar navigation training.

The optics calibration worked smoothly with reproducible results. An interesting phenomenon observed during these sightings was a very dim mirror image of the earth reflected in the sky portion of the sextant field-of-view.

Passive thermal control was entered and executed per the checklist with excellent results each time.

During a change of the reference stable member matrix (REFSMMAT), option 1 of the inertial measurement unit realignment program was used with the coarse-align mode. Only once during the mission did this provide an alignment of sufficient accuracy to allow auto optics to place the stars in the sextant field of view. The standard technique used was to place the spacecraft in stabilization and control system attitude hold, with a minimum deadband, and record the shaft and trunnion for each star selected in the final option 3 platform realignment program. These values were then used to reacquire the stars in the sextant following the coarse alignment. This is a very comfortable and rapid technique even when the telescope is of marginal utility. The one time that the pulse-torque option was executed was during an off-normal portion of the flight plan and a spacecraft attitude maneuver was required in order to avoid gimbal lock.



### 9.5.5 Midcourse Correction

The only translunar coast midcourse correction was executed at the second option point. It consisted of a short single-bank firing of the service propulsion system. The thrust was positive with a definite delay between the time that the ball valves opened and the time that thrusting was sensed. One surprising feature of the checkout was that gimbal motor start was not evident on the fuel cell bus, but was quite apparent on the battery bus. Because of the service propulsion system pressure transducer shift and the uncertainty associated with the readout, Mission Control requested that the tanks be pressurized by selecting the "manual" position of the helium valves prior to the firing. This procedure allowed ground personnel to understand the transducer shift so that they could accurately update the service propulsion system fuel and oxidizer pressure limits for subsequent maneuvers. The service propulsion system pressure warning light remained on for the remainder of the mission, since it uses the same reference as the gaging system.

### 9.5.6 Scientific Instrument Module Door Jettison and Boom Deployment

Scientific instrument module door jettison was normal. There was a very noticeable sound/shock associated with this pyrotechnic event. It was approximately one-half the magnitude of the spacecraft/lunar module adapter separation event. A considerable amount of debris was produced. The door left with a high velocity and was tumbling.

Release of the mass spectrometer and gamma-ray spectrometer boom tie-downs and the X-ray solar monitor door gave a very low-level sound/shock indication of actuation. Both booms were observed during their first deployment. The outer several feet could be seen from command module window 5.

### 9.5.7 Observations Prior to Lunar Orbit Insertion

Just prior to lunar orbit insertion, the crew noticed that there was almost a half moon in earthshine. The apparent size was such that it was approximately  $2/3$  the size of the window when viewed from a distance of several feet from the window. There was sufficient illumination to show the larger rayed craters in Oceanus Procellarum and the major features to the west. The outer rings of Orientale were clearly visible.

## 9.6 LUNAR ORBITAL OPERATIONS PRIOR TO DESCENT

### 9.6.1 Lunar Orbit Insertion and Descent Orbit Insertion

Lunar orbit insertion was executed normally with the exception of bringing the gimbal motors on the line 20 minutes prior to scheduled ignition. This allowed time to execute the command module computer gimbal drive check, remove erasable program EMP 509, and recover from any inertial measurement unit-command module computer problem associated with these events. The service propulsion system fuel and oxidizer pressure transducers had been analyzed by this time and a new set of maneuver rules incorporated. The service propulsion system pressure warning light came on at ignition and immediately went out. It came back on at the end of the firing, as predicted. The lunar orbit insertion maneuver was initiated on bank A and bank B was added approximately 5 seconds later. At the time bank B was brought on line, there was a small change in chamber pressure and an attendant sensation of thrust change. The chamber pressure then increased from 95 psi to about 100 psi at a rate of roughly 1 psi/min for the remainder of the firing. There was no noticeable change in chamber pressure at propellant tank crossover. The propellant utilization gaging system was operated in accordance with the preflight plan; however, the propellant utilization valve was not used. The unbalance indications were identical to those displayed in the command and service module mission simulator.

The descent orbit insertion maneuver was executed using the same procedure adopted for the lunar orbit insertion maneuver.

### 9.6.2 Landmark Tracking

The first landmark tracked was a training target to the west of the crater Theopholis. This target was selected to provide practice in landmark recognition and tracking speeds under conditions closely approximating those anticipated for the scheduled tracking of the landing site on the day of powered descent. This was a very useful exercise and a confidence builder. The next training target was a feature in the landing area. This target was tracked even though the spacecraft attitude was not ideal. The landed lunar module was not tracked because of the alterations to the timeline caused by the delay in powered descent initiation (discussed in sec. 9.6.4).

It is the judgement of the Command Module Pilot that low-altitude tracking should be used as a vernier adjustment to the predicted location, and that this technique should not be expected to handle large dispersions because of the combined problems of target acquisition and sensitivity of

the optics shaft rates to the spacecraft relative roll angles. Tracking from all altitudes is accurately simulated by the command and service module mission simulator. The Command Module Pilot was surprised by the heat sensed by the eye while viewing the lunar surface.

### 9.6.3 Lunar Module Activation and Checkout

The lunar module activation and checkout in preparation for powered descent proceeded normally according to the flight plan, with lunar module ingress occurring about 40 minutes early. The early ingress allowed the crew ample time to overcome a possible restraint zipper problem experienced previously with the Lunar Module Pilot's suit. No problem was experienced with the Lunar Module Pilot's zipper; however, closing the Commander's restraint zipper was difficult and caused a delay of about 10 minutes. Lunar module activation went well. The crew was 20 to 30 minutes ahead of schedule and waiting for acquisition of signal before proceeding with the S-band antenna checkout, pressurization of the reaction control system, and activation of other systems which ground personnel desired to monitor.

Activities in the command module in support of lunar module activation and undocking were normal. The timeline was full, but adequate. The use of separate command module and lunar module communications with the Mission Control Center simplified procedures. Preparations for undocking were completed only 10 minutes prior to the scheduled time, which is none too soon.

When cocking the latches for undocking, latch 10 required only one stroke to cock. The force required to cock this latch was significantly less than that required to cock the first stroke of the other latches.

The S-band checkout went fine until the lunar module steerable antenna test. At that point, the steerable antenna would not move in the yaw axis (see sec. 14.2.3). This condition persisted throughout the flight. Because of the steerable antenna problem, Houston was not able to uplink a reference stable member matrix (REFSMMAT) or state vector, so a manual update of the computer was performed. The Commander was pressurizing the reaction control system at about the same time. Immediately upon doing so, reaction control system A indicated a high pressure condition (sec. 14.2.4). Because of this, some of the reaction control system propellant in system A was transferred into the ascent tanks to provide enough ullage volume for the maneuver. The transfer was accomplished by cycling the ascent stage feeds open and closed while maintaining ascent tank pressure to less than 180 psi. Except for these two anomalies, the activation and checkout proceeded well and on schedule through undocking.

#### 9.6.4 Undocking to Powered Descent Initiation

Following separation, the lunar module was maneuvered so that the command module could be viewed. The maneuvers were planned to allow photography of the command module from the Lunar Module Pilot's and Commander's windows with 16-mm and 70-mm cameras (fig. 9-4). To improve uplink communications, the lunar module attitude was changed to point the steerable antenna toward earth. This prevented the lunar module crew from view-



Figure 9-4.- Command and service module photographed from the lunar module.

ing the landing site; however, a visual sighting had been made on a previous revolution and the landing site looked accessible. The checklist and procedures went according to schedule during the front-side pass after undocking. The platform was realigned but the optical alignment sighting was omitted in order to provide additional time to prepare for the circularization maneuver. This was deemed prudent because of the desire to be as methodical as possible with the modified procedures used to protect against a recurrence of the false gimbal lock indication in the computer.

The first two landing radar checks were not acceptable because of an attitude which pointed the landing radar at the lunar surface and caused interference. Later, when in a better attitude, the landing radar check was acceptable.

Circularization maneuver preparations went well until the service propulsion system secondary yaw gimbal checks. The secondary yaw gimbal appeared normal when the motor was started; however, it exhibited rapidly diverging oscillations when the position was disturbed by trim settings (see sec. 14.1.10). The oscillation was confirmed by vehicle dynamics and the gimbal motor was deactivated. Subsequent tests showed the same response in all control modes and resulted in the decision to delay the circularization maneuver. A final change that had been made to the flight mission rules approximately one week before the flight required that four servo loops be operative in order to execute this maneuver.

During preflight discussions, the flight controllers and the crew had agreed that in the event of a "no-go" for powered descent a "brute force" rendezvous would be executed when the lunar module and command and service module were at their closest point of approach, approximately 2000 feet. The lunar module and command and service module crews discussed execution of the join-up but decided not to expend command and service module reaction control system propellant until ground personnel had an opportunity to assess the situation. The lunar module crew then turned to the section in the checklist which was the wave-off for powered descent and configured the systems for normal lunar orbit.

The Command Module Pilot established visual contact with the lunar module and maintained contact throughout the subsequent revolution until requested to maneuver to an attitude which provided good high-gain antenna coverage in order to allow the Mission Control Center to monitor the gimbal tests in real time. Two complete gimbal tests were executed for evaluation. During the final test it appeared that the gimbal oscillations became neutrally damped at an amplitude slightly greater than  $\pm 1$  degree.

The Mission Control Center requested that a "brute force" rendezvous be initiated at the next closest point of approach of the two vehicles, and provided an estimated initiation time. A retrograde service module reaction control system engine firing near apolune was recommended. At

the time the maneuver was to be executed, the command and service module was leading the lunar module, and the distance between the vehicles was slightly greater than 1/2 mile with the distance increasing at a rate of 1 ft/sec as indicated by the lunar module radar. The maneuver was initiated; however, the Commander was concerned that with the resulting lowering of the perilune, the command and service module would not have sufficient translational authority as it approached perilune, and requested that the closing differential velocity be removed until such time that the instructions could be clarified. Throughout these events, the lunar module rendezvous radar and the VHF ranging were in close agreement.

The crew was requested to continue the "brute force" rendezvous commencing just prior to perilune, and an initial closing differential velocity of 5 ft/sec was established. The two vehicles, which were about 7000 feet apart at that time, commenced closing at about 3 1/2 ft/sec, as indicated by the radar. Two more engine firings provided the closing differential velocity necessary for rendezvous.

The technique employed for the rendezvous was to use the lunar module rendezvous radar inertial line-of-sight error needles to detect line-of-sight changes and have the Commander call out ground-controlled-approach-type directions to the Command Module Pilot to null the line-of-sight rates to zero. Range and range-rate information was also provided from the rendezvous radar.

The lunar module tracking light was very effective throughout the rendezvous and tracking with the crew optical alignment sight verifying the line-of-sight control. The lunar module outline was clearly visible at 1/2 mile in earthshine. At approximately 500 feet range, the optical alignment sight was the most accurate tool for close-in line-of-sight control. Range rates were difficult to assess, even when the vehicles were close.

Following the ground determination that the yaw gimbal problem was understood and the mission could safely continue, the command and service module executed a radially-inward separation maneuver that returned the two vehicles to the normal relative trajectories for the circularization maneuver. Because of a limited time for maneuver preparation, the separation maneuver was executed using the service module reaction control system and three-axis thrusting.

The circularization maneuver was executed. The only alterations to normal procedures were to start the secondary yaw gimbal motor after the gimbal tests had been conducted and to execute the maneuver with 90 degrees of roll to provide the maximum middle gimbal protection.

## 9.7 POWERED DESCENT AND LANDING

### 9.7.1 Preparations for Lunar Module Powered Descent

As a result of the reaction control system regulator leak, lunar module maneuvers were performed to keep the reaction control system pressure in system A from exceeding relief pressures. These maneuvers were conducted on the back side of the moon and consisted of an automatic maneuver to observe the command and service module, an automatic maneuver to the powered descent initiation attitude, and frequent yaw pulses (plus and minus) in order to minimize the orbit perturbations.

Reaction control system engine firings had to be minimized at signal acquisition to maintain omnidirectional S-band communications with the Mission Control Center. This apparently resulted in rupture of the burst disk in reaction control system A, followed by normal venting through the relief valves.

During three lunar orbit revolutions, one platform realignment was completed in the first revolution following the planned circularization maneuver that was not executed and one realignment was completed during the revolution prior to powered descent initiation.

The lunar module was given "go" for powered descent about one and one-half revolutions prior to initiation. Without the S-band steerable antenna, the S-band omnidirectional antennas had to be used for computer data up-link. Consequently, the lunar module was yawed 20 degrees right from the normal powered descent initiation attitude to point the lunar module omnidirectional antenna toward the earth. It appeared that the signal strength margins from the S-band omnidirectional antenna were improved, thus allowing the final computer data up-link. The state-vector update and procedures were transmitted at circularization. At acquisition of signal, after activating the ascent batteries, a new up-link was received from Houston and powered descent was commenced on time. Powered descent was initiated with the command and service module monitoring VHF communications until after lunar module touchdown.

### 9.7.2 Powered Descent Initiation to Landing

According to the Mission Control Center, the powered descent was initiated at a point 16 000 feet to the south of the original ground track and at an altitude of 66 000 feet. With these data, the crew expected to see the lunar module moving from south to north at pitchover, and expected to have slightly less than the planned amount of propellant for hover time near the surface. The lunar module descent propulsion system throttle-up was smooth and on time. The physiological cues of the descent propulsion

engine operation were readily apparent; automatic ullage engine thrust at 10 percent, full throttle-up, and throttle-down to 55 percent were all evident. An 800-foot downrange correction was entered into the computer 2 minutes after ignition. The altitude and velocity lights which indicate landing radar lock-on went out in the vicinity of 50 000 feet. Throughout the descent, the fuel indication remained about 2 percent lower than the oxidizer indication. At 20 000 feet, based on a premission study which indicated the possibility of viewing the landing site prior to pitchover, the Commander put his eye near the normal crewman optical alignment sight position and he was able to see nearly parallel to the minus-X axis. The western edge of Stone Mountain and South Ray Crater were clearly visible. It was apparent from this early view that the lunar module was targeted nearly perfectly into the landing site ellipse. At approximately 14 000 feet, the entire landing site (Flag, Spook and Double Spot Craters) became visible to the Commander.

Descent propulsion system throttle-down was on time and pitchover occurred at 7200 feet. After pitchover, a comparison of the landing point designator with the computer and the movement of the vehicle showed that, if no further trajectory corrections were made, the lunar module would land approximately 600 meters north and 400 meters west of the center of the landing ellipse. Therefore, between altitudes of 3000 and 4000 feet, an estimated total of five redesignations to the south were made. The vehicle responded properly. At a much lower altitude an estimated five additional redesignations were made as the lunar module was approaching Double Spot Craters. It was clear that the vehicle was going to be north and west of the premission-designated landing spot (75 meters north of Double Spot Craters). However, there was no major attempt to land at the premission-designated spot, nor had there been any intent to do so prior to flight because the surface traverse capabilities of the lunar rover negated the requirement to land precisely at the designated landing spot.

At about 450 feet altitude, the Lunar Module Pilot observed the lunar module's shadow from his window. At an altitude below 200 feet, as the Commander yawed the vehicle toward the right, he also noticed the shadow. Observation of the lunar module shadow allowed the crew to reasonably estimate their absolute altitude above the surface and descent rate, and to make an excellent objective estimate of the size of the craters that they were seeing on the surface.

The lunar module velocity was decreased rapidly as Double Spot Craters were passed. The Commander controlled the lunar module with the attitude-hold control mode at about 250 feet altitude and maintained a very slow forward velocity. The rate of descent at this time was about 11 feet per second, and this rate was quickly reduced to 5 feet per second. From 200 feet altitude to the surface, the Commander did not look inside the vehicle. Small traces of dust were evident at approximately 80 feet, and



the dust increased all the way to touchdown; however, the vehicle had lunar contact before the visibility obstruction due to dust prevented the Commander from seeing craters or small boulders on the surface.

A small crater (15 meters in diameter) had to be cleared prior to landing. The vehicle was brought to a hover at an altitude of approximately 20 feet and moved forward and to the right. The rates were then nulled and the lunar module was landed. At probe contact it was evident from out-the-window observation that the vehicle was not close to the surface, so the engine stop button was not depressed for approximately 1 second. When the engine stopped, with an estimated rate of descent of 1 1/2 feet per second, there was a sinking sensation when the vehicle settled an estimated 2 1/2 to 3 feet to the lunar surface. Later, inspection of the probes showed that the lunar module had contacted the surface with a slight forward velocity.

In the opinion of the pilots, there is no way to reasonably judge shallow slopes in the landing area, as the lunar module approaches touchdown, except in the craters where shadows are visible. Inspection of the region during extravehicular activity indicated that, had the lunar module landed 25 meters in any direction from the actual site, it could have been on a local slope of 6 to 10 degrees. The attitude of the vehicle after touchdown was essentially zero roll, 2 1/2 degrees pitch up, with a slight yaw to the south. The lunar landing training vehicle was considered excellent training for this mission phase because its dynamic response is identical to that of the lunar module.

The only area in the nominal sequence which might be improved during the command and service module activities is that a 30-minute period should be scheduled following landing of the lunar module to allow the Command Module Pilot to restow the command module prior to becoming engrossed in the solo timeline.

## 9.8 LUNAR SURFACE OPERATIONS

### 9.8.1 Postlanding Activity

Immediately following touchdown, the crew went through the abbreviated powerdown to conserve power (a change from Apollo 15). The powerdown circuit breaker configuration was the same as the surface extravehicular activity circuit breaker configuration except the a-c bus, the S-band antenna, and the guidance computer circuit breakers were pulled. Because of the powerdown of the a-c bus and the guidance computer, emergency no-communication lift-off block times (given in ground elapsed time) became meaningless because, with the mission timer disabled, the crew had no ground elapsed time reference. If this maximum powerdown configuration

is used on future missions, emergency no-communication lift-off time should be given in central standard time for use with the crew wristwatches. The lack of a mission timer was inconsequential to the remainder of the lunar stay activities because the Mission Control Center provided timeline information during extravehicular activity preparations and post-extravehicular periods. For the first time, the inertial measurement unit was coarse-aligned to gimbal lock to eliminate gyro drift and pulse-integrating-pendulous-accelerometer bias upon powerup, which had caused problems on previous missions. The crew estimated that they were 20 minutes ahead of the timeline at the completion of the powerdown.

After powerdown, the suits were doffed and lubricated. The Lunar Module crew then ate their first meal on the lunar surface and reconfigured the cabin for sleep since they had been directed to postpone the first extravehicular activity until after a sleep period. Changes were made to the original plan in real time as the revised procedures were transmitted by the Mission Control Center. When the cabin gas return valve was placed in the "automatic" position, there was a chattering sound and the cabin gas flow was very low and was intermittent (sec. 14.2.5). The cabin gas return valve was then placed in the "open" position and the flow became normal. In preparation for the first extravehicular activity, the tool carrier fell off the portable life support system (sec. 14.3.11).

### 9.8.2 Extravehicular Activity

First extravehicular activity.- Following the first sleep period and normal preparation for surface activities, the Commander egressed slightly ahead of schedule. Because of the steerable antenna failure, there was no television coverage of the Commander stepping onto the lunar surface. Deployment of the modular equipment stowage assembly by the Commander was normal and, after its deployment, the Lunar Module Pilot egressed. The modular equipment stowage assembly was slightly lower than the crew had been used to in training; however, after a few moments of manipulating the straps, the assembly was adjusted to the proper height.

The lunar module had been landed on the inner flank of a subdued crater. The almost level attitude of the lunar module made operating around the vehicle much like that of the training environment. The crew felt very familiar with the lunar surface environment. Consequently, the familiarization period for lunar surface operations is not necessary.

The lunar module thermal panels, which had exhibited a shredded-wheat like appearance, and the S-band steerable antenna were inspected.

The minus-Y strut and the descent engine bell were both next to, although well clear of, small boulders. There was no apparent landing gear stroking.

The rover was examined and the walking hinges had to be reset prior to deployment. Upon pulling the rover release handle, the vehicle deployed to the proper position. Normal deployment was obtained by pulling the tapes; however, three of the wheels had to be locked into place and the hinge pins that locked the chassis were protruding slightly in two locations. The pins were placed in the locked position with the contingency tool. The rear steering was inoperative during rover powerup, but instructions were received to continue with the vehicle loading. Loading the quad-3 pallet tools on the rover was easy; the only problem associated with the tool load-up was that a cable strap holding one of the penetrometer pins in place pulled free (sec. 14.4.11).

The ultraviolet camera/spectroscope was extremely easy to remove from stowage on the quad-3 pallet. Transporting the camera to the observing site was much easier than had been anticipated from 1-g training. The camera was emplaced according to the cuff checklist diagram.

The Apollo lunar surface experiments subpackages were off-loaded by the Lunar Module Pilot and placed together. The T-handles for removal of the subpackages were not used, nor would they be required in the 1/6-g environment for abnormally high or low positioning of the descent stage on the lunar surface. No difficulty was encountered in any of the operations with the scientific experiments package at the lunar module.

Subpackage 2 was laid flat on the surface so that the radioisotope thermoelectric generator could be serviced. The subpackage was then re-oriented in order to provide the Lunar Module Pilot a clear access path to the radioisotope thermoelectric generator housing. The reorientation may have forced dust into the locking collar which, later, could have prevented the Lunar Module Pilot from making a positive lock-on to the carrying bar. The radioisotope thermoelectric generator was fueled and then the hike to the Apollo lunar surface experiments package deployment site was begun. About half-way out, subpackage 2 separated from the bar and fell to the lunar surface. The subpackage was examined and, when no damage was found, it was reconnected to the bar and carried to the deployment site.

Because preflight data had indicated the landing area would be hummocky and blocky, a suitable Apollo lunar surface experiments package deployment site was to have been selected by the Commander using the lunar roving vehicle to explore 100 meters in front of the lunar module. However, the Commander became involved in a retake of earth imagery photography using the far ultraviolet camera/spectroscope, so it was necessary for the Lunar Module Pilot to carry the Apollo lunar surface experiments package to the best possible site that he could select on foot. The site chosen was about 100 to 150 meters southwest of the lunar module and was typical of the region. Exploration with the lunar roving vehicle would probably not have resulted in the selection of a significantly better site.

The deployment of the experiments was normal with the following exceptions:

a. Installation of the radioisotope thermoelectric generator power cable connector to the central station was more difficult than it had been in training.

b. The passive seismic experiment had to be emplaced on the side of a small subdued crater which made leveling difficult. When the shield (with its sun indicator) was removed, proper orientation did not point the passive seismic experiment directly downsun, which surprised the Commander.

c. The heat flow experiment cable was inadvertently broken when it became entangled with the Commander's legs as he was working near the central station. (See section 14.4.1 for details.) The Commander did not know that the cable had broken because pressure suit mobility is restrictive and a crewman cannot normally see his lower legs or feet. It is well known that the Apollo lunar surface experiments package cables have memory and stand off the surface in the 1/6-gravity environment. This condition requires a crewman to jump clear of cables which he cannot adequately see. In order to insure that cables are not inadvertently broken by a crewman, cables must be designed with strain relief.

The drilling for the first heat flow experiment probe was normal. The hole for the second probe was not drilled because of the broken cable. The drill seemed to "auger in" to the depth required for the first two sections, but some back pressure on the drill was required for the remaining sections. The deep core was removed using the extraction tool provided for that purpose and it was of great benefit. The core was placed on the back of the rover, separated into two sections, and placed on the tripod at the experiments package site for retrieval at the end of the extravehicular activity.

The lunar surface magnetometer was located within about 2 meters of a small embedded block on the surface. Lunar surface magnetometer leveling required more time than had been anticipated because of a small slope in the locality of the instrument.

Prior to deploying the experiments around the central station, the Commander used the rover to select a traverse route for the active seismic experiment. The lunar roving vehicle was driven out 100 meters on a heading of 290 degrees to both explore for the best route for laying out the 100-meter geophone cable and also to insure that it was laid in a straight line. Upon the second rover powerup, the rear steering was found to be operative. Thereafter, the front and rear steering mode was used throughout the remainder of the lunar surface activities. The geophone cable was accurately deployed on a heading of 290 degrees which was not

directly down the sun line. Subsequent photography shows that the cable diverges, at most, 1/3 meter from a straight line in the 100-meter length of the cable. The initial extension of the first several meters of the power and geophone cables produced a high rotational release force on the spindles which moved the central station so that it had to be realigned. The terrain over which the active seismic experiment cable was deployed was both hummocky and blocky. There was at least one 6-meter-diameter subdued crater between the second and third geophone stations and numerous blocks in the vicinity of the third geophone station. Active seismic experiment geophone thumper firings were normal except that, at the fourth geophone station, because of a crew procedural error, the initial attempt at firing the thumper was unsuccessful. Emplacement of the mortar package base was delayed when one of the four legs of the mortar package base could not be deployed (sec. 14.4.2). The base was emplaced with three legs at their full extent, and it was level. The mortar firing package level bubble was free from its ring.

While the Commander was engaged with the active seismic experiment, the Lunar Module Pilot was taking photographs of the emplaced experiments. He noted that a small amount of lunar soil had been deposited on the thermal curtain of the passive seismic experiment. Once the active seismic experiment was completed and some sampling had been accomplished in the area, the rover was loaded up with the equipment needed for the geological traverse to Flag Crater.

In driving to Flag Crater, the terrain was similar to that in the vicinity of the lunar module - hilly and hummocky, with 1-meter-size or smaller blocks that ranged in density from about 50 percent to 10 percent of the surface area. Flag Crater was found with no problems. The checklist activities at Flag Crater were accomplished on time and the rover was driven back along the outgoing tracks to Spook and Buster Craters where sampling was accomplished according to the checklist and a lunar portable magnetometer measurement was taken. Lunar portable magnetometer deployment was identical to the 1-g training deployments. The magnetometer stowage cable deployment pull force was very much the same as had been noted on the preflight backup unit during the delta crew compartment fit and function checks at Cape Kennedy. The only difference was that the cable deploy forces increased with each deployment.

A good radial sample was taken at Buster which is a rocky-rimmed crater that has boulders of 2 to 3 meters in size in the bottom and up the northeast and southwest flanks. Station 3 of the first traverse was back at the Apollo lunar surface experiments package site for the lunar roving vehicle Grand Prix. This was accomplished in about 2-1/2 minutes. Throughout the entire extravehicular activity, the extravehicular mobility unit performed beautifully, and all other equipment performed as advertised.

Second extravehicular activity.- Cabin depressurization and egress were normal. The rover load-up procedures were adequate and no difficulty was experienced except with the sample container bags and the method of attachment of the bags onto the portable life support system tool harness (sec. 14.4.8). During each attempt, it was very difficult to attach the bottom Velcro strap to the portable life support system tool harness. A more efficient means should be devised whereby the bags could be positively retained on the tool harness.

With load-up accomplished, the crew drove the rover to an area on Stone Mountain. The long traverse had been mapped to extend over the Cayley Plain, across the contact of the Cayley and Descartes formations, and up the Descartes formation to the Cinco Craters. The traverse route was toward the south and it crossed ridges trending in an east-west direction and having large topographic relief, on the order of 10 meters. The ridges were covered with craters ranging in size from as small as 1 meter up to about 30 meters in diameter; also, many secondary craters were noted along the route. Approaching the face of Stone Mountain, the block frequency varied from ridge to ridge. During the traverse, some areas were crossed that had block coverage as low as 10 percent. The blocks were angular to subangular and up to a meter in diameter with a few isolated ones as large as 3 meters. The predominant size was about 20 centimeters in diameter. Some of the areas had as much as 40 to 50 percent block coverage. The rover's suspension system handled this type of terrain adequately and the crew felt quite at home travelling through this area.

Survey ridge was a predominant feature that was in view each time a ridge was topped enroute to Stone Mountain. Cinco Craters, and well beyond, could be seen quite clearly throughout the traverse. The general impression gained was that South Ray ejecta was definitely being crossed where the rays thickened and thinned from ridge to ridge. Nowhere did the crew feel that they were completely out of the rays. At Survey Ridge, a more southwesterly heading was taken. The traverse down Survey Ridge was easy at a speed of 7 or 8 kilometers per hour and after clearing the ridge the rover was again turned to a southerly heading for the climb up Stone Mountain. At that point, a series of secondary craters which were 5 meters or so in diameter made trafficability a little more difficult, but not impossible.

Once started up Stone Mountain, the crew had no feel for the steepness of the slope while going uphill. Upon reaching the area of station 4 (in the Cinco Craters area) and turning the rover back downhill to find a parking place, the actual severity of the slope became apparent. The rover pitch meter indicated slopes up to 20 degrees. The traverse up Stone Mountain again crossed some very sharp craters which appeared to be secondaries. The stop at station 4 was made on time, all activities were

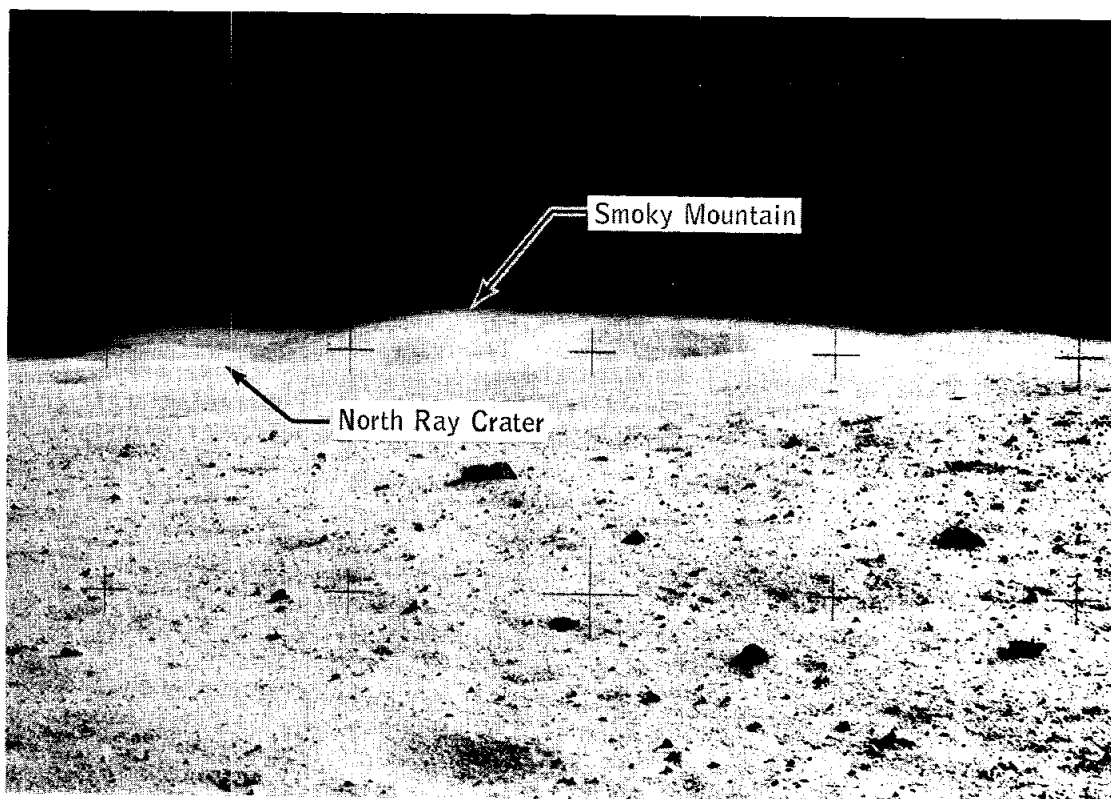


Figure 9-8.- View of Smoky Mountain from station 9.

The tasks were accomplished at station 10 as outlined except for digging the soil mechanics trench, which had been deleted. The rover tracks were examined as a part of the soil mechanics experiment, and the penetration or compression of the regolith was not as much as from the crew's footprints. The penetrometer activity with the 0.2- and 0.5-inch diameter cones went well at stations 4 and 10.

The extravehicular activity closeout equipment transfer and ingress into the lunar module were normal. The sample container bags, sample return containers, and the pallets were easily handcarried while ascending to the ascent stage. The lunar equipment conveyor was used by the Commander to load the equipment transfer bag when the Lunar Module Pilot was inside the vehicle. Repressurization was normal.

Third extravehicular activity.- Load-up of the lunar roving vehicle proceeded on schedule. The Lunar Module Pilot noticed that his watch crystal had apparently fallen out before leaving the lunar module and shortly thereafter the movement stopped (see sec. 14.3.12). After having driven less than 100 meters from the lunar module, a 10-meter ridge was

climbed which might have been the rim of an old, subdued crater. Shortly thereafter, the block frequency from the South Ray ejecta declined drastically such that, by the time Palmetto Crater was reached, the block frequency in the regolith was on the order of 1 percent or less. There were some blocky rim craters near Palmetto and, in one instance, there was a block sticking through the regolith about half-way down the inner side of Palmetto. The traverse proceeded as planned past Palmetto Crater, and on past End and Dot Craters to the objective, the rim of North Ray Crater where stops were to be made at combined stations 11 and 12.

Throughout the previous extravehicular activities, the 16-mm camera had apparently performed flawlessly. During this extravehicular activity, the camera was started at about Palmetto Crater and it appeared to be working normally. Also, during the previous extravehicular activities, the Lunar Module Pilot attempted to provide traverse review film for the geologists of the areas in which television coverage could not be obtained because of rover motion.

End Crater was a blocky-rimmed crater, and appeared to be blocky as a fairly fresh impact crater would be. The most striking part of the traverse was the lack of the cobble-size debris and the pronounced subdued nature of the craters which were 1 to 5 meters in diameter. It was almost like driving across a craterless area in that the lunar rover hardly responded to these subdued craters. The depth-to-width ratio of these craters was felt to be much shallower for their size than any previously seen. It was much like driving across sand dunes with only very minor undulations due to old craters. Having passed Palmetto Crater, and descending off an east-west ridge into a broad valley that was, perhaps, 200 to 300 meters wide, the going was quite smooth and maximum speed for the rover was obtained on level terrain. The terrain, trending mostly to the northwest, then sloped up toward North Ray Crater. This area was almost crater-free; however, there were scattered isolated blocks to 5 meters in diameter. One of these was selected for a radial sampling on the return traverse and became known as "Shadow Rock" at station 13 (fig. 4-10). At about this point, a swale between Smoky Mountain and the rim of North Ray Crater was seen. This area had one of the greatest concentrations of large blocks seen during the traverse. Unfortunately, it was out of the traverse area and could not be sampled. The blocks were grayish-black in color with the exception of one large pure-white block, which was at least 5 meters across. This rock was very angular and, unfortunately, was not visible from any of the stops that required 500-mm photography. The boulder debris radials from North Ray Crater were evident up the side of Smoky Mountain and toward Ravine Crater.

The North Ray area was composed of two predominant rock types: a breccia of white matrix origin with black clasts, and a black-matrix rock with white clasts. Also, some of the largest clasts that occurred in the



The last stop was in the vicinity of the lunar module, northwest of the Apollo lunar surface experiment package site. Some crystalline rocks with a sugary texture were collected as well as some breccias. A final lunar portable magnetometer reading was made to the east of the lunar module where the rover was parked for ascent television. This reading was not as had been expected preflight; in fact, all of the lunar portable magnetometer readings were some of the highest lunar surface readings seen. (The readings are given in sec. 4.7.) A crystalline rock was located and placed on top of the lunar portable magnetometer for the final reading. This rock was bagged and returned in one of the sample collection bags.

Closeout was performed on schedule and repressurization of the lunar module was as expected. Equipment jettison was performed on schedule after a short delay due to an overabundance of rocks. However, no rocks had to be jettisoned and all the samples that were collected were returned.

Far ultraviolet camera/spectroscope problems.- The camera had to be moved twice to keep it out of the sun. It was moved on the second extravehicular activity because the sun was across the bottom half of the spectroscope imagery box; it was moved on the third extravehicular activity because the sun was across the first upper 4 centimeters of the cassette handle.

Initially, the camera was difficult to align in azimuth (sec. 14.4.9) and it became increasingly difficult to move each time a change was required. Setting the azimuth on the third extravehicular activity moved the camera off level because of the torque force required. In several realignments, it was impossible to move the leveling bubble to the center of the ring because of the geometry of the three camera legs on the slopes and the time available for releveling.

The battery cable lines did not lay flat and continually tangled up in the Commander's legs almost every time he approached the camera. Fortunately, the battery moved rather than the camera.

The crew had received training with the qualification ultraviolet camera a week before launch and had discovered that camera mode changes produced noise on the VHF radio. There was no other apparent electromagnetic interference resulting from the power supply operation.

Cosmic ray detector experiment problems.- When the Commander pulled the red-ring lanyard to shift the shade in panel 4, the shade moved only about one-fourth of the desired distance and the lanyard broke (see sec. 14.4.4). Upon examination of the cosmic ray experiment at the completion of the first extravehicular activity, the temperature labels were off-scale high; therefore, the experiment was moved to the minus-Y landing

gear strut footpad. At the end of the third extravehicular activity, the cosmic ray experiment panels were hung up inside the frame. It was necessary to use a pair of pliers to get sufficient grip on the experiment panels to break them free for stowage.)

### 9.8.3 Cabin Activity

Sleep.- The crew slept exceptionally well although the cabin temperature varied. The ear plugs were not used; it was felt that they were unnecessary. For the first sleep period on the lunar surface, the Commander donned only his sleeping bag, whereas the Lunar Module Pilot wore his liquid cooled garment while in his sleeping bag. For the second and third sleep periods, both crewmen wore their liquid cooled garments while in the sleeping bags. The intravehicular garments were never used. There was some light leakage into the cockpit; however, it did not prevent the crew from sleeping. The Lunar Module Pilot aided his first sleep period by taking Seconal; however, he was awakened three times - the first two times by master alarms caused by the reaction control system A problem, and the third time by an apparent loss of communications lock during a handover which produced noise in his earphones. The first sleep period lasted about 8 hours. In general, the cabin configuration is acceptable to get a good night's sleep.

Extravehicular preparations and post-extravehicular activity.- The part of the timeline preceding the first extravehicular activity went normally even though the crew had to rewrite the first extravehicular activity section of the procedures in real time. The crew experienced no problems throughout any of the periods preceding and following extravehicular activities except for a communication carrier microphone problem. Prior to the first extravehicular activity, orange juice had leaked into the Lunar Module Pilot's communication carrier and the Lunar Module Pilot could employ voice communications only after he had blown out his left communication carrier microphone boom and refastened the right microphone boom tip (see sec. 14.3.5). The communication carrier is a single point failure for the lunar surface operation; another one should be carried as a spare.

Portable life support system recharges were normal. Good recharges were accomplished after both the first and second extravehicular activities. The only troublesome problem occurred during suit donning. Extreme difficulty was encountered in closing the restraint zippers on both the Commander's and Lunar Module Pilot's full pressure suits. A restraint zipper closure aid is needed to eliminate the high probability of being unable to close the restraint zipper. The prescribed lubrication procedures were used to keep the pressure sealing zipper freely operable and to lubricate the O-rings and all connectors. The pressure sealing zipper

was adequately lubricated as it would close smoothly during each suit donning. The best time to lubricate the pressure-sealing zipper was after doffing the suit because the suit stands erect in 1/6-g, greatly improving zipper access. The crew ran out of suit lubrication during the preparation for the third extravehicular activity. The required equipment was jettisoned without difficulty at the end of the third extravehicular activity.

The major concern with housekeeping, on post-extravehicular doffing of the pressure garment assemblies, was dust in the cabin. A jettison bag was placed over both legs of the suit and the suits were laid on the engine cover as prescribed. There was a considerable amount of dust on the suits around the neck, around the helmet, on top of the oxygen purge system, and on the back of the portable life support system. Most of this dust ended up on the floor of the lunar module. The dusty floor was cleaned by wetting a rag, caking the dust into mud, and picking it up in the rag; however, there was no way to remove the dust from the Velcro on the floor. Since the Velcro does not restrain the crew to the floor in zero gravity, it is not needed.

Because of the dust problem, the lower limbs of the liquid-cooled garments were dirty. Each crewman had to help the other crewman remove his suit. Consequently, there was appreciable dust on each crewman's hands and up to the elbows of the liquid-cooled garments. There is no way to avoid this problem; the crewmen's hands could not be cleaned while on the lunar surface after the first extravehicular activity.

The dust was always a major cause of concern in that the crew never knew when dust might get into some equipment and compromise the lunar module or extravehicular mobility unit environmental control systems. A program to improve housekeeping procedures must be actively pursued to reduce the amount of dust in the spacecraft as rapidly and as simply as possible.

On each occasion that the drink bag was installed into the suit, the crew encountered leakage due to interference between the drink bag nozzle and the left microphone boom. In the case of the Lunar Module Pilot, this interference resulted in an estimated 4 to 5 ounces of orange juice leaking on his helmet, his face, and the pressure suit neck ring. After the second extravehicular activity, the effect of leaking orange juice on the neck rings of both crewmen caused both pressure suit helmets to be practically impossible to remove. It was necessary to thoroughly clean the helmet neck ring with water to remove the orange juice. The drink bags carried in the suit are a necessity to provide the crew with liquid while they are working 7 to 8 hours on the lunar surface, but the bags must not leak.

The crew had a continual problem of donning and doffing the gloves because there was dust in the wrist ring pull connectors (see sec. 14.3.4). Even though the connectors were blown out repeatedly and appeared to be free of dust, it was extremely hard to pull the wrist ring devices in or out and, in fact, rotate the glove on or off. Some type of wrist dirt seal over these connectors is necessary.

The crew used liquid-cooled-garment pump cooling repeatedly. This type of cooling has a very quick heat removal capability. Donning and doffing the full pressure suit produces the highest heat workload in intravehicular activity. If the crew has just completed donning the pressure suit, air cooling will allow body core temperatures to rise because it cannot remove the heat, but a quick shot of cold water in the liquid-cooled garment immediately removes this heat and will minimize the amount of perspiration that the crew gives off while they are operating on the air-cooled system. In addition, the use of water cooling during the extravehicular preparation allows the crew to stow the air hoses away from the front of the suits to minimize the interference of the bulky and difficult-to-handle suit connectors. The use of water cooling alone allows the crew to maintain cooling on both crewmen until just before their final pressure suit integrity check. The crew believes that this serious attempt to minimize heat-up of body core temperature and remove perspiration during the long-term wearing of the pressure garment assembly was a major factor in their physical well-being during the lunar module operations.

A continuous problem throughout the extravehicular activity preparations was the portable life support system tool harnesses. Whenever the harness straps caught on the numerous fittings in the lunar module, the harness would fall off (see sec. 14.3.11). During the first extravehicular activity preparation, both crewmen had completely donned their suits and backpacks and were in the portable life support system oxygen-supplied heat-up mode when the Lunar Module Pilot's tool harness pulled loose. It was extremely difficult for the crewman to put the tool harness back in place because of the volume limitations due to the fully suited crewmen and the cooling limitations at the time.

#### 9.8.4 Extravehicular Equipment

Extravehicular mobility unit.- The mobility of the extravehicular pressure garment assembly with the portable life support system unit attached was exceptional. The crew had discovered in 1/6-g aircraft training that they could pick up rocks from the lunar surface and perform major bending operations which were necessary to deploy and load the lunar roving vehicle as well as deploy every experiment. The dynamics experienced in the 1/6-g flights were applicable to the conditions encountered on the lunar surface, including the surface footing.

The cooling performance of the portable life support system was such that the Commander's maximum diverter valve position was half-way between the "minimum" and "intermediate" cooling positions, even on the third extravehicular activity. During the driving portion of the extravehicular activities, both crewmen used the "minimum" position except on the third extravehicular activity when the Commander's valve stayed in the aforementioned position.

The extravehicular mobility unit visors provided excellent protection from the sun and shielding during the S-band lunar communications relay unit antenna alignment. On the third extravehicular activity, the Commander's extravehicular mobility unit overvisor would not retract; this was due to dust that had accumulated on the helmet as a result of the loss of a rear fender from the lunar roving vehicle.

On the first extravehicular activity, the Commander's purge valve pin pulled loose three times (see sec. 14.3.10). This was probably caused by the seat belt pulling over the pin. Downward visibility restriction prevented the exact determination of what was causing the purge valve pin to be pulled. For the second and third extravehicular activities, the purge valve was reversed so that the pull pin was not in contact with the lower part of the seat belt.

The Lunar Module Pilot had intended to use the food bar but, because of his leaking drink bag, did not get a chance to try it. The drink bag on the Commander's suit was installed after the suit was donned for the first extravehicular activity; this resulted in an installation in which the Velcro was not properly mated so that the drink bag nozzle pulled free. Therefore, the Commander was unable to drink during the first extravehicular activity on the lunar surface.

The crew was rushed at ingress when concluding the first extravehicular activity because the Lunar Module Pilot's portable life support system was almost out of water. The extravehicular communications system antennas were not placed in the stowed position and the Commander's antenna was broken upon ingress (see sec. 14.3.2). Crews should consider leaving the antennas stowed except when they may have to walk back to the lunar module from a disabled rover, or when using the lunar module communications at extended ranges.

Because of extensive dust coverage, the Commander's remote control unit was difficult to read. An attempt was made on the surface to dust it off with a glove and the abrasive dust badly scratched the remote control unit face. After the remote control unit oxygen gage was scratched, it was impossible to read oxygen quantity on the lunar surface and it could be read only marginally inside the lunar module. A scratch resistant material should be used to cover the remote control unit face.

The ability to reach the extravehicular mobility unit controls varied on each extravehicular activity. Both crewmen were sometimes unable to reach their primary oxygen and water valve shutoffs; however, they were always able to reach their cooling and auxiliary water valves.

Making left turns in the rover and performing certain overhead operations, such as unstowing the quad-3 tool pallets and the far ultraviolet camera, caused the Commander's right wrist ring to cut the skin. The Commander used a Lunar Module Pilot's wristlet during the second and third extravehicular activities to protect the wrist.

Because of the loss of the rear fender, both of the extravehicular mobility units, (the oxygen purge system, the top and sides of the suit, and the front of the connectors) were covered with small dust clots. The only method discovered to satisfactorily remove the dust from the pressure suits was to beat the appendages of the suit against a surface area such as the lunar roving vehicle tool pallet, the lunar module landing gear struts, or the lunar module ladder. Dusting with the brush caused a coated layer of dust. Therefore, dusting with the dust brush should be the last resort in cleaning the suits.

The extravehicular maneuvering unit gloves were very fatiguing on the long 7-hour extravehicular activities. When an object is held in the pressure suit glove, a crewman must continually hold pressure on the object to prevent dropping it. In a short period of time, the fingers become so tired that they are aching. The hands cannot successfully be required to apply continual pressure to grasp, hold, or manipulate objects on a long-term basis, and no amount of preflight exercise will condition them to do so. For long-duration operations in space the finger joints must have stability in the same manner that the leg or elbow convolutes maintain stability.

The sample collection bag attachment to the tool harness was unsatisfactory. On one occasion, one half-full bag of rocks fell off the tool harness and, fortunately, lodged between the rear fender and the frame of the lunar roving vehicle. Because the Velcro is subject to clogging with dust, the manner in which it is used to attach the bags to the portable life support system tool harness will not assure positive retention of the sample collection bags on the portable life support system tool harness. This is discussed further in section 14.4.8.

The numerous equipment problems that the crew encountered in real time (the sample collection bag falling from the portable life support system tool harness, documented sample bags falling off the cameras, failure of the gnomon, and failure of the retractable tether) were detriments to crew performance. In every instance, these problems were resolved in real time by using a normal earth-like method of carrying the sample collection bags and the documented sample bags, using tools in place of the

gnomon scale, and carrying the tongs by hand. Normal earth-like procedures for lunar surface sampling operations are needed to reduce crew training and equipment malfunctions.

Lunar roving vehicle.- Manual vehicle deployment was readily accomplished. The crew had to reset both sets of walking hinges, extend three of the four wheels manually, and insert two of the four outboard hinge pins. The forces required to insert the hinge pins were as expected from preflight training.

At initial powerup of the vehicle, the rear steering was inoperative. However, the next time the vehicle was driven, both front and rear steering was operative. The crew has no opinions on what caused the inoperative rear steering on first powerup. Mounting and dismounting of the rover was comparable to the 1/6-g training operations in the KC-135 aircraft.

At times, the Lunar Module Pilot's portable life support system would hang up on the rubber bumper in the rear of the seat, requiring him to bend forward and slide back into the seat. The Commander had some difficulty because of the tightness of his seat belt in that a major effort was needed to push down the handle for seat belt fastening. Nevertheless, the seat belt adjustments made with the seat inserts on the lunar roving vehicle at the Kennedy Space Center mission simulation required no readjustment on the lunar surface for both the Commander and Lunar Module Pilot.

The crew noted a higher than expected temperature on battery 2 which resulted in a power reconfiguration to allow battery 2 cool-down. An off-scale low temperature reading was noted at the completion of the traverse on the third extravehicular activity.

Performance of the lunar roving vehicle was good. The terrain when driving to station 1 on the first extravehicular activity was blocky and hummocky with many subdued-rim craters. Visibility was poor while driving to station 1 in the zero-phase direction. It was impossible to see far enough ahead to drive at maximum speed. Speed on the outbound leg probably averaged less than 5 kilometers per hour. Slopes up to 7 or 8 degrees were negotiated. The visibility effect of zero-phase, in some cases, caused the rover to bounce through subdued craters (2- to 3-meters in diameter) that could not be seen.

The vehicle had no tendency to break out at slow speeds and control was excellent. On the return from station 1 to station 2, the rover tracks were used as directional aids, and tacking out of the sun line allowed an increase in speed to approximately 10 kilometers per hour. At this speed, there was a tendency for the rear wheels to break out during sharp turns. Control was easily regained by turning into the breakout direction. Little wheel slippage was noticed. Rooster tails were noticed when the front and back wheels were driving, as shown in figure 9-10.

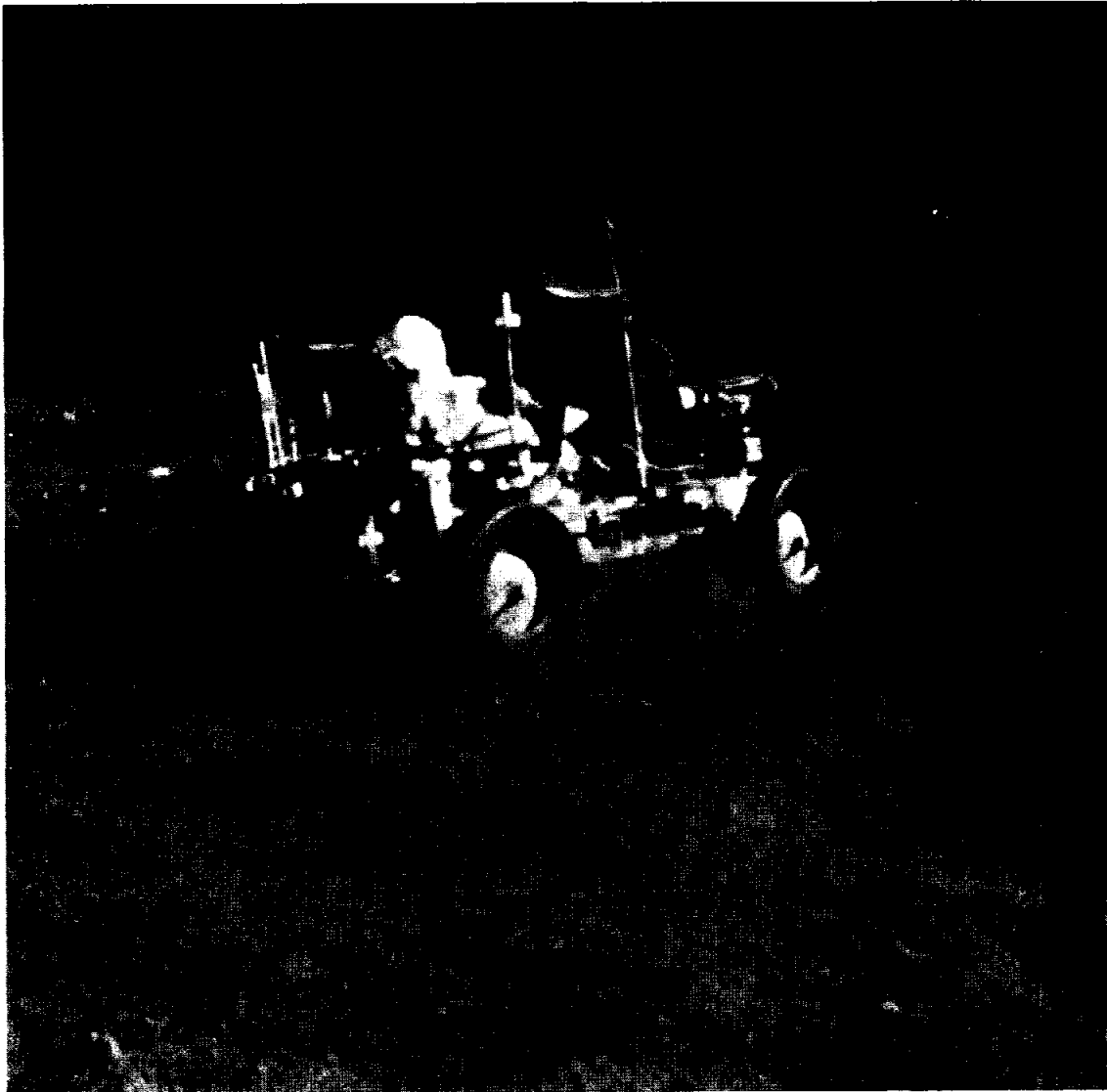


Figure 9-10.- Commander driving lunar roving vehicle during "Grand Prix".

The Survey Ridge region traversed during the second extravehicular activity was so blocky and highly cratered that it was necessary to drive through the smaller secondary craters in order to avoid the larger steep-walled secondary craters. The vehicle ran in and out of the smaller secondaries with ease and it was in this region that the crew experienced the first of three boulder scrapes on the underside of the vehicle frame. The suspension dynamics as the vehicle bounced out of a secondary crater resulted in the rover scraping a boulder which it normally would have cleared.



The vehicle climbed very steep slopes going up Stone Mountain. In several instances, the pitch needle was pegged at 20 degrees, although the face of the pitch gage fell off as the crew departed Survey Ridge (sec. 14.6.4). The only way the crew was able to judge upslope vehicle movement in the lunar environment was by the reduction in the speed of the vehicle as it climbed the slope. The best way to negotiate slopes in the rover is to go straight up and straight down. Going cross-slope or parallel to contour lines produces right or left rolls of 10 to 15 degrees. The feeling is very uncomfortable, even though the vehicle was never unstable during cross-slope driving. At station 4, the lunar roving vehicle was parked in a flat bottom crater in order to eliminate the possibility that the vehicle would roll down the hill.

The right rear fender was lost at station 8. Subsequently, the right rear wheel produced a shower of dust over the vehicle which appears in the 16-mm motion picture photography as falling snow. However, a great deal more dust was actually produced by the wheel than shows up in the film. The crew and the front of the vehicle, particularly the instrument panels, were covered with dust. The instrument panel and the start, stop, and closeout decals had 1/4 inch of dust over them at the completion of the third extravehicular activity.

Driving north of Palmetto Crater on the third extravehicular activity, it was possible to leave the throttle at a maximum setting to achieve speeds of 10 to 12 kilometers per hour while continuing on a straight course. One turn at this speed produced a rear-wheel breakout of approximately 60 degrees. This was corrected by hardover steering in the opposite direction, after which the brakes were applied. When stopped, the vehicle was pointing about 110 degrees and the direction was opposite to that at which breakout occurred. There were no full spin-outs during any traverse. When the vehicle broke out, even at high speed, the turn into the breakout with simultaneous braking always produced a stable stop. The dynamic vertical motions of the vehicle during the Grand Prix were exaggerated because of the single crewman. The weight of two crewmen appeared to give the vehicle more stability and to minimize the height of bounces.

The navigation system was noted to have failed as the crew departed station 9 on the second extravehicular activity (see sec. 14.6.3). Driving north, the crew took a heading of 30 degrees to intercept the earlier tracks of the outbound leg to station 4 on Stone Mountain. The lunar module was acquired visually at a distance of 200 meters, however, and the outbound tracks were not intercepted. The navigation system was reset at the lunar module and it performed accurately during the third extravehicular activity. It was a major aid in locating the rim of North Ray Crater.

The vehicle handled very much like the 1-g trainer except that the pilot-induced lateral high-speed oscillations which were experienced in the 1-g trainer were not apparent in 1/6-g. The steering sensitivity that had been anticipated from reading the Apollo 15 mission report did not exist. The most likely reason that the lateral sensitivity was not experienced was that the excellent restraint of the seat belt prevented the Commander's arm from moving and putting inadvertent feedback into the controller.

The battery covers were opened at the completion of each extravehicular activity. Opening the battery covers threw dust onto the battery mirror surfaces; therefore, the mirrors were completely brushed after each extravehicular activity and were brushed twice at final rover parking after completing the third extravehicular activity. Even though the mirror surfaces were brushed as well as possible, battery 2 temperature caused the actuation of a caution and warning flag while driving to station 11/12.

The crew felt, subjectively, that they were riding 1/2- to 1-inch higher than they had ridden in the 1-g training vehicle. The reason for this is that, in 1/6-g, the crewman sits much higher inside the pressure suit than he does in 1-g.

The maps and the map holder were inaccessible while the rover was in motion. The only map used during the traverses was the contour map with the bearings and distances to stations on it. A fastening clip would allow the Lunar Module Pilot to use the contour map while the rover is in motion.

During initial lunar communications relay unit installation on the lunar roving vehicle, the integrity of the power cables was difficult to maintain. When the Lunar Module Pilot released the cable to check the connection, the cable memory would cause the connector to pull free from the attach point.

At the last two stations of the third traverse, the rover was parked on slopes such that the lunar communications relay unit antenna mast was essentially vertical when the antenna was pointing at the earth. Therefore, any motion on the antenna handle in yaw produced motions in roll and pitch. This made antenna alignment more time-consuming at the last stations. The Lunar Module Pilot assisted in pointing the antenna in several instances. There were also several instances in which the Commander could not use the automatic gain control meter when aligning the antenna because he was standing in front of the lunar communication relay unit. In those cases, a quick vector from the Lunar Module Pilot enabled S-band high gain acquisition. The final lunar communications relay unit alignment tune-up always placed the earth image in the antenna alignment sight.

The lunar communications relay unit was brushed at all extravehicular activity stops and was brushed after opening the battery covers. The thermal cover was folded over the lunar communications relay unit switches at the final stop as stated in the preflight instructions.

## 9.9 LUNAR ORBITAL SOLO OPERATIONS

### 9.9.1 Plane Change Maneuver

The command and service module plane change maneuver was delayed until just prior to lunar module ascent. The procedures used were the same as for all previous service propulsion system maneuvers.

### 9.9.2 Visual Observations

Techniques.- Man has several unique capabilities which can be used to complement data obtained with remote sensors. These are judgement, curiosity, and an eye with far greater dynamic range and color sensitivity than any existing or proposed imaging sensor. During preflight training exercises, it was repeatedly demonstrated that the human eye, intelligently directed, could see and identify geologic features which either failed to appear, or which appeared but could not be recognized on photographs. Resolution, although a measurable quantity, never seemed to be the entire key to recognizing a geological feature. Perhaps the human observer's ability to absorb a big picture and then follow it to a detailed small-scale feature enhances his ability to recognize the many subtleties of interpretive observation. Another advantage of the human eye is the ability to almost simultaneously observe features in a wide range of illuminations.

During the Apollo 16 mission, the average viewing time of a selected target was slightly over 1 minute. Apollo missions are characterized by extremely high levels of crew activity and, therefore, time for visual reconnaissance is at a premium. The spacecraft attitudes which provided the most comfortable viewing were those chosen for forward and north-oblique photography with the mapping camera. The least desirable attitude was in the minus-X scientific instrument module data collection mode because the target was at its closest point of approach at the same time it came into the observer's field-of-view, making acquisition difficult.

Preflight training was conducted by flying a T-38 aircraft at 40 000 feet where the resolution of the unaided eye is roughly equivalent to that obtained with a 10-power magnification from 60 miles, and the angular rates of the line-of-sight are similar. Several lessons became apparent. The

first was the necessity to develop a habit of observing and verbally describing simultaneously. The second was the requirement for an observation plan. The third was the necessity of sketching subtle features that are anticipated not to be obvious from the accompanying photography. The last was that, since time is at a premium, every possible effort must be made to efficiently set the camera, acquire the target in the camera field-of-view, and record the camera frame and magazine identification.

Considerable training time was spent in the study of lunar processes and theory and in learning lunar geography. The latter study proved to be a key element in the efficient utilization of the Command Module Pilot's time by allowing him to recognize his location and the major geologic questions associated with a particular region without having to refer to a map.

The effectiveness of the observational techniques used on Apollo 16 has been clearly demonstrated; however, future improvement can be realized by considering:

- a. The use of optical devices with more magnification and some form of image stabilization.
- b. The allocation of more film to document unscheduled observations.
- c. The use of a 35-mm camera, with through-the-lens viewing and internal light meter, to aid in rapid photographic documentation.
- d. A polaroid-type camera system would allow efficient planning of subsequent observations and also aid the crew in determining which aspects of a given scene do not show up clearly in photographs.

Visual impressions of the lunar surface.- During the early revolutions in lunar orbit, the earthshine illuminated a relatively large amount of detail; however, this detail was lost in time as the earth's effective reflecting area became smaller. Photographs should be taken at a time when the earth is presenting its maximum lighted surface.

Craters on the moon can occasionally appear as hills when looking out the window just as they do when looking at photographs. This inversion occurred most often while looking out of window 5 while in the scientific instrument module attitude, and almost always over the more non-descript areas of the far side.

There is very little around the moon to aid in forming a feel for the size of objects. Since the moon is so heavily cratered at all scales, it looks very similar from 8 miles or 60 miles. The difference is really in the types of features which can be detected at different ranges. For

instance, the small-size lineations, which are typical of all of the moon except for the mare surfaces begin to show up somewhere between 25 and 30 miles to the unaided eye.

In an attempt to settle the question of the moon's color, a wheel was carried on Apollo 16 which had color chips for comparison. The concept was that the crew would hold a color chip up and compare it with the lunar surface. However, two difficulties showed up the first time this was attempted in flight. First, the crew could not arrive at a consensus on the color chip that most nearly matched. All crewmembers agreed that none of the chips actually matched (the colors chosen were quite different to their eyes). The second problem was the difficulty in getting both the color chip and the lunar surface in the same lighting. The Command Module Pilot saw very obvious tonal differences, especially in the western maria, but could not quantitatively describe them. The color impressions of an area of backside highlands changed with the sun angle.

During the early lunar revolutions, the horizon was clearly definable within a few minutes of entering the umbra. The time between losing earthshine and detecting the horizon increased as the mission progressed, implying a dependence on the solar corona.

The horizon gradually increases in definition as the sky takes on a radiance near the ecliptic. The actual sunrise is very abrupt and can catch an observer off guard since the intensity increase takes an apparent step function as the sun's disk comes into view.

The Command Module Pilot was observing the lunar horizon and star patterns from a totally darkened cockpit at about 122:55 when he noticed a white flash which occurred some distance below the horizon. This flash was only momentary and was brighter than the brightest star or planet. The Command Module Pilot did not see any of the light flashes that other crewmen have seen during lunar missions. It is possible that this was his only observation of such a phenomenon even though he personally feels that he saw something external to the spacecraft.

Particles in orbit with command and service module.- Particles could be seen in lunar orbit with the command and service module during the period between spacecraft sunrise/sunset and the terminator crossing. These particles could not be identified but appeared to be rotating since they would flash or wink. It was not possible to judge their distance from the command and service module. The particle density was low and essentially constant during the mission.

### 9.9.3 Photography

Ten of the scheduled seventeen low-light-level photographic sequences were accomplished. The procedures were adequate for all conditions except the condensation on the windows.

The portable tape recorder was used to provide timing and instructions during the execution of the sunrise solar corona and zodiacal light sequences. Without this technique, the sequences could not have been accomplished.

The moon, in either earthshine or sunlight, was in the camera field-of view on several sequences, including Skylab contamination study photography and one attitude for Gegenschein photography.

The attempt to photograph the lunar surface in earthshine should provide some very useful data about the western areas.

### 9.9.4 Scientific Instrument Module Problems

The first time the panoramic camera was turned on, it was accompanied by a master alarm and a main bus B undervoltage warning. The camera was immediately deactivated and subsequent analysis indicated that the problem was caused by the spacecraft heaters coming on simultaneously with the panoramic camera.

The mass spectrometer boom did not fully retract following its first full extension (sec. 14.1.8). The panel 230 indicator remained at full barberpole although the proximity sensor indicated a safe retraction. The lunar module crew had reported that the boom appeared to be retracted. The Mission Control Center was used as the primary source of retraction data thereafter. Just prior to lunar module jettison, the boom stalled near its fully-deployed position. This stall was confirmed by both visual observation from the lunar module and ground telemetry. The boom was subsequently jettisoned. The jettisoned boom smoothly left the spacecraft with no visually detectable angular rates.

Retraction of the mapping camera required more than 3 minutes the first time, but the retraction time seemed to be progressively shorter as the mission continued (sec. 14.5.1). During the transearth extravehicular activity, the stellar glare shield was found to be partially extended when the camera was in the retracted position (sec. 14.5.2).

The gamma-ray spectrometer boom failed to retract completely during transearth coast and finally stalled just prior to the final midcourse correction. This anomaly is discussed in section 14.1.9.

## 9.10 ASCENT, RENDEZVOUS AND DOCKING

### 9.10.1 Ascent

The normal powerup procedure for ascent preparation was modified slightly; lunar surface alignment stars were deleted and reaction control system A was shut off before the ascent system feeds were turned on (after insertion, the cross feed was opened to use both reaction control systems). The crew was about 20 minutes ahead of the procedures at lift-off minus 35 minutes. After a 15-minute hold, the helmets and gloves were donned and the ascent tanks pressurized. The crew was then ready for lift-off. The countdown to lift-off proceeded normally and, at auto ignition, a slight pop was heard, followed by a smooth lift-off. Program pitchover was on time and the profile was normal throughout the lunar ascent firing.

### 9.10.2 Rendezvous

Lunar module.- The maneuver residuals were so small at insertion that no trim firing was required. The vernier adjustment was very small; minus 10 feet per second in the Z axis and minus 2 feet per second in the X axis. The vehicle was pitched up automatically upon using the rendezvous navigation program. An automatic rendezvous radar lock-on was obtained at a distance in excess of 150 miles. Both crewmen visually acquired the command and service module at this range. Although the command and service module could not be seen through the tinted crewman optical alignment sight, it was seen to the side and from below the sight. Since the command and service module can be visually acquired, the desirability of performing the state vector and the radar checks in the simulators to acquire radar lock-on at extreme ranges following insertion was demonstrated. Approximately 23 marks were obtained with the rendezvous radar and they were fed directly into the abort guidance system. Tracking was accomplished in both the automatic and pulse-control modes of the primary guidance and navigation system.

All four solutions for the terminal phase initiation firing were in substantial agreement (Mission Control Center Real-Time Computer Complex, the command module computer guidance, the lunar module abort guidance, and the lunar module primary guidance). Terminal phase initiation was performed with the ascent propulsion system. The maximum residuals from the firing were about 5 feet per second in the X axis and these were trimmed to zero. During this maneuver, the radar, which was near the antenna limits of mode-1 lock-on, broke lock. The vehicle was pitched up in the transfer phase midcourse program and radar lock-on was quickly reacquired.

Because of a procedural error in hitting the enter button too quickly when reloading the W matrix, a second reloading of the W matrix was necessary. Therefore, only five marks instead of the normal seven were obtained for the first midcourse correction. The first midcourse solution had a maximum value per axis of 0.9 foot per second, and the second midcourse solution was even smaller. After the second midcourse correction, no line-of-sight corrections were made until the lunar module was within 7000 feet of the command and service module.

The braking phase did not commence until 3000 feet separation because the relative velocity, when passing through 6000 feet, was less than 29 feet per second. Line-of-sight control corrections during the remainder of the rendezvous were minimal. Care was taken not to exceed the command and service module rescue capability braking limitations which meant that the normal lunar module braking gates were approached conservatively.

When the lunar module was stationkeeping with the command and service module, the Mission Control Center requested a lunar module 360-degree yaw maneuver to allow the Command Module Pilot to inspect damaged panels on the rear of the lunar module that had been seen on television at lift-off (see sec. 14.2.2). The inspection revealed that the outer thermal cover on the rear of the ascent stage had been bent and torn, but the thermal blankets underneath appeared to be intact. Following the lunar module yaw maneuver, the command and service module performed a pitch and a 360-degree roll maneuver to allow the Lunar Module Pilot to take pictures of the scientific instrument module bay and of several bubbles produced by heating of the thermal coating on panels of the command and service modules.

Command and service module.- The stabilization and control system was used for attitude control during the rendezvous to prevent optics usage from exercising the thrust vector control relay and running the risk of a repetition of the inertial measurement unit coarse alignment problem. Generally, the command and service module was flown to attitudes under command module computer control; however, during tracking and service propulsion system thrusting routines, it was flown using the stabilization and control system. This procedure was much the same as the standard "Rendezvous Procedures with No Inertial Measurement Unit."

The digital event timer on panel 1 began to count incorrectly during the rendezvous and it malfunctioned intermittently thereafter. This anomaly is discussed in section 14.1.13.

The Command Module Pilot had planned to optically track the lunar module at insertion, which was scheduled to occur prior to sunset. This did not prove feasible since identification of the lunar module was not



possible using the scanning telescope and the prelaunch state vector was inadequate for automatic acquisition with the sextant. A new state vector was received from the Mission Control Center and tracking was initiated at sunset using the sextant to acquire the lunar module tracking light. VHF ranging and the lunar module rendezvous radar were again in close agreement.

The sextant and scanning telescope were boresighted closely. The lunar module tracking light was not very obvious in the scanning telescope until near terminal phase initiation. During the lunar module braking maneuver, following rendezvous, the two forward firing reaction control system engines appeared as flashlights which blinked on periodically. The rendezvous was normal and all terminal phase initiation solutions were consistent.

The requirement for television coverage of the lunar module approach was deleted so that the Space Flight Tracking and Data Network could use the 210-foot antennas for lunar module communications since the lunar module was transmitting on omnidirectional antennas instead of the steerable antenna.

In accordance with instructions from the Mission Control Center, the Command Module Pilot did not don his pressure garment assembly for the rendezvous operations.

## 9.11 LUNAR ORBITAL OPERATIONS - DOCKING TO TRANSEARTH INJECTION

### 9.11.1 Docking

Lunar module docking was very gentle, with contact being made at a low closure rate of about 0.2 foot per second. The probe did not capture the lunar module until some delta-velocity was applied by the command and service module. There was no indication of the lunar module bouncing away from the command and service module at contact. Following lunar orbit docking, latch 10 functioned normally.

### 9.11.2 Post-Docking Activities

Lunar module post-docking powerdown was to be performed according to procedures in the contingency checklist under "Docked Deactivation - Staged" with minor modifications. These procedures were implemented immediately after docking and, at the same time, all the rocks and the experiments that were being returned from the lunar surface were transferred

to the command module. Articles were transferred exactly as they were to be stowed and this stowage went ahead of schedule. Because a rapid dry-out of the water boiler was anticipated, the crew was requested to delete the transfer of a few items such as the personal preference kits and the data storage electronics assembly. However, because of a slow dry-out, all equipment was transferred prior to final lunar module powerdown and tunnel closeout. The water boiler dry-out was so slow, in fact, that some equipment was reactivated to decrease the dry-out time.

During the equipment transfer, a large amount of dust had begun floating around and much of it was transferred to the command module cabin. The vacuum cleaner failed after it had been used for about 20 minutes. Therefore, all the dust could not be collected. Most of the sample collection bags were free of dust and debris and the only things that really needed cleaning were the deep core sample and the big rock bags. Dust particles in the lunar module cabin atmosphere did provide some hindrance to the crew during the unsuiting and the dry-out period.

The lunar module could have been jettisoned at this time and would have resulted in a shorter day than was experienced; however, early on rendezvous day, the decision had been made by Mission Control to delay lunar module jettison until the following day in an attempt to shorten the length of the rendezvous day. This change in the lunar module-jettison timeline created confusion and inefficiency in that several hours were consumed on transearth-injection day with lunar module powerup, pressure garment donning and lunar module jettison taking the place of regularly scheduled activities.

Upon completion of water boiler dry-out, the lunar module was finally powered-down according to the procedures. The crew ingressed to the command module, closed out the lunar module tunnel hatch and the command module hatch, and commenced their rest period at the same time they would have if the lunar module had been jettisoned on rendezvous day.

### 9.11.3 Lunar Module Jettison

Upon completion of the rest period following the rendezvous and docking the crew received a series of flight plan and procedures updates which modified two different sections of the contingency checklist and one section of the timeline book. By this time, the timeline book was becoming very messy because of deletions and additions and it was difficult to follow the procedures through. However, the crew felt that the proper switch, circuit breaker, and systems configurations had been identified.

About the time of loss of signal, the crew had donned their suits and commenced final closeout. Final closeout was completed on the backside of the moon. The up-linked differential velocity program was verified, the

guidance computer and digital autopilot were verified, and the mode control switch was placed in "attitude-hold" (versus the required "auto" position). The command module was ingressed on time and a suit integrity check was initiated at about the time of acquisition of signal. (The pre-separation pressure garment integrity checks were never satisfactorily concluded due to the crew falling behind the new timeline.)

Houston noted that the mode control switch was in "attitude-hold" instead of "auto", but the crew was given a "go" for lunar module jettison nevertheless since that configuration was acceptable. The lunar module was jettisoned a few minutes late. At the time of jettison, the lunar module began a slow tumbling maneuver in all three axes, and a thruster was never fired as far as the crew could tell (sec. 14.2.6). Once lunar module jettison was accomplished, the crew unsuited and initiated the two-revolution preparations for transearth injection.

Another problem which had been encountered during lunar orbital operations was that two lithium hydroxide canisters tended to stick during removal (sec. 14.1.15). The first one had been used 9 hours longer than the normal time because the changeout was overlooked during one of the solo periods when a large number of flight plan updates were being made. This canister was snug when removed at about 152 hours. The second incident occurred on the night following rendezvous. This canister was removed on schedule but removal was extremely difficult.

#### 9.11.4 Subsatellite Launching

There were no vibrations or sounds associated with the launching of the particles and fields subsatellite. All indications were that it was normal.

#### 9.11.5 Transearth Injection

The transearth injection maneuver was conducted normally using the same procedures that had been used for the plane change maneuver with the exception that the pitch-2 and yaw-2 circuit breakers were pulled after gimbal startup. There was no explanation from the ground as to why the philosophy in the use of these circuit breakers had been changed.

Two unexpected observations were made during the maneuver. The first was that the command and service module oscillated between both sides of the roll deadband; whereas, on other long firings, the spacecraft remained on one side of the roll deadband. The second unusual observation was the presence of a slight "buzz" approximately 30 seconds into the maneuver.

Throughout the firing, the entry monitor system, guidance and navigation, and voice update values were in agreement.

## 9.12 TRANSEARTH FLIGHT

### 9.12.1 Transearth Extravehicular Activity

The transearth extravehicular activity was conducted exactly according to the checklist procedures. A great deal of training time had been invested in the procedures for stowage, extravehicular activity preparations, and post-extravehicular operations. This certainly paid off and allowed the crew to speed up the preparations. The timeline and procedures were more than adequate. The television camera and oxygen purge system were stowed after the post-extravehicular activity sequences; however, these items should not have been stowed since they were subsequently used.

Preparations.- The final days of preflight training disclosed that, through an oversight, the time allowed for pre-extravehicular activity pressure garment donning was insufficient. Therefore, the planned time for hatch opening was delayed 1 hour. The Mission Control Center allowed the crew to sleep an extra hour on the day of the scheduled extravehicular activity, which once again put them behind the timeline; however, the crew was able to make up approximately 45 minutes of this delay due to the excellent procedures developed for this segment of the operation. Approximately 1 hour was spent on extravehicular activity preparations on the day of transearth injection, but there was not a great deal that could be done without interfering with the sleeping and eating cockpit configurations.

Quite a bit of unopened food was jettisoned in order to provide space for the post-extravehicular activity stowage. This problem was aggravated by reducing the length of the mission by one day, but was basically caused by an overabundance of food.

The extravehicular mobility unit maintenance kit was approximately three times the thickness of the lunar module kit (sec. 14.3.9). The packages of pressure garment assembly helmet wipes in the command and service module kit were approximately five times larger than those of the lunar module kit.

The extravehicular activity preparations and checkout were normal. The Lunar Module Pilot and Commander's pressure garment assemblies were lubricated again and this resulted in much easier glove and helmet donning. The command module suit circuit integrity check was expedited by using the hatch equalization valve to drop the cabin pressure to 5 psi.

While the hatch equalization valve was open, a continual stream of debris was being sucked out of the cabin including a small screw which went through the valve just prior to cabin depressurization. A debris screen should be installed over this valve to prevent an object from becoming permanently lodged in the valve.

Moving around in the cabin in pressurized suits is relatively easy (much easier than in the water immersion facility); however, it is a little harder to see some of the main display console because of the natural tendency to float closer to it. Ground support personnel monitored the spacecraft systems for the crew throughout the extravehicular period.

The counterbalance was removed from the side hatch by backing out the pin which locks the two bellcrank assemblies together. Both removal and reinstallation of this pin were extremely simple. There was no problem with interference between the cam nut and hinge since the crew had been trained to adjust the relative positions of these items during hatch opening and closing. The rate of cabin depressurization decreases markedly when the cabin pressure drops below 0.5 psi. Because of this, the hatch was opened with a small positive differential pressure remaining in the cabin. This produced a noticeable force on the hatch as soon as the dogs were clear of the striker plates. There was very little frictional load on the hatch during opening and closing.

Visibility.- The sun angle chosen for the extravehicular activity was excellent from an operational point of view. It was, however, very difficult to look at the unipole, when installed, or to look in the direction of quad D while standing in the hatch. Visibility of the scientific instrument module bay was good. The only area seen to be in a dark shadow was between the scientific instrument module bay bulkhead and the side of the mapping camera. After the panoramic and mapping camera cassettes were removed, visibility into the empty cassette spaces was excellent.

Mobility.- The extravehicular activity was as easy as it was in KC-135 aircraft training. The "dutch shoes" worked fine and did not exhibit a tendency to release the Command Module Pilot, even when leaning sideward. Getting into and out of the shoes was easy and positive. The traverse path is excellent and allows flexibility in orientation and sequence of operation. The only mobility problem encountered was an extremely stiff left wrist joint on the Command Module Pilot's extravehicular glove. This increased stiffness, compared to the right glove, was evident as soon as the gloves were donned. A concentrated effort was required to move the wrist joint about the axis which corresponds to a yaw control input on a hand-controller. As the wrist became fatigued, the right hand was used to position the left wrist. Fortunately, the wrist joint remained stable in any position in which it was placed.

Retrieval of the panoramic and mapping camera film cassettes was very easy and went just as practiced.

The umbilical was not in the way and its presence required consideration only during ingress when it had to be positioned by the Lunar Module Pilot.

Extravehicular activity hardware.- All equipment functioned as anticipated. The temperature was good, both in the cabin during depressurization and during the extravehicular activity. The only nuisance item was the extravehicular activity hook. The opaque sun visors of the Commander's lunar extravehicular visor assembly were very easy to deploy but were impossible to raise with one hand. The trap door in the visor center section allowed adequate visibility.

During a suit pressure check, a pressure of 3.5 psi was observed on the Commander and a pressure of 3.8 psi was observed on the Lunar Module Pilot (sec. 14.3.8). Both crewmen were on the cabin suit loop at the time.

Scientific instrument module bay observations.- The scientific instrument module door pyrotechnic cut was smooth all the way around. The spacecraft-lunar module adapter/service module pyrotechnic cut was quite jagged, similar to cuts seen on test specimens.

The mapping camera stellar glare shield was partially deployed and the "cuckoo door" was resting on the extravehicular handrail (sec. 14.5.2).

The gamma-ray experiment was retracted with the tapered portion of the guide pins sticking through their shoes. The door was open approximately 30 degrees and was loose enough to be jiggled a couple of degrees. There was no evidence of the cause of the incomplete retraction.

The paint on the service module cork covering and on the reaction control system quad housings was blistered. The coatings on the radiators looked clean. There was no ice on the command module dump nozzles.

Unipole operations and microbial response experiment.- The pole was easy to install and remove. Because of the sun orientation, the data acquisition camera could not be verified to be operating by looking at the camera light; however, it could be felt to be running.

Removal of the data acquisition and television cameras from the pole was easy as was installation of the microbial ecology evaluation device. However, two problems arose with the device. First, a Velcro strip (provided to keep the locking ring in place) continually floated to a position that interfered with viewing the sun sight, and second, the cover of the device did not automatically lock when it was closed. Locking the cover was a three-handed operation. One hand was required to hold the Command Module Pilot in position, one to close the lip and compress the seal, and the third to rotate the lock pin. As a result, the microbial ecology evaluation device was passed into the Lunar Module Pilot who performed the operation inside the command module. The cover was open approximately 3 to 5 seconds beyond the planned time and was not in direct sunlight during this time.

The sun sight worked fine and is an excellent concept. Because of the previous problems with the digital event timer, the Commander timed the exposure of the microbial ecology evaluation device with his wrist-watch.

Hatch closing and post-extravehicular activity.- Hatch closing was easy and went as planned. It would have been desirable to have a positive means of determining that the hatch dogs are over center by indications from the hatch dogs themselves rather than relying on the gear box indications alone.

The post-extravehicular activity reconfiguration was a real thrill. This took several hours and was greatly aided by the assistance of the Mission Control Center in the execution of the flight plan.

#### 9.12.2 Transearth Coast Problems

Several problems occurred during transearth coast. The inertial subsystem warning light mysteriously came on and went off several times accompanied by an inertial coupling unit failure warning on the computer display keyboard (sec. 14.1.4). In troubleshooting this problem, it appeared that a "no-digital-autopilot" configuration was required in order to do the malfunction procedure test of the error needles.

The crew couch Y-Y shock-attenuating strut was very hard to extend and lock prior to entry (sec. 14.1.17). It seemed as though the Y-dimension of the spacecraft had changed with respect to the couch.

## 9.13 ENTRY, LANDING AND RECOVERY

The entire entry sequence was normal. The entry stowage was completed the night before except for stowing one pressure garment assembly and tying down loose items such as the jettison bag. On entry day, it took less than 2 hours to finish the cabin preparations. As previously mentioned, several inertial subsystem warnings were observed during the final hours prior to entry. A set of entry procedures similar to those used during the major service propulsion system maneuvers had been worked out. These procedures incorporated the use of erasable program EMP 509 and zero coupling data unit (verb 40), and were quite straight-forward and well explained.

All pyrotechnic events occurred on schedule. The entry profile followed predictions. Due to extensive entry training in the simulators, the crew felt completely comfortable about entry procedures. The Command Module Pilot had no difficulty maintaining an effective instrument scan under the entry deceleration, which exceeded 7-g. The only unexpected condition was the magnitude of the command module oscillations once the drogue parachutes were deployed. The oscillations may have been the same as programmed into the command and service module mission simulator but, without the dynamics, may not have been fully appreciated.

The command module reaction control system isolation valves were closed at approximately 3000 feet and the direct coils mode was activated in the plus- and minus-yaw directions. The yaw jets were heard when firing in the plus-yaw direction (which was fired first) but not in the minus-yaw direction.

The firing of the command module negative pitch jets could be confirmed only by changing spacecraft rates.

The landing was flat and much harder than the Commander recalled from the Apollo 10 mission. The parachutes immediately pulled the vehicle into the stable-II attitude. The Command Module Pilot and Lunar Module Pilot jettisoned the parachutes and immediately initiated uprighting procedures. Uprighting took an estimated 4 1/2 minutes, and the command module stayed for what seemed to be an excessive time in an attitude in which the vehicle seemed almost ready to upright into the stable I attitude. Post-flight inspection showed that the center uprighting bag was only partially inflated.

The recovery operation proceeded smoothly until a swimmer opened the hatch and placed a large bag inside. The swimmer said that the bag contained a temperature monitoring device which must be taped to the main display console. The crew had not seen this device before nor had they



been briefed on it. (Editor's Note: The temperature measurements were made to determine the temperature changes after landing that may be anticipated in the Skylab program.) This unexpected operation resulted in some confusion and an unnecessary 5 to 10 minutes was expended inside the cabin, which slowed down the quickest crew recovery ever. The time from spacecraft splashdown until the crew was on the deck of the USS Ticonderoga was less than 37 minutes.

## 9.14 GENERAL OBSERVATIONS AND RECOMMENDATIONS

### 9.14.1 Spacecraft Systems

Lightweight headset and communications carrier.- The lightweight headset was used extensively by the Lunar Module Pilot while the Command Module Pilot and Commander chose to use the "Snoopy" hat almost exclusively. The difficulty with the lightweight headset arises from the requirement to hold the microphone in close proximity to the mouth. This requires the use of at least one hand to maintain good communication. As a general rule, however, it is much more convenient to have both hands free for note taking and/or manipulating switches while talking. The lightweight headset is too bulky to be conveniently worn on the head.

The existence of the crewman's communications umbilical slows down operations by putting unwanted forces on the crewman's body, by presenting a constant snag potential, and by requiring a unique path around hardware. The control head and the tee adapter are also cumbersome. The suit adapter is very stiff which means that as the crewman moves around, the torques coming from the umbilical are transmitted to the headset. If the headset is the lightweight type, it is going to be repositioned or knocked off, and if the headset is the "Snoopy" type, it is going to be a constant personal nuisance. Either a lightweight headset like those used in the Mission Control Center or a squawk box like the executive conference telephone adapter should be provided. The latter is preferable because it alleviates all the problems associated with umbilicals. (Editor's Note: A configuration exists for the attachment of the lightweight headset to the constant wear garment which frees both hands for normal work. However, the head must return to a preselected "talk" position because the microphone is maintained at constant position relative to the body.)

The requirement for someone to monitor the communications at all times resulted in the Command Module Pilot wearing the communications carrier the entire mission. When the communications carrier is worn continually, it can present a personal hygiene problem. For long flights, consideration should be given to carrying additional cloth helmets since they are separate from the electronics. A spare set of electronics should be considered.

Onboard voice and data recording.- There is a need for continuous recording of onboard voice. The Apollo equipment has several shortcomings which are:

- a. The voice is recorded simultaneously with the spacecraft data.
- b. The ground controls the record and playback sequence; consequently, the crew must refer to the flight plan or ask the ground for the current configuration.
- c. The tape recorder talkback indicator in the cabin indicates tape motion and not direction.
- d. The data storage equipment uses a separate recording amplifier and the crew does not know the sound level being recorded.
- e. All data recorded may not be recorded on the ground as it may be recorded over before that portion of the tape is dumped.

Voice-operated keying circuit.- The voice-operated keying circuit worked flawlessly throughout the mission as long as the communications carrier was used. The Command Module Pilot used this mode almost continuously while solo in orbit and during a large portion of transearth coast.

Guidance and navigation optics.- Auto optics worked well when the inertial measurement unit was realigned. There was more trunnion overshoot than anticipated when acquiring targets. The Command Module Pilot had the distinct impression that the amount of overshoot and the time to damp oscillations increased with mission duration. Toward the end of the lunar orbit period, the initial overshoot exceeded the sextant field of view. This overshoot, based on optics position indicator readings, occurred primarily in trunnion.

Sextant reticle illumination was normally comfortable when used at the maximum intensity, providing good star/reticle balance. The scanning telescope illumination had to be reduced to a minimum to allow star identification. The command and service module mission simulator displays are quite accurate. During training, Kennedy Space Center simulations personnel had added a filter to the scanning telescope which reduced the star intensity. This was a significant aid in providing a good feel for the amount of time necessary to acquire stars with the scanning telescope. The star patterns, under the best conditions, were never as obvious through the scanning telescope as they were out the window.

The scanning telescope must be in focus before stars can be seen. It was focused on the reticle for best results. The focus seemed to be quite sensitive and would drift, even when taped. Also, the sextant focus adjustment was at one extreme of its travel. Improper use of the Teflon

locking nut which locks the eyepiece guard cup in place caused the eyepiece to unscrew in zero-g. The crew was not properly trained for this operation.

Tape was applied to the eyepieces to retain them after the scanning telescope eyepiece was found floating around the cabin.

There was a noise when the shaft was driven at the higher speeds. The noise, which increased throughout the mission, sounded like that made by the optics position indicators on the command and service module mission simulator. The noise was apparently proportional to the rate of drive and did not seem to be affected by switching from the "resolve" to the "direct" settings. This anomaly is discussed further in section 14.1.14.

The scanning telescope was generally useless while the vehicles were docked because of the large amount of light reflected off the lunar module steerable antenna and one of the reaction control systems quads. Discrimination between lunar module paint debris and stars was not a problem when using the sextant because the debris particles were always out of focus.

One realignment was performed using the earth and sun during translunar coast. The earth was not full at the time and some difficulty was experienced in defining the center of the disk.

Command module computer.- Useful modifications and additions to the Apollo software continue to become apparent as operational experience is gained. Several erasable memory programs were tested and formalized prior to flight for use as both planned evolutions and contingency work-arounds. The EMP 509 procedure, to prevent coarse alignment of the inertial measurement unit in the presence of the coupling display unit transients, was one of these and, as previously discussed, played a major role during the mission. This is a classic example of the utility of developing procedures to handle certain critical situations even though a reasonable cause cannot be predicted.

Perhaps the most useful addition to the command module computer normal procedures was a set of addresses that could be interrogated to display the maneuver completion time during a digital-autopilot-controlled automatic maneuver. The crew routinely executes maneuvers requiring up to 15 minutes for completion, followed immediately by a scheduled activity. The efficient execution of real-time flight plan changes resulted directly from being able to determine the acceptability of the selected maneuver rate. Future autopilot design should provide an option which would allow specifying maneuver completion time. Another useful feature would be an autopilot which would allow non-symmetrical and/or discrete deadbands for each control axis.

Prior to flight, a program to monitor for a stuck-on thruster was developed which would turn on the inertial subsystem warning light and master alarm if the spacecraft exceeded its deadband by some specified amount. This program was used during the translunar coast and during each lunar orbit sleep period. It allowed the Command Module Pilot to sleep in lunar orbit without concern for the reaction control system consumables.

Electrical power.- The systems checklist requires that the battery manifold be vented to vacuum after charging the battery. Ground support personnel requested that the manifold not be vented below cabin pressure. The valve configuration makes it more a matter of luck to retain a positive pressure. The manifold pressure rose rapidly following each venting before stabilizing.

During the charge on battery B prior to the transearth extravehicular activity, the crew detected a definite odor in the lower equipment bay. This odor was described by the Lunar Module Pilot as being like hot electrical insulation, while the Command Module Pilot thought it was reminiscent of an automobile battery charger odor.

Cabin environment.- Following insertion into earth orbit there was quite a bit of debris floating around the cabin. This contamination consisted of small screws, fasteners, ends trimmed from wiring and general trash. The quantity of this cabin debris remained fairly constant throughout the mission. At times, the suit circuit return valve (cabin air return) had to be cleaned more than once a day in order to keep the oxygen demand regulator flows at their normal values.

Once the transfer of equipment from the lunar module began, the command module cockpit became noticeably dusty with quite a few rock chips floating around. The dust could be found on almost all surfaces although there was never any problem with floating dust.

The cabin fan filter was installed on the first day of the flight. After rendezvous, the cabin fan was turned on prior to opening the lunar module hatch and ran continuously until after transearth injection when it made a very loud moaning noise and was turned off (sec. 14.1.11). The cabin fan inlet screen was generally covered with a great deal of trash. After the fan was turned off, a piece of paper was taped over the cabin fan inlet screen in an attempt to retain the dust within the ducting. There was no problem with dirt coming out of the duct, even when the fan filter was removed for entry.

The vacuum cleaner failed after less than 1 hour of use while attempting to clean items in the lunar module that were to be transferred to the command module.

The suit hoses were arranged such that the Lunar Module Pilot's hoses were alongside stowage container A8, the center hoses were wrapped around the inside of the tunnel, and the left hoses were along the minus Y side of stowage container A2. There was never any sensation of inadequate ventilation or circulation.

The cabin temperatures were comfortable during translunar coast. Each crewmember found his own combination of clothing which was most comfortable. Wearing only the constant wear garment while in the sleeping bag was comfortable to everyone during the translunar coast and transearth coast sleep periods. While in the 60- by 8-mile lunar orbit, the cabin felt considerably warmer and the most comfortable attire was the constant wear garment only. During solo operations in the 60-mile circular orbit, the cabin cooled noticeably. In order to sleep, the Command Module Pilot had to wear his inflight coverall garment in addition to the constant wear garment. Once the lunar module crew returned to the command and service module, the cabin temperature was comfortable again.

The cabin walls and windows began to collect a great deal of condensation following transearth injection. The quantity of condensate slowly increased throughout the transearth coast and did not diminish even in passive thermal control. By the time the Skylab dump photography was attempted at approximately 246 hours, the windows had to be wiped between each photographic sequence.

One characteristic which has been jokingly mentioned on previous flights is that loose objects seem to eventually end up collecting in the lunar module/command module tunnel area. This phenomenon was evident throughout the flight either with coupled reaction control system engines or unbalanced jet configurations.

A qualitative observation is that the tunnel area was almost always cooler than the rest of the spacecraft cabin.

Water/glycol temperature control valve problem.- The primary water/glycol temperature inlet valve started oscillating rapidly while in earth orbit. The crew was advised to select the manual mode of operation and that mode was used for the remainder of the mission. The minimum valve rotation seemed to cause a 10-degree shift in the evaporator outlet temperature. The temperature inlet valve was initially adjusted during the early hours of translunar coast passive thermal control. The valve was cycled just prior to the transearth extravehicular activity by going to the automatic mode for several minutes, then returning to the manual mode. The valve appeared to be working normally in the automatic mode; however, the crew elected to leave it in manual for the extravehicular activity.

Water/glycol temperature decrease during extravehicular activity.-  
The water/glycol evaporator inlet temperature dropped during cabin depressurization for the transearth extravehicular activity, but the mixing valve position did not change since it had been placed in the manual mode position. There was a considerable amount of water in the cabin. In fact, the crew observed ice floating out of the hatch throughout the extravehicular activity.

#### 9.14.2 Crew Station

Pressure garment donning, doffing and stowage.- Approximately 1 hour was required for the Commander and Lunar Module Pilot to doff and stow their A7LB pressure garment assemblies. The actual donning and doffing was accomplished most easily in the lower equipment bay with a second crewman assisting, as needed, from the couch position. Zipper closure is probably the most difficult part of the donning operation. During the second scheduled (third actual) lunar module manning, the Commander and Lunar Module Pilot used the lunar module cockpit for donning to obtain more room for zipping the suits. This seemed to speed up the donning activity and was a more convenient place to work.

The Command Module Pilot required approximately 10 minutes to don or doff his pressure garment assembly in the lower equipment bay by himself. Having another crewman to assist in zipping saves approximately 3 minutes.

The most time-consuming part of doffing the suits is the actual stowage of the suits in their bag. Although stowage of three pressure garment assemblies (two A7LB's and one A7LB-CMP) in the bag had been accomplished several times during training, it proved to be impractical in flight. Several factors may be involved in this difference. First, in flight, there is no gravity to help fold the pressure garment assemblies and keep them in place. Second, the accessory pockets were more prominent on the flight suits than on the training suits. A third possible factor is that the best possible care is taken of the pressure garment assemblies in flight, which means that there is a minimum of pulling and bending on the zipper. Another possible factor is that the simulator and mockup training bags have become stretched with use.

To alleviate the stowage problem, the Command Module Pilot's suit was stowed under the left couch. In order to provide access to stowage containers A1 and A2, it was not tied in place.

Following the transearth extravehicular activity, all three suits were stowed in the pressure garment assembly bag through the generous use of kick-and-shove techniques. The center couch had to be removed at the

marmon clamp in order to accomplish this. The size of the pressure garment assembly bag should be enlarged and some extra volume made available in the area between the center couch and the rotation hand controller junction box.

Pre/post sleep configurations.- The pre-sleep checklist takes approximately 30 uninterrupted minutes to complete. Several other items, such as filling a drink bag for each crewman and taking one last drink before chlorinating the water, takes additional time. The drink bags were very useful since all the crewmen found that they would awaken during the night and be thirsty. It is impossible for someone to move around without waking the others, so having a drink bag handy helps avoid sleep interruptions. For the same reason, each crewman should take care of his waste management requirements before the sleep period begins. All of this adds up to the pre-sleep checklist taking approximately 1 hour of time. Several items were added to the pre-sleep checks during the mission. These were winding the watches, stowing the optics to prevent being periodically awakened by the sun, and verifying that the Mission Control Center was receiving an adequate biomedical signature on the desired crewman.

There should be some uninterrupted time of about 30 minutes following crew wake-up to provide an opportunity for the crew to clean up the cabin, compile the morning reports, review the flight plan, and go to the bathroom.

Cabin lighting.- The electroluminescent lighting provided just the right illumination for easy monitoring during sleep periods. The addition of some form of switch position indication would make an excellent instrument and control display.

The floodlights were used almost continuously except during sleep and low-light-level photography periods. To avoid afterglow problems with the photography, a set of cardboard shades was prepared and the shades were taped to the floodlights nearest window 4.

The floodlights, including the fixed ones, do not provide sufficient illumination for interior photography using color interior film (ASA 500) except in selected locations.

The window shades worked quite well on all windows.

Stowage.- Flight experience indicated that the many hours of training time that was spent on stowage and cabin reconfigurations was well spent. The three segment nets inside the large stowage containers (A1, A2, and A8) were very useful as stowed items began to "loosen up" from their original placement.

Prior to lunar orbit insertion the crew reconfigured the cabin to a preplanned lunar orbit configuration which used containers F1 and F2 for camera and film stowage. Each night, the crew would group the next day's supply of film magazines for easy access.

All command and service module mission simulator timeline training during the 2 months prior to the mission was done with the lunar-orbit stowage. This established habit patterns that prevented spending time looking for items.

Control and collection of waste material is a continuing problem in space flight. Apollo 16 was equipped with three standard jettison bags for this purpose. The difficulty in using one of these large bags for waste stowage stems from the method of inserting trash in zero-g. Keeping trash which has already been deposited in the bag from floating out when the bag is reopened was a problem. Using a smaller bag like the lunar module purse or the urine stowage overwrap bag for intermediate stowage of trash items, and periodically transferring them to the big bag helped. A temporary stowage bag for each crewman's personal use was most practical.

Another problem on an Apollo J mission is the necessity for the use of a trash bag following the transearth extravehicular activity. Two standard jettison bags had been completely filled at the time of lunar module jettisoning and the third was almost full at the time of the transearth extravehicular activity. Two urine overwrap bags were used for the extravehicular activity trash jettisoning in order to retain the third jettison bag for the final two days of the mission. This last jettison bag was almost completely full at the time of landing. An additional jettison bag would be a very useful item.

The addition of a fourth jettison bag should be provided with, perhaps, a removable entrance seal such as the slit membrane presently used on the command module waste compartment entrance.

The pouches were well located and proved to be very useful.

Spacecraft windows.- The windows were generally free of contamination on the outsides, although there appeared to be some condensation on the surfaces between the inner and outer panes. This was not a significant problem; however, window 5 had an additional contaminant which appeared as a light semi-opaque band, approximately 2 inches wide, running along the plus-X side of the outer pane.

Crew equipment.-

Portable tape recorder: A speed repeatability test was conducted on



the portable tape recorder to serve as calibration for the experiment sequences which were timed using a countdown tape. A test tape having audible time increments was used. The playback was consistently 1 second fast in 2 minutes of playing time; that is, 121 seconds of recorded material was played back in 120 seconds. Speed stability was adversely affected if the recorder was hand-held rather than free-floating.

A countdown tape was made for use with the sunrise solar corona and zodiacal light sequences. This was done inflight rather than preflight in order to absorb any speed variations induced by the unaccelerated environment.

Recorder battery performance varied widely; one operated only one cassette, whereas another one played both sides of three full cassettes.

During lunar orbit, the Command Module Pilot was unable to depress the red record button; however, it operated properly during transearth coast. There is a possibility that the tape involved was one of the pre-recorded ones and, therefore, was interlocked to prevent recording.

Razor: The mechanical rotary razor worked satisfactorily at the beginning of the mission up to about the time of surface activities, when the crew chose not to shave. After the beard had grown reasonably long, the razor seemed to snag rather than cut. Cleaning the razor head with a wet tissue while the razor was functioning helped. A band-type blade razor and brushless shaving cream were also carried, but there is no satisfactory way to clean the blade after it is caked with the cream/hair combination. Shaving with the mechanical razor took approximately 15 minutes while almost 45 minutes were required with the band razor.

Binoculars: Ten-power binoculars were flown for the first time aboard Apollo 16. A comparison of these binoculars and the previously flown monocular indicated a significant improvement in recognition of features. The capability provided by the binoculars could be improved by (1) the incorporation of higher magnification with some form of image stabilization (2) increasing the field of view and/or providing a zoom capability, and (3) providing a system with which a scene could be photographed without having to change instruments.

Two problems were experienced in using the binoculars. The first was the problem of jitter, and the second was the difficulty encountered in acquiring a desired target because of the rather limited field of view. The technique which seemed to work best for acquiring a target was to track the desired target with the unaided eye and then slide the binoculars into the observer's line of sight. The binocular lenses had to be cleaned several times a day to maintain clarity.

Sunglasses: The lenses of the sunglasses were not dark enough for comfortable use in lunar orbit. A significant amount of eye fatigue was experienced after looking out the window for extended periods, even with the glasses on.

Cameras: There was only one crew-option color exterior film magazine for the electric 70-mm camera which inhibited the crew from taking many potentially useful photographs.

The 35-mm camera system is a most useful tool. Unfortunately, the inability to change film types without discarding the unused portions of a magazine inhibits its use. One simple improvement would be to load less film on each magazine and carry more magazines, although the ultimate solution would be the incorporation of a removable-magazine concept.

Interior photography is frequently inhibited by the difficulty in obtaining adequate lighting. Higher speed films do not appear to be the best solution since the scenes of interest generally include extremes in illumination caused by the location of cockpit floodlights and windows. An electronic flash is a possible solution. The 35-mm system is the best choice for interior photography because of its fast lens, through-the-lens focus, and integral light meter.

Mechanical timer: Future spacecraft should have such a device built into various areas. Ideally, these timers would not only be capable of being set to some arbitrary time difference, but also could be slaved to the occurrence of events, such as a boom deployment.

Scratch pad: A Skylab scratch pad was useful for writing down procedures which were then displayed by taping them around the cockpit. It was also used as a place to record instructions and as a drawing pad for sketches.

Flight data file: The Apollo 16 flight data file was very complete and effective. However, the flight plan volumes should be reduced in thickness to a size compatible with the available clips. Items such as logs and summary charts should be relocated to make the flight plan only that. Since the flight plan was in constant demand in order to allow timeline execution, the inclusion of information such as menus and medical logs meant that either the timeline had to be interrupted or the data had to be logged from memory at a later time.

The circular wheel containing photographic data and time-longitude corrections was extremely useful.

The concept of a separate checklist containing all experiment procedures and data records made it possible to handle the large number of real-time flight plan changes.

The simulated oblique views of landmarks did not prove to be particularly useful on this mission.

### 9.14.3 Flight Plan

The flight plans have become progressively more detailed and complex, requiring ever increasing amounts of preflight preparation and coordination. Apollo missions consist of three distinctly different sets of requirements. The first is a safe and efficient plan to travel to and from the moon and land at a selected location. The second and third sets are concerned with maximizing the scientific return from the lunar surface and the orbital environment. These two are considered separately because of the different way in which they are dependent on time. The surface operations are, by nature, quite flexible and constrained in time only by consumables, crew fatigue, and the requirement to descend from and ascend to lunar orbit. In contrast, the orbital operations can be made only at discrete times which are a function of the spacecraft position and orbital plane. This dependence on time increases the reliance on a preplanned sequencing of events.

For Apollo 16, the flight plan was constructed to maximize the return of scientific data by integrating multiple requirements into a workable timeline which was developed through many iterations. This vastly increased the potential for science return. The penalty of this choice, however, is a complex flight plan and the, perhaps, unreasonable amount of preflight preparation and training required. The flight plan was written in sufficient detail so that, as the crew became fatigued, there would be a minimum requirement for thinking procedures through in real time.

Previous problems.- Several problem areas were reported during previous Apollo missions. The first was a feeling that there was never adequate time in flight to do the things practiced on the ground. Factors which caused this were the time criticality of functions plus the subtle problems arising from operating in zero-g. Much time was lost previously in clock watching to insure that functions were initiated precisely on time. To alleviate this problem, the capsule communicator was responsible for calling all time-dependent actions when real-time communications were available.

A second source of unproductive crew time is monitoring attitude maneuvers which may require up to 15 minutes to complete. This monitoring is required to insure that excessive middle gimbals angles are not attained and to insure that the maneuver is completed in time to support subsequent activities. To alleviate this problem, the crew flew each attitude sequence preflight in the simulators which verified the time history of the inertial measurement unit gimbals and established the adequacy of the planned maneuver times.

A third area for potential improvement in orbital timelines was that a rigorous plan was needed to develop housekeeping habits which would insure that the crew instinctively knew where each piece of equipment was stowed and the development of an efficient orbital stowage plan. This was accomplished by flying all orbital timelines in a flight-configured simulator.

Another problem reported by a previous crew was that the operation of the scientific instrument module and orbital experiments was too complex to allow the Commander and Lunar Module Pilot to train adequately without sacrificing important areas of their surface training. The plan for Apollo 16 was to have the Command Module Pilot be exclusively responsible for these items and to take maximum advantage of real-time help from the Mission Control Center.

Evaluation of the flight plan.- The Apollo 16 flight plan was an outstanding one thanks to a monumental effort on the part of the flight planners, simulator crews, and the capsule communicators. The following lessons were emphasized during this mission.

- a. Crew eat, rest, hygiene, stowage and exercise periods should be rigidly adhered to and should be kept free of distractions such as communications and experiment reconfigurations.
- b. Each day should begin and end with at least 30 minutes of quiet time to permit the crew to get themselves and their spacecraft squared away.
- c. One hour per day should be included in the flight plan to handle personal hygiene.
- d. The density of crew activities that can comfortably be handled is less when three men are aboard the command module than when it is operated solo.
- e. The preflight mission plan should be adhered to as closely as possible in order to maximize the scientific return.
- f. Communications that are completely public inhibit free discussion.

#### 9.14.4 Visual Light Flash Phenomenon

The Apollo light flash moving emulsion detector was to have been used by the Command Module Pilot. However, by the time the experiment was to be conducted, the Command Module Pilot had seen no flashes, whereas the Lunar Module Pilot was consistently observing them. Therefore, the Lunar

Module Pilot was substituted for the Command Module Pilot in the experiment. The Commander saw some flashes, although less frequently than the Lunar Module Pilot. The Lunar Module Pilot did not notice any demonstrable variation in frequency associated with his location within the spacecraft. In fact, the Lunar Module Pilot also saw the flashes while in the lunar module on the surface. The Command Module Pilot never observed this phenomenon because, qualitatively, he seems to have less acute night vision than the other two crewmen.

#### 9.14.5 Metabolic Input/Output Analysis

A metabolic input/output analysis was attempted. This analysis included the requirement for measuring and logging all fluid and food intake and the timing and collection of selected urine samples. The purpose of this analysis is to reduce the likelihood of inflight arrhythmias and to further investigate the causes of body potassium loss during space flight. The following sources of error were observed in conducting this analysis:

- a. When a conflict arose between logging and drinking, the crew chose to drink without logging the quantity and tried to estimate the consumed fluid later.
- b. Personal estimates of the quantity of water from the drink gun were very unreliable.
- c. The amount of water delivered from the food preparation ports was not the same because the volume of an ounce of hot water was not the same as the volume of an ounce of cold water. Gas entrapment further added to the uncertainty.
- d. Apollo urine collection devices have varying amounts of back-pressure and, when added to the crewman's natural caution, results in totally unrepeatable results.

One additional difficulty with these procedures occurs during sleep periods when any attempt to obtain and log data invariably results in waking the other crewmen.

#### 9.14.6 Physiological and Medical Observations

Fecal collection.— The collection of fecal material is a time-consuming and demanding chore which takes between 30 and 45 minutes as a rule. This operation requires a good bit of room and the total concentration of the participant. The first step is to Velcro all of the necessary equipment within easy reach (scissors, tissues, overwrap, germicide, wipes, and trash bag) and clear an area. The next step is to strip

completely since the one-piece constant wear garment is not at all compatible with this operation. It is advisable to insert the germicide pouch into the collection bag at the start. The sticky seal is indispensable. It should also be kept in mind that urine will be collected with each fecal sample. Cleanup operations would be greatly enhanced with a mirror. The present collection bags are marginal in size if very many tissues are required. This problem is aggravated by a diet which results in loose stools.

Another problem is the requirement to physically break the germicide pouch inside the filled collection bag. This requires a great deal of pressure in an environment where one would rather not have to exert any more force than necessary since a rupture of the bag or leak around the seal would not be worth taking much of a risk. It would seem possible that a bag could be fabricated with the germicide already inside and having some form of chemical covering which would be dissolved by the fecal material. The finger cot must be pulled out prior to use and it does not help in clean-up.

A Skylab fecal stowage bag was used to collect the sample bags. This required constant venting through the waste vent system to keep odors out of the cabin. Unfortunately, the scientific instrument module bay operations prohibited doing this as often as desired. Retaining the bags through the cabin depressurization poses additional concern, since these collection bags are all packed at 5 psi. The possibility of having to live with a ruptured bag in a closed environment is disturbing. This material should be removed from the cockpit at every opportunity.

The stowage transfer lists call for jettisoning some of the unused fecal bags. The crew elected to retain these in light of their high usage and in consideration of the even higher usage which might be incurred should someone develop diarrhea or vomiting.

Personal hygiene.- The basic list of personal hygiene equipment is complete with the exception that no soap is provided.

Urine collection and removal.- The operation of the scientific instrument module experiments dictates that urine be stored onboard and dumped only at selected times. An additional requirement for Apollo 16 was that a one-day urine sample was to be collected and returned. The Gemini bags, used in conjunction with an emergency water/urine bag for stowage, worked well for this purpose.

The procedure for urine dumps specifies that the dump lines be purged for approximately 5 minutes. The crew understood that the purge should be conducted until the particles ceased to appear outside, but not less than 5 minutes. During this mission, it consistently required purges on the order of 15 to 20 minutes for the particles to stop.

The urine receptacle assembly was used three times during the mission because of scientific instrument module constraints; however, the Gemini bag is a cleaner procedure because the vacuum on the urine receptacle assembly is insufficient to prevent a bubble from forming around the cap, even when left on vent for approximately 15 minutes.

Physiological impressions.- With the lunar module attached, reaction control system activity is recognized by the sound of thruster impingement on the lunar module skin and the sound of structural bending and skin "oil canning." The vehicle dynamic response to maneuvers is characterized by a great deal of flexing and pulsing. With time, the crew becomes attuned to the sensation of the reaction control system firings and there is a slight momentary sound as the engine is fired. The Command Module Pilot felt that the sound of a continuously firing thruster would not attract a crewman's attention unless the lunar module were attached.

Orientation.- One frequently asked question is "Do you have any sensation of being upside down?" There were several times during the mission when the command module would appear to be in a stable II attitude. These instances seemed to follow periods in the lunar module and in the tunnel area with the head in the minus-X direction. There seemed to be a natural preference for the orientations used in training even though they were not the most efficient. On the other hand, the spacecraft orientation with respect to external objects was never annoying.

The Command Module Pilot had occasional problems with target acquisition looking in the retrograde direction. This was possibly due to the fact that this orientation provides the minimum surface field of view in the anticipated target area. This orientation is exactly opposite from the normal search mode.

Physical fatigue and sleep.- The Command Module Pilot felt that the flight of Apollo 16 was less fatiguing than the preflight preparations. In fact, he was considerably more rested on the final day of the mission than on launch day. He slept soundly and continuously on only two nights, the first solo day in lunar orbit and the night following transearth injection, but he never felt sufficiently tired to be able to go to sleep. The sleep obtained during the other nights could, at best, be classified as intermittent. Terrestrially, the Command Module Pilot averages about 6 1/2 hours of sleep per night and is generally physically tired when going to bed. Seconal was not used by the Command Module Pilot. Qualitatively, the Command Module Pilot feels that zero-g had no effect on his ability to sleep unless the attendant lack of muscular fatigue is involved. The Command Module Pilot could recall no dreams.

The only eye fatigue experienced by the Command Module Pilot was a very noticeable eye strain resulting from observation of the lunar surface with sunglasses during the first two days in orbit. The eye strain

noticeably reduced on subsequent days and eventually allowed comfortable viewing of the moon without sunglasses.

The ultraviolet attenuator was kept in place throughout the mission except when the metal window shades were used or when the cardboard shield was in place during the ultraviolet photography experiments.

A continuing problem in spaceflight is the requirement to view scenes with significantly different illumination levels. For example, looking outside the cockpit and then reading instruments inside.

Exercise.- As a rule, one 30-minute period per day was accomplished. The most severe limitation associated with the exercises is the inability to remove the heat generated both in the exercise device and the crewman. In order to minimize this problem, the exercises tended to be the isometric types and the Command Module Pilot generally felt better at the conclusion of an exercise period.

Adaptation to spaceflight environment.- Adaptation to zero-g and subsequent readaptation to one-g were immediate and very natural. The zero-g environment can best be described as exhilarating. The one lingering nuisance of the zero-g environment is that the sinuses never stay clear for very long.

Operation and movement within the cockpit, even when totally dark, was no problem.

Previous crews have commented on pains in the lower back. The Apollo 16 Command Module Pilot felt none of these.

Stress.- The Command Module Pilot was under more than the desired amount of physical and emotional stress during the final phases of pre-flight preparation. Since the flight itself was rather hectic, this appears to be an undesirable situation. Some of the factors responsible were:

a. The one-month launch postponement resulted in a new lunar orbital flight plan which had to be completed by working evenings until one week prior to launch.

b. The Command Module Pilot demonstrated an elevated Bilirubin level during the physical given two weeks prior to flight. It was the Command Module Pilot's impression that this was an indication of impending hepatitis. The effects of this type of stress are quite real in view of the replacement of a crewmember for medical reasons on Apollo 13.

c. The prelaunch quarantine is based on sound principles; however, it must be flexible enough to accommodate some relief from the work atmosphere of living in the crew quarters and simulation facility.



Medical aspects.- Changeout of the biosensors in flight generally required 20 minutes and should be undertaken only on a non-interference basis in lunar orbit. Attention to sensor problems should be delayed until the next scheduled sensor maintenance period. The use of felt-tip pen markings on the skin saved considerable time in sensor replacement by making the positioning very simple.

Frequent and loose bowel movements plagued all crewmen and constituted a major problem. Although the inflight diet may be the primary factor, the adoption of a low-residue prelaunch diet might have minimized this problem.

The crew made a conscious effort throughout the flight to drink fluids as often as possible in an attempt to minimize the possibility of becoming dehydrated.

Beginning with Apollo 15, the spacecraft have been purged of all traceable amounts of nitrogen through repeated cabin depressurizations. In the belief that maintaining some trace amounts of nitrogen is desirable, the crew did not vent the nitrogen from the command module side hatch counterbalance bottle into the cabin until after the lunar module was jettisoned.

#### 9.14.7 Skylab Equipment and Experimental Gas/Water Separator Evaluation

Three Skylab contingency fecal bags were evaluated during the mission. All comments concerning the Apollo bag apply to this one as well. In addition to the shortcomings of the Apollo bag, the proposed Skylab bag has several other undesirable features. The stiff reinforcement around the open end, while helping with positioning, prevents obtaining a gas-tight seal when it is closed and introduces additional bulk into the overbag. The addition of the Velcro strap is superfluous.

Several Skylab food packages were evaluated and photographically documented during one meal. The use of cans around the plastic bags containing rehydratable foods presented several problems in the Apollo environment. The cans represented two additional nonproductive pieces of trash per item. The tear-off tops have very sharp edges which aggravate the waste stowage problem and pose a potential safety hazard. One crewman received a very deep cut during the preflight evaluation by inadvertently running his thumb along the torn edge of the can top. The bags used in these cans have no feed port but, rather, a single water valve in the center. The use of this bag requires cutting the valve off, thus providing an opening for access to the food. The problem encountered was that in zero-g, the food wets the entire inner surface of the bag so that the crewman is trying to cut into the middle of a bubble. This is very messy. Germicide tablets are hard to retain in open cans.

Peaches with syrup were packaged in a can with no interior bag. As soon as the top of the can was cracked open, peach syrup spewed out. These peaches had been packaged at 14.7 psi.

An accordian-type juice bag was evaluated. This bag has many useful features including a shut-off valve which can be actuated with the crewman's teeth. This feature allows the crewman to pause during drinking without losing the fluid. Unfortunately, all of these valves leaked.

A redesigned gas/water separator was to be evaluated. The unit appeared to have an excessive back pressure since no water came out of the outlet, but did come out around a crack in the inlet side (sec. 14.3.3). The unit was not examined for damage prior to attempted use; therefore, the origin of the crack was unknown. This unit was not delivered in sufficient time to be checked out with the spacecraft water system before flight.

#### 9.14.8 Meals and Food Preparation

Meals.- A definite learning curve is apparent in preparing and eating a meal in flight. Initially, over an hour of constant activity was required to prepare a meal, whereas, later in the flight, all three crewmen were able to complete a meal in about 30 minutes although no more than 10 minutes of this time spent in actual eating.

The first lesson learned was that, rather than having each crewman handle his own meal preparations and cleanup, it was far more effective to set up an assembly line. The best method was to have only one person in the lower equipment bay while the others remained in the couches. The Command Module Pilot would cut open the meal packages and sort out the meals into those items requiring hot water, those requiring cold water, and the nonrehydratables. He would then cut open the water inlet valves and pass those requiring cold water to the Commander, who would handle the hydration. While the cold items were being hydrated, the Command Module Pilot would cut open the valves on the hot water items. These items would then be hydrated by the Commander. The Lunar Module Pilot would get out the accessory items such as a trash bag, the tissues, the germicide tablets, and then help with the food mixing. Upon completion of the hydration, the Command Module Pilot would cut open the eating ports. Then, everyone would eat and clean up together.

It generally was best to have an intermediate size trash bag available at mealtime and, when full, empty it into the jettison bag. In order to minimize the trash volume, a little extra time was taken to eliminate as much gas as possible from the bags prior to throwing them away. The volume of trash generated from a meal was several times greater than

the unopened meal package. In summary, the eating periods require a full-time occupation of the entire crew. Eating in parallel with other activities always took longer.

Food preparation station.- Some learning was required in the use of the food preparation station water dispensers in order to obtain consistent results. The cold water dispenser required a little more patience than did the hot water dispenser. If a short time was taken between the time the cold water plunger snapped in and the time it was cocked for a subsequent shot, the quantity of water delivered more closely approximated that delivered from the hot water port.

Gas was not a nuisance until the third day. At that time, the gas quantity approached 50 percent in the hot water and something less in the cold water, with gas production apparently greater if the water dispenser plunger was actuated at a rapid pace. The cigar-shaped gas separator was installed and, after purging, seemed to work for the remainder of the mission. The gas separator would always form a large bubble on the outlet end when the plastic cap was left off. When the cap was used, there was no problem with dripping or bubble formation. The hot water is very hot when it comes out and the hot water capacity was never exceeded.

Food and equipment.- The only problem with the hot water foods was that they cooled quite rapidly while being mixed. The wet packs need some method of warming to make them palatable. While the cold wet packs were not very appetizing, they were eaten because the crew felt that they needed solid foods in their diet.

The crewmen were not too successful in closing the juice bag feed ports by pinching, once drinking had started. If the feed tube was folded up, it would make a good seal; however, that took more time than just finishing the drinks.

The spoon bowl packages worked quite well. The only ones that presented a problem were the very thin packages such as tomato soup and lobster bisque. The wetting action of these liquids would cause the fluid to form a bubble around the opening. The bubble would start to form as soon as the package was opened. If the package was opened wide, the bubble formation was minimized. The only practicable disposal method with most foods was to eat the entire quantity.

The wet wipes included with each meal were not very wet and were too small to be of much help. Their use always required the supplementary use of a towel.

The drinks, except for the coffee, have a very similar taste. One of the most satisfying thirst quenchers was the water directly from the gun.

The heat seals on several of the cocoa bags prevented water, introduced through the valve, from reaching the food area.

#### 9.14.9 Liquid Dumps

Exit plume patterns.- None of the command module dump nozzles are visible from within the cabin. The hatch nozzle is approximately 6 inches beyond the limit of visibility out the window. The one opportunity to view a nozzle during a dump came during the first lunar orbit rendezvous when a waste water dump was performed while the command and service module was stationkeeping with the lunar module. The lunar module crew observed that the effluent sprayed out at an apparently high velocity with the cone angle remaining quite small and definite out to several feet from the nozzle. During the dump, the Commander observed an icicle form on the nozzle and then dissipate. A definite translation was imparted to the command module as a result of this dump. This particular dump appeared to be like a very heavy rain. Individual particles are not distinct. When the dump valve is closed, the velocity of the particles rapidly diminishes; however, the apparent particle density remains constant for a considerable time. As the exit velocity slows, the individual particles become obvious and appear more like snowflakes.

During transearth coast, a 5-pound bag of water was dumped through the auxiliary side hatch nozzle using the cabin pressure to expel the fluid. This provided a direct comparison of urine and water dumps under identical pressures. The heater was turned on approximately 10 minutes before the dump was to begin. However, as soon as the dump was started, the nozzle apparently froze. The quick disconnect was removed and the inlet was exposed to the cabin atmosphere for several minutes when it once again started to flow. The water line was reconnected and the bag was emptied with no further difficulty.

A great deal of time was spent observing the characteristics of these dumps. The crew looked for evidence of curved tracks and returning particles. The only time particles were observed to change direction was when they bounced off the lunar module or collided with a particle which had bounced off the lunar module. While following the transearth coast dump photography, an area of increased luminosity was observed when looking down-sun along the dump vector. Urine dumps did not differ in appearance from waste water dumps; however, the velocity of the particles appeared lower and, therefore, the individual particles were more apparent. There is no detectable color difference.

#### 9.14.10 Mass Measurement in Zero-Gravity

This experiment was executed but not documented because of the time required to assess the inertial subsystem alarms on the day prior to entry. The scheme was to use a spring to accelerate a mass across a grid while photographing the translation with the 16-mm data acquisition camera. The experiment was dynamically evaluated in flight, but not photographed because of poor lighting. A qualitative observation was that, with very little practice, the mass could be smoothly accelerated with little or no rotation, indicating relatively stable and repeatable initial conditions.

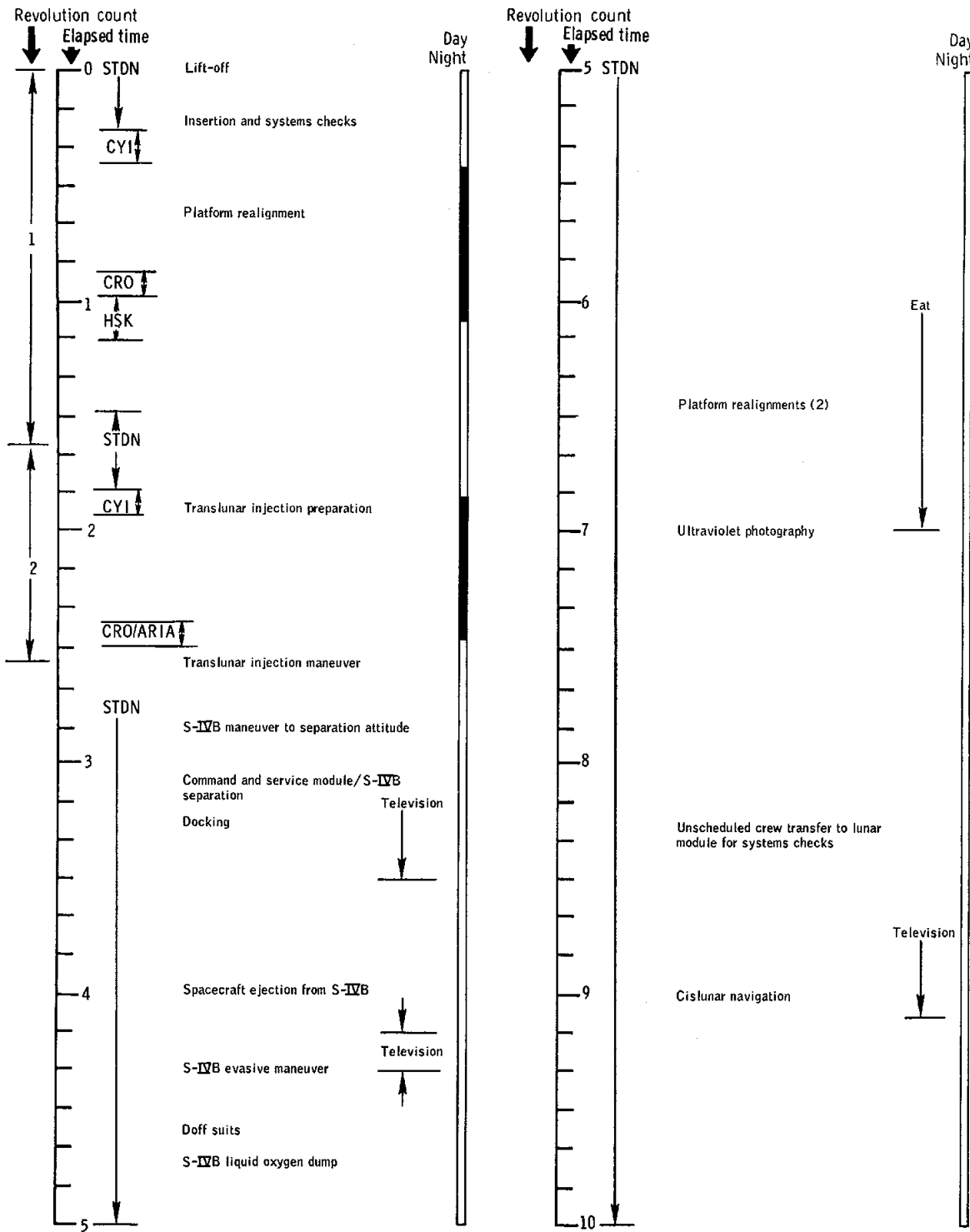
#### 9.15 CREW EVALUATION OF THE MISSION

Despite the decision to return a day early and the delay in the lunar landing, most major objectives were successfully completed. The success was made possible, primarily, because both the flight crew and Mission Control Center teams were very familiar with the mission plan.

In spite of the delay in landing, all orbital items scheduled for the day of powered descent were accomplished except tracking of the landed lunar module and a strip of earthshine photography.

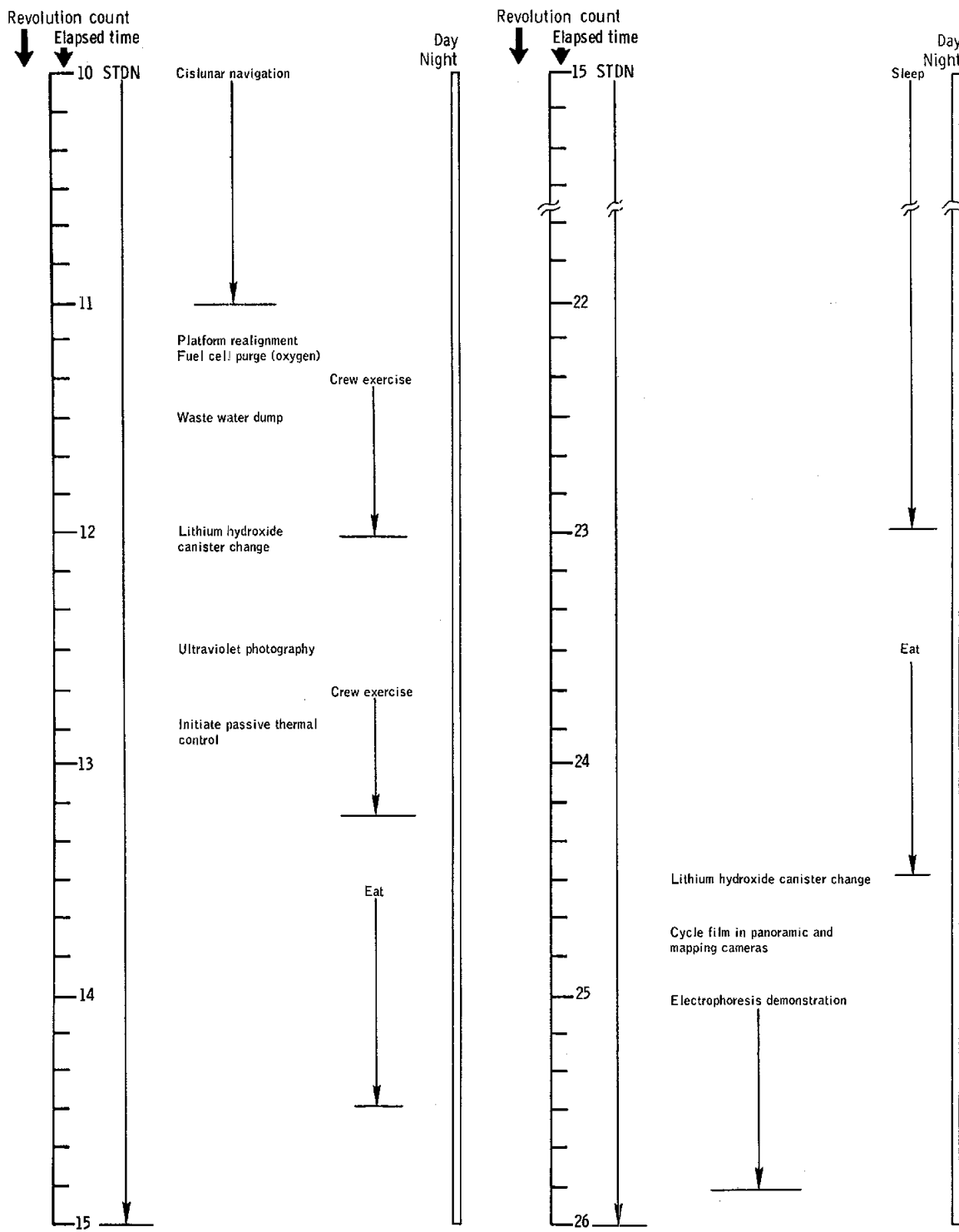
The first full day of solo operations went quite smoothly until the effects of rescheduling the plane change maneuver and retaining the lunar module after rendezvous began to surface. From this point on, the Command Module Pilot never had the full grasp of the "big picture". As the mission progressed, the flight crew was backed into a posture of only responding to the Mission Control Center requests, and had the disturbing sensation of just hanging on.

Changing the lunar module jettison time resulted in getting the crew to sleep at the same time as the original timeline and created quite a bit of confusion the following day because of the interdependency of spacecraft stowage, timeline execution and experiment performance.

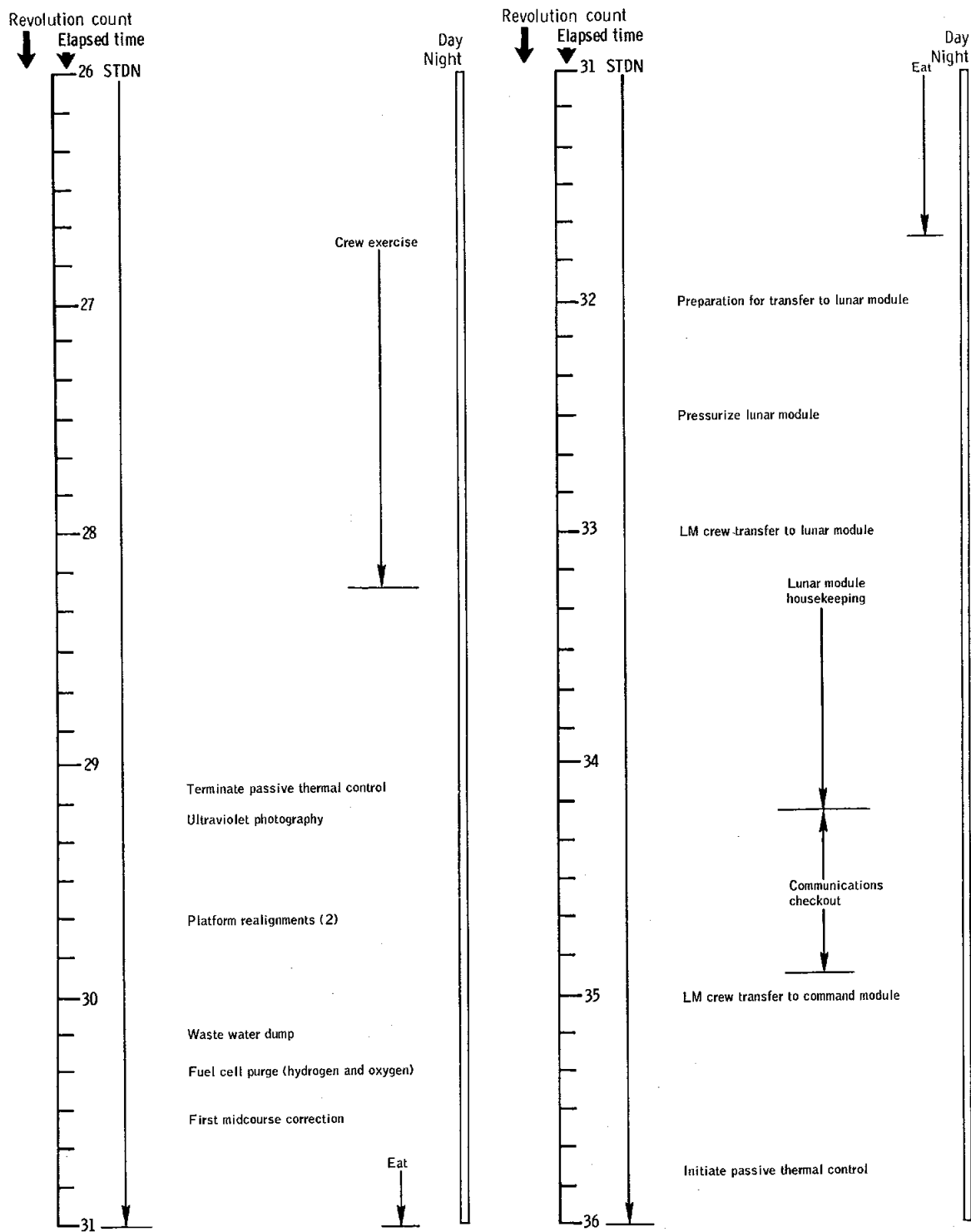


(a) 0 to 10 hours.

Figure 9-1.- Flight plan activities.



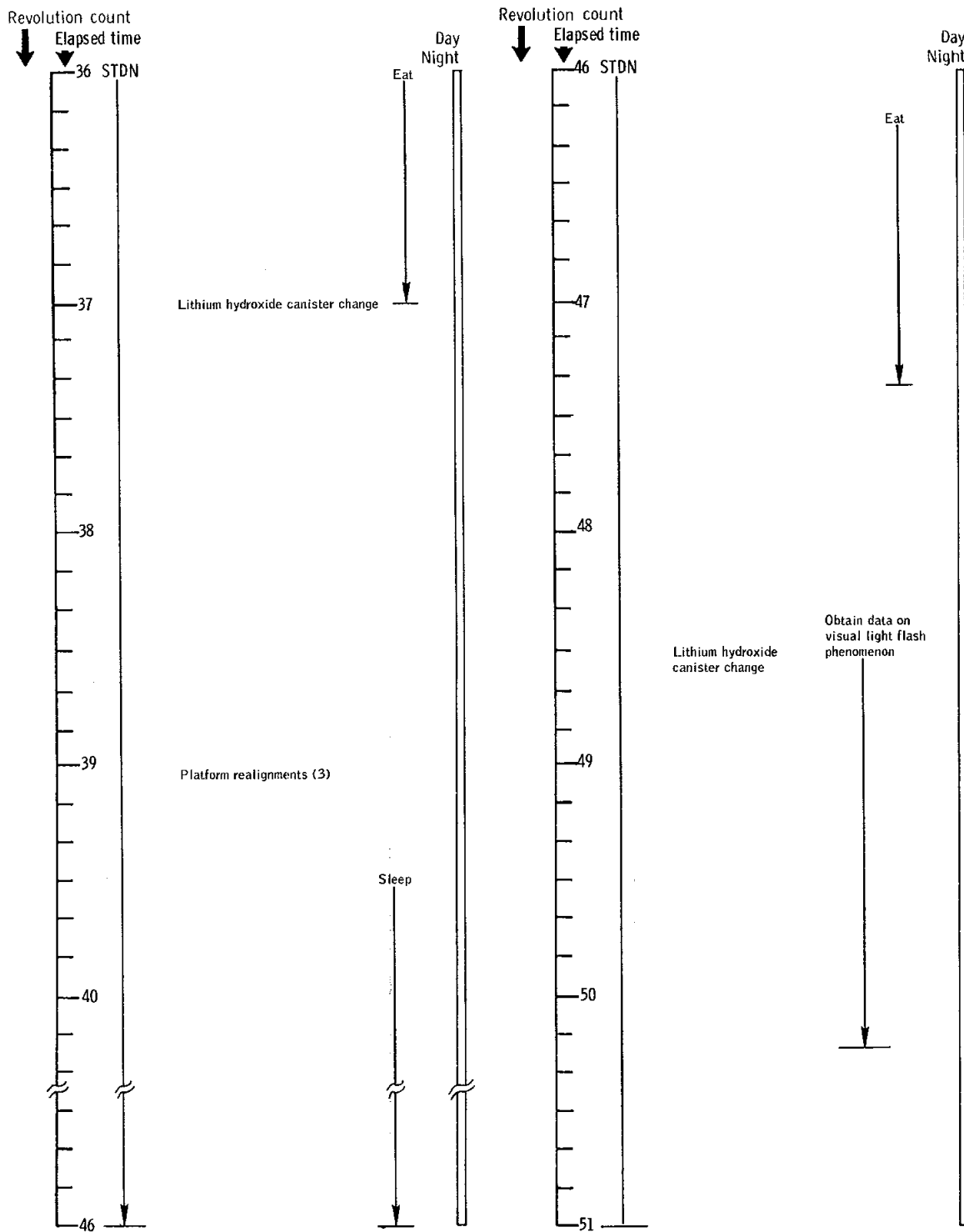
(b) 10 to 26 hours.  
Figure 9-1.- Continued.



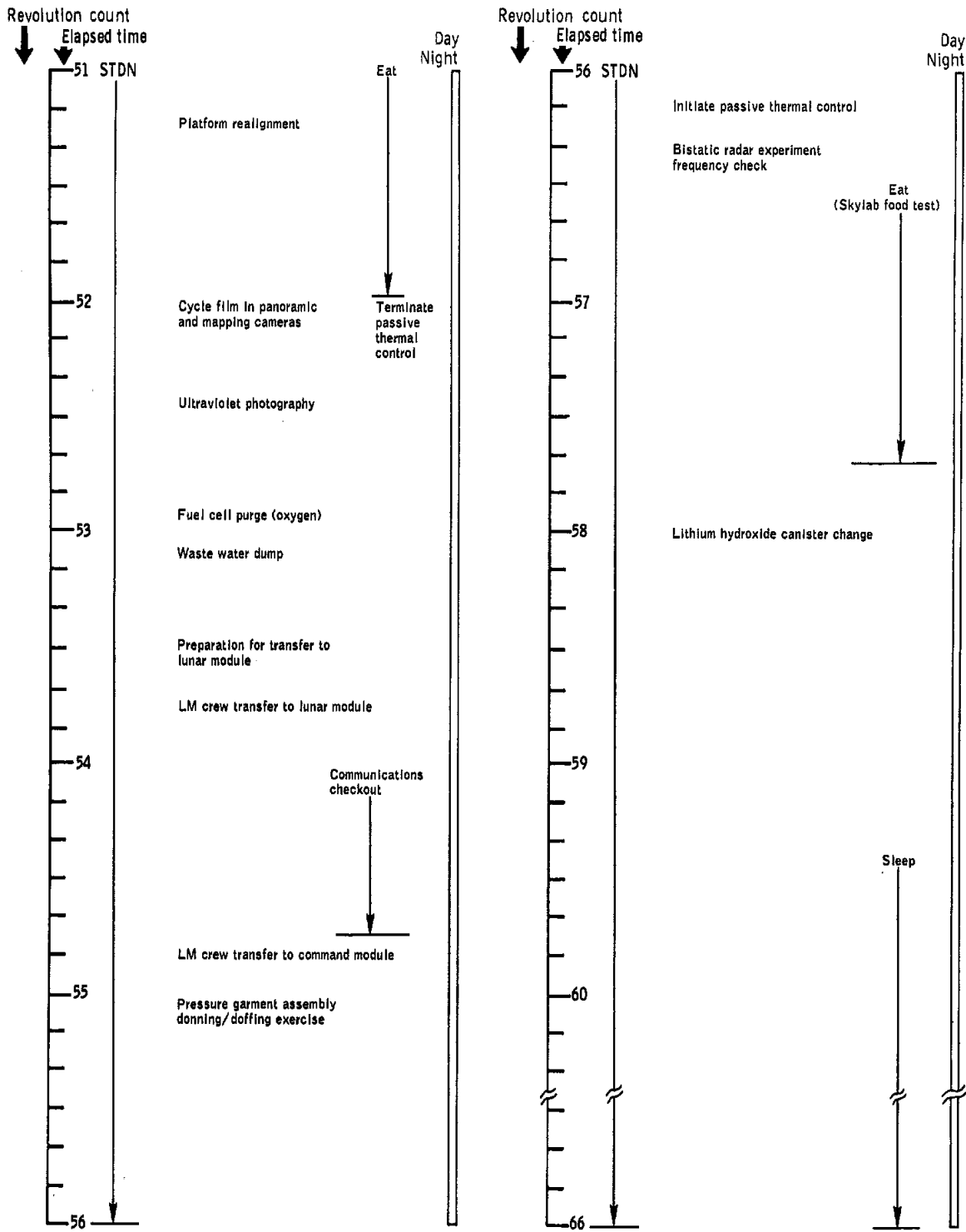
(c) 26 to 36 hours.

Figure 9-1.- Continued.

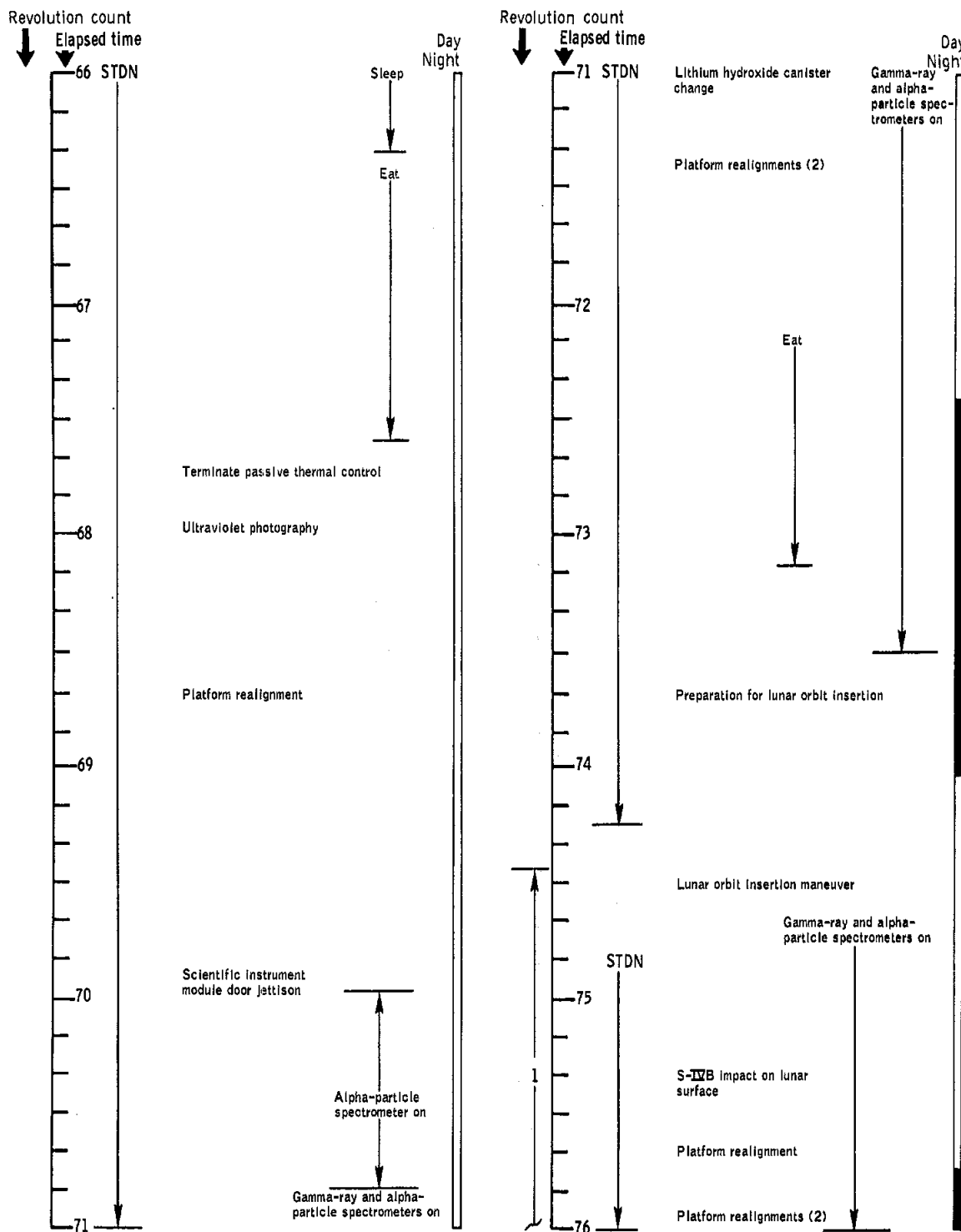




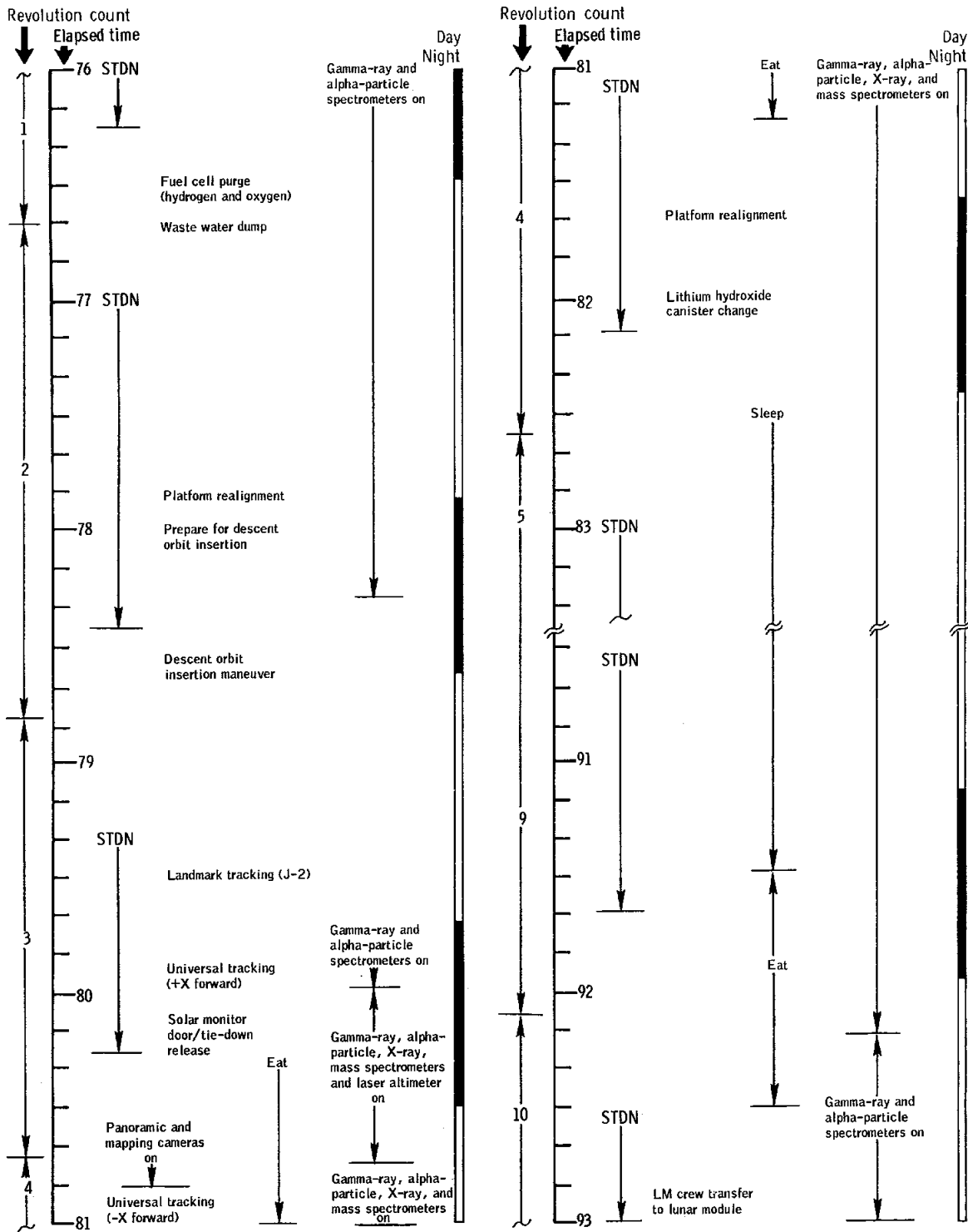
(d) 36 to 51 hours.  
Figure 9-1.- Continued.



(e) 51 to 66 hours.  
Figure 9-1.- Continued.

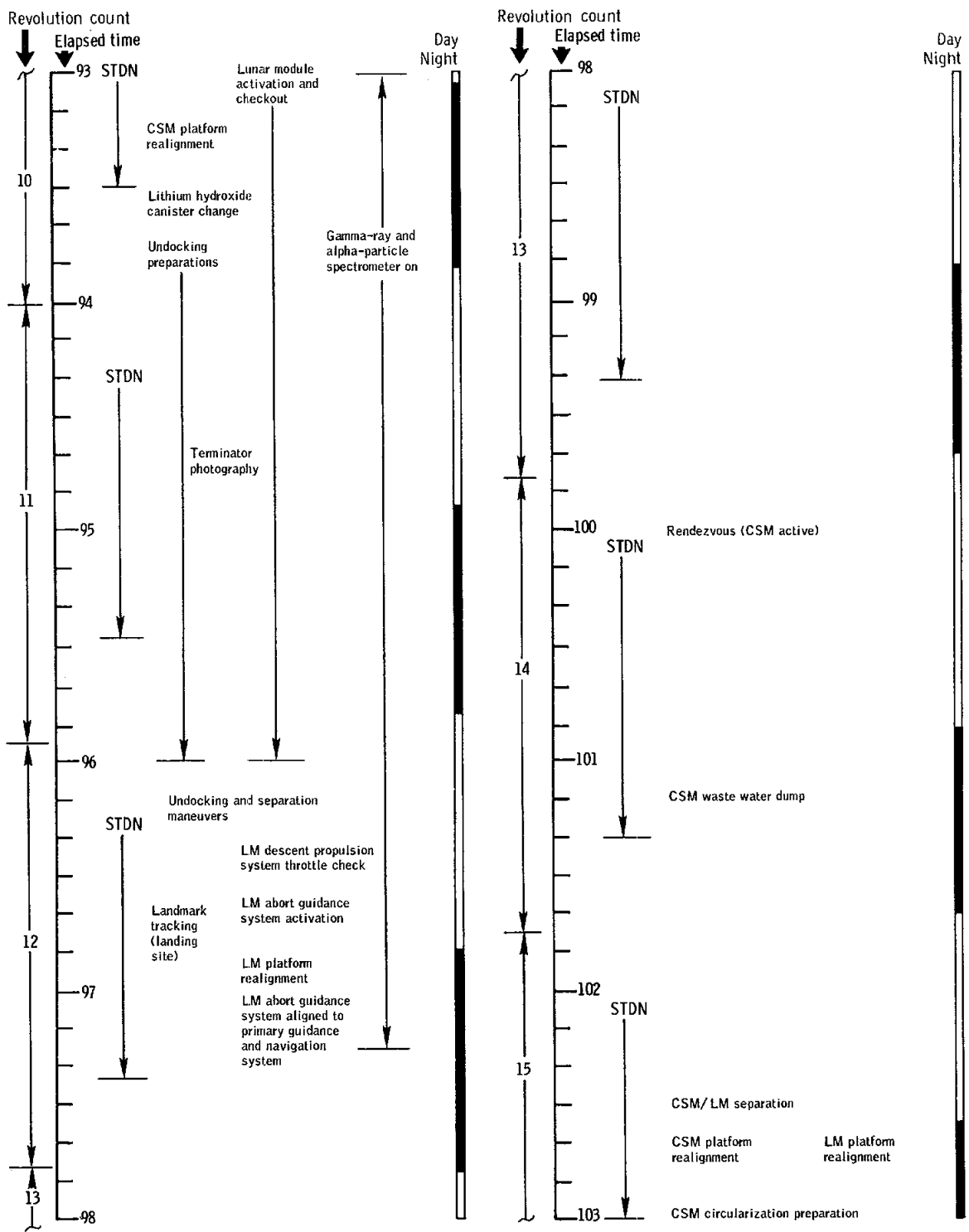


(f) 66 to 76 hours.  
Figure 9-1.- Continued.



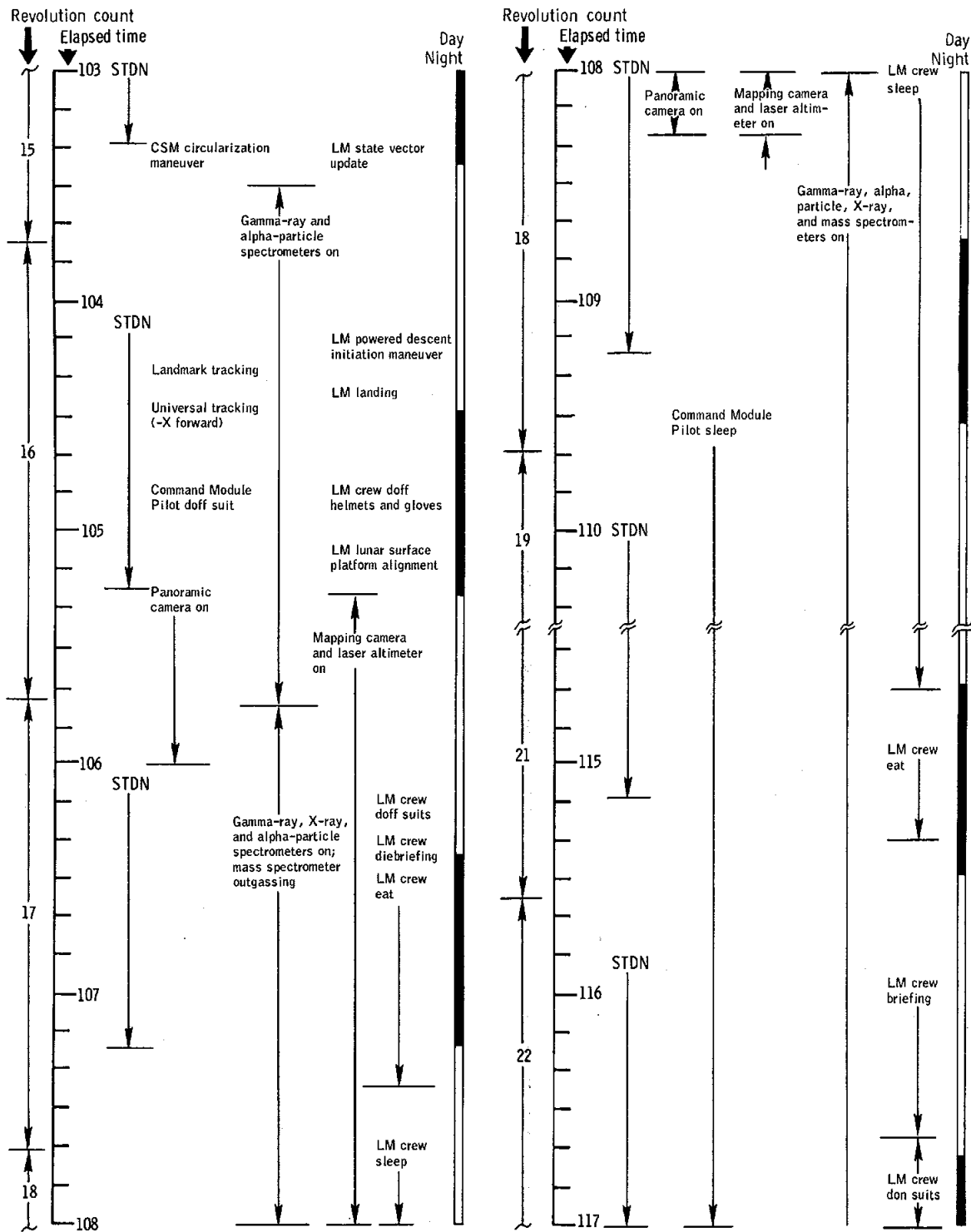
(g) 76 to 93 hours.

Figure 9-1.- Continued.

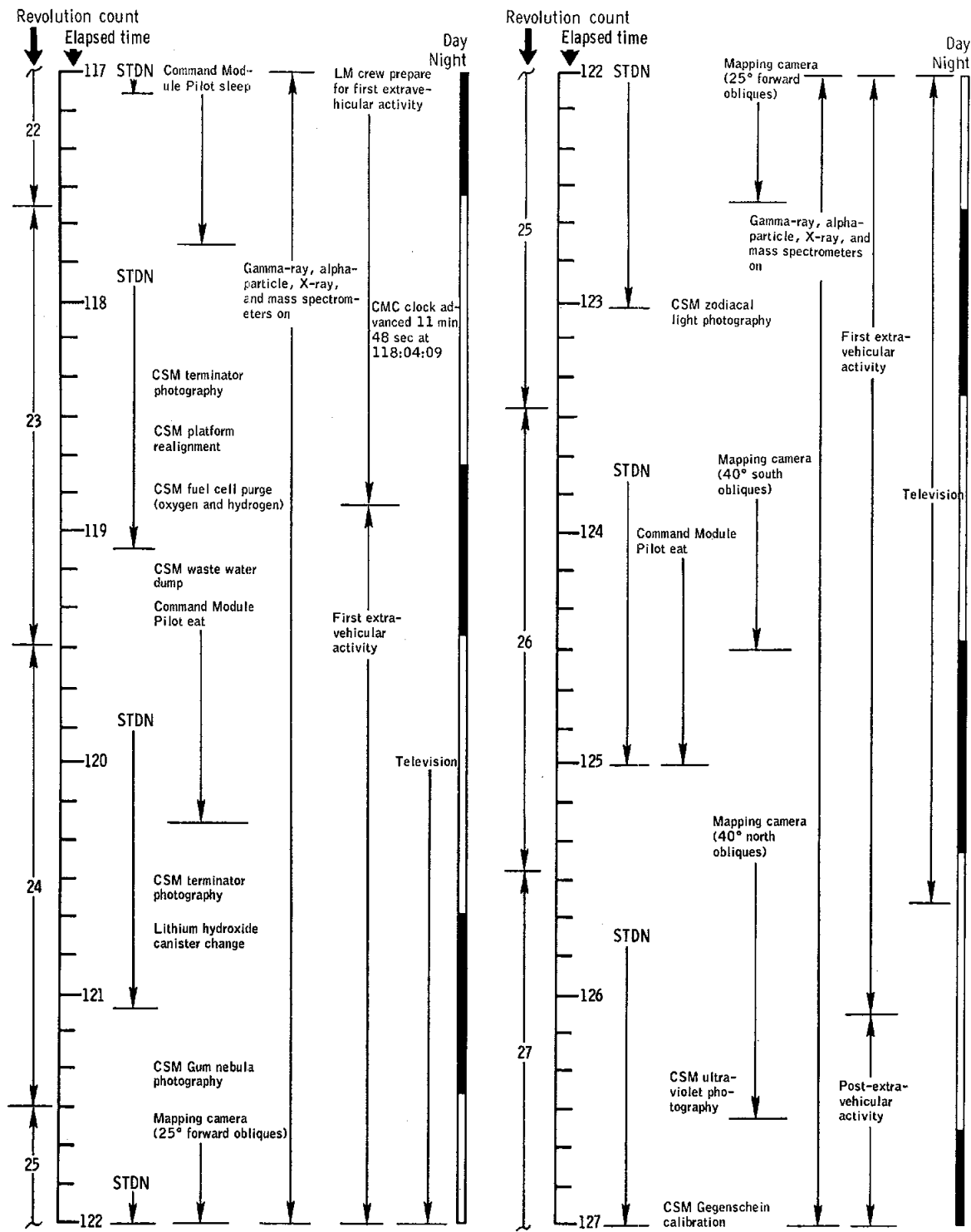


(h) 93 to 103 hours.

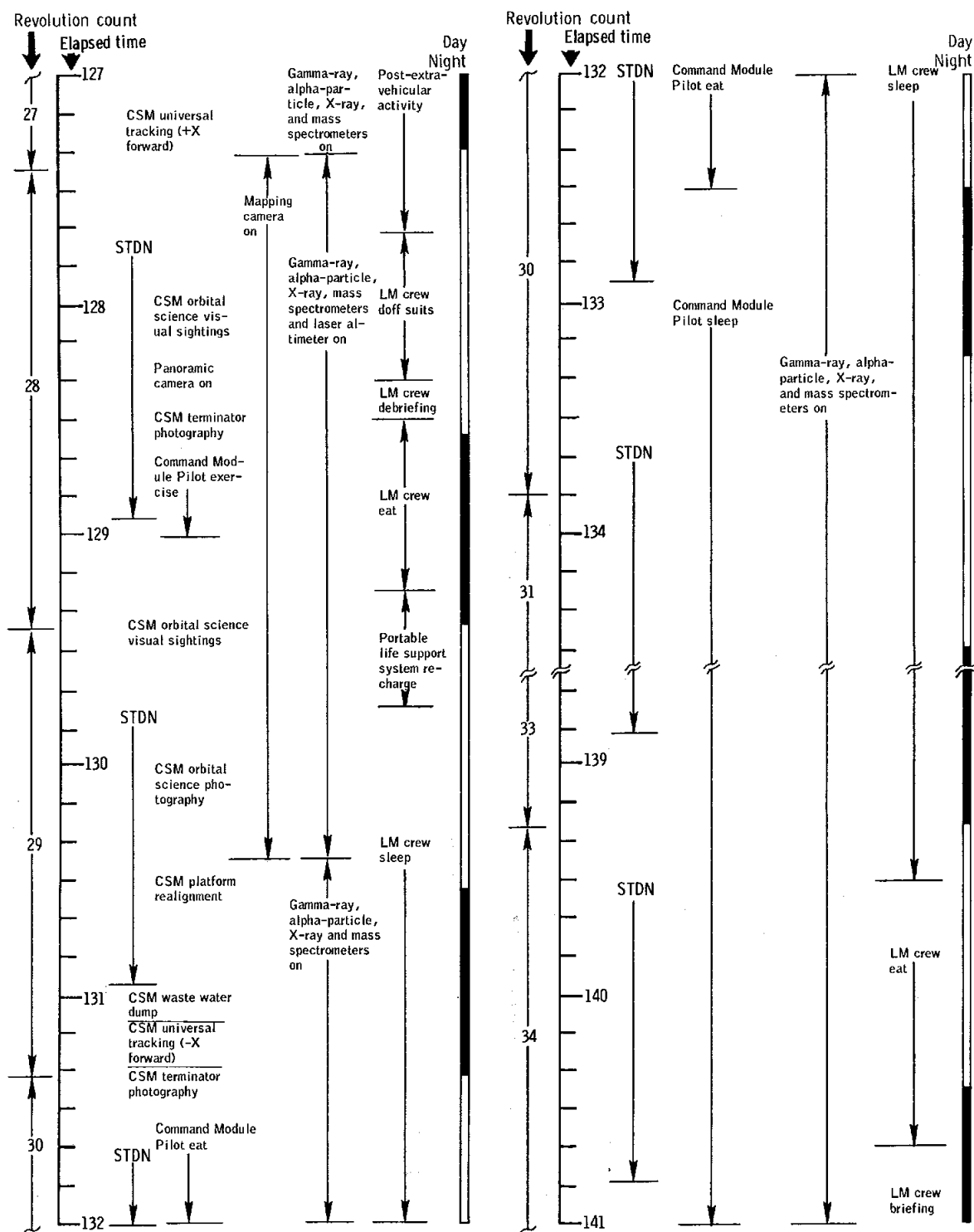
Figure 9-1.- Continued.



(1) 103 to 117 hours.  
Figure 9-1.- Continued.



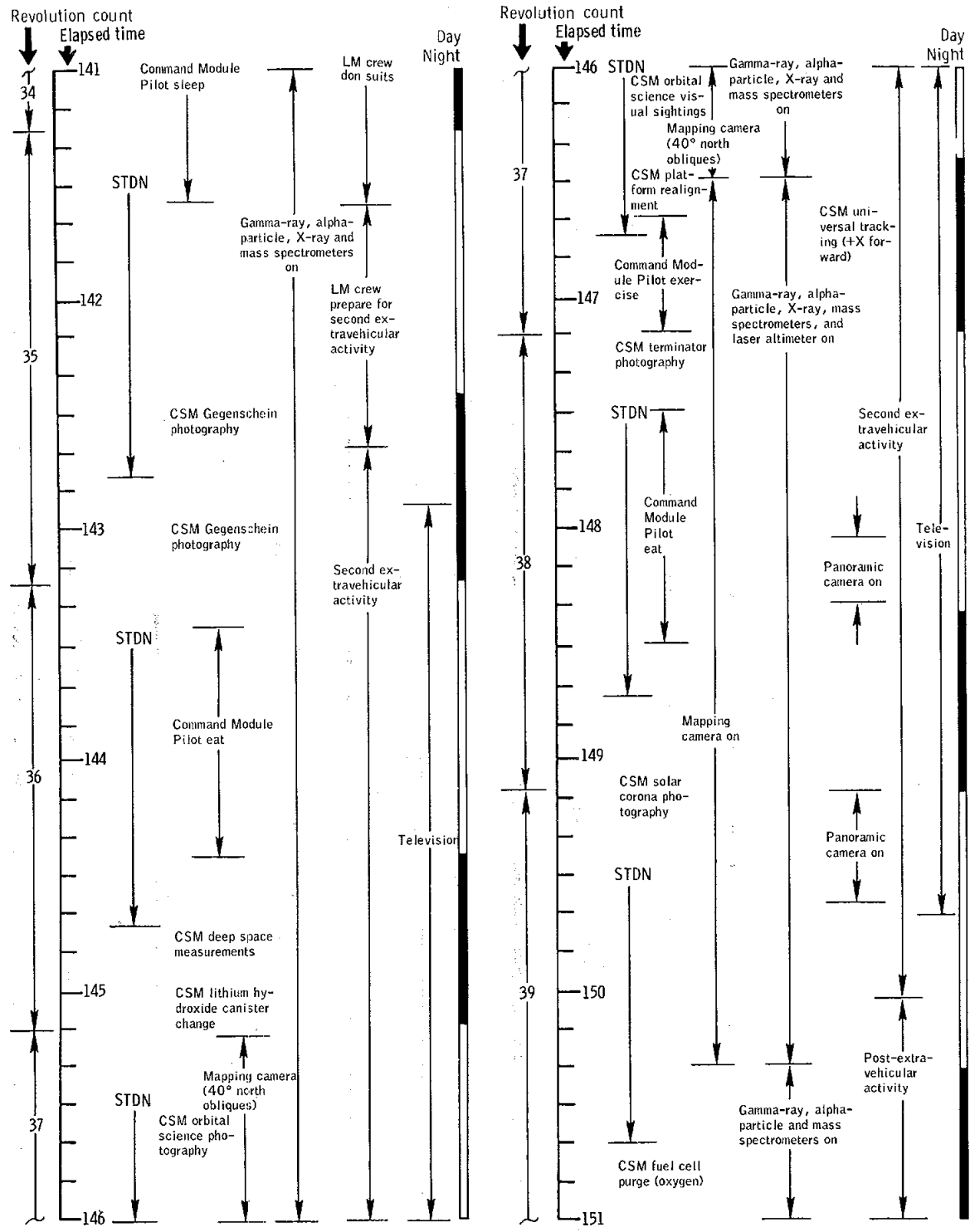
(j) 117 to 127 hours.  
 Figure 9-1.- Continued.



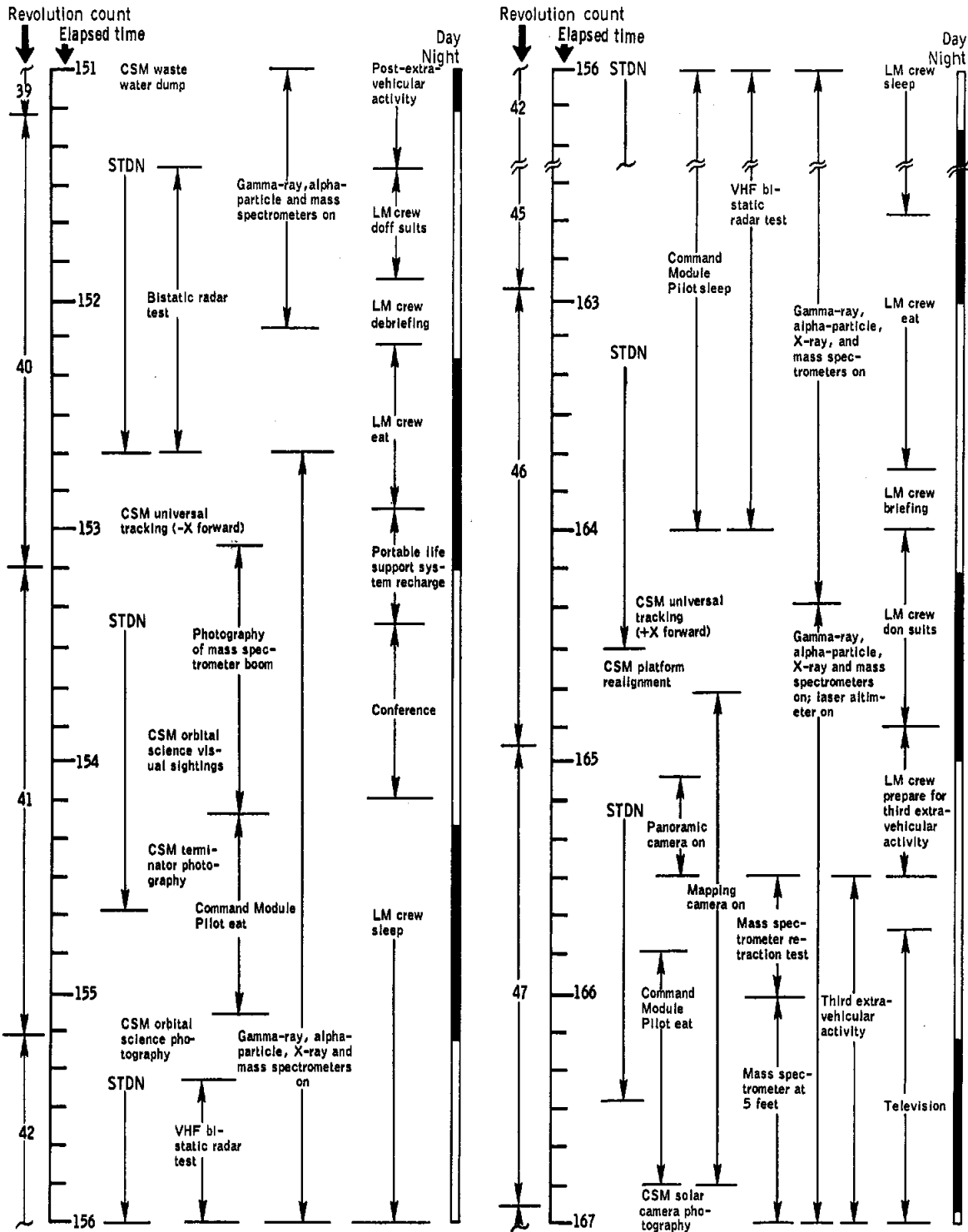
(k) 127 to 141 hours.

Figure 9-1.- Continued.

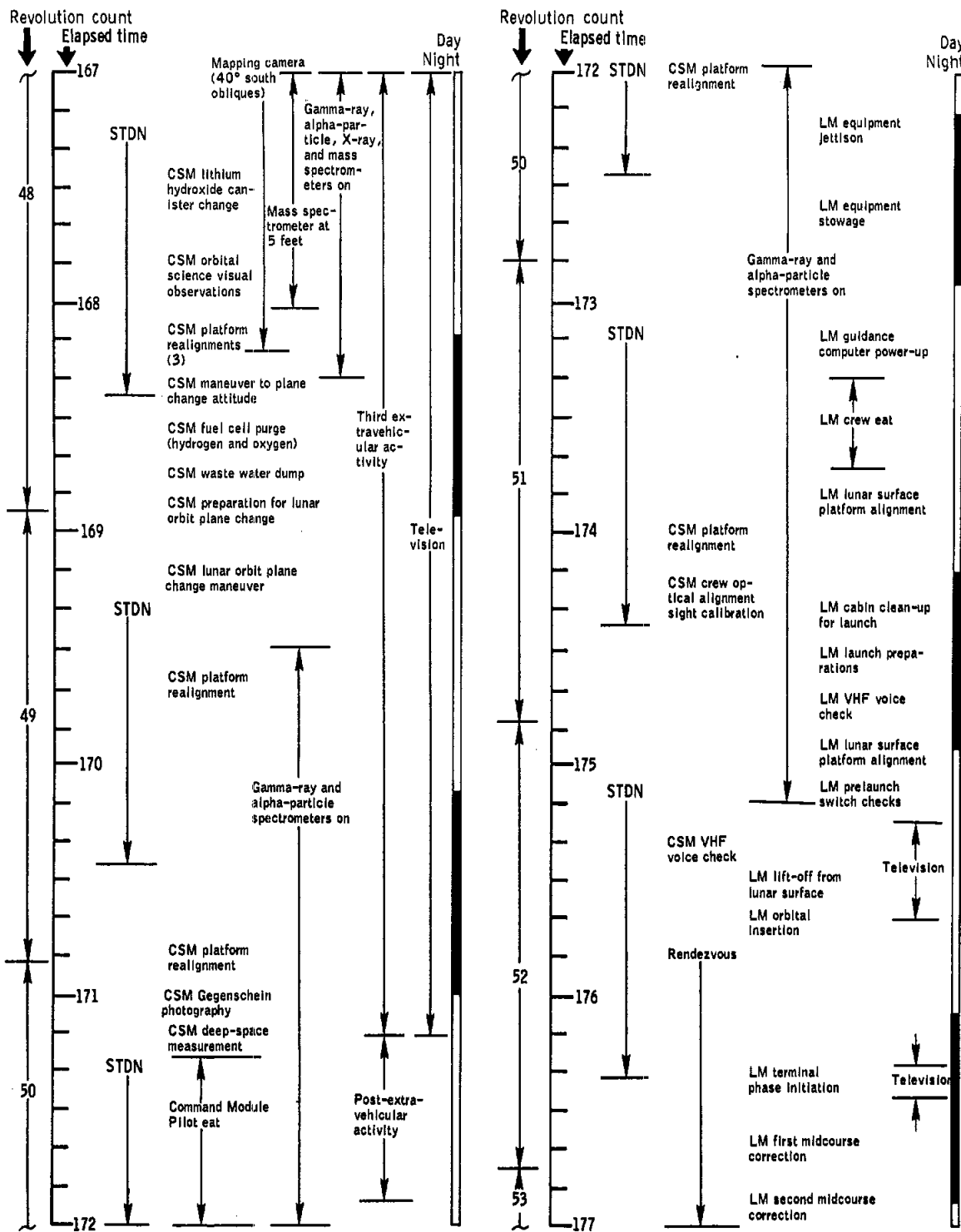




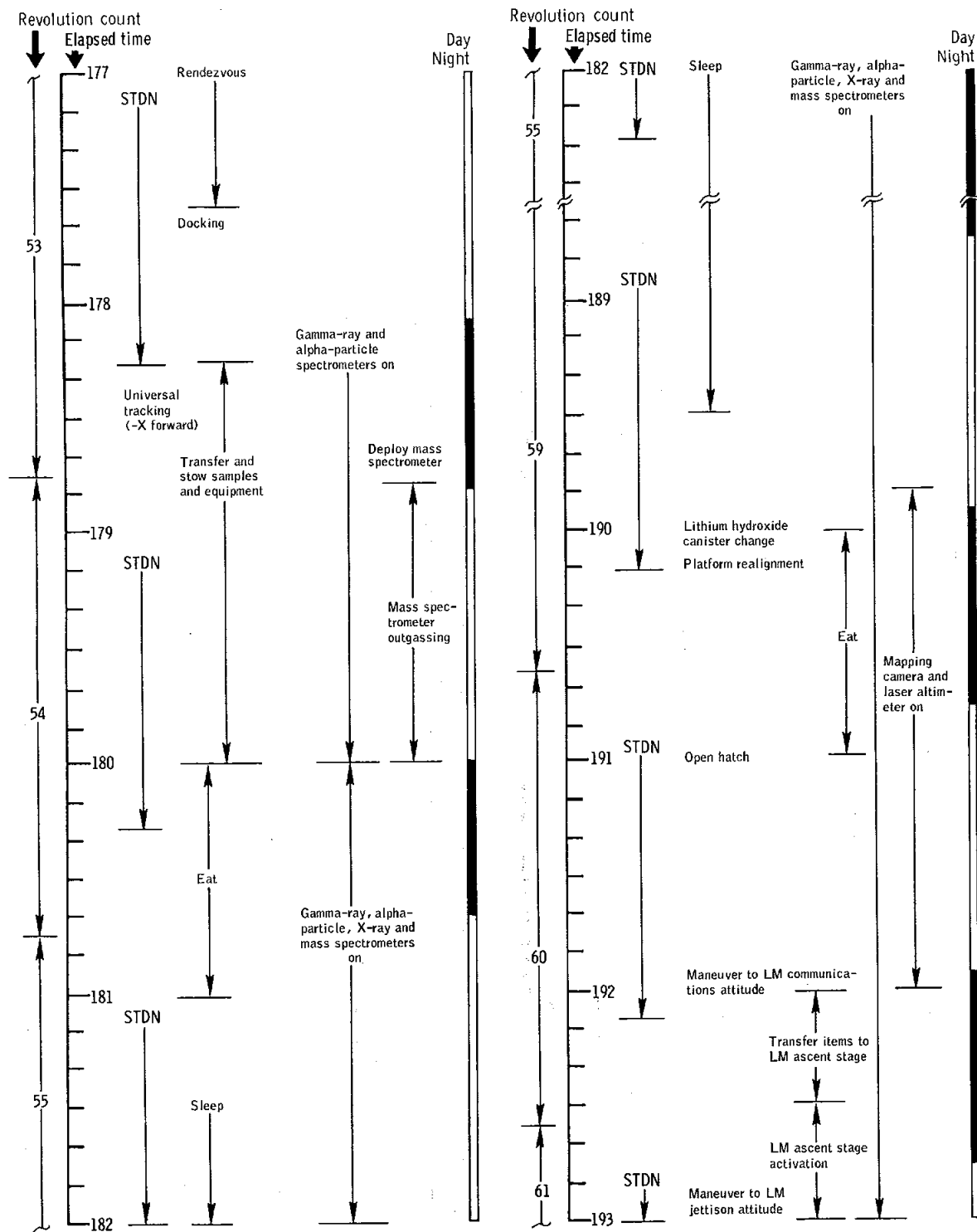
(1) 141 to 151 hours.  
Figure 9-1.- Continued.



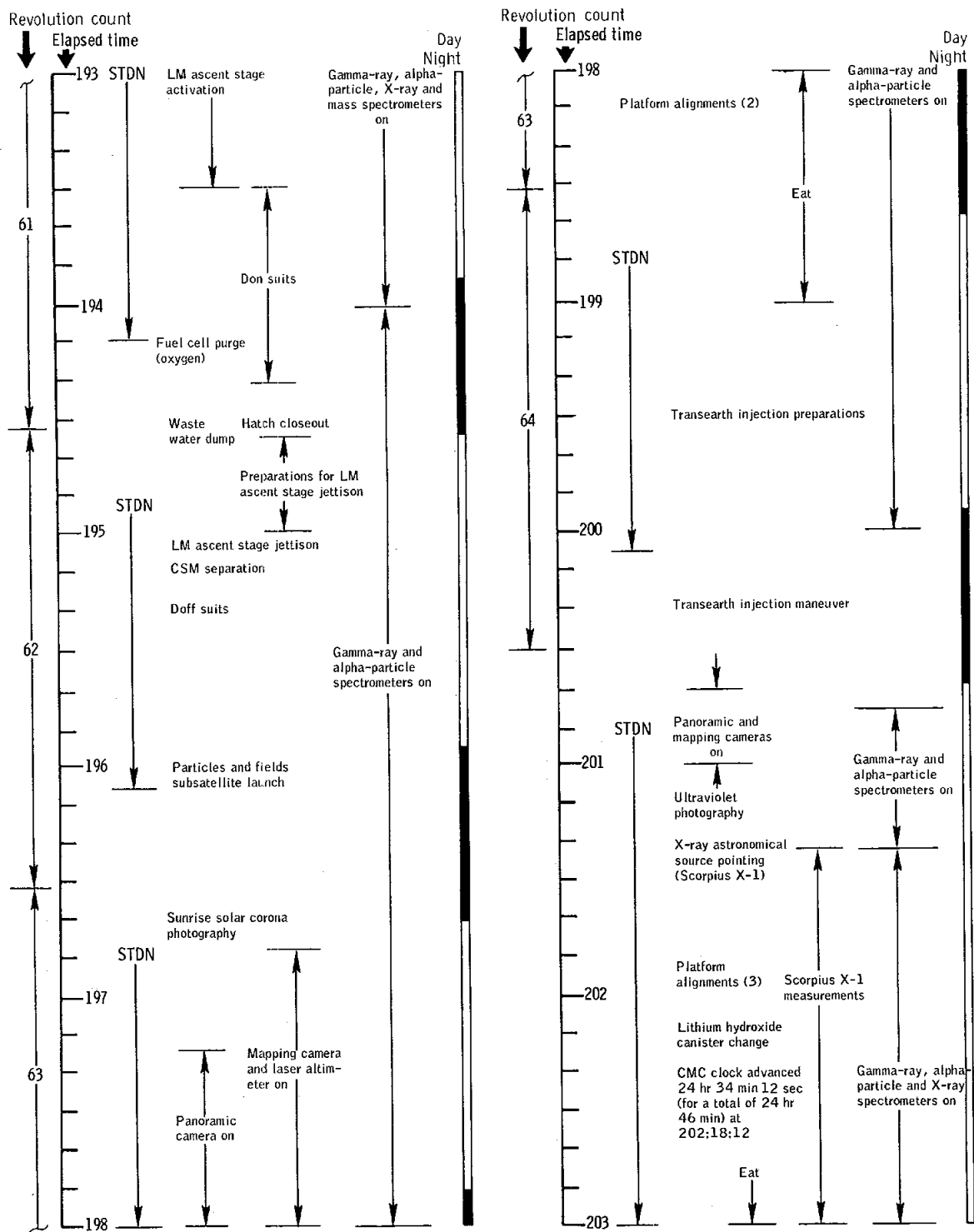
(m) 151 to 167 hours.  
 Figure 9-1.- Continued.



(n) 167 to 177 hours.  
Figure 9-1.- Continued.

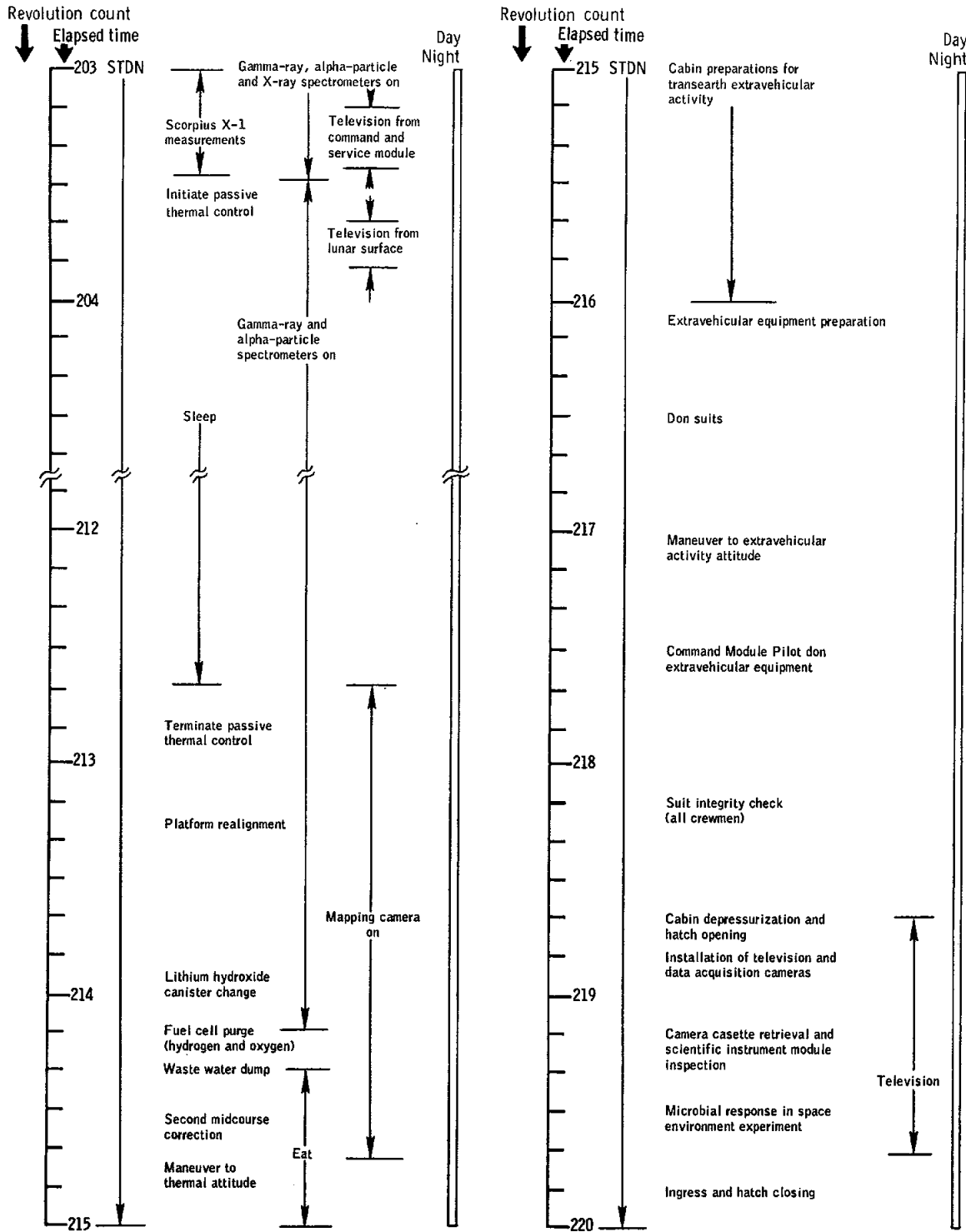


(o) 177 to 193 hours.  
 Figure 9-1.- Continued.

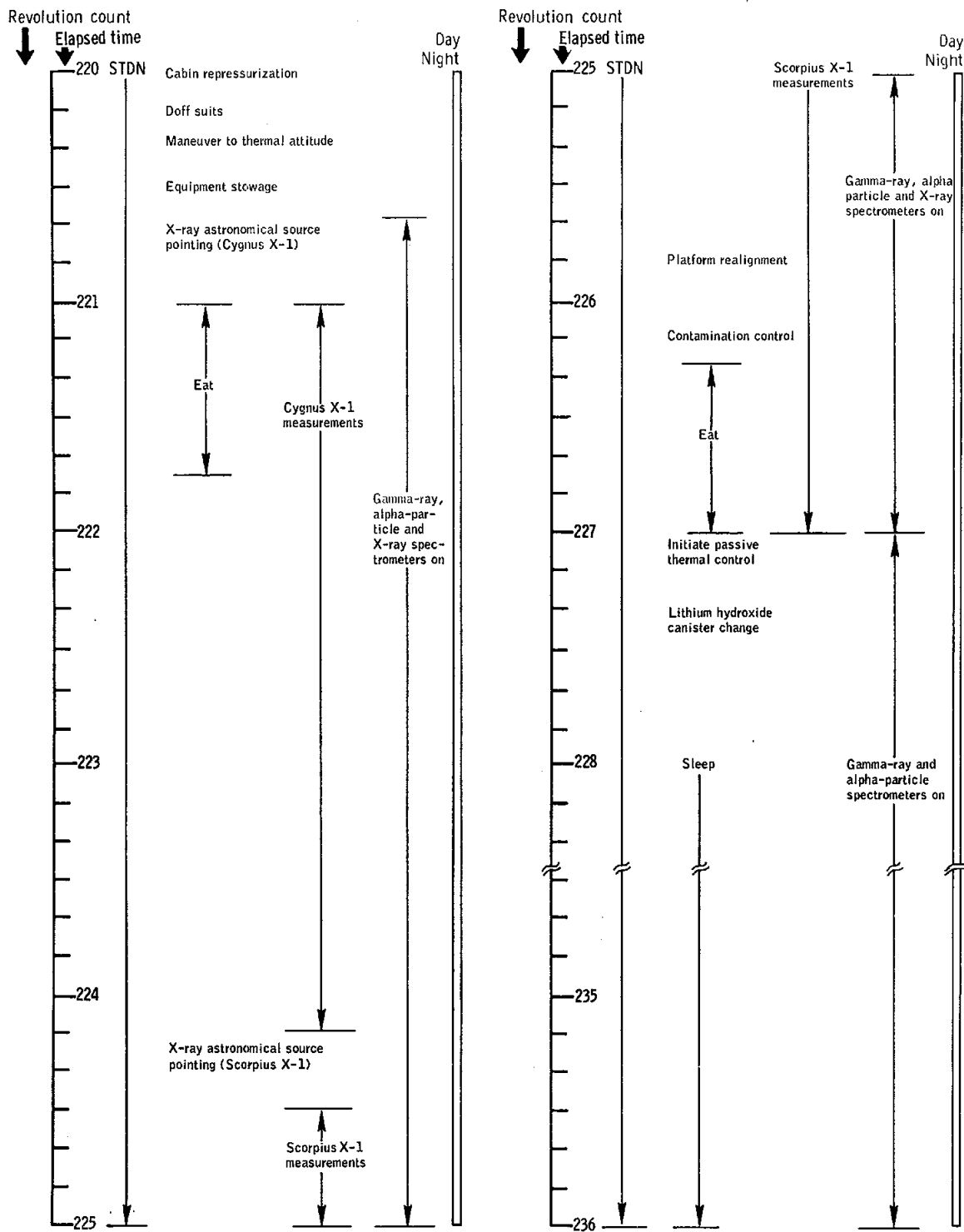


(p) 193 to 203 hours.

Figure 9-1.- Continued.

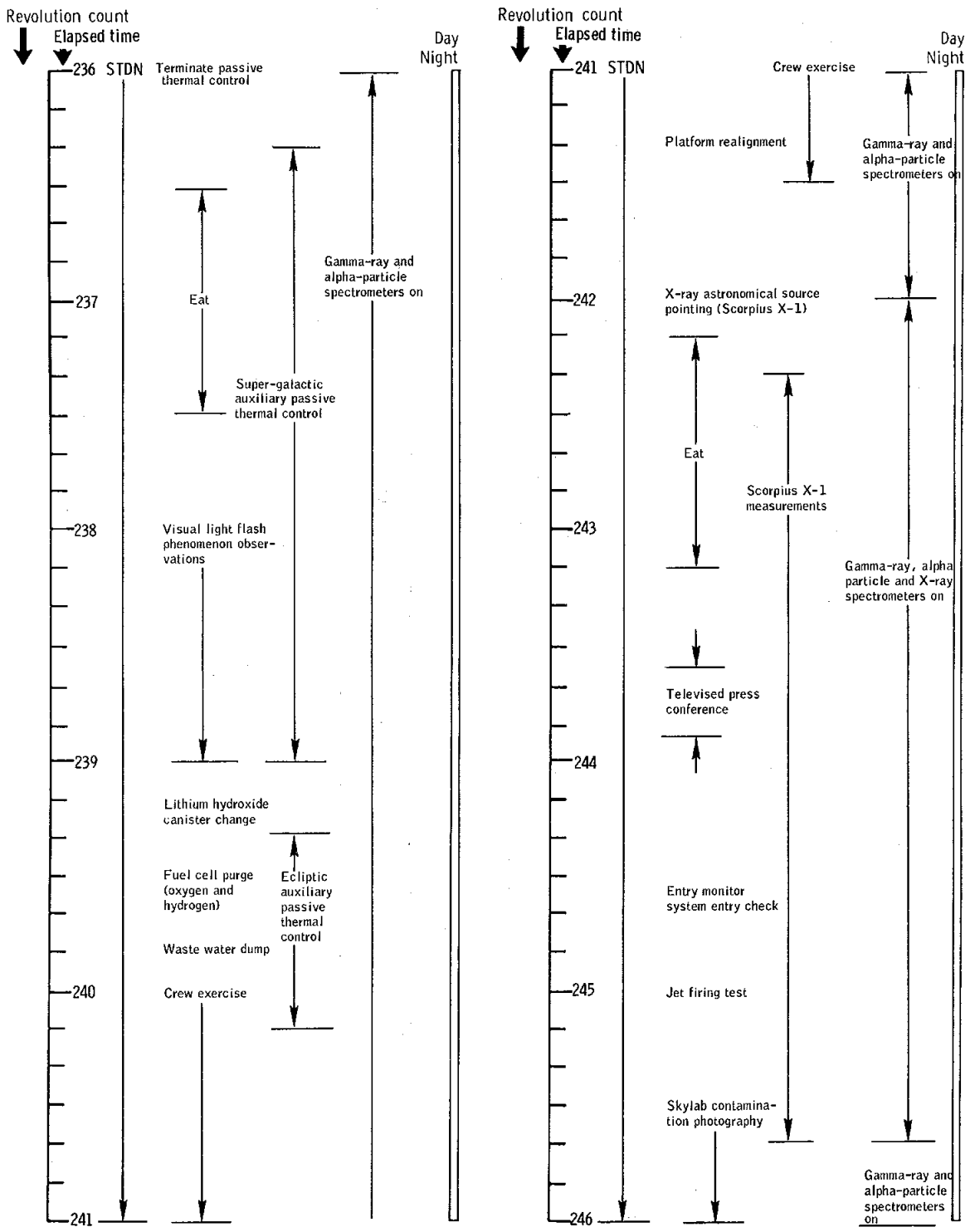


(q) 203 to 220 hours.  
Figure 9-1.- Continued.



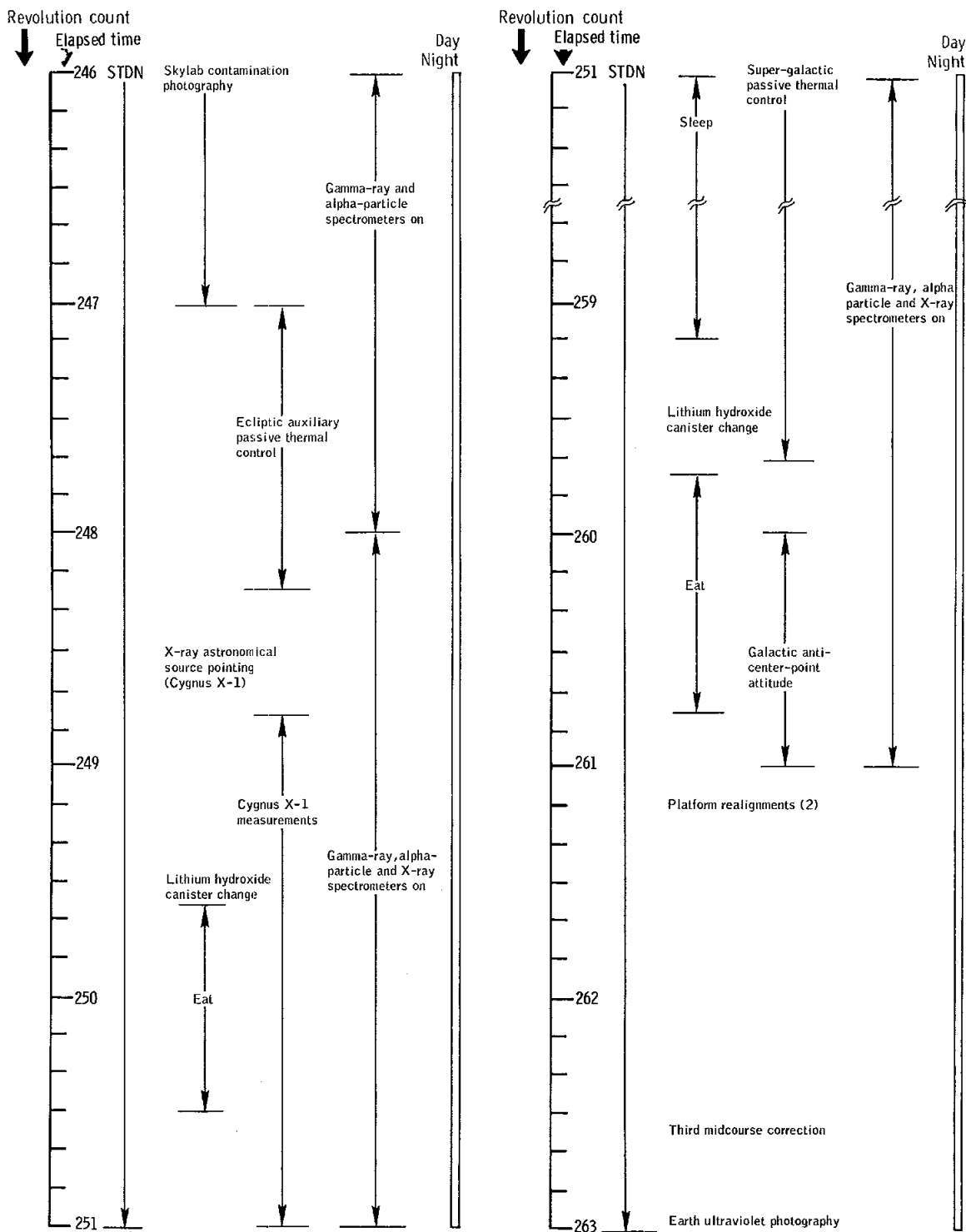
(r) 220 to 236 hours

Figure 9-1.- Continued.



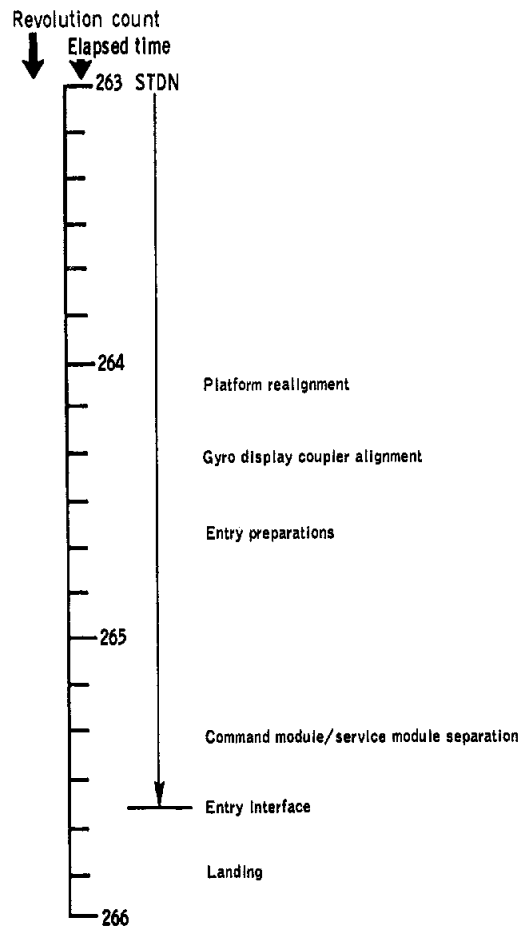
(s) 236 to 246 hours.  
 Figure 9-1.- Continued.





(t) 246 to 263 hours.

Figure 9-1.- Continued.



(u) 263 to 266 hours.  
Figure 9-1.- Concluded.

## 10.0 BIOMEDICAL EVALUATION

This section summarizes the medical findings based on a preliminary analysis of the biomedical data. A total of 797 1/2 man-hours of space-flight experience was accumulated during the 11-day mission. The flight crew health stabilization program implemented on this mission was similar to that used for Apollo 15, except for the addition of a control group. The crewmen remained in good health throughout the mission.

### 10.1 BIOMEDICAL INSTRUMENTATION AND PHYSIOLOGICAL DATA

The quality of the physiological data obtained throughout the mission was good. The infrequent degradations of physiological data were caused by loose biosensors, with restoration of good data upon reapplication of the sensors. Physiological data losses resulting from trapped air under the electrodes were not experienced on this mission because the electrodes were modified with small vents.

All physiological measurements were within expected ranges. The crew heart rates during launch ranged from 77 to 125 beats per minute. The heart rates of the Commander, a veteran of three space flights, were generally lower than those of the other two crewmen, who had not flown previously. The Commander's heart rates ranged from 70 to 104 beats per minute during lunar descent and from 80 to 105 beats per minute during lunar ascent (figs. 10-1 and 10-2). The metabolic rates of the Commander and Lunar Module Pilot during the three lunar surface extravehicular periods were correlated with the heart rates (figs. 10-3 through 10-5). A summary of the average metabolic rates and averaged heart rates for the four periods of extravehicular activity is presented in table 10-I.

The Command Module Pilot's relatively high heart rate (table 10-I) during the transearth extravehicular activity was attributed to excitement rather than high workloads or cardiovascular deconditioning. Post-flight exercise tolerance tests on the Command Module Pilot showed only minor cardiovascular deconditioning and verified that the high heart rate was caused by excitement rather than cardiovascular conditioning.

Table 10-II shows that the prelaunch metabolic rate predictions for lunar surface activities were slightly lower than the actual values measured. The metabolic rates were higher for the Lunar Module Pilot.

TABLE 10-I.- AVERAGE HEART AND METABOLIC RATES  
DURING EXTRAVEHICULAR ACTIVITIES

Activity	Heart rate, beats/min	Metabolic Rate, Btu/hr
First extravehicular activity		
Commander	84	872
Lunar Module Pilot	101	1013
Second extravehicular activity		
Commander	84	784
Lunar Module Pilot	84	827
Third extravehicular activity		
Commander	86	815
Lunar Module Pilot	87	825
Transearch extravehicular activity		
Commander	(a)	(a)
Lunar Module Pilot	(a)	(a)
Command Module Pilot	120	<2200

<sup>a</sup>No data

TABLE 10.II.- ACTUAL OBSERVED METABOLIC RATES (BTU/HR)  
COMPARED WITH PREDICTED

Lunar surface activity	Metabolic rates, Btu/hr					
	Commander		Lunar Module Pilot		Both crewmen	
	Actual	Premission prediction	Actual	Premission prediction	Actual	Premission prediction
Lunar roving vehicle traverse	508	550	454	550	482	550
Geological station activities	889	950	982	950	936	950
Overhead	987	1050	1023	1050	1006	1050
Apollo lunar surface experiments package activities	823	950	1024	950	924	950
All activities combined	818	907	901	907	859	907

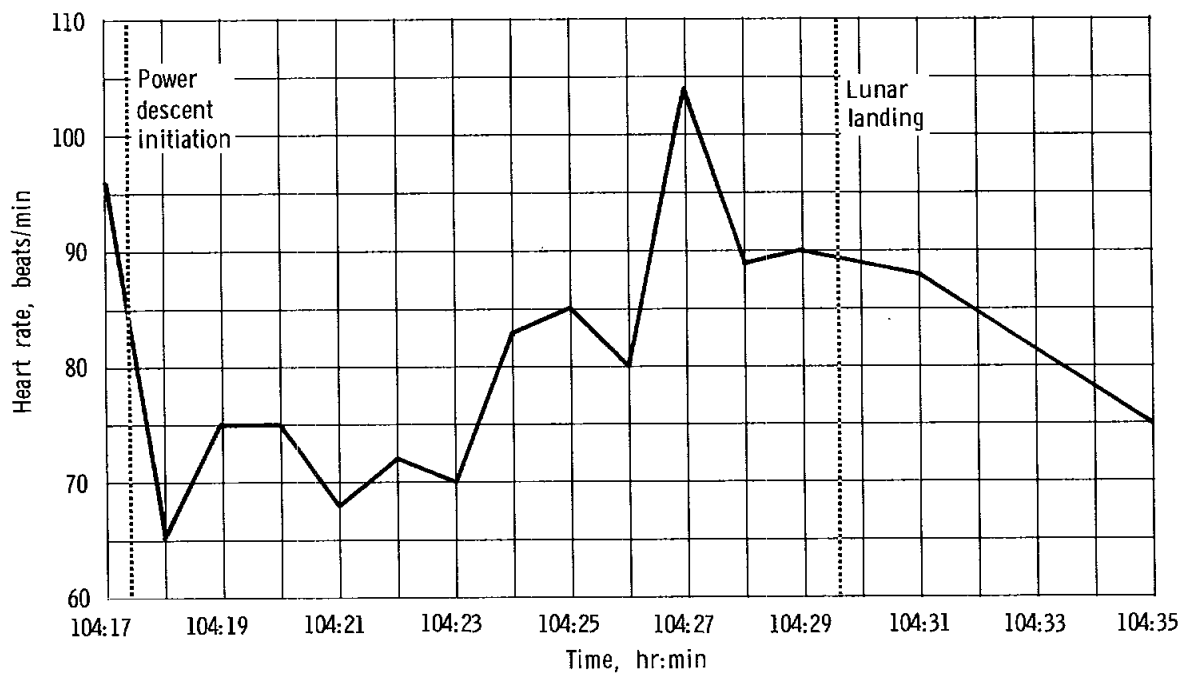


Figure 10-1.- Heart rates of Commander during lunar descent.

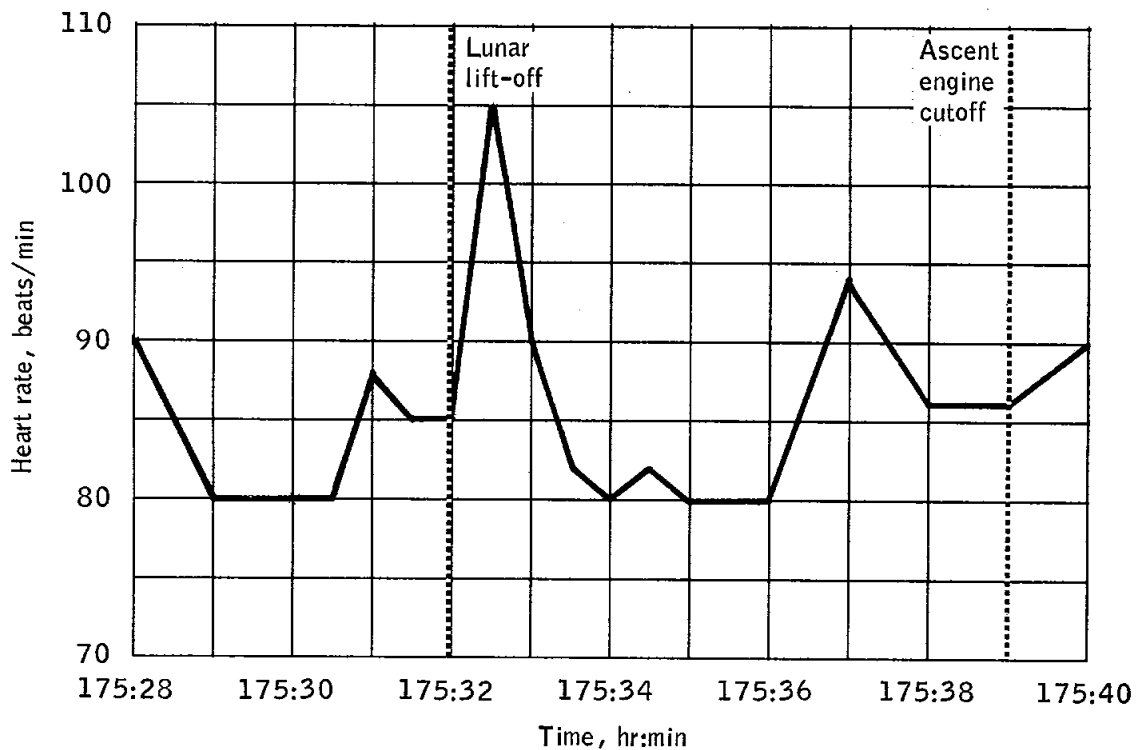


Figure 10-2.- Heart rates of Commander during lunar ascent.

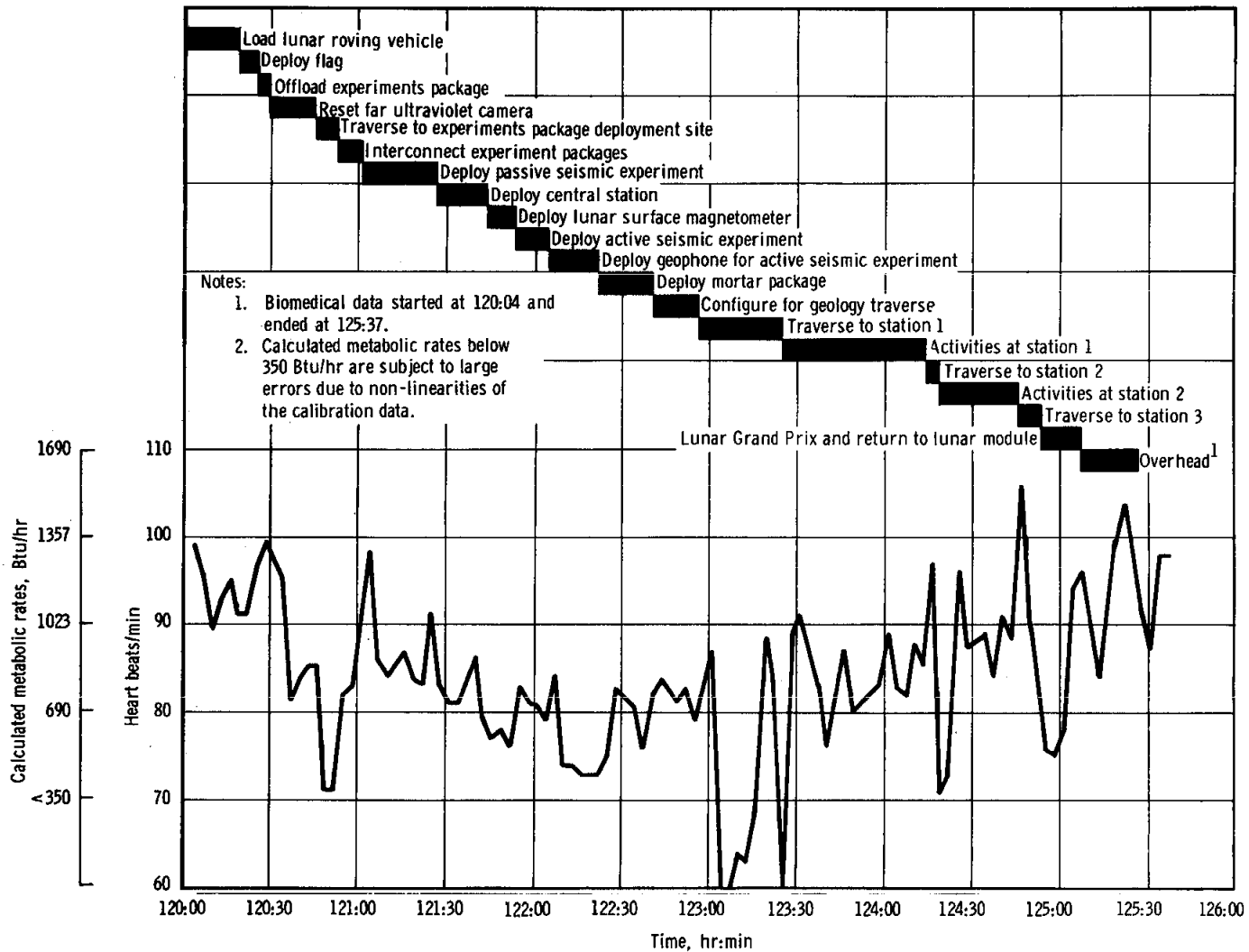
## 10.2 MEDICAL OBSERVATIONS

### 10.2.1 Adaptation to Weightlessness

Shortly after earth orbital insertion, two crewmen experienced the typical fullness-of-the-head sensation that has been reported by all previous flight crews. This sensation lasted for several hours. The Command Module Pilot did not experience this sensation. No redness of the face was observed by the crew and all three crewmen adapted rapidly to weightlessness and did not experience any giddiness, nausea, vomiting, or disorientation.

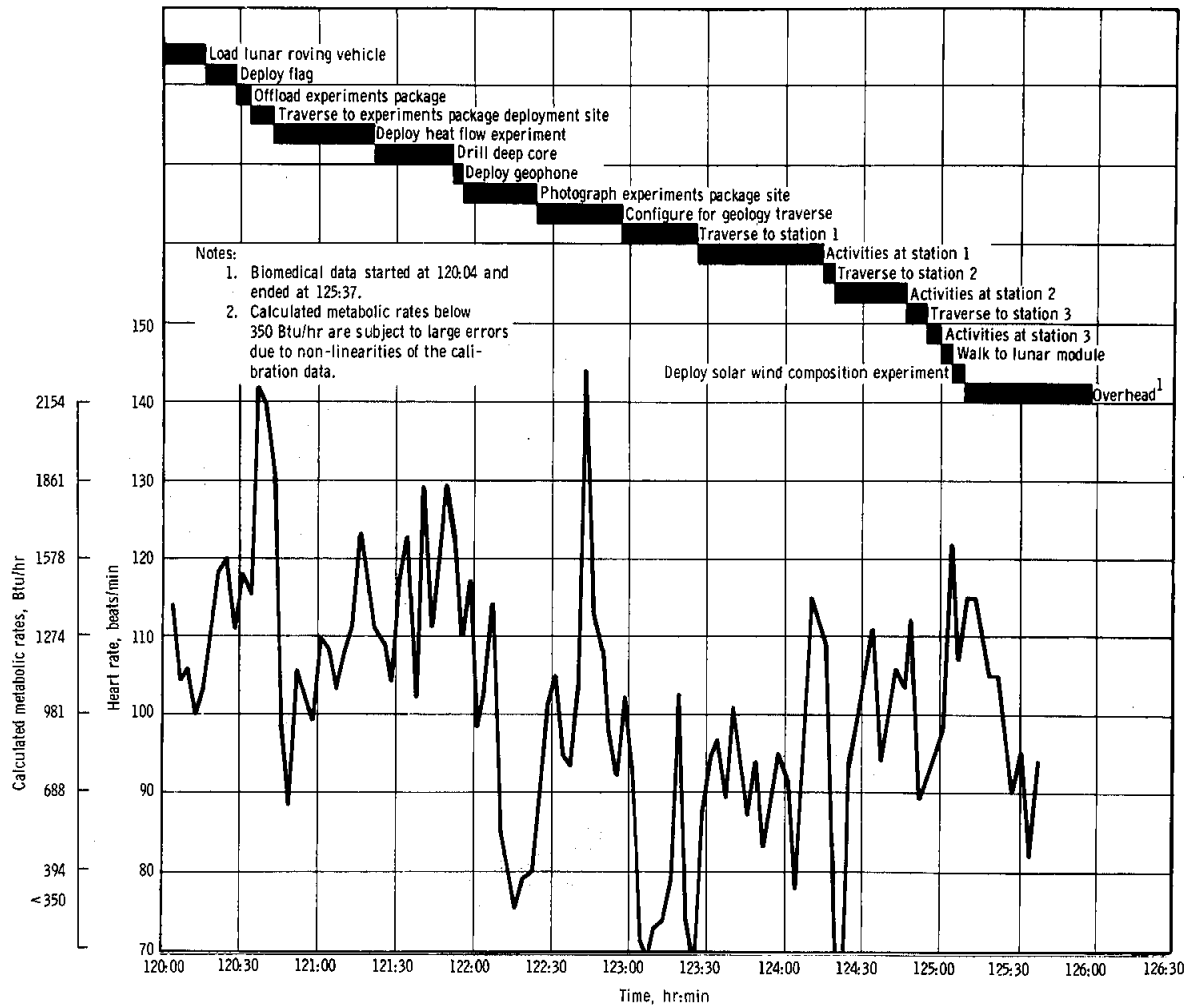
### 10.2.2 Medications

The Lunar Module Pilot used three 100-milligram Seconal capsules for sleep induction during the mission. One capsule was taken on the night prior to lunar descent and the other two capsules were used for the first and second lunar surface sleep periods, respectively. In the postflight



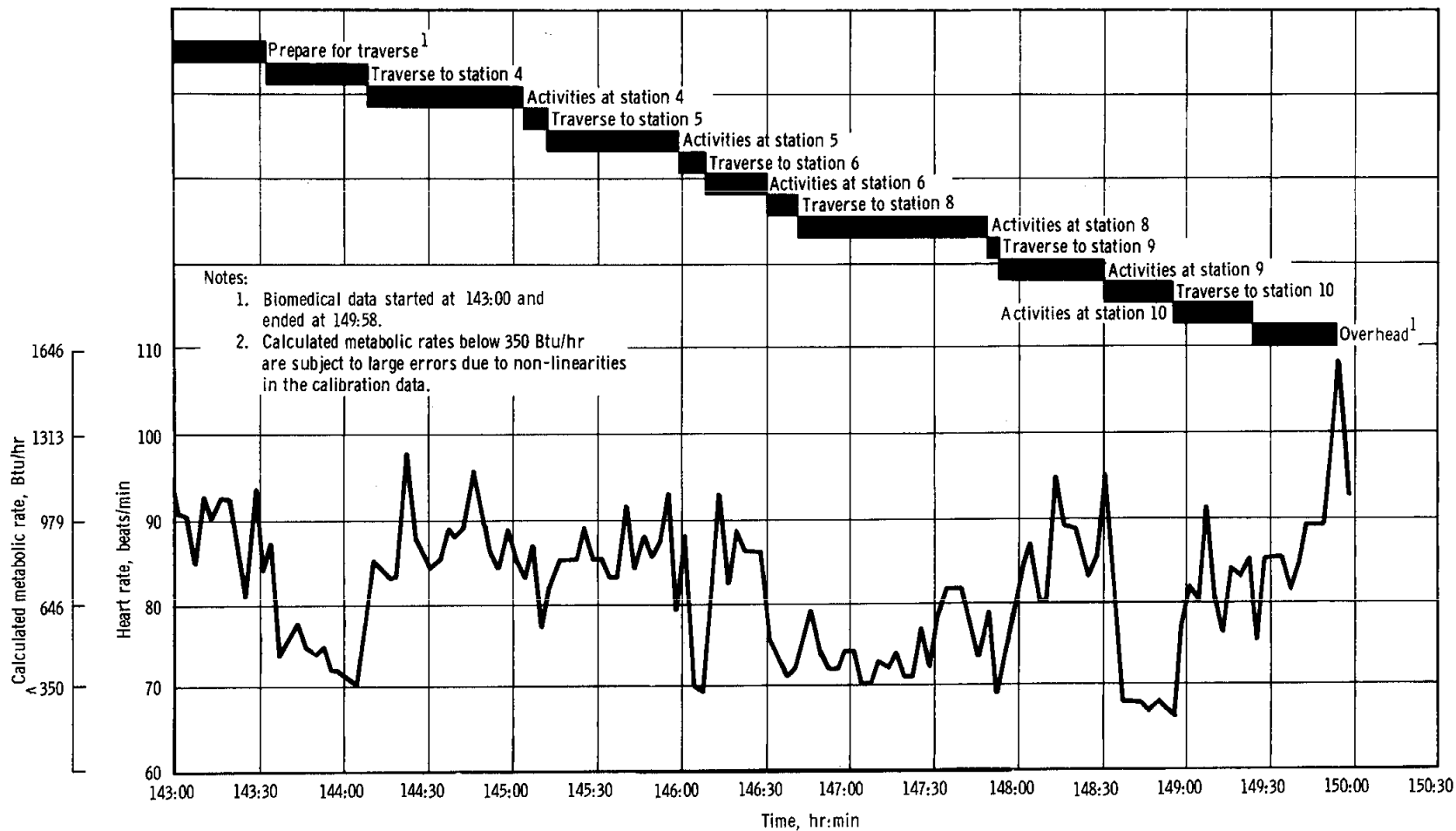
(a) Commander

Figure 10-3.- Heart rates and calculated metabolic rates during first extravehicular activity.



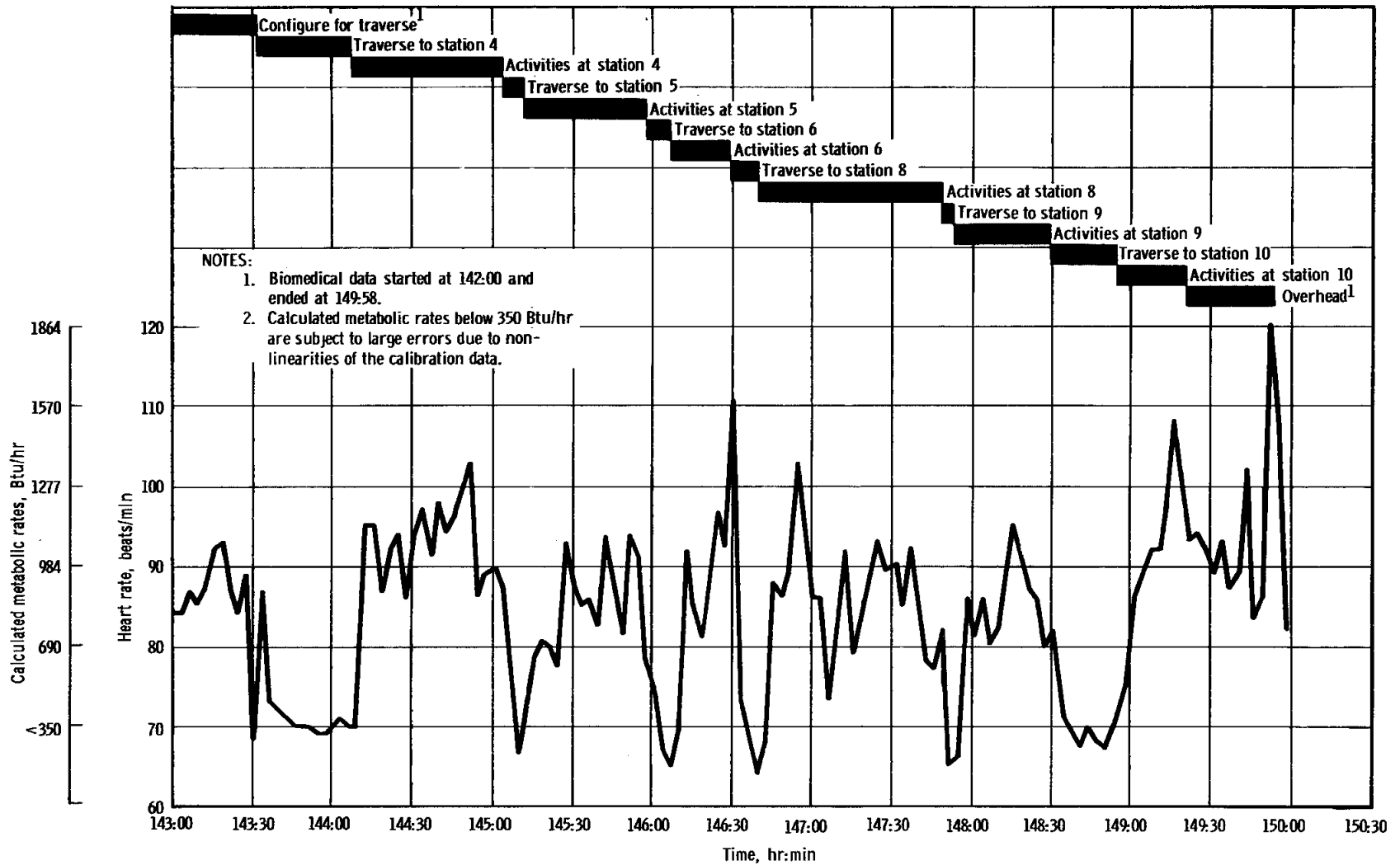
(b) Lunar Module Pilot  
 Figure 10-3.- Concluded





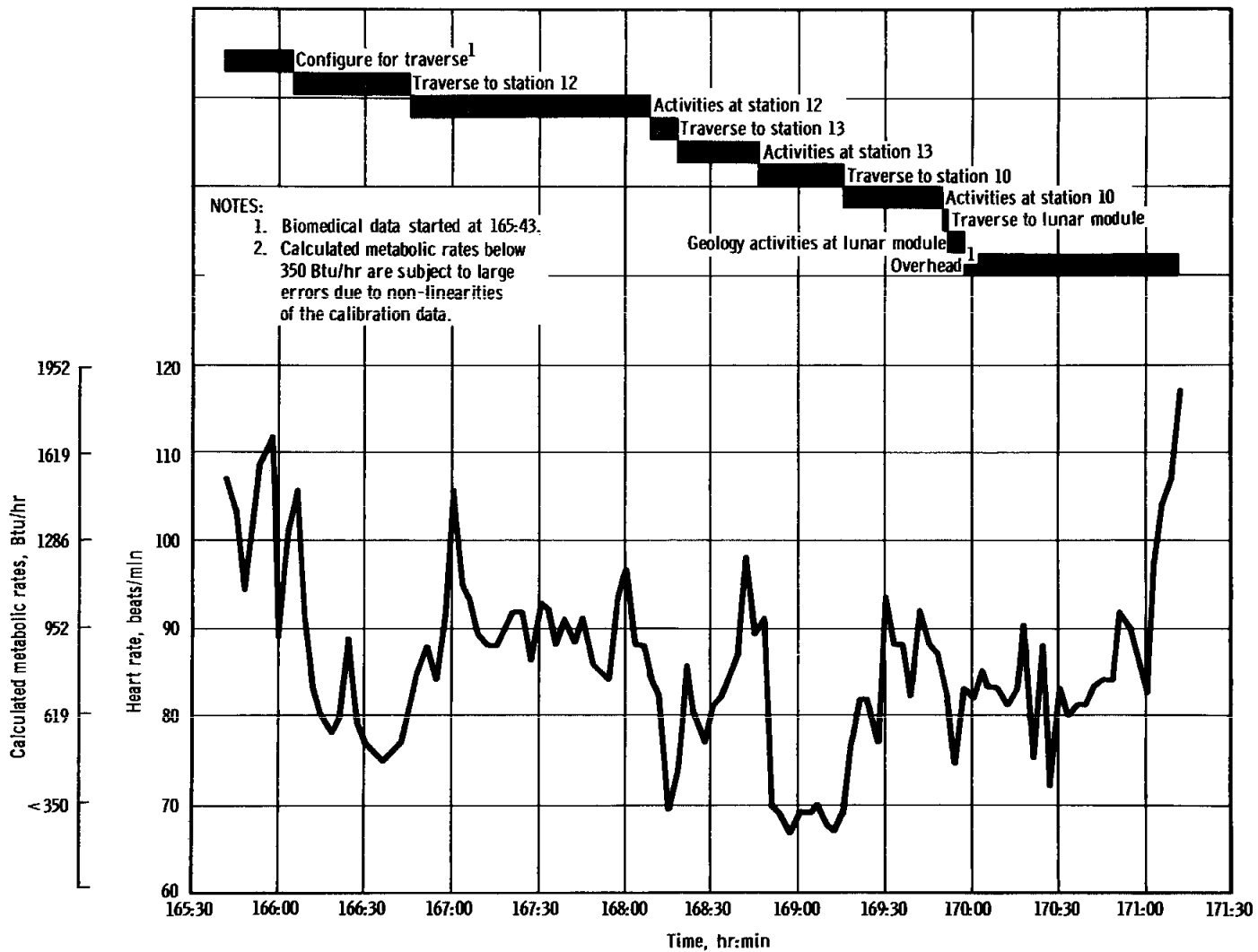
(a) Commander.

Figure 10-4.- Heart rates and calculated metabolic rates during second extravehicular activity.



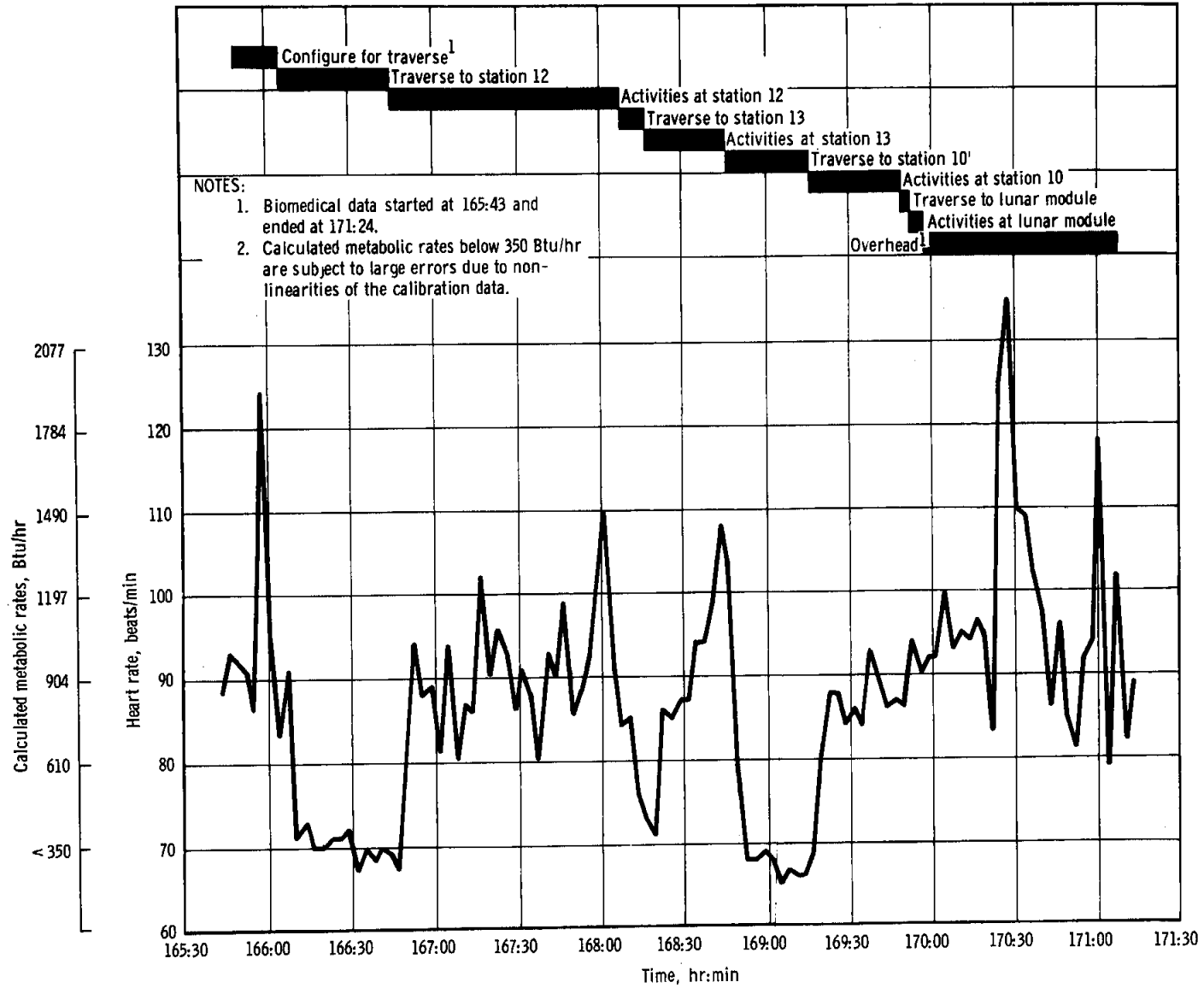
(b) Lunar Module Pilot.

Figure 10-4.- Concluded.



(a) Commander.

Figure 10-5.- Heart rates and calculated metabolic rates during second extravehicular activity.



(b) Lunar Module Pilot  
Figure 10-5.- Concluded

medical debriefing, the Lunar Module Pilot reported that the Seconal was effective in producing a rapid onset of good sleep. The only other item from the medical kits used by the crew was skin cream to reduce irritation at the biosensor sites.

### 10.2.3 Sleep

In contrast to the Commander's Apollo 10 experience, he slept well during all the scheduled sleep periods. Typically, the Commander's sleep was uninterrupted for 4 to 5 hours after which he would awaken, get a drink of water, and return to sleep for the rest of the night. The Lunar Module Pilot slept well during all sleep periods except the first. However, the Command Module Pilot reported that he slept uninterrupted only two nights of the mission and, characteristically, would awaken about once every hour. He also stated that he never felt physically tired nor had a desire for sleep.

On this mission, displacement of the terrestrial sleep cycle ranged from 30 minutes to 5 hours during translunar coast, and from 3 1/2 hours to 7 hours during the three lunar-surface sleep periods. This shift in the sleep cycle on the lunar surface contributed to some loss of sleep; however, this was the first mission in which the lunar module crewmen obtained an adequate amount of good sleep while on the lunar surface. This assessment of the amount of sleep is based on a correlation of heart rate during the mission sleep periods with preflight sleep electroencephalograms and heart rates. The estimates of sleep duration made by ground personnel were in general agreement with the crew's subjective evaluations.

### 10.2.4 Radiation

The personal radiation dosimeters showed the total absorbed dose to the crew was approximately 0.5 rad at skin depth. This is well below the threshold of detectable medical effects.

This was the first Apollo mission in which three minor solar flares occurred. Although the nuclear particle detection system registered a slight increase in proton and alpha particle fluxes, no measureable radiation dose increment was received by the crew from these flares.

### 10.2.5 Cardiac Arrhythmias

Both Apollo 15 lunar surface crewmen demonstrated cardiac arrhythmias (irregularities) following completion of their extravehicular activities. Laboratory data obtained after the flight showed a significant decrease in exchangeable body potassium levels. This deficiency of body potassium was

considered to be an important factor in the genesis of the Apollo 15 arrhythmia. As a result of these findings, several changes were instituted on this mission to reduce the likelihood of inflight arrhythmias and to further investigate the causes of body potassium loss during space flight. These changes included the following:

- a. A high-potassium diet was instituted, commencing 72 hours prior to launch and continuing until 72 hours after the mission.
- b. A metabolic input/output analysis was made with accurate daily inflight reporting.
- c. Anti-arrhythmic medications (procaine amide, atropine, and Lidocaine) were provided in the onboard medical kits.
- d. A daily high-resolution electrocardiogram was taken from each crewman.

No medically significant arrhythmias occurred during the mission, but isolated premature heart beats were observed in two of the three crewmen. The fact that the frequency (less than one per day) and character of these prematurities remained consistent with electrocardiographic data obtained on these same crewmen during ground-based tests clearly indicates that they were not related to or resultant from space flight. Postflight exchangeable body potassium levels were normal and indicate that the increased dietary potassium intake, discussed in section 10.2.7, apparently was effective in maintaining a state of normal potassium balance. It is not possible at this time to equate normal levels of exchangeable body potassium with suppression of cardiac irritability and prevention of arrhythmias. For example, fatigue, stress, or excitement can also produce arrhythmias. The absence of arrhythmias on this mission can best be attributed to a combination of factors, such as high dietary intake of potassium, better fluid and electrolyte balance, more adequate sleep, and less fatigue.

#### 10.2.6 Water

The crew reported that the taste of the drinking water in both the command module and the lunar module was good. The crew experienced difficulty injecting the chlorinating solution during the third daily water chlorination in the command module. A small amount of chlorine leakage occurred and is attributed to a failure of the inner bag of the chlorine ampule. Section 14.1.7 contains a discussion of this anomaly. The last two inflight water system chlorinations were not performed because the injection device had been misplaced. Postflight analysis of the command module water showed an increase in bacterial counts and no free chlorine; however, no pathogenic microflora were found.

The use of the bacterial filter in the lunar module was not required on the mission because the preflight iodine residual in the potable water supply was adequate for maintenance of sterility throughout the flight.

The crew reported that there was no dissolved gas in the command module water system during the first three days of the mission. Thereafter, however, sporadic occurrences of gas bubbles, particularly from the hot water port, were noted. No interference with food reconstitution resulted from these gas bubbles.

#### 10.2.7 Food

Menus were designed to provide a minimum of 130 milli-equivalents of potassium per man per day for this mission. Foods high in natural potassium were selected and some beverages were fortified with potassium gluconate. The menus supplied approximately 2600  $\pm$ 100 kilocalories per man per day. This value was based on the calculated nutritional requirements of each crewman.

For the first time on an Apollo mission, a preflight and postflight control diet was provided to the crew. The purpose of this control diet was twofold; to insure that each crewman was in an optimum nutritional state prior to launch, and to facilitate postflight interpretation of medical laboratory data. The control diet was initiated three days prior to flight and terminated two days after recovery. In addition, food and fluid intake was closely monitored during the flight.

Preliminary estimates of the inflight food consumption, based on crew reports, indicate that an average of 2150, 1408, and 1900 kilocalories per day were consumed by the Commander, Command Module Pilot, and the Lunar Module Pilot, respectively. Postflight, the crew commented favorably on the quality of the food, but stated that they could not consume the quantity provided. They also stated that they had an inadequate amount of time to prepare and eat their food because the meal periods were continually interrupted and shortened by other activities.

Six in-suit beverage assemblies were included in the lunar module food system. Each assembly consisted of a drinking device and a 32-ounce bag of potassium-fortified orange drink. Several minor problems with the use of these assemblies were experienced. Inadvertent activation of the tilt valve by the communications cable or the microphone caused some release of fluid into the Lunar Module Pilot's helmet prior to lunar landing. Prior to the first period of extravehicular activity, the Commander installed the in-suit beverage assembly after donning his pressure suit and could not properly position the assembly. Thus, he was unable to consume any fluid during the first extravehicular activity. The Lunar Module Pilot encountered no difficulties and drank 32 ounces of water during

this time. On the second and third periods of lunar surface activities, each crewman consumed the fortified orange drink. In-suit food bars were not used during extravehicular activities.

Four different types of Skylab food packages were evaluated for function under weightless conditions by each crewman. These included a rehydratable soup package, a beverage package, a peanut wafer package, and a liquid table-salt package. The crew suggested improvements of some of the Skylab food packages.

### 10.3 PHYSICAL EXAMINATIONS

Each crewman received a comprehensive physical examination 29, 15, and 5 days prior to launch, with brief examinations conducted daily during the last 5 days before launch. Comprehensive physical examinations conducted shortly after landing showed that the crewmen were in good health. The body weight losses incurred by the Commander, Command Module Pilot, and Lunar Module Pilot during the mission were 7 1/2, 6 1/2, and 5 1/2 pounds, respectively. All crewmen suffered varying degrees of skin irritation at the biosensor sites. This skin irritation resulted principally from the crew's desire to wear the biosensor harnesses continuously in order to save the long donning/doffing time (15 to 20 minutes) required. The skin irritation subsided within 48 hours without medical treatment. The Commander had some sinus congestion which responded promptly to medication, and also a slight reddening and retraction of the right eardrum.

In contrast to Apollo 15, the crew returned to their preflight baseline levels in lower body negative pressure measurements and bicycle ergometry tests by the third postflight day. The response pattern of these tests, unlike Apollo 15, was consistent with other Apollo missions.

The lack of a significant decrement in the Command Module Pilot's exercise performance was a surprising postflight finding. Because of the high degree of preflight aerobic capacity demonstrated by this crewman, a significant postflight decrement had been anticipated.

### 10.4 IMPROVED GAS/WATER SEPARATOR AND FECAL COLLECTION BAG

The improved gas/water separator was not evaluated because a structural failure of the device allowed water leakage and precluded the unit from functioning properly. Section 14.3.3 contains a discussion of this anomaly.



The improved fecal collection bags were evaluated by the crew. The lap belt and stiffened seat flange were found to offer no particular advantage over the existing system. The modifications made on the finger cot did not improve its function.

#### 10.5 APOLLO TIME AND MOTION STUDY

Analysis of the lunar-surface traverses on level surface and downhill produced findings closely paralleling those of Apollo 15. Carrying of bulky equipment, such as the Apollo lunar surface experiments package, resulted in a significant increase of metabolic rate. During one of the long traverses, the metabolic rates were similar, 1112 Btu/hr and 1185 Btu/hr, with one crewman using a conventional walking gait and the other a hopping gait, respectively.

A comparison of metabolic data from ground-based training tasks and lunar surface tasks showed that the metabolic rates were about 90 percent higher during the training sessions. The major contribution to the higher ground-based metabolic rate is the 100 pounds of extra weight carried by the crewman. However, the total metabolic cost of the lunar surface tasks was only 10 percent lower than for ground-based training. The fact that the lunar surface tasks were spread over a longer period of time accounts for the small total difference.

#### 10.6 STEREOMETRIC BODY VOLUME MEASUREMENT

Body volume measurements were performed 15 and 5 days prior to launch and immediately after recovery. The stereophotogrammetric method was used to obtain front- and back-view stereophotographs of the crewmen. The photographs were then analyzed to derive the precise displacement of a large number of coordinates from the body reference plane. The coordinates were used to compute an exact volume of the three-dimensional image of each crewman.

Postflight testing showed that the Lunar Module Pilot had a body volume decrease of 2.5 liters and that the Command Module Pilot had a decrease of 6.9 liters. Unexpectedly, the Commander showed no net loss of body volume even though he was the smallest crewman and had lost the most weight during the mission. Observation of body density change together with known caloric deficits would imply that the losses of fatty tissue predominated in the lunar surface crewmen, whereas the Command Module Pilot lost proportionately more body water.

## 10.7 VESTIBULAR FUNCTION TESTS

Vestibular function tests were performed because of the transitory postflight vestibular disturbance experienced by one of the Apollo 15 crewmen and to fulfill the need for better quantitative data on the effects of weightlessness on the vestibular system. Two different types of tests were performed. The first test evaluated the postural stability with and without the aid of vision. All crewmen were within normal limits during preflight tests. However, three days after recovery, two of the crewmen exhibited a significant decrement when deprived of all visual sensory cues. Performance was similar to the preflight baseline when these crewmen were retested one week after landing.

The second test consisted of graphic recording of nystagmus (eye movement) induced by water irrigation of the right and left auditory canals. The water used was at temperatures of 34.0° C and 35.5° C. Two of the crewmen displayed apparent hypersensitivity of the semicircular canals during postflight testing, as evidenced by an increase in the frequency of nystagmus and an increase in the slow-phase velocity of caloric-induced nystagmus. Repetition of this test one week after recovery indicated that these crewmen had returned to normal baseline conditions.

## 11.0 MISSION SUPPORT PERFORMANCE

### 11.1 FLIGHT CONTROL

Flight control provided satisfactory operational support for all areas during the Apollo 16 mission. Ground facility difficulties experienced during this mission were resolved satisfactorily with no effect on the mission.

The S-IVB stage, the command and service module, the lunar module, and the lunar roving vehicle all had some systems problems which required special work-around or management procedures. These problems ranged in seriousness from a mere nuisance to a potential mission termination prior to the lunar landing.

The lunar landing was delayed about 5 3/4 hours while resolution of a service propulsion system problem was obtained. This delay caused a major impact on the mission timeline; consequently, a new flight plan had to be developed. The lunar surface portion was relatively easy to define - the major issue being how many extravehicular activities could be accomplished. The resolution of this question depended on the lunar module consumables analysis and a management decision regarding crew work/rest cycles. Since a third extravehicular activity was available, even though it was only 5 hours' duration instead of 7, the lunar surface activities were not greatly perturbed.

The flight plan revision for orbital operations required that planned activities be moved to different times or orbits. However, since the orbital events must occur at specific times, the updating of the crew had to be accomplished by dictating each specific change. This was a laborious and time consuming process. It also required a great deal of time to prepare the flight plan updates, and in at least two instances, the updates were not completed in time to allow an adequate review by the entire flight control team prior to being read to the crew.

A contributing factor to the orbital operations planning difficulties was the decision to perform transearth injection a day earlier than originally planned. This resulted in a loss of one day of lunar orbit science experiment operations, and therefore, major changes were made in the flight plan to accomplish as many as possible of the higher priority items.

## 11.2 NETWORK

The support of the Space Flight Tracking and Data Network was good for the Apollo 16 mission.

There were three significant communications problems that caused a loss of data. They were: system failures at Monrovia, Maryland, switching station prior to lift-off; poor performance of the communications processor at Goddard; and the inability of the Jet Propulsion Laboratory 210-foot Mars station to process lunar module high-bit-rate data when the lunar module was transmitting on an omnidirectional antenna and the command and service module was transmitting on the high-gain antenna.

During the period between the Apollo 15 and Apollo 16 missions, the Space Tracking and Data Acquisition Network and the Manned Space Flight Network (MSFN) were combined into a single network to support both manned and unmanned flights. The designation of the combined network is the Space Flight Tracking and Data Network (STDN).

## 11.3 RECOVERY OPERATIONS

The Department of Defense provided recovery support for the Apollo 16 mission. Recovery ship support for the primary landing area in the Pacific Ocean was provided by the aircraft carrier USS Ticonderoga. Air support consisted of five SH-3G helicopters and one E-1B aircraft from the primary recovery ship, and two HC-130 rescue aircraft staged from Hickam Air Force Base, Hawaii. Three of the SH-3G helicopters carried recovery swimmer team personnel. The first, designated "Recovery", also carried the flight surgeon and was used for both command module and flight crew retrieval operations. The helicopter, designated "Swim", served as a backup to "Recovery". The third helicopter, designated "ELS" (earth landing system), was used for retrieval of the main parachutes. A fourth helicopter, designated "Apex" was used for drogue parachute and apex cover retrieval operations. The fifth helicopter, designated "Photo", served as a photographic platform for both motion picture photography and live television coverage. The E-1B aircraft, designated "Relay", served as a communications relay. The two HC-130 aircraft, designated "Hawaii Rescue 1" and "Hawaii Rescue 2", were positioned to track the command module after it had exited from S-band blackout, as well as to provide pararescue capability had the command module landed uprange or downrange of the target point. Figure 11-1 shows the relative positions of the recovery ship, its aircraft, and the two HC-130 aircraft prior to landing. The recovery forces assigned to the mission are shown in table 11-I.

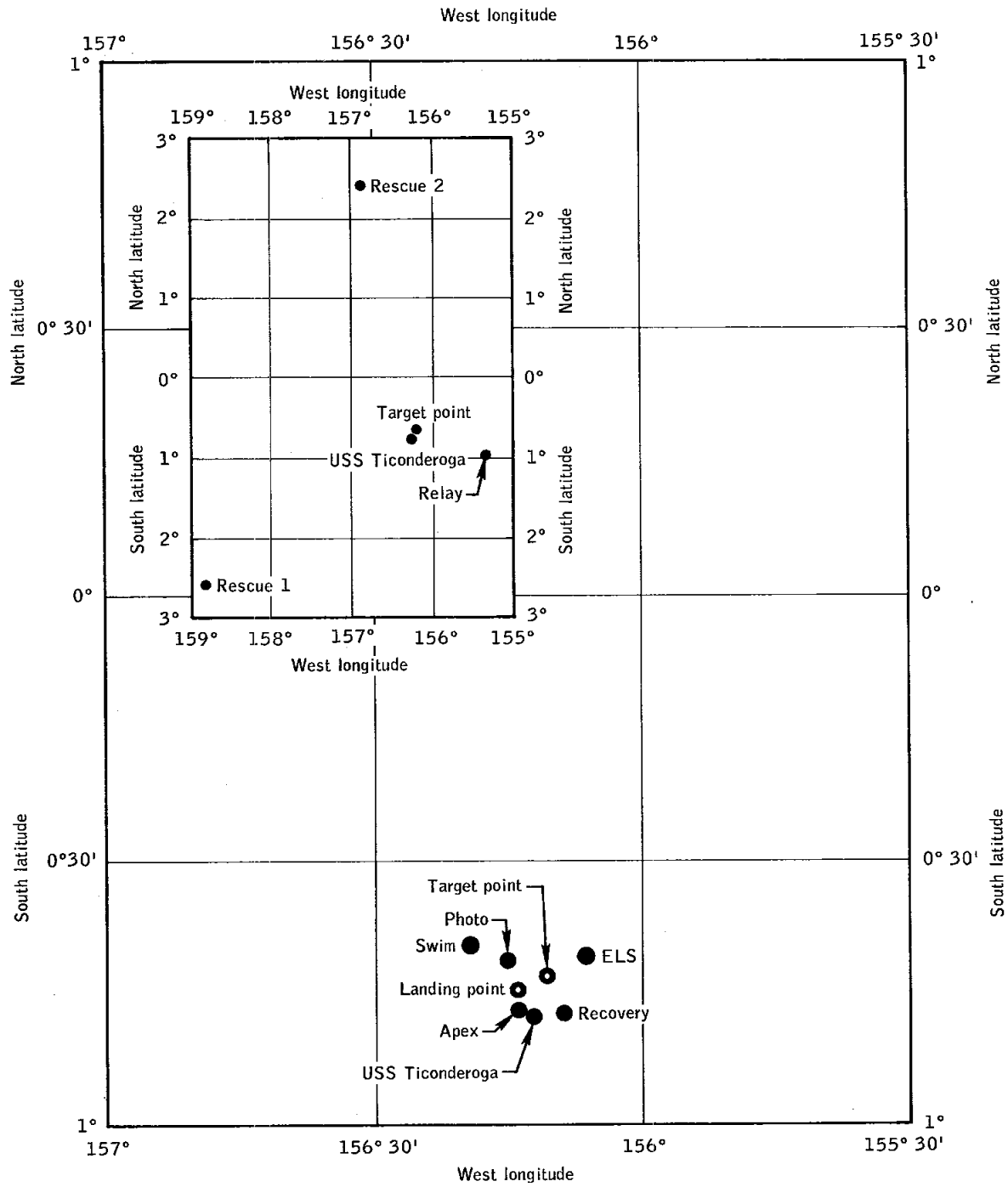


Figure 11-1.- End of mission recovery support.

TABLE 11-I.- APOLLO 16 RECOVERY SUPPORT

Type	Number	Ship name/ aircraft staging base	Responsibility
ARS	1	USS Opportune	Launch site area and sonic boom measurements
MSO	1	USS Alacrity	Sonic boom measurements
MSO	1	USS Exploit	Sonic boom measurements
DD	1	USS Goldsborough	Earth orbital target points (Standby in Pearl Harbor)
AO	1	USS Ponchatula	Refuel USS Ticonderoga and sonic boom measurements
CVS	1	USS Ticonderoga	Deep-space secondary landing areas in the mid-Pacific and the primary end-of-mission landing area
Aircraft			
HH-53C	2 <sup>a</sup>	Patrick Air Force Base	Launch site area
HC-130	1 <sup>a</sup>	Eglin Air Force Base	Launch abort area and West Atlantic recovery area
HC-130	1 <sup>a</sup>	Pease Air Force Base	Launch abort area and West Atlantic recovery area
HC-130	1 <sup>a</sup>	Lajes Air Force Base	Launch abort area and contingency landing support
HC-130	1 <sup>a</sup>	Ascension Island	Deep space Atlantic Ocean secondary recovery zone
HC-130	2 <sup>a</sup>	Hickam Air Force Base	Mid-Pacific earth orbital recovery zone, deep space secondary landing area on the mid-Pacific line and primary end-of-mission landing area
SH-3G	5	USS Ticonderoga	Deep space secondary landing area and primary end-of-mission landing area
E-1B	1	USS Ticonderoga	Communications relay for primary end-of-mission landing area

<sup>a</sup>Plus one backup.

### 11.3.1 Command Module Location and Retrieval

Radar contact with the command module was made by the Ticonderoga at 1934 G.m.t with a visual sighting of the command module occurring 5 minutes later. This initial sighting was prior to apex cover jettison; thus, the entire descent sequence was observed. Shortly after the main parachutes were deployed, two-way voice communications were established between the Apollo 16 crew and the recovery forces. Table 11-II is a chronological listing of events during recovery and post-recovery operations.

Landing occurred at 1945 G.m.t. Based upon a navigation satellite (SRN-9) fix obtained at 1916 G.m.t., the Ticonderoga's position at the time of landing was determined to be 0 degrees 46 minutes 30 seconds south latitude and 156 degrees 12 minutes 12 seconds west longitude. Using this fix of the ship's position along with visual and radar bearings and ranges to the command module, the landing point coordinates of Apollo 16 were determined as being at 0 degrees 44 minutes 18 seconds south latitude and 156 degrees 14 minutes 6 seconds west longitude.

The command module landed in the stable I attitude and immediately went to the Stable II (apex down) flotation attitude. Uprighting to the Stable I attitude required approximately four and one-half minutes. Swimmers were deployed to the command module and had the flotation collar installed and inflated by 2000 G.m.t. The crew were delivered aboard the USS Ticonderoga 22 minutes later.

Command module retrieval occurred at 2124 G.m.t. when the spacecraft was lifted aboard the Ticonderoga. In addition, all three main parachutes were recovered.

The crew remained aboard the Ticonderoga about 21 hours for a medical checkup after which they were flown to Hickam Air Force Base, Hawaii. After a brief welcoming ceremony, a C-141 aircraft flew them to Ellington Air Force Base, Texas.

The command module arrived at North Island Naval Air Station, San Diego, California, on May 5 at 2400 G.m.t. On May 7, while removing the propellants from the command module, an explosion occurred in the ground support equipment. Section 14.1.20 gives additional information. The command module was not damaged and was delivered to the prime contractor at Downey, California, on May 12 at 1030 G.m.t., for postflight testing.

TABLE 11-II.- SIGNIFICANT RECOVERY POSTRECOVERY EVENTS

Event	Time, G.m.t.	Time relative to landing day:hr:min
	<u>April 27, 1972</u>	
Radar contact by Ticonderoga	1934	-0:00:11
Visual contact	1939	-0:00:06
VHF recovery beacon contact by Ticonderoga	1940	-0:00:05
Voice contact with Apollo 16	1941	-0:00:04
Command module landing	1945	0:00:00
Swimmers deployed to command module	1950	0:00:05
Flotation collar installed and inflated	2000	0:00:15
Hatch opened for crew egress	2004	0:00:19
Flight crew aboard helicopter	2016	0:00:31
Flight crew aboard Ticonderoga	2022	0:00:37
Command module aboard Ticonderoga	2124	0:01:39
	<u>April 29, 1972</u>	
First sample flight departed Ticonderoga	1145	1:16:00
First sample flight arrived Hawaii	1414	1:18:29
First sample flight departed Hawaii	1503	1:19:18
Flight crew departed Ticonderoga	1730	1:21:45
Flight crew arrived Hawaii	1921	1:23:36
Flight crew departed Hawaii	2007	2:00:22
First sample flight arrived Houston	2232	2:02:47
	<u>April 30, 1972</u>	
Command module arrived Hawaii	0330	2:07:45
Flight crew arrived Houston	0340	2:07:55
	<u>May 1, 1972</u>	
Command module departed Hawaii	1800	3:22:15
	<u>May 5, 1972</u>	
Command module arrived North Island, San Diego, California	2400	8:04:15
	<u>May 11, 1972</u>	
Command module deactivated	2400	14:04:15



TABLE 11-II.- SIGNIFICANT RECOVERY POSTRECOVERY EVENTS (Concluded)

Event	Time, G.m.t.	Time relative to landing day:hr:min
Command module departed San Diego Command module arrived Downey	<u>May 12, 1972</u>	
	0300 1030	14:07:15 14:14:45

## 11.3.2 Postrecovery Inspection

Visual inspection of the command module in the recovery area revealed the following:

a. Three of the ground-plane whiskers on the number two VHF recovery antenna and one ground-plane whisker on the number one VHF antenna were bent.

b. There were small sections missing out of the aft heat shield in the plus Y and plus Z quadrants.

c. There were minor rips in one of the sleep restraint bags and in the back pan of the center couch.

12.0 ASSESSMENT OF MISSION OBJECTIVES

Three primary mission objectives were assigned to the Apollo 16 mission (ref. 5). These were:

- a. Perform selenological inspection, survey, and sampling of materials and surface features in a pre-selected area of the Descartes region.
- b. Emplace and activate surface experiments.
- c. Conduct in-flight experiments and photographic tasks.

Table 12-I includes the eleven detailed objectives which were derived from the primary objectives plus twenty-five experiments (ref. 6) which were conducted. Preliminary analysis of the experiments and detailed objectives indicates a successful mission with a weighted completion average of greater than 90 percent. Loss of the heat flow experiment was the only prime loss.

The Department of Defense and the Kennedy Space Center performed seven other tests which are as follows:

- a. Chapel Bell (classified Department of Defense test)
- b. Radar skin tracking
- c. Ionospheric disturbance from missiles
- d. Acoustic measurement of missile exhaust noise
- e. Army acoustic test
- f. Long-focal-length optical system
- g. Sonic boom measurement.

TABLE 12-I.- DETAILED OBJECTIVES AND EXPERIMENTS

Description	Completed
Detailed Objectives	
Service module orbital photographic tasks	Yes
Visual light flash phenomenon	Yes
Command module photographic tasks	<sup>a</sup> Partial
Visual observations from lunar orbit	Yes
Skylab contamination study	<sup>a</sup> Partial
Improved gas/water separator	<sup>b</sup> No
Body fluid balance analysis	Yes
Subsatellite tracking for autonomous navigation	<sup>a</sup> No
Improved fecal collection bag	Yes
Skylab food package	Yes
Lunar rover vehicle evaluation	Yes
Crew-Participation Experiments	
Lunar geology investigation (S-059)	Yes
Heat flow (S-037)	<sup>c</sup> No
Lunar surface magnetometer (S-034)	Yes
Passive seismic (S-031)	<sup>d</sup> Partial
Active seismic (S-033)	<sup>e</sup> Partial
Far ultraviolet camera/spectroscope (S-201)	Yes
Solar wind composition (S-080)	Yes
Soil mechanics (S-200)	<sup>f</sup> Partial
Portable magnetometer (S-198)	Yes
Cosmic ray detector (sheets) (S-152)	<sup>g</sup> Partial
Gamma-ray spectrometer (S-160)	Yes
X-ray fluorescence (S-161)	Yes
Subsatellite:	
S-band transponder (S-164)	Yes
Particle shadows/boundary layer (S-173)	Yes
Magnetometer (S-174)	Yes
Down-link bistatic radar observations of the moon (S-170)	Yes
S-band transponder (CSM/LM) (S-164)	Yes
Alpha particle spectrometer (S-162)	Yes
Mass spectrometer (S-165)	Yes
Ultraviolet photography-earth and moon (S-177)	<sup>a</sup> Partial
Gegenschein from lunar orbit (S-178)	Yes
Microbial response in space environment (M-191)	Yes

TABLE 12-I.- DETAILED OBJECTIVES AND EXPERIMENTS - Concluded

Description	Completed
Passive Experiments	
Bone mineral measurement (M-078) Biostack (M-211) Apollo window meteoroid (S-176)	Yes Yes Yes
Operational Tests	
Lunar module voice and data relay	Yes
Inflight Demonstration	
Fluid electrophoresis in space	Yes

- <sup>a</sup>Timeline changes caused data loss.
- <sup>b</sup>Separator failed before it could be evaluated.
- <sup>c</sup>Electronics package cable broken.
- <sup>d</sup>No lunar module ascent stage impact.
- <sup>e</sup>The fourth mortar will not be fired.
- <sup>f</sup>No trench dug - timeline.
- <sup>g</sup>Partial deployment of panel 4.

## 13.0 LAUNCH PHASE SUMMARY

### 13.1 WEATHER CONDITIONS

The weather conditions at the launch site and in the surrounding areas on the day of launch were gently southwesterly winds extending from the surface to an altitude of 25 000 feet. The main weather feature was a ridge of high pressure extending from the Atlantic westward over Florida. Broken strato-cumulus clouds were present in the early morning, but the skies were clear by mid-morning with scattered cumulus clouds noted about 11 a.m. The surface temperature was 88° F with the maximum winds of 41 knots from 270° azimuth at 39 000 feet.

### 13.2 ATMOSPHERIC ELECTRICITY

Lightning strikes were recorded on March 5 and March 31 on the launch umbilical tower and mobile service structure of launch complex 39. No damage was noted in the spacecraft or associated ground support equipment as a result of these strikes.

### 13.3 LAUNCH VEHICLE PERFORMANCE

The performance of the ninth manned Saturn V space vehicle, AS-511, was satisfactory and all objectives were accomplished except the precise determination of the S-IVB stage lunar impact point and time.

The ground systems supporting the launch vehicle portion of the Apollo 16 countdown and launch performed satisfactorily with no unscheduled holds. Propellant tanking was accomplished satisfactorily. Damage to the pad, launch umbilical tower, and support equipment was minimal.

The vehicle was launched on an azimuth 90 degrees east of north. A roll maneuver was initiated 12.7 seconds after range zero and the vehicle was placed on a flight azimuth of 72.034 degrees east of north. The trajectory parameters from lift-off to command and service module separation were nominal. Earth-parking-orbit insertion conditions were achieved at the planned altitude, but 0.72 second later than planned, and at a velocity of 0.2 meter per second greater than planned. Translunar injection conditions were achieved 1.78 seconds earlier than planned with altitude and velocity 2.0 kilometers less than planned and 1.9 meters per second

greater than planned, respectively. The trajectory parameters at command and service module separation deviated somewhat from planned since the event occurred 38.6 seconds later than predicted.

All S-IC propulsion systems performed satisfactorily and performance was very close to predicted. Likewise, the S-II propulsion systems performed satisfactorily throughout the flight with all engine performance parameters near the predicted values. However, during the S-II engine start transient, an unusually large amount of helium was expended from the engine 4 helium tank. The most probable cause of the anomaly is slow closing of the engine purge control valve allowing excessive helium to be vented overboard. Tests, analysis, and examination of valves from service are being conducted to determine the cause and solutions for engines on subsequent stages. The accumulator system was effective in suppressing POGO-type oscillations.

The S-IVB propulsion system performed satisfactorily throughout the operational phase of the first firing and had normal start and cutoff transients. Firing time for the first S-IVB firing was 142.6 seconds, 0.4 second longer than predicted. Engine restart conditions were within specified limits, and restart, at the full-open position of the mixture ratio control valve, was successful. The firing time for the second S-IVB firing was 341.9 seconds, 2.4 seconds less than predicted. This difference is primarily due to the slightly higher S-IVB performance and lighter vehicle mass during the second firing. Auxiliary propulsion system module 1 experienced an external helium leak which started at about 1 hour and continued to 06:20:00. The maximum leak rate experienced was 585 psi/hour. The other module 1 systems functioned normally. Auxiliary propulsion system module 2 experienced internal leakage from the high pressure system to the low pressure system during the flight. The regulator outlet pressure began to increase above the regulator setting at approximately 970 seconds. The pressure continued to increase to 344 psia, the relief setting of the low-pressure-module relief valve. The regulator outlet pressure remained between 344 and 203 psia until loss of data. During periods of high propellant usage, the regulator outlet pressure decreased, but not low enough for regulator operation. The regulator is the prime suspect for this internal helium leakage. Data from preflight pressurization of the auxiliary propulsion system indicates that the system probably was on the secondary regulator at lift-off. Another leak path being examined is the common mounting block for the high- and low-pressure helium system pressure transducer.

The navigation, guidance, and control system successfully supported the accomplishment of all mission objectives. The end conditions at parking orbit insertion and translunar injection were attained with insignificant navigation error. Several minor problems did occur: The stabilized platform subsystem exhibited a shift in crossrange velocity output during

lift-off vibration, probably because of accelerometer pickoff contact with a mechanical stop. The termination of the tower avoidance yaw maneuver occurred about a second late because of an implementation flaw in the launch vehicle digital computer flight program.

The launch vehicle electrical systems and emergency detection system performed satisfactorily throughout the required period of flight. However, the S-II ignition bus voltage measurement indicated an anomalous drop during and after the ignition sequence. This may be a measurement failure, but suggests a possible failure in the electrical networks. The S-IVB forward battery 2 depleted early as on AS-510 and did not deliver its rated capacity. Operation of all other batteries, power supplies, inverters, exploding bridge wire firing units and switch selectors was normal.

Temperatures were maintained within desired limits throughout the launch vehicle. The instrument unit environmental control system performed satisfactorily for approximately 5 hours. However, at approximately 5 hours, coolant fluid circulation ceased due to an excessively high gaseous nitrogen usage rate which depleted the thermal conditioning system storage sphere. After cooling ceased, temperatures began to increase but were within acceptable values at termination of instrument unit telemetry.

The performance of the command and communications system was satisfactory up to 7:40:43, at which time the instrument unit telemetry sub-carrier was inhibited. At about 27:09:59, the Madrid, Ascension, Goldstone, Bermuda and Merritt Island stations suddenly lost the signal carrier. Short duration signal dropouts occurred in the command and communications system downlink beginning over 8 hours prior to the complete signal loss. These dropouts were very sharp and, in most cases, did not produce any more than an instantaneous loss of lock.

After the complete signal loss, repeated reacquisition attempts by several ground stations were unsuccessful. Therefore, it is assumed that the command and communications system downlink flight hardware was not operational.

All aspects of the S-IVB stage and instrument unit lunar impact mission objectives were accomplished successfully except the precise determination of the impact point and the time of impact. Based upon analysis of available tracking data, the S-IVB stage and instrument unit impacted the lunar surface at approximately 2.10 degrees north latitude and 22.1 degrees west longitude, which is about 320 kilometers (173 miles) from the premission target point. The final determination of the impact point will be published by the Marshall Space Flight Center after review of all tracking and seismic data.

## 14.0 ANOMALY SUMMARY

This section contains a discussion of the significant anomalies that occurred during the Apollo 16 mission. The discussion is divided into six major subsections: command and service modules, lunar module, government-furnished equipment, lunar surface experiments, orbital experiments, and lunar roving vehicle.

### 14.1 COMMAND AND SERVICE MODULE ANOMALIES

#### 14.1.1 Water/Glycol Temperature Control Circuit Failed in the Automatic Mode

About 3 hours into the mission, the water/glycol temperature control circuit (fig. 14-1) malfunctioned in the automatic mode. The malfunction allowed an excessive amount of hot water/glycol to bypass the radiator causing the mixed water/glycol temperature to exceed the upper control

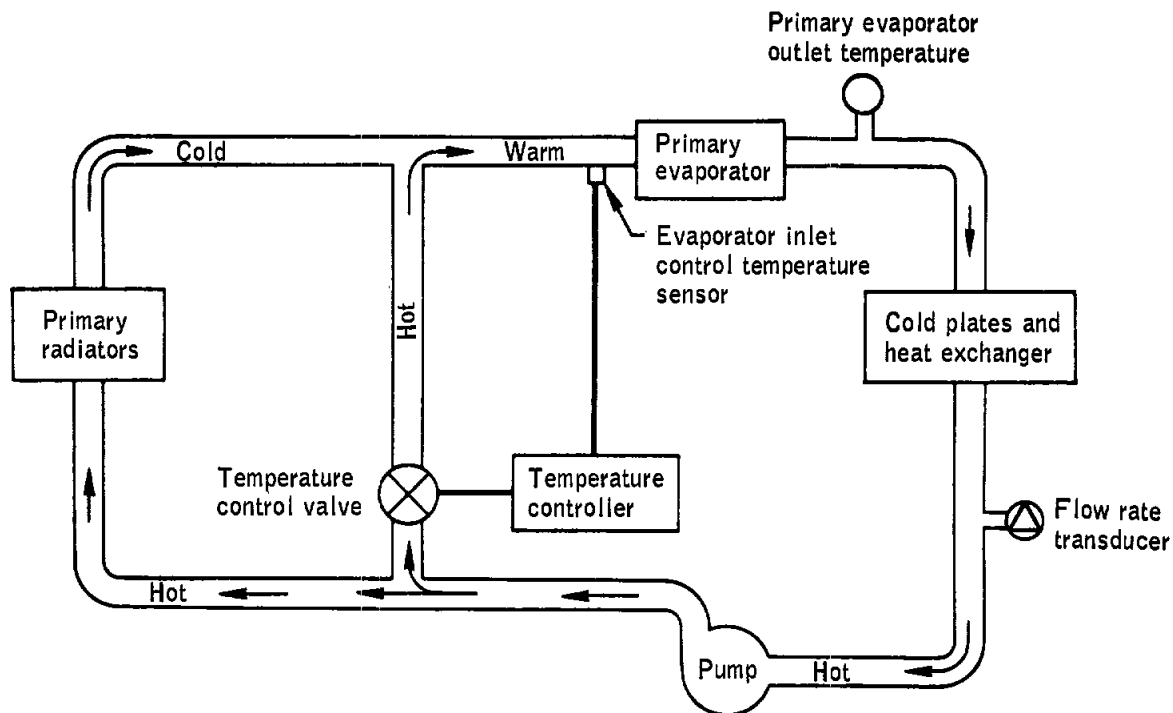


Figure 14-1.- Primary water/glycol coolant loop.



limit of 48° F. After remaining in this maximum bypass position for 5 minutes, the temperature control valve cycled regularly between maximum and minimum flow to the radiators for about 14 minutes before stopping again at maximum bypass. The control was changed to manual and back to automatic to restart the valve operation and, finally, left in manual at the desired valve position. Variations in the evaporator outlet temperature and total system flow rate for the period are shown in figure 14-2. Control valve operation is evident from the variation of system flow rate. Total flow rate increases as the flow control valve opens since the total system pressure drop decreases.

The temperature control valve was subsequently positioned manually several times to maintain acceptable coolant loop temperatures under various thermal conditions. During an attempt to position the valve automatically before the transearth extravehicular activity, the valve appeared to position correctly, but only for a short time. In another attempt after the extravehicular activity, the valve again showed excessive bypass flow and high evaporator outlet temperatures.

Most likely, a malfunction occurred in the water/glycol temperature controller which modulates the control valve by supplying signal pulses with a duration proportional to the error of the mixed temperature sensed.

Postflight testing has isolated the problem to the valve controller. Two separate problems have been identified in the controller. The first is an intermittent condition in a feedback loop. The second is a loss of control of the output silicon-controlled rectifiers. A component analysis is being performed to determine the cause of each problem.

A controller also malfunctioned on Apollo 17 during ground tests. Bench testing of this controller indicates that the problem is also loss of control of the output silicon-controlled rectifiers.

This anomaly is open.

#### 14.1.2 Service Propulsion System Oxidizer Tank Pressure Measurement Shifted

The service propulsion system oxidizer tank pressure measurement shifted upward 15 psia after the spacecraft reached a vacuum environment. The measurement responded to normal changes in pressure throughout the mission, but always read 15 psia high as verified by other measurements in the system.

Previous experience with this type of transducer showed that the reference cavity can leak through the feed-through tubes in the header and at

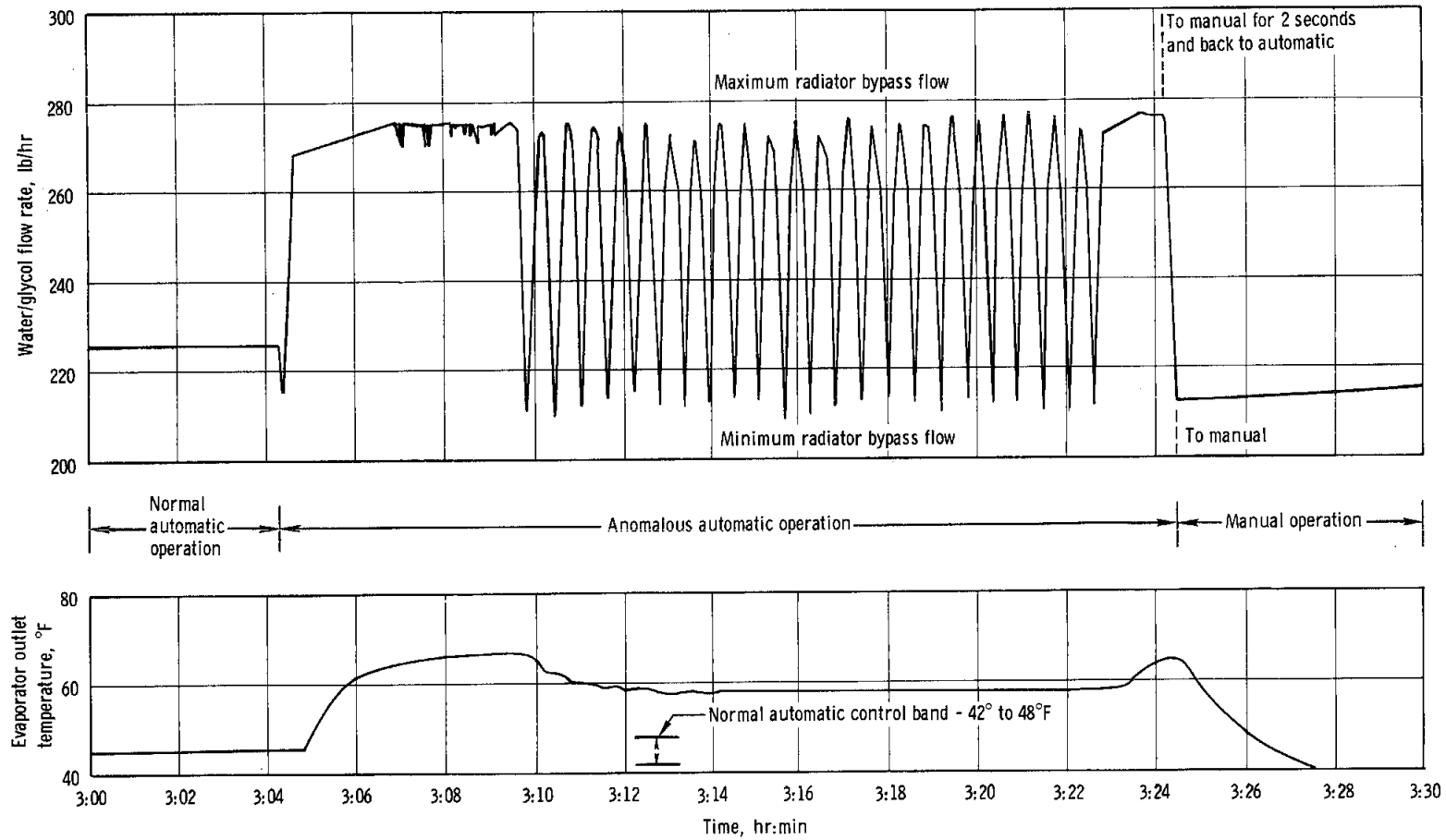


Figure 14-2.- Evaporator outlet temperature and system flow rate during anomalous period.

the header-to-case weld (fig. 14-3). During altitude chamber tests for Apollo 16 and during the Apollo 12 mission, a similar transducer showed the same type of failure. The Apollo 16 transducer (replaced after the altitude chamber tests) had not had a vacuum check since 1965 to verify that the reference cavity was leak tight. The altitude chamber test is adequate to verify the integrity of this type of pressure transducer.

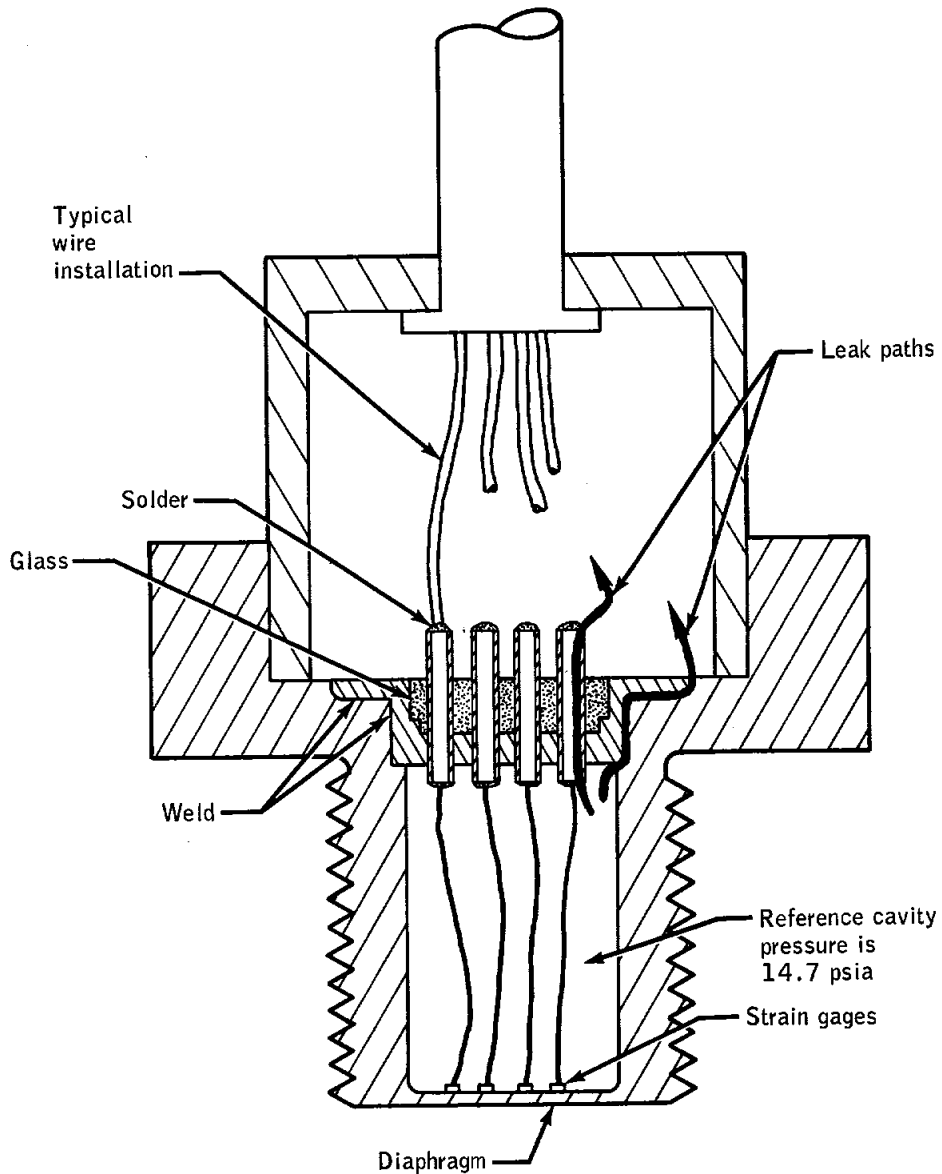


Figure 14-3.- Service propulsion system pressure transducer failure.

For all future spacecraft, replacement transducers which have a sealed reference cavity and are installed after altitude chamber testing is complete will undergo a 12-hour vacuum check prior to installation. In those areas where this type of transducer is critical for the mission, a redundant measurement or means of determining the pressure will be provided. In the case of this specific measurement, redundant fuel and oxidizer pressure measurements will be added to the Apollo 17 vehicle.

This anomaly is closed.

### 14.1.3 Erroneous Gimbal Lock Indication

At 38:18:56, the computer issued a gimbal lock indication when no gimbal lock condition existed. The vehicle was in the passive thermal control mode, rolling at minus 0.3 degree per second, and the computer was in the platform realignment program. At 38:18:54.7, the computer idling program was selected. This caused the thrust vector enable discrete to be removed from the coupling data unit assembly. Removing the discrete causes a relay to switch the source of an 800-hertz excitation voltage. Interrupting the 800-hertz voltage caused a transient which was electromagnetically coupled into the middle gimbal angle coupling data unit read counter which erroneously set the 90-degree bit. The computer sensed the change in the read counter and determined that the middle gimbal angle was greater than 85 degrees (gimbal lock condition). The computer then downmoded the inertial subsystem to the coarse align mode which caged the platform to the present body reference angles. The crew realigned the platform by taking optical sighting on both the sun and earth.

To prevent caging the platform if the erroneous gimbal lock indication recurred, the crew used an erasable program whenever the thrust vector enable relay was used. This program inhibited the computer from changing the coarse align relay.

Figure 14-4 is a simplified representation of the pertinent circuits in the middle gimbal angle coupling data unit. The purpose of the read counter is to store, in digital form, the platform gimbal angle. If the gimbal angle changes, the analog signal is no longer the same as the digital signal from the read counter and the resulting error signal causes a pulse train to be generated. The pulse train increments or decrements the read counter until it matches the analog gimbal angle. The read counter is a series of flip-flop logic circuits whose only inputs are a pulse train and timing pulses. The 90-degree bit is unique, however, because it can also be set by an ambiguity discrete. The purpose of the ambiguity discrete is to prevent the platform from going to an ambiguous position when the inertial measurement unit is turned on.

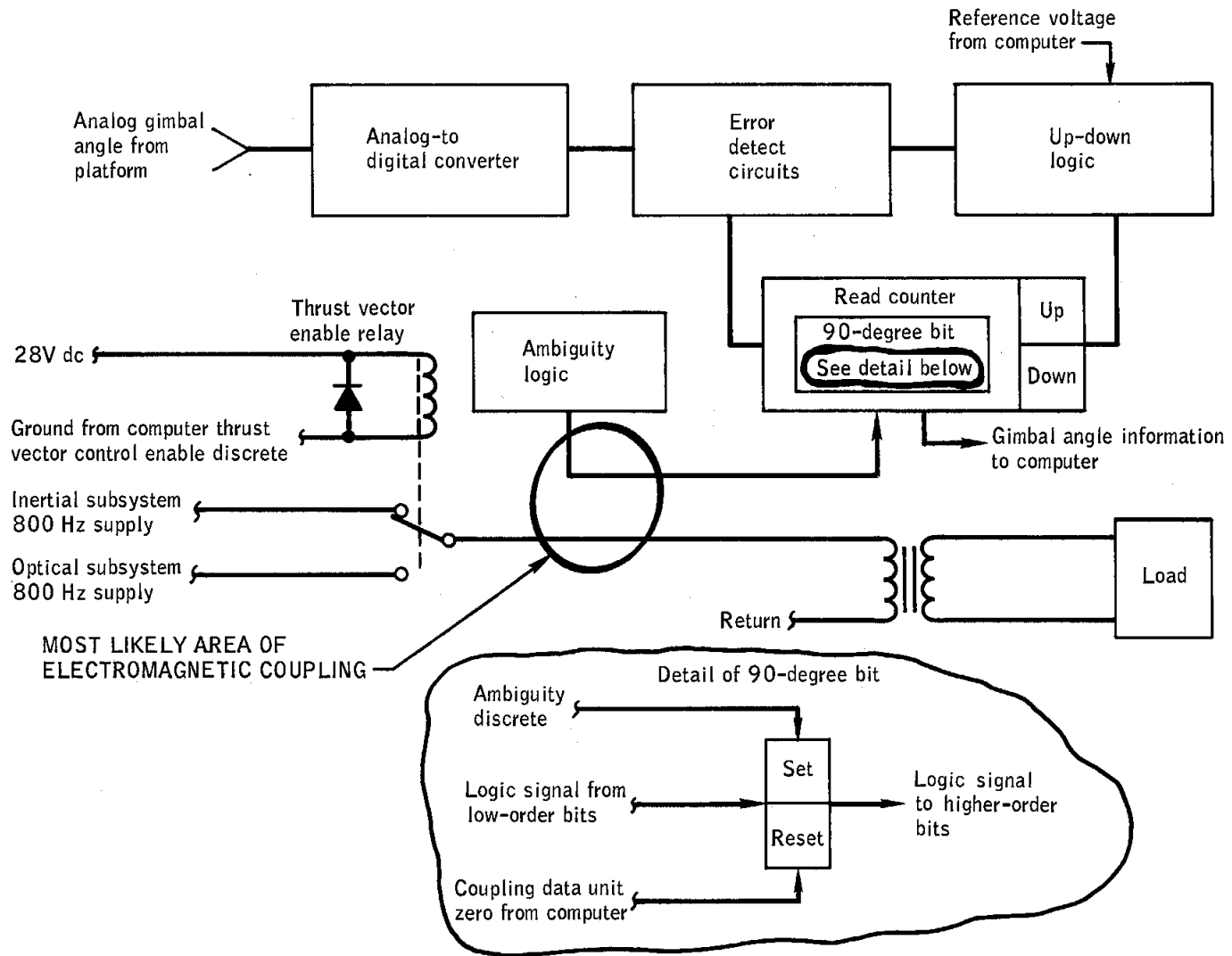


Figure 14-4.- Coupling data unit functional diagram.

The cause of the problem is contact bounce in the thrust vector enable relay (fig. 14-4). The relay switches between two 800-hertz excitation-voltage power sources which are applied to a transformer in the digital-to-analog converter portion of the coupling data unit. A relay without a coil spike suppression diode will transfer between contacts in about 0.5 millisecond with the transients caused by the power interruption and collapsing field of the transformer inconsequential. The addition of the suppression diode across the relay increases the dropout contact transfer time to about 6 milliseconds.

Two relay problems were found during postflight testing. One was that some relays exhibited contact bounce when energized. The other was that when some of the relays were deenergized, the movable contact would begin the transfer cycle, then remake with the contact it had just left, and then complete the transfer to the other contact. The Apollo 16 relay exhibited the latter problem.

In either condition if the relay contact initially closes the circuit to the transformer (fig. 14-4) at the beginning of either half cycle of the 800-hertz wave form, the current taken by the transformer during the first 3/4 cycle of the 800-hertz excitation voltage will reach 4 to 5 times the steady-state level. If this higher-than-normal current is interrupted by the relay contact reopening, the transformer will feed back a voltage transient as high as 250 volts on the line to the relay. Both of these problems result in circuit-interruption (bounce) durations that would cause high voltage spikes; however, the bounce must occur, as stated previously, at the right time in the 800-hertz waveform.

Corrective action will be the addition of a filter across the primary of the transformer in the digital-to-analog converter portion of the coupling data unit.

This anomaly is closed.

#### 14.1.4 Inertial Subsystem Warnings and Coupling Data Unit Fail Indications

The inertial subsystem warning light was observed to illuminate six times during the transearth portion of the flight. Each illumination was accompanied by a program warning of an inertial coupling data unit failure. The warning indications were intermittent; the first four cleared themselves, and the last two were removed by bumping an access panel in the lower equipment bay.

The coupling data unit assembly contains failure detection circuits which monitor the performance of each unit and a failure discrete is sent

to the computer if one or more of the following conditions exist for more than 3 to 7 seconds. The first three conditions would be directly observable from flight data; the last two may not necessarily be detected from flight data.

a. Coarse error detect - A disagreement of approximately 30 degrees between a read counter and the 1X gimbal resolver.

b. Fine error detect - A disagreement of more than 0.7 degree between a read counter and the 16X gimbal resolver.

c. Cosine ( $\theta - \psi$ ) - Voltage less than 4 Vrms. This voltage is normally 4 Vrms when the read counter agrees with the resolver voltage.

d. Read counter limit cycle - The read counter changes the direction in which it is counting at a rate greater than 160 times per second.

e. 14-volt-dc power supply - The 14-volt-dc power supply in the coupling data unit decreases to 8 volts dc or less.

The time delay associated with the failure discrete to the computer was measured in flight as approximately 5 seconds. The failure indications persisted for 4, 12, 16, 894, 10, and 38 seconds, respectively.

Data during each occurrence has been reviewed and no abnormalities were observed. If a real failure of the coupling data unit had occurred and lasted as long as 894 seconds, then some data indication should have been observed. For this reason, an intermittent short in the wiring harness or associated connectors shown in figure 14-5 is indicated. However, other possible causes may be an intermittent in the failure detection logic circuits or the input logic to the computer.

Postflight tests on the individual subassemblies are in progress.

This anomaly is open.

#### 14.1.5 High Heat Leak Into Hydrogen Tank 3

The heat leak into cryogenic hydrogen tank 3 was abnormal during the early hours of the mission. Analysis of the Kennedy Space Center data has shown that the heat leak of this tank was normal prior to lift-off. As shown in figure 14-6, the leak decreased from a high value of 15 to 20 Btu/hour to a normal 2 to 6 Btu/hour by 70 hours and remained normal thereafter. All other parameters were normal.

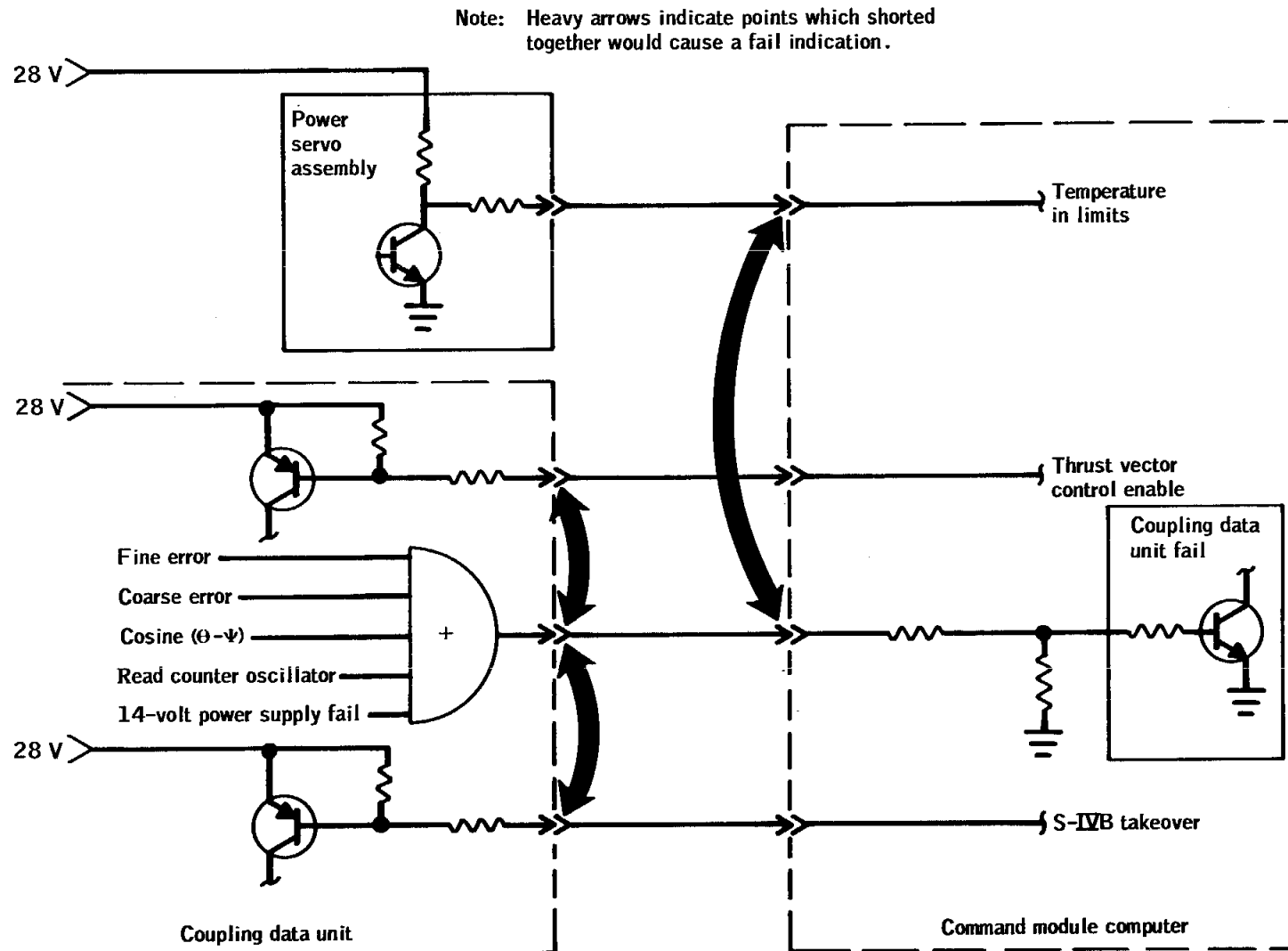


Figure 14-5.- Coupling data unit fail indication.



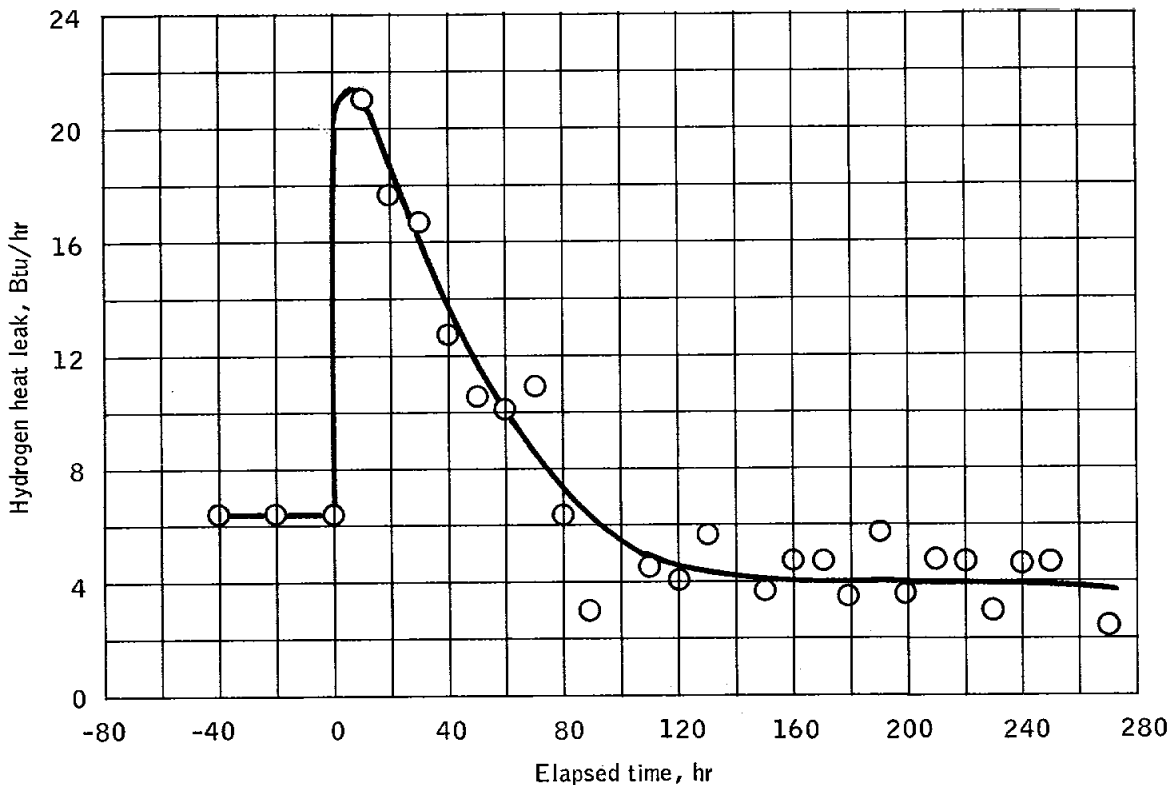


Figure 14-6.- Hydrogen tank heat leak data.

The insulation for this tank consists of several layers of gold-coated H-film in a vacuum annulus that is formed between the inner pressure vessel and the outer shell (fig. 14-7). The primary insulation system is, however, the vacuum annulus. Degradation of this insulating vacuum will cause a significant increase in the heat leak into the tank as shown in figure 14-8. The analysis indicates that the high initial heat leak resulted from a degradation of this vacuum by approximately one decade (approximately  $10^{-6}$  to  $10^{-5}$  torr). This degradation could have been caused by any of three conditions.

- a. If thermal insulation layers rubbed together during the launch phase vibration, the condition could have caused the release of previously entrapped or absorbed gas molecules into the annulus (hereafter referred to as "insulation scrubbing").
- b. A hydrogen leak from the pressure vessel into the annulus.
- c. An ambient air leak into the annulus during launch.

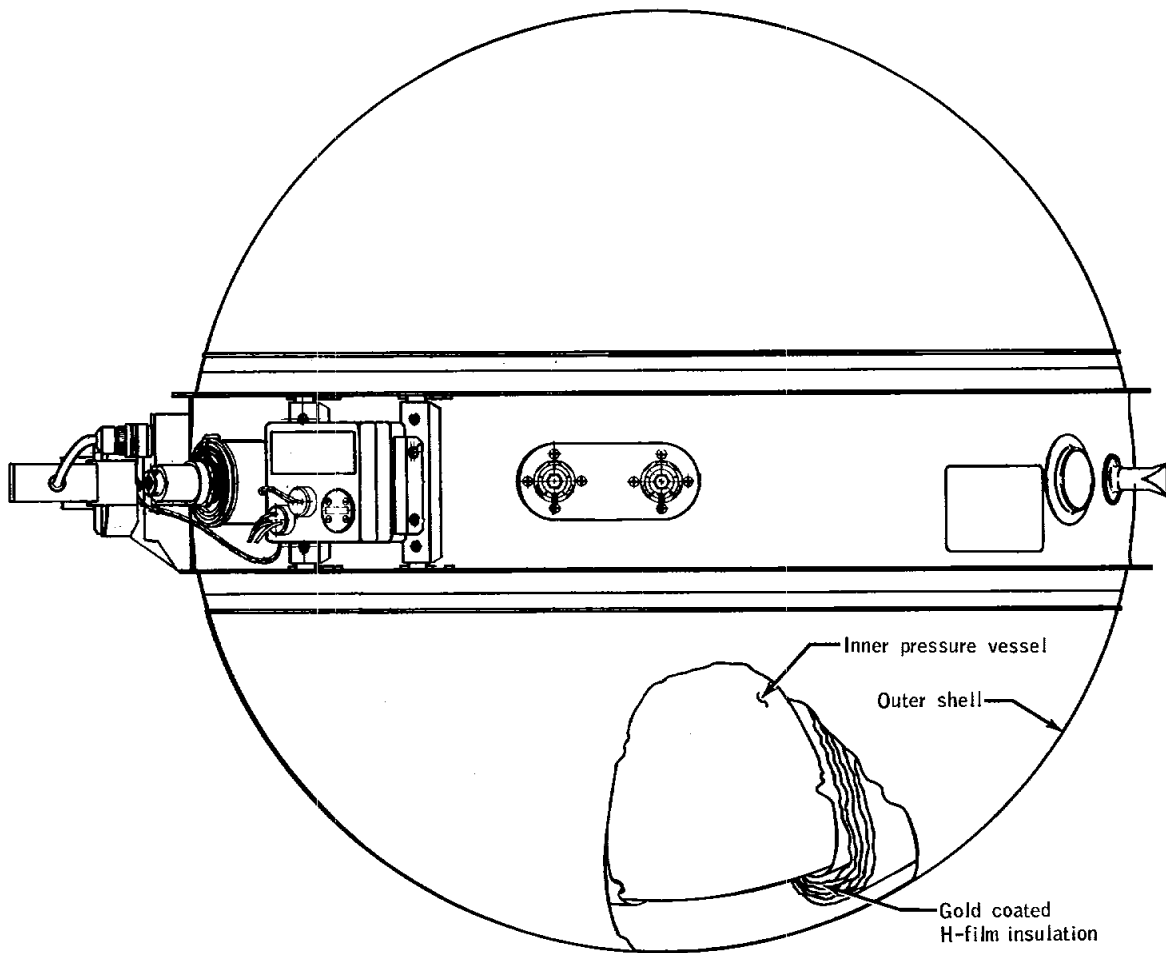


Figure 14-7.- Hydrogen tank.

Condition a.- Insulation scrubbing has been analytically ruled out as a possible cause of the high heat leak. A non-condensable gas such as hydrogen or helium would have produced a constant heat leak since cryopumping would not occur at the observed temperatures. If the gas were condensable, cryopumping would rapidly decrease the pressure at the pressure vessel, preventing the observed heat leak. Nitrogen or oxygen, if originally cryopumped, would have sublimed later in the flight, causing the heat leak to increase to a high level (e.g., 100 Btu/hr at 185 hours), which was not observed.

Condition b.- Hydrogen leak was also eliminated as a possible cause since the leak would have continued throughout the flight and would also have produced a much higher heat leak than was observed.

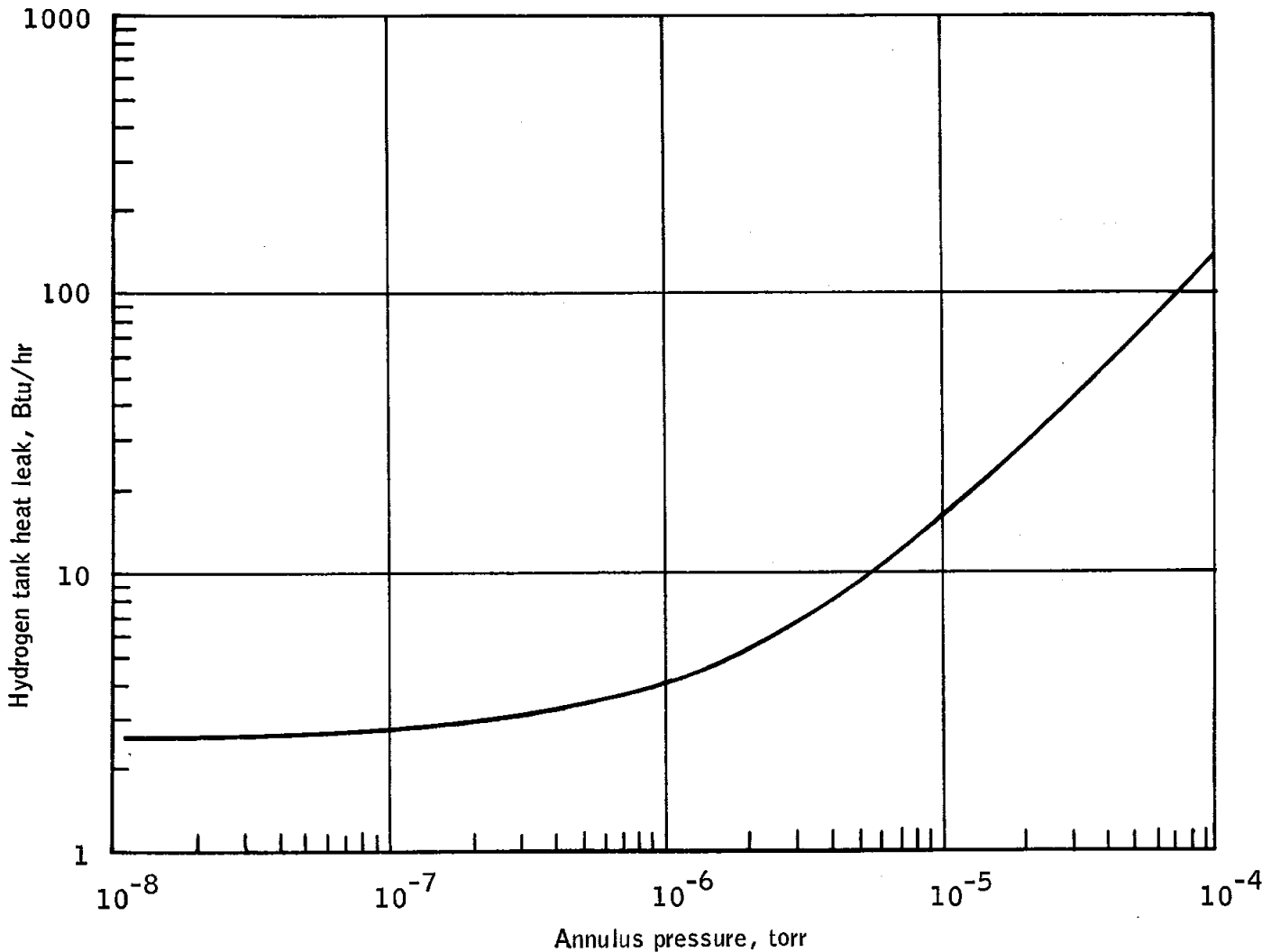


Figure 14-8.- Hydrogen tank heat leak as a function of annulus pressure.

Condition c.- An ambient air leak is the most probable cause of the high heat leak. Figure 14-8 shows that a pressure of  $5 \times 10^{-5}$  torr in the annulus would produce a heat leak of 21 Btu/hr, which is the average observed for the first 10 hours of the flight. The heat leak returned to a normal value of 6 Btu/hr by 80 hours, which corresponds to approximately  $2 \times 10^{-6}$  torr. Assuming that a small hole opened in the outer shell during the launch phase, the annulus pressure would quickly build up to that required to produce the observed heat leak. As the bay pressure continued to decrease and fall below that in the annulus, the annulus pressure would follow the decrease slowly and drop to a final value sufficient to provide the normal heat leak observed by 80 hours. Analysis shows that the area of the opening was at least  $2.2 \times 10^{-3}$  sq cm. For an opening of this size, iterative analysis places the formation of the crack or hole at approximately 2 1/2 minutes into the flight to produce the observed conditions.

A thorough review of manufacturing, test, and checkout records was performed in an attempt to discern any unusual or abnormal conditions to which the tank may have been exposed. Although the investigation failed to produce any definite reason for the failure, it did show one variance from normal procedures that could have affected the tank. This tank was returned to the vendor in October, 1969, for rework of broken wires on the vacuum ion pump power supply. Receiving inspection revealed two abnormal conditions: water was in the bottom of the shipping container and the tank assembly was not secured in any way to the container cradle ring assembly. Normally, the shipping container should be dry and the tank bolted to the shipping container. The broken wires were repaired and tests performed to verify electrical continuity, heater and fan operation, and vacuum ion pump operation (which checks annulus vacuum). Also, an ambient boil-off test was performed with cryogenic hydrogen. The tank was then X-rayed and shipped to the prime contractor. A comparison of these data and X-rays with data from the original acceptance tests indicates that the tank was normal in all respects. The fact that the tank heat leak was nominal prior to launch also verifies that the tank was normal at that time.

The most likely cause of the high heat leak rate early in the mission was the formation of an ambient air leak into the insulation vacuum annulus at approximately 2 1/2 minutes after lift-off. Decreasing ambient pressure gradually returned the annulus vacuum and, likewise, the heat leak rate to normal levels by 80 hours.

No corrective action will be taken since the preflight procedures and inspection of the tanks are adequate. In the event a leak occurs in the outer shell during launch, the vacuum condition will be reestablished later without significantly affecting the total heat input to the tank.

This anomaly is closed.

#### 14.1.6 Up-data Link Command Capability Loss

The spacecraft failed to respond to uplink real-time commands at 42:23:09 and again at 207:14:36. In each case, the condition existed until the crew cycled the up-telemetry command reset switch from "normal" to "off" and back to "normal". This restored normal operation.

A similar problem was experienced on Apollo 9. Extensive review of the spacecraft data, testing of flight hardware, and analysis of the command system did not identify a specific cause of the problem. A special low-voltage test did show that a low-voltage transient could change the vehicle address register and inhibit receipt of any commands until power is cycled to "off" and back to "on", resetting the register. However, on Apollo 9, telemetry data failed to indicate any voltage transient conditions that could be expected to change the vehicle address.

The up-data link message acceptance signal was not present in the spacecraft telemetry data during periods when the command capability was lost. This indicated the problem was associated with a logic lock-up within the up-data link package. The only postulated causes of lock-up are a transient on the spacecraft power system or a transient developed within the up-data link package.

Transients external to the up-data link have been ruled out on the basis of telemetered spacecraft bus voltages, performance of other sensitive spacecraft equipment at the time the problem occurred, and post-flight verification of spacecraft up-data link wiring integrity, including coil transient suppression in the antenna switching relay. Attempts to introduce a malfunction by injecting noise into the up-data link through external wiring were also unsuccessful.

During all attempts to duplicate the mission problem, performance of the up-data link has been satisfactory. With the equipment in the spacecraft, a series of 200 commands switching between omnidirectional antenna D and the high-gain antenna were sent via the S-band system. The up-data link was then removed from the spacecraft and again subjected to a series of 2000 commands without any evidence of malfunction. Monitoring of wiring external to the up-data link did not indicate the presence of internally generated transients.

The up-data link package was opened and measurements were made which verified normal operation of the logic power supplies and the coil transient suppression diodes on each of the real-time command relays.

The up-data link was closed and then subjected to nine impact shocks ranging from 20 g to 50 g while commands were being received to screen for a possible workmanship problem.

No corrective action is planned because it has not been possible to duplicate the flight problem and isolate the malfunctioning component or circuit. If the condition should occur in flight, normal operation can be restored by crew cycling of the up-telemetry command reset switch.

This anomaly is closed.

#### 14.1.7 Leakage During Inflight Chlorination

During the third daily water system chlorination, difficulty was experienced in injecting the chlorine solution. (The chlorine ampule is placed in an injector before use.) Rotation of the injector knob which causes the fluid to be expelled from the ampule seemed stiffer than usual. Fluid leakage (noted at the interface between the needle assembly and the injector when the injector was removed) stopped quickly upon injector removal.

Upon further examination by the crew, the chlorine ampule appeared to be broken (leaking) and the inner bladder was visible after having been extruded past the base plate. Inner bladder extrusion has been observed before but has not been associated with leaks. Figure 14-9 shows typically how the Teflon bladder can be forced past the injector base plate. The body sidewall is not sufficiently rigid to prevent the bladder from extruding around the base plate and being creased, which would be conducive to leaks. Subsequent chlorine injections were satisfactory. The specific ampule which caused the problem was later jettisoned with the lunar module and was not available for postflight inspection.

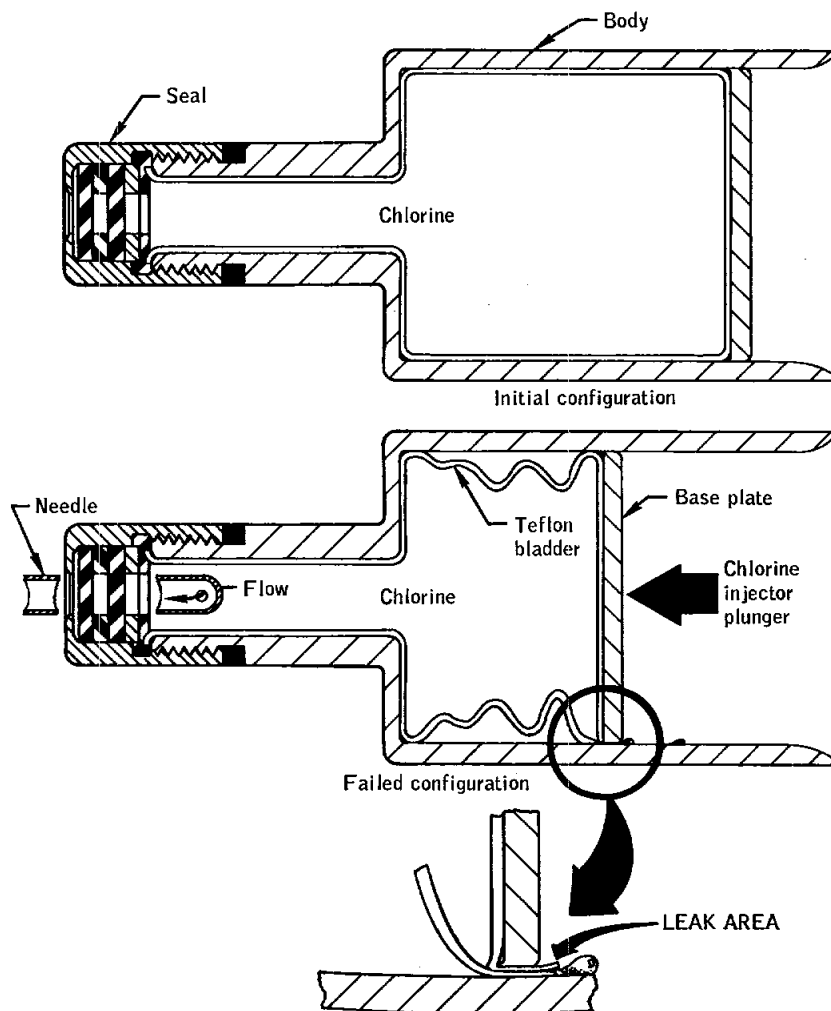


Figure 14-9.- Chlorine ampule failure.

Inspection of the 15 chlorine and 16 buffer ampules returned revealed that 60 percent had loose base plates and 30 percent had bonding adhesive adhering to the inner wall. Eight (five chlorine and three buffer) of the unused ampules were leak-tested. One buffer ampule leaked because the bladder was pinched between the base plate and the side wall.

Corrective action consists of checking all ampules for detection of bonding material on the ampule sidewall or adhesion of the bladder to the sidewall. In addition, the fluid will be evacuated for entrapped air to help preclude the base plate from being loosened due to bladder disorientation resulting from increased pressure in the ampule as the entrapped air expands with cabin pressure decrease.

This anomaly is closed.

#### 14.1.8 Failure of Mass Spectrometer Boom to Fully Retract

During scientific instrument module experiment operations, the mass spectrometer boom mechanism stalled and would not fully retract. The proximity switches indicated that the mechanism always retracted past the safe service propulsion system firing position except before transearth injection. At that time, the mechanism stalled two-thirds out (approximately 200 inches) and would neither extend nor retract. Since the motor had been previously stalled with the current left on for more than 40 minutes, the motor apparently burned out. The boom mechanism and experiment were jettisoned prior to the transearth injection maneuver.

The stalls prior to the last event are believed to be caused by bunching or snagging of the coiled experiment power cable during retraction as this had occurred previously during 1-g testing. On Apollo 15, the failure of the boom to fully retract was attributed to cable bunching and some design modifications were made to help alleviate the problem (see sec. 14.1.6, reference 4).

Apollo 16 data were examined in an attempt to determine why the boom stalled, but nothing in the data revealed the cause. The data indicates that both motors on the mass spectrometer functioned correctly up to the moment of the final failure. The booms always retracted in a normal fashion to within the range of the proximity switch, except in the case of the final failure.

In the absence of any specific evidence, it is assumed that the initial cause of the failure of the boom to fully retract was jamming of the cable in the boom housing. The repeated and prolonged stalling of the motors caused the final failure of the boom in mid-stroke.

The Apollo 17 lunar sounder has two HF antennas which are deployed and retracted by a mechanism that is the same in concept as the mass spectrometer and the gamma ray boom mechanisms. However, the HF antenna mechanism is a simpler design and the antenna has no cables that are required to travel in and out with the antenna. Therefore, the suspected Apollo 16 failure cause is not applicable to the Apollo 17 design; consequently, no corrective action is required.

This anomaly is closed.

#### 14.1.9 Gamma Ray Spectrometer Boom Mechanism Stalled

During lunar orbit scientific instrument module bay operations, the gamma ray boom mechanism stalled and would not fully retract on three of five retractions. The boom mechanism always retracted past the "safe service propulsion system firing" position as indicated by the proximity switch. The cause of the retract failure is not known, but bunching or snagging of the coiled experiment power cable during retraction is considered the most probable cause since this has happened on other occasions during 1-g ground testing.

As in the case of the mass spectrometer boom, Apollo 16 data were examined in an attempt to determine the cause of the incomplete retractions, but the cause was not determined. It is apparent that both motors on the gamma ray spectrometer functioned correctly. The boom always retracted in a normal fashion to within the range of the proximity switch.

In the absence of any specific evidence, it is assumed that the initial cause of the failure of the boom to fully retract was jamming of the cable in the boom housing. No further action will be taken since this mechanism will not be used on spacecraft for any future Apollo missions.

This anomaly is closed.

#### 14.1.10 Service Propulsion Engine Gimbal Actuator Oscillations

During the pre-ignition checklist for the lunar orbit circularization maneuver, an oscillation was detected in the yaw axis of the secondary servo system for the service propulsion engine gimbal actuator. Figure 14-10 is a functional diagram of the servo loop. The oscillation was present in all modes of operation, but only when the secondary yaw servo loop was used. The oscillation was limited at  $\pm 1.0$  degree and at 2.4 hertz with the gimbal correctly following commands to different positions. Figure 14-11 shows one occasion that the oscillation did not occur when repositioning the engine which implies that the failure is electrical in nature.



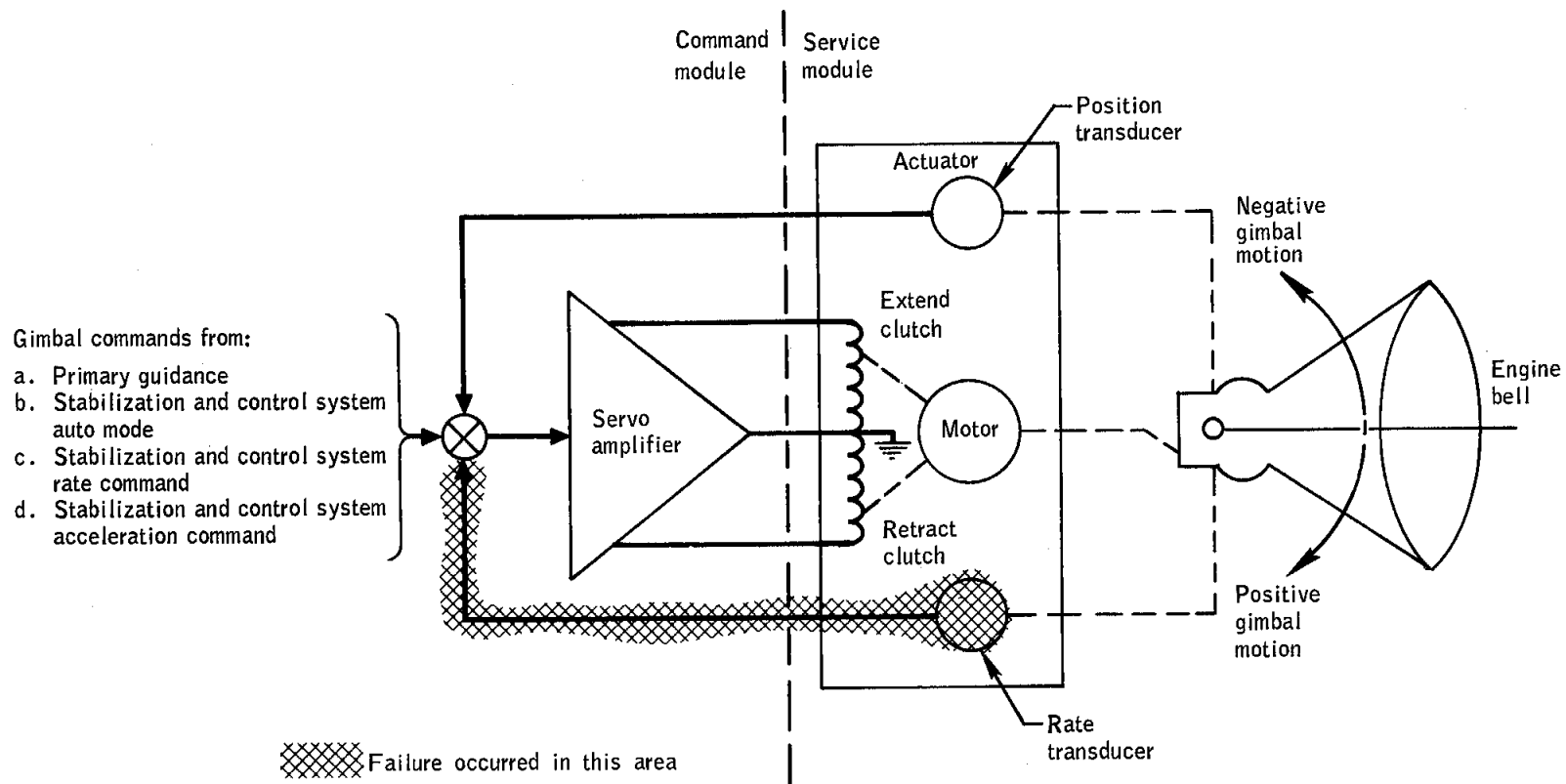


Figure 14-10.- Service propulsion system gimbal servo diagram.

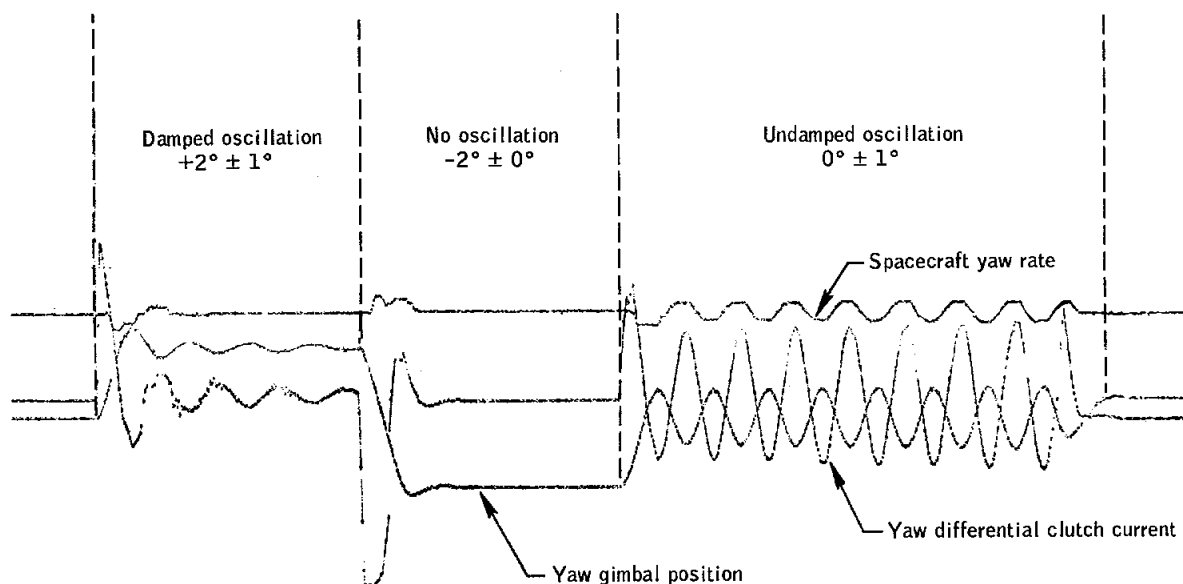


Figure 14-11.- Secondary yaw gimbal drive test  
(primary guidance control).

Inflight results were matched by simulations of system performance with an open in the rate feedback loop of the yaw servo system. It was also demonstrated that the oscillations would have damped after ignition because of the side load forces exerted on the engine bell while thrusting. Therefore, the secondary yaw servo system was considered safe to use if the primary servo system were to fail and it became necessary to switch over to the secondary system.

The cause of the failure was an open in the rate feedback loop of the secondary yaw servo system. Postflight testing of command module wiring and connectors and bench testing of the thrust vector servo assembly did not reveal any abnormalities. Therefore, the failure must have occurred in the service module wiring or connectors. Possible pin corrosion on the engine gimbal actuator wiring harness connectors or broken wires in the yaw gimbal wiring loop are the most probable causes of the flight problem. A broken wire would result from inadequate strain relief (see fig. 14-12) due to cable flexing. Wiring harnesses to the actuator assembly on three other vehicles were reviewed and found to move when the engine was gimballed. Motion of the actuator produced a strain on the harness at the lower clamp. The position of this clamp was changed for the remaining vehicles to provide strain relief.

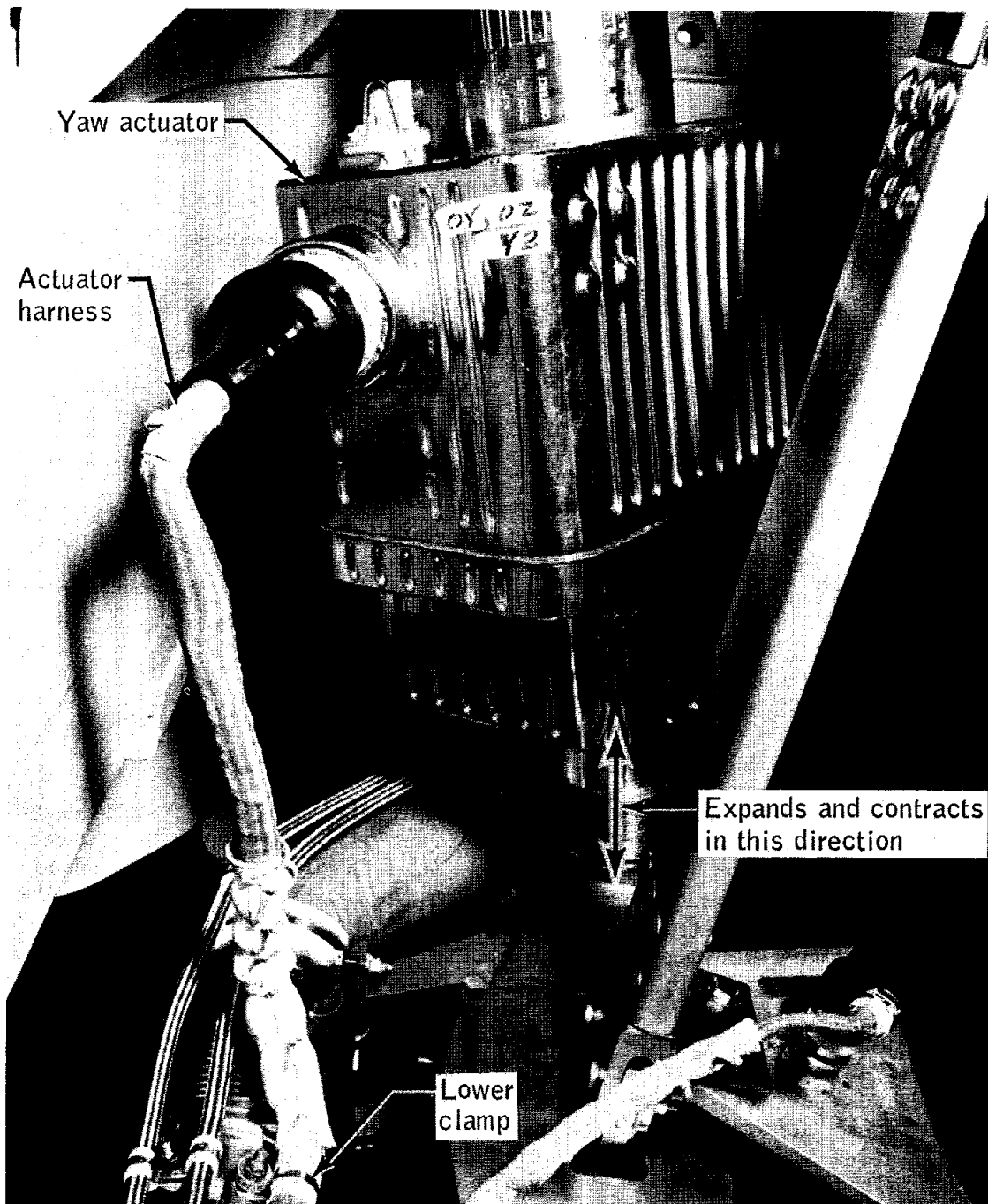


Figure 14-12.- Yaw actuator assembly and interconnecting wiring.

Routing of the wiring harness to the actuator assembly on Apollo 17 has been changed to provide adequate strain relief and prevent harness flexing when engine gimbaling occurs.

This anomaly is closed.

#### 14.1.11 Noise From Cabin Fans

Approximately 2 hours after transearth injection, the cabin fans started making a loud moaning sound. They were turned off and not used again during the mission.

When the spacecraft was received for postflight testing, the cabin heat exchanger inlet duct screens were blocked with lint and debris with paper taped over the screens. However, this had no effect on the operation of the fans. Operation and sound level were normal and the fan current was within specification. Visual inspection of the fans did not show any nicks or indications of interference. Two small pieces of gray tape, approximately 1/4 inch in diameter, and dust were found on the cabin fan exhaust filter (which is installed by the crew after leaving earth orbit).

The most probable cause for the fan noise was some object which got into the fan and was later freed.

This anomaly is closed.

#### 14.1.12 Erroneous Suit Pressure Transducer Reading

While the cabin was depressurized during the transearth extravehicular activity, the indicated environmental control system suit loop pressure transducer reading was 4.6 psia (fig. 14-13). Specification values for this regulated pressure are 3.5 to 4.0 psia and the control point determined from Kennedy Space Center altitude chamber testing was 3.8 psia. The Commander's and Lunar Module Pilot's suit cuff gage readings of 3.5 and 3.8 psia indicated that pressure regulation was satisfactory and that the transducer reading was erroneous.

Prior to the reduced cabin pressure operations, the suit transducer performed acceptably and read within 0.1 psi of the cabin pressure transducer with the suit loop open to cabin. After cabin repressurization, the suit transducer again appeared to read correctly above 4.6 psia.

The suit pressure transducer was removed from the command module during postflight testing and a reduced-pressure test and calibration check

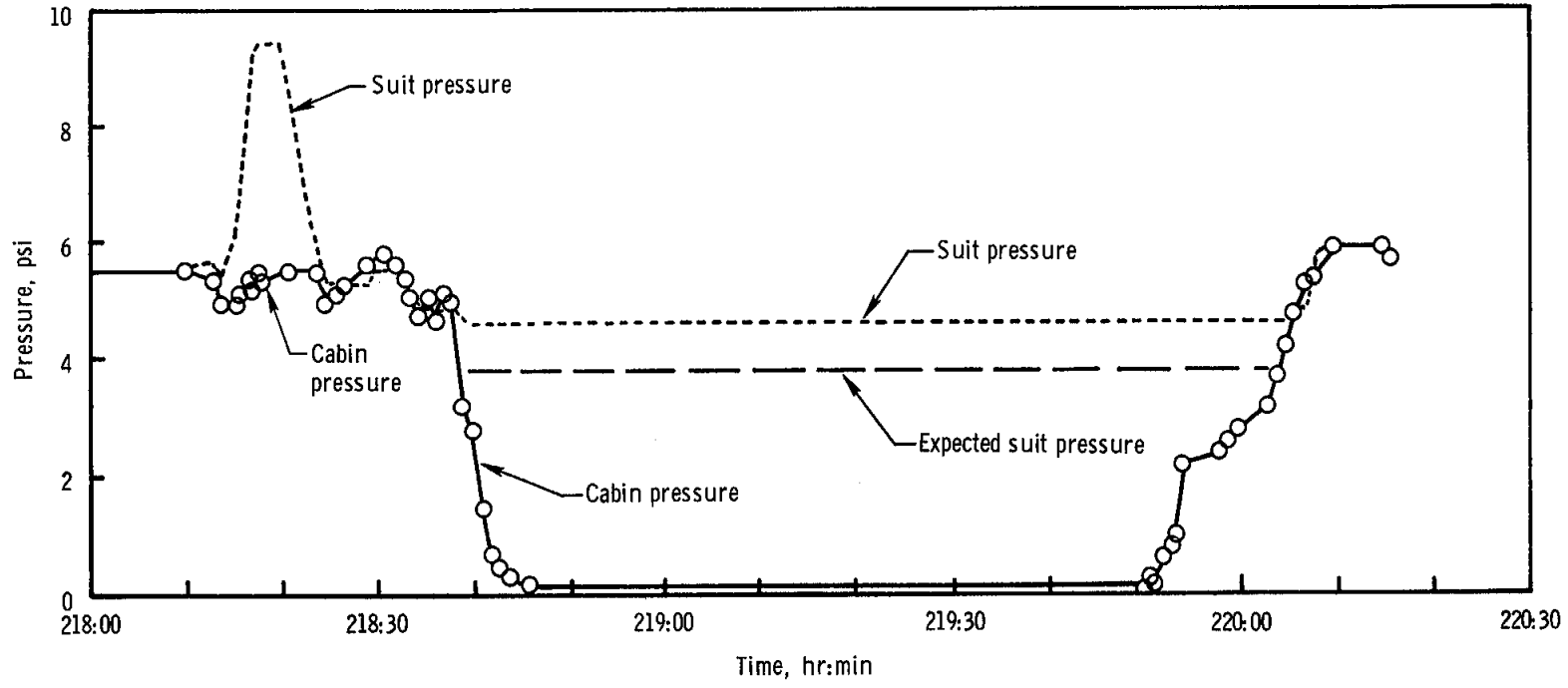


Figure 14-13.- Suit loop pressure data.

were conducted. The results were within tolerance. Teardown analysis revealed three particles of calcium aluminum silicate (lunar origin) ranging from 500 to 2000 microns in size in the sense cavity. If one of the lunar particles had been caught in the air gap (see fig. 14-14) of the variable reluctance element, the armature would transmit an incorrect signal. Normal readings were obtained when the cabin was repressurized and a suit pressure in excess of 4.6 psia was obtained. This could have freed any particle that might have been lodged in the air gap.

The corrective action for Apollo 17 and later spacecraft will be to add a 5-micron filter in the suit pressure sense line to protect the suit pressure transducer.

This anomaly is closed.

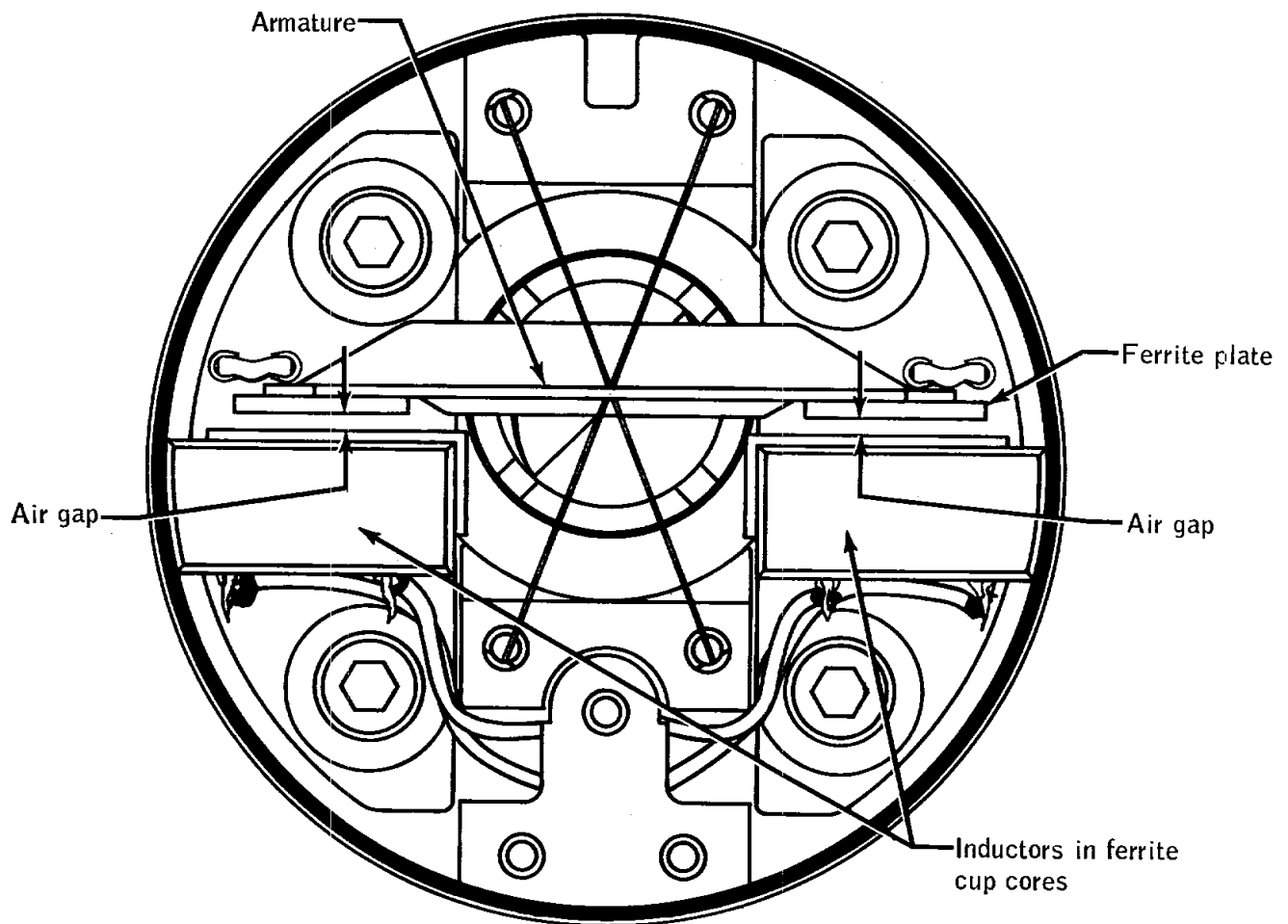


Figure 14-14.- Suit pressure transducer.

#### 14.1.13 Digital Event Timer Counted Erratically

The digital event timer, located on panel 1, indicated erroneous time (compared to computer time) after counting up or down over a preset time interval. It had performed satisfactorily during the early portion of the flight, but began to malfunction approximately midway through the mission. Postflight testing verified that the "tens of seconds" wheel would not update, counting either up or down, and would cycle for several seconds when the timer was reset (the maximum time should have been 0.3 second).

Inspection of the digital event timer showed that the bearing points in the magnesium motor plates had been elongated. The idler gear is free to rotate on the shaft (fig. 14-15); however, the design permits the stainless steel shaft to also rotate which would account for the wear in the motor plates. The elongated bearing points permitted the idler gear to rub against the number wheel. This interference rubbed paint off the number wheel and the paint particles prevented the slip rings and brushes from making good contact which affected proper counting of the seconds wheel.

The bearing points also elongated on the Apollo 15 digital event timer. The idler gear shaft can be prevented from rotating by staking at the bearing point in the motor plates. For Skylab, corrective action will be to secure the shafts of digital event timers, that require opening of the case for other rework. For Apollo 17, the units will be visually inspected for signs of wear.

This anomaly is closed.

#### 14.1.14 Uneven Drive Rates of the Scanning Telescope

The crew reported that the scanning telescope shaft axis drove erratically and seemed to get worse with time. The condition was observed in the computer mode and the zero optics mode and only through the telescope. The uneven drive rate was related to a change in the characteristic noise level when the optics was being driven. The crew could not be certain whether the uneven drive rates were directly or inversely proportional to the noise level.

The telescope shaft axis is slaved to the sextant shaft through 1X resolvers in each unit. No drive problem was reported with the sextant; however, it is doubtful whether uneven drive rates would have been detectable by the crew because of the differences in the magnification and field of view of the two instruments. No uneven drive rates have been observed in flight data.

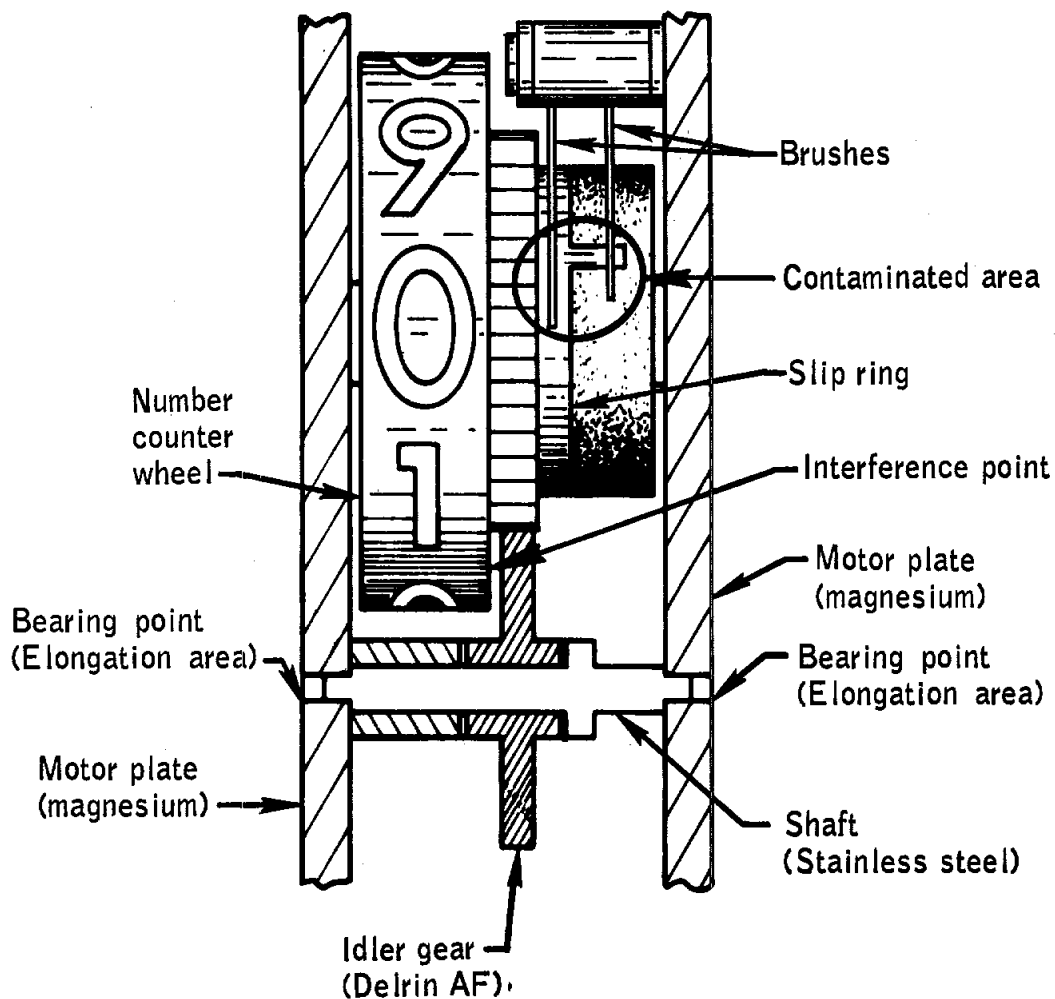


Figure 14-15.- Digital event timer seconds counter.

The optical unit assembly was thoroughly soaked during recovery by salt water which caused extensive corrosion. The unit was cleaned, however, and tested. The intermittent flight condition was reproduced by wiggling the scanning telescope wiring harness in the optical unit assembly. An examination of the female connector on this harness revealed 9 of 61 contact springs (fig. 14-16) were cracked or broken. Also, several contact springs were found broken in a 91-pin connector in the optical unit assembly. The cause of the broken springs is being investigated.

This anomaly is open.



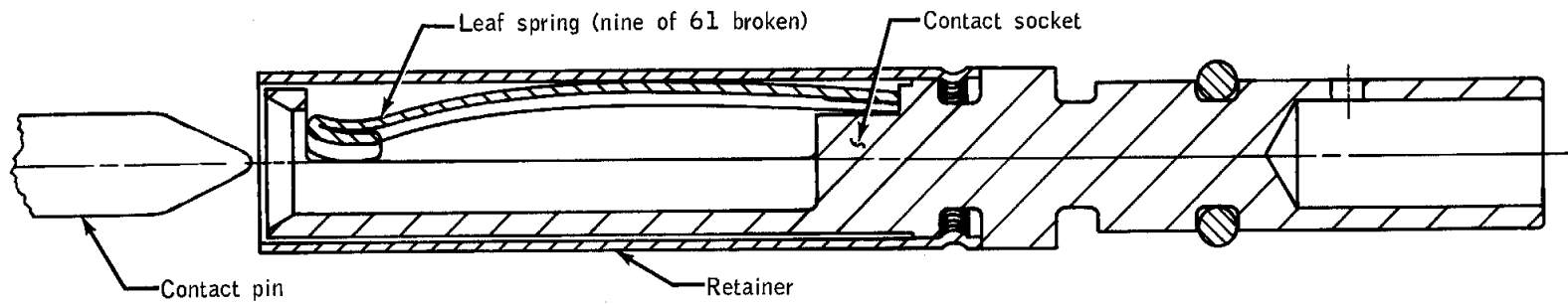
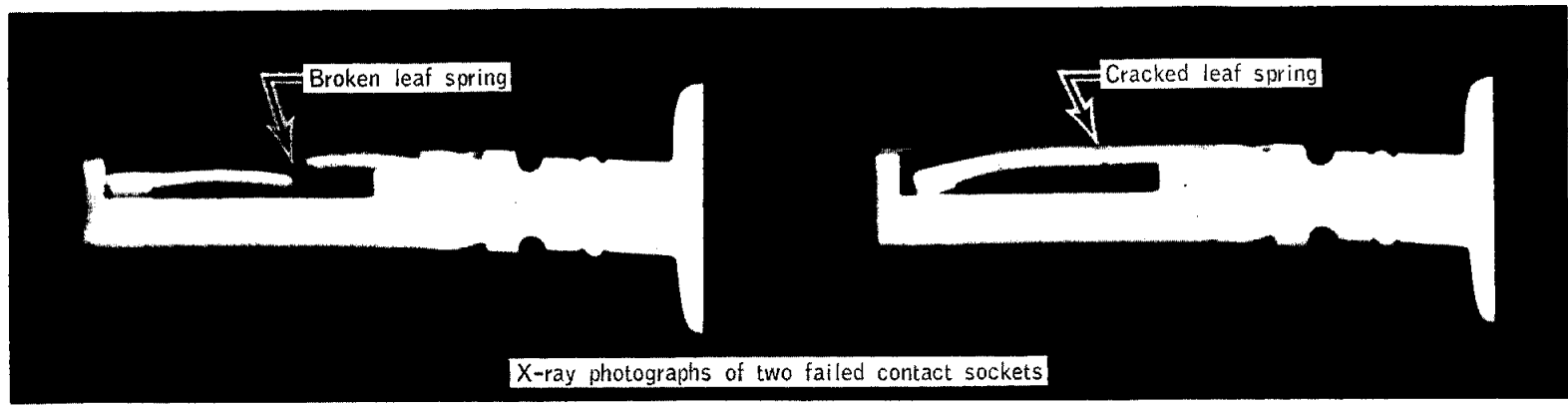


Figure 14-16.- Contact and leaf spring arrangement of optical unit connector.

#### 14.1.15 Sticking Lithium Hydroxide Canister

During the first lithium hydroxide canister change performed after redocking with the lunar module, considerable trouble was experienced in removing used canister 12 from side B of the environmental control unit. Some minor sticking was also noted during an earlier change (at approximately 152 hours) while removing canister 10 from side B. No problems were encountered removing other canisters.

Both canisters had been used extensively during lunar orbit solo operations. Under conditions of high flow, low temperature, and low carbon dioxide supply, the exothermic reaction is insufficient to drive off the atmospheric and reaction moisture which accumulates in the canisters. The canisters apparently expanded due to the retention of the excessive moisture.

Conditions conducive to this problem were present during the solo period. The Command Module Pilot noted that he had positioned the suit flow control valves to "suit full flow", allowing significantly higher gas flow through the environmental control unit carbon dioxide canister than had occurred during the comparable period on previous missions. The average flow was 56 cu ft/min during the Apollo 16 solo period as compared to 36 cu ft/min during the Apollo 11, 12, 14, and 15 solo periods. The valves were positioned to cabin flow during these previous missions.

Although canister 10 was jettisoned with the lunar module, canister 12 was returned for inspection and analysis. Figure 14-17 shows a cross-section of the lithium hydroxide canister. The lithium hydroxide swells while it is being used, and to account for this swelling, the units are fit checked in the spacecraft with 0.030-inch shims on all sides. Additionally, the pull force required to remove the canister is checked with the shims in place. An analysis performed on five separate layers of the chemical bed indicated that approximately 32 percent of the lithium hydroxide had been used. In addition, the analysis showed the moisture content to be approximately 21 percent compared to a range of 5 to 10 percent found in canisters used during the solo period on previous flights.

A dimensional analysis showed both sides of the environmental control unit canister receptacle to be within specification, although postflight removal forces using the canisters indicated a tighter fit in side B (53-lb pull) than side A (22-lb pull). The preflight pull force for this canister was 18 pounds. Normally, pull forces for these canisters are 10 pounds or less.

The combination of the adverse environment and the initially tighter-fitting canister apparently accounted for the removal difficulty.

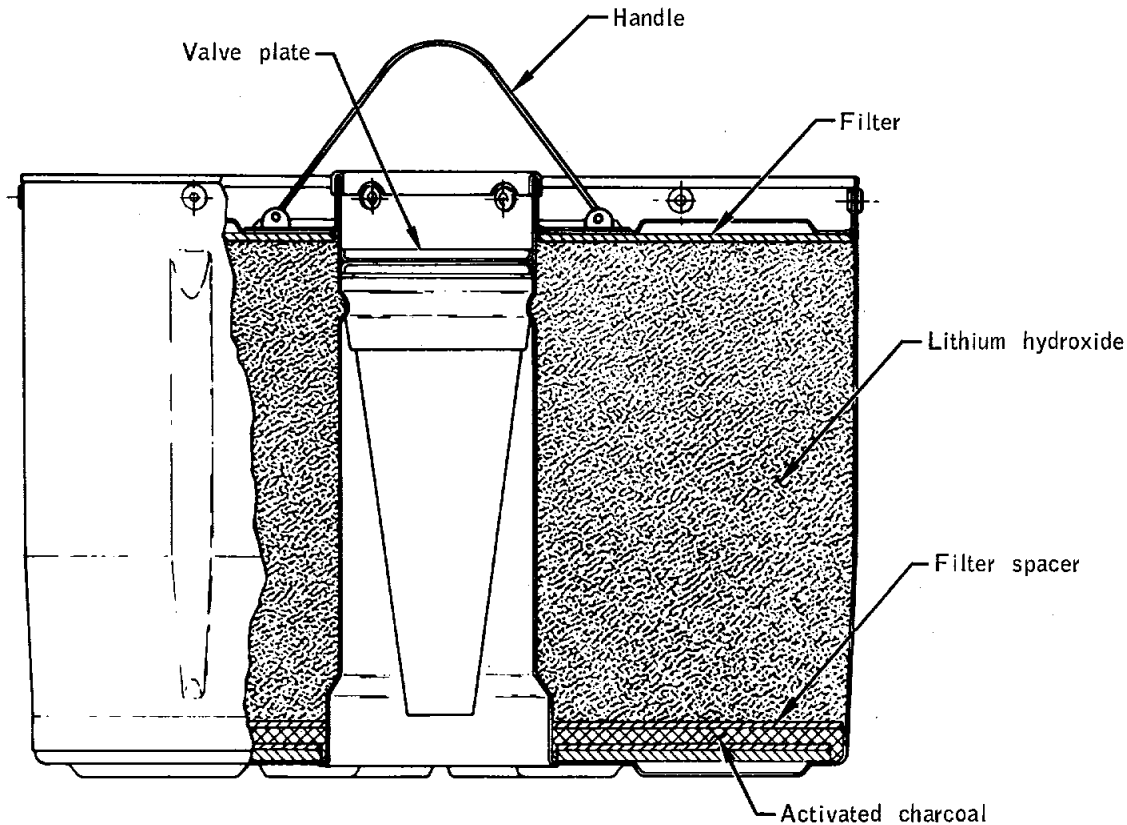


Figure 14-17.- Lithium hydroxide canister.

To prevent recurrence of this problem during the Apollo 17 mission, the prelaunch insertion and removal force specification during fit checks at the Kennedy Space Center will be changed from 30 pounds to 8 pounds for the canisters to be used during the solo activities. The maximum allowable force on the remaining canisters will be reduced to 15 pounds. In addition, flight procedures will be changed to insure that the suit flow control valves are positioned to cabin flow for solo operation.

This anomaly is closed.

#### 14.1.16 High Gain Antenna Would Not Acquire

High-gain antenna operation was lost for approximately 1 1/2 hours beginning at 234:14 while the command and service module was in the passive thermal control mode and the crew were asleep. Communications with

the spacecraft were being maintained by ground-commanded switching between the high-gain antenna and omnidirectional antenna D. The initial indication of a problem occurred at about 234:04 when the high-gain antenna reached the scan limit and failed to drive to the position set on the manual controls. Figure 14-18 shows the path taken by the antenna prior to the anomaly, where it stopped, and the position to which it should have driven. The antenna remained at the position indicated until the crew awakened about 1 1/2 hours later and cycled the high gain antenna track mode switch from "reacquisition" to "manual" and then back to "reacquisition".

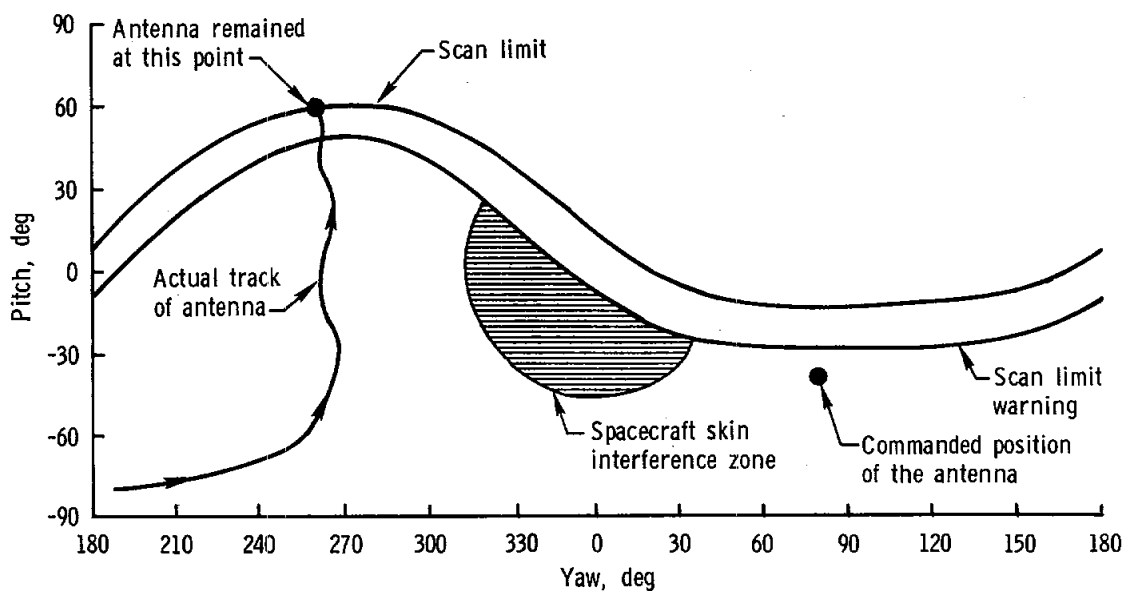


Figure 14-18.- High gain antenna scan limit.

Figure 14-19 shows the pitch and yaw positions and signal strengths in the time frame of the problem. This figure indicates normal high gain antenna operation up to and immediately following entry into the scan-limit region. The step decrease in both uplink and downlink signal strength was due to switching from narrow to wide beam. Such a beam switch results when the logic latchup circuit 2 latches (fig. 14-20). Logic latchup circuit 2 latches when logic latchup circuit 1 latches and logic latchup 1 latches when the antenna with the "reacquisition" track mode selected, tracks from the clear track area to the scan limit. Latching of logic latchup 1 also internally switches the antenna to manual track. For the

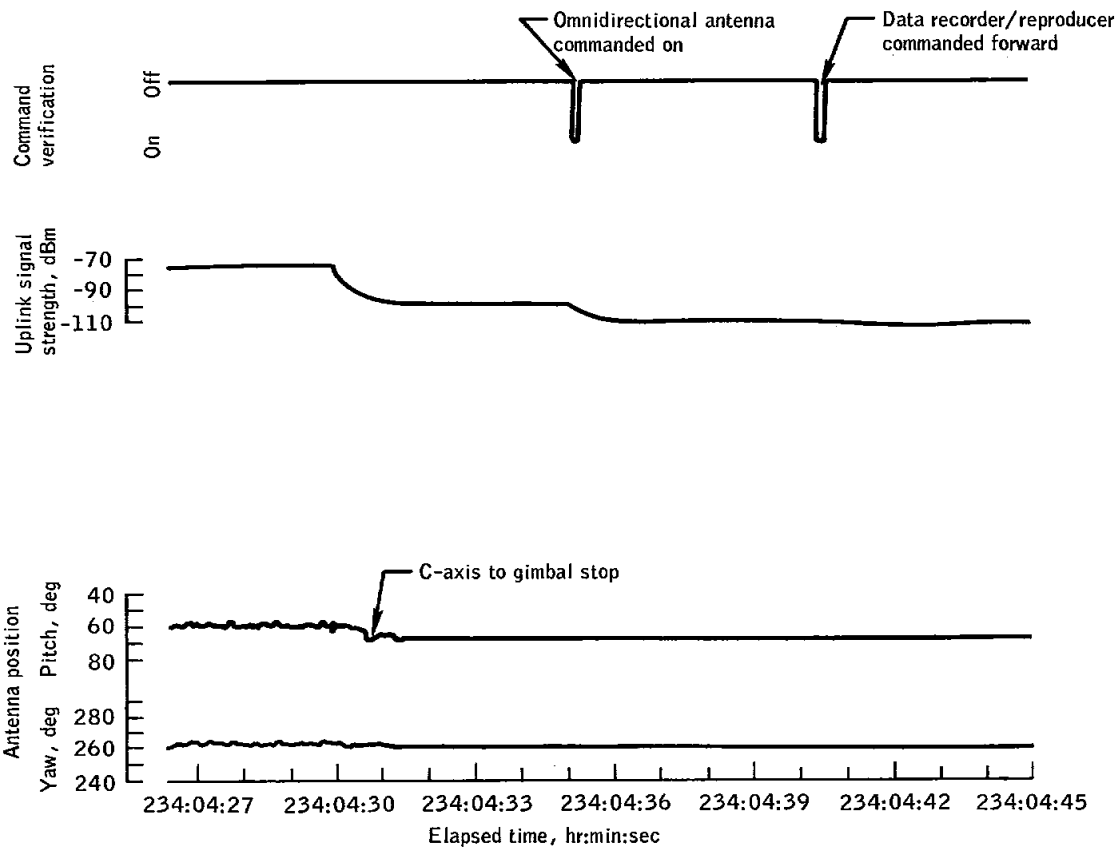


Figure 14-19.- High-gain antenna data at beginning of anomalous period.

antenna position (pitch = 60 degrees and yaw = 258 degrees at the scan limit) and the commanded position (pitch = -44 degrees and yaw = 84 degrees), the C-axis error signal is large and it should drive the C-axis to the gimbal stop upon switching to "manual". The A-axis should also start rotating, but its response is very slow because it is essentially 180 degrees away from the commanded position. The A-axis manual error signal also has a false unstable null 180 degrees away from the true null. The rapid change in pitch shortly after the beam switching, shown in figure 14-19 (from approximately 59 deg to 71 deg) is verification that the C-axis drove to the stop as expected. Normally, the C-axis would remain against the gimbal stop until the A-axis rotated approximately 90 degrees and then would drive away from the stop to the commanded position.

Shortly after the C-axis drove to the stop, the noise on the high-gain antenna pitch and yaw readouts disappeared until the problem cleared following the switch to "manual" track. Noise has been observed on the high-gain antenna pitch and yaw measurements in the past. Essentially,

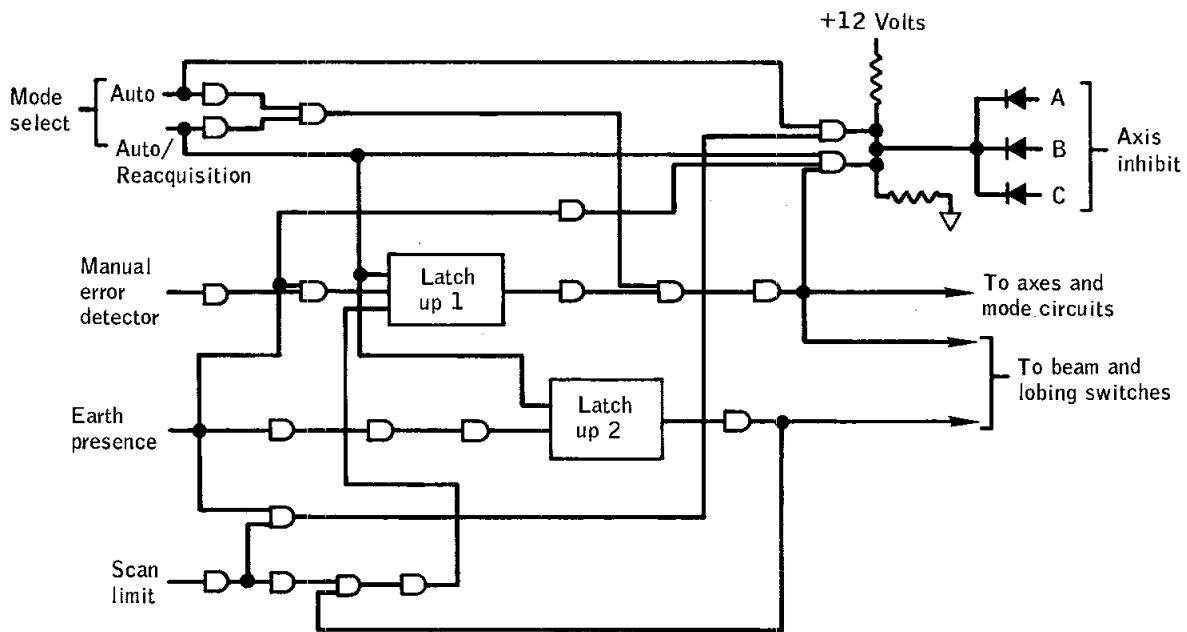


Figure 14-20.- High-gain antenna logic diagram.

no noise has been associated with the "inhibit" mode. Figure 14-20 shows that selecting the "automatic" mode and reaching the scan limit triggers an "inhibit" circuit.

The noise on the pitch and yaw readouts reappeared following the track mode switch. The high-gain antenna acquired and operated normally after cycling the mode select switch to "manual" and then back to the "automatic reacquisition" position.

In summary, the data showed:

- a. The antenna remaining near the "earth set position" instead of driving to the "predicted earth rise position" after entering the scan limit.
- b. Noise disappeared on the high gain antenna pitch and yaw readouts.
- c. Cycling the track mode switch from "reacquisition" to "manual" cleared the problem.

The variations in current, combined with the resistance between the electronic box common ground and spacecraft ground cause noise on the high-gain antenna pitch and yaw readouts. An inhibit reduces the gain of the mode switch circuits so that the current variations, and hence the noise, are reduced. The reduction in noise, consequently, indicates that the logic went to the "inhibit" mode.

Tests associated with logic operation, for the high-gain antenna operating conditions involved, revealed no condition or combination of conditions in the logic of a normal circuit that could cause the anomaly. This included elimination of a possible A-axis false null hang-up. Furthermore, the tests showed that the noise on the pitch and yaw readouts did not disappear when a false null hang-up was induced.

Tests did indicate, however, that the anomaly could be the result of simultaneous selection of both the "reacquisition" and "automatic" track modes. In this case, an inhibit would result if the antenna entered, and remained inside the scan limit (fig. 14-20). Simultaneous selection of both "reacquisition" and "automatic" track would require a fault, or malfunction in the mode select switch, associated spacecraft wiring, or internally in the high-gain antenna electronics. Although the telemetry data indicate no voltage on the "automatic" select line, such a condition could occur and not be detected. The mode select switch and the associated wiring, however, were thoroughly checked, including disassembly and inspection of the switch, and no discrepancies were noted.

Stray voltage on the "automatic" select line is highly unlikely since tests showed that 13 to 14 volts at the electronics box input were required to select a track mode. A review of the electronic box circuits involved indicated no internal malfunction that could result in simultaneous "automatic" and "reacquisition" track, then be cleared by cycling the track mode switch, and not exhibit other unique symptoms. The other possibility for the cause of the anomaly is that one of the two logic inhibit gates may have malfunctioned.

The integrated circuit generating the inhibit is shown in figure 14-21. These types of devices have been found susceptible to contamination from internal floating particles. A particle can move as a result of acceleration or electric fields, and create an internal short which changes the state. Additional acceleration or changes in the electric fields can result in the particle moving again and either clearing the problem, or showing itself as an intermittent problem.

The particular integrated circuit was manufactured prior to incorporation of passivation which reduced the likelihood of floating particle contamination.

A particle resulting in any one of the following shorts (fig. 14-21) would result in an unscheduled inhibit.

- a. Collector-to-base -  $Q_{12}$ ,  $Q_{13}$ ,  $Q_{22}$ , or  $Q_{23}$
- b. Collector-to-emitter -  $Q_{11}$ ,  $Q_{12}$ ,  $Q_{21}$ ,  $Q_{22}$
- c. Base-to-collector supply -  $Q_{12}$ ,  $Q_{13}$ ,  $Q_{22}$ ,  $Q_{23}$

An internal short of this type would have to clear when the track mode switch was changed from "reacquisition" to "manual".

No corrective action is planned because experience shows contamination in the electronics box has a low probability of occurring. Further, if the problem became permanent in one electronics box, the secondary unit can be selected.

This anomaly is closed.

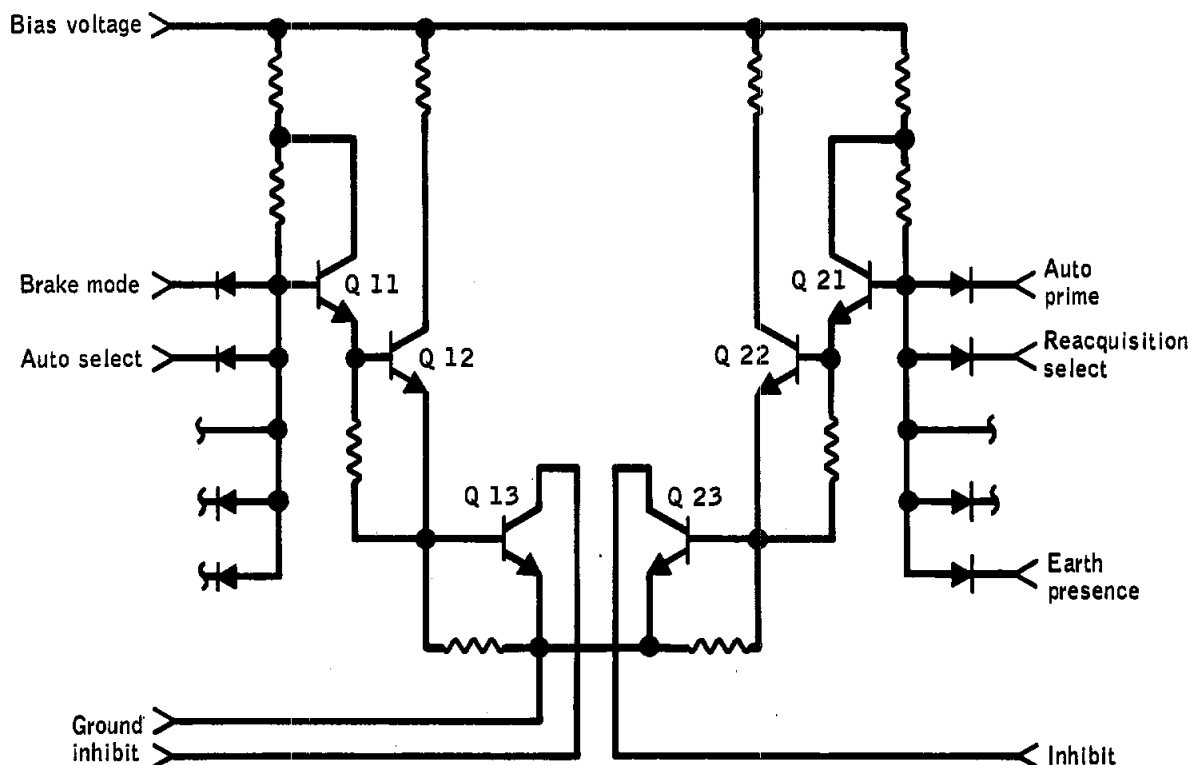


Figure 14-21.- Schematic of integrated circuit within uplink package.



#### 14.1.17 Difficulty in Extending and Locking the Y-Y Strut

The Command Module Pilot had difficulty in extending and locking the Y-Y strut in preparation for entry and commented that he could not discern any clearance between the strut pad and command module wall.

Postflight investigation showed no significant binding during strut operation. Visual examination (fig. 14-22) showed:

- a. Wear areas along the keys
- b. The strut barrel was 2.757 inches in diameter and should have been between 2.740 and 2.750 inches
- c. The set screws which provide a stop for the strut piston in the strut barrel were bottomed out against the piston.

The strut barrel was deformed by the set screws and caused the wear along the keys because the barrel became within tolerance as soon as the set screws were adjusted to the specified gap of 0.002 to 0.005 inch.

A similar condition was reported on the Apollo 17 spacecraft and corrected by adjusting the set screws. Engineering has been released to verify these dimensions prior to installation for future spacecraft.

Postflight investigation of Apollo 16 also verified a sidewall clearance of 0.044 inch which compares to 0.041 prior to launch. The Apollo Operations Handbook has an inflight procedure to remedy this situation.

This anomaly is closed.

#### 14.1.18 Holes in Canopy of Main Parachute

Inspection of the canopy of one of the recovered main parachutes indicated numerous small burn holes which are similar to the burn holes observed on parachutes from previous missions (fig. 14-23). The cause of the earlier holes had been attributed to the reaction control system oxidizer.

During the final descent, at an altitude of about 350 feet, the crew manually fired the two plus-yaw engines for the planned 1-second, then fired the two minus-yaw engines, again for about 1 second. This procedure was performed to bleed off the pressure trapped between the engine valves and the propellant isolation valves which are closed at about 3000 feet altitude (the firings were thus referred to as the "burp firing").

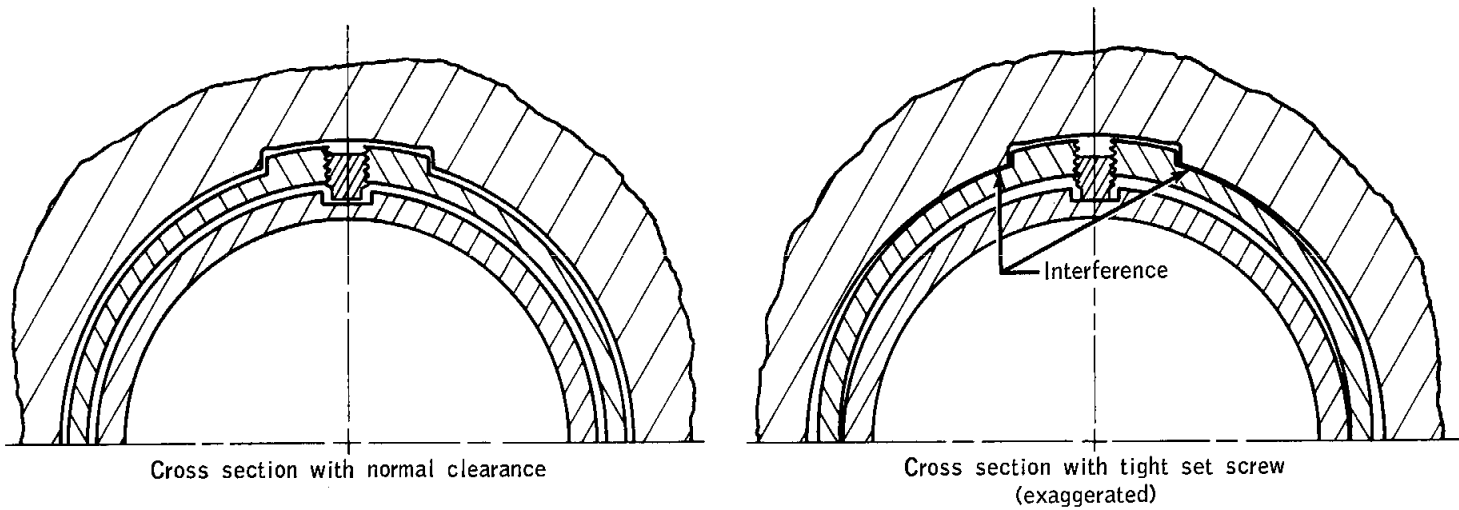
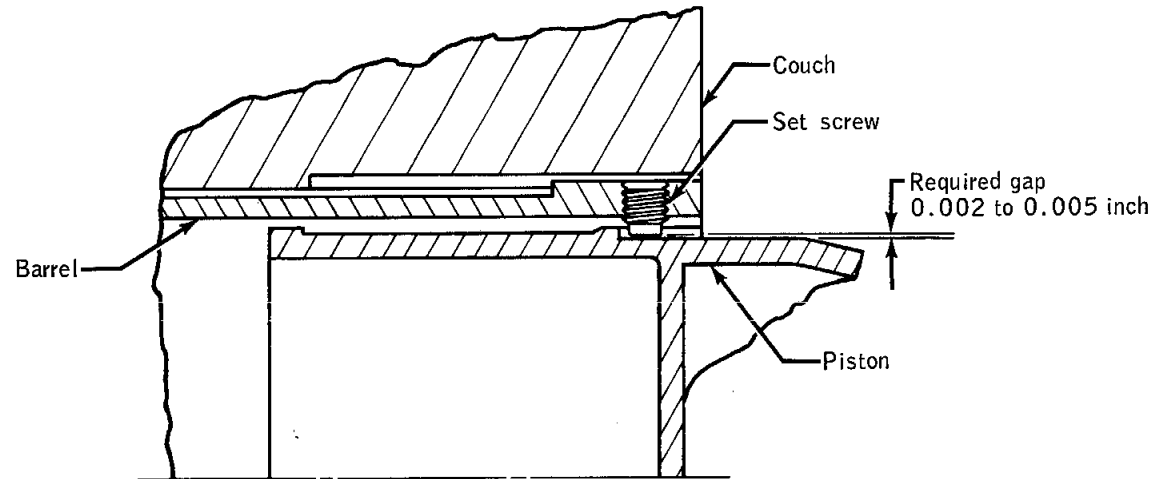
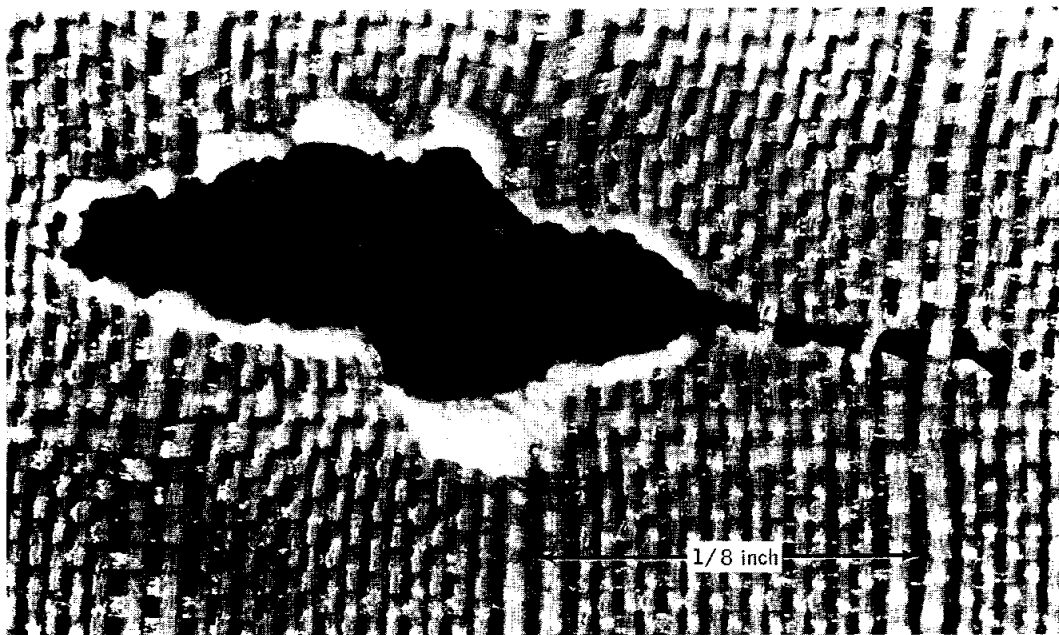
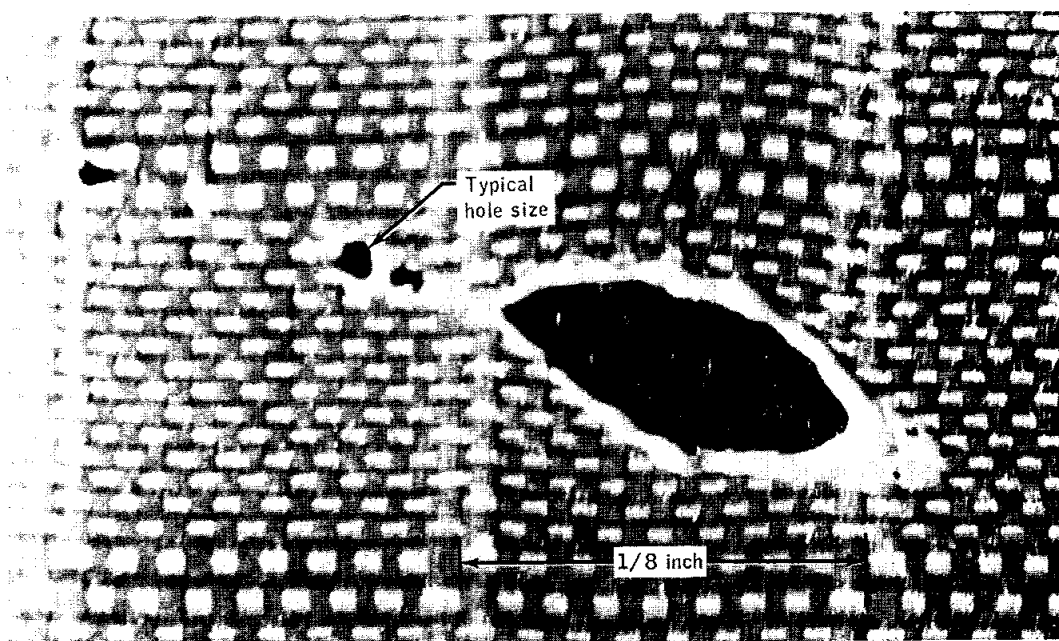


Figure 14-22.- Couch strut interference.



(a) Apollo 4 parachute.



(b) Apollo 16 parachute.

Figure 14-23.- Typical burn holes found in recovered parachutes.

Analysis of films of the burp firing indicated that flame was produced outside of the plus-yaw engines for a period of about 0.5 second. This flame started at the engines and extended upward toward the risers before extinguishing itself. Oxidizer flow also appeared for about 1 second as evidenced by a red vapor cloud.

The basis for this firing was the concern that the pressure increase resulting from the sea-water wetting of the reaction control system lines between the isolation valve and the thruster could cause the pressure to reach the burst limits of the weakest component which is the thruster assembly. The temperature of the reaction control system lines prior to landing is about 55° F; however, after landing, wetting can raise the temperature of the lines to about 85° F. The actual pressure profile in the system due to a temperature change of about 30° F will be determined by testing a spacecraft system. The results will show whether a "burp firing" is necessary. Normally, the isolation valve will relieve any pressures up to 800 psi that may be trapped between the isolation valves and the thrusters.

A leak in the isolation valve bellows can prevent the valve from relieving but this is the only failure which could prevent the isolation valve from operating normally. For the condition of the isolation valve not relieving, a test is being conducted to determine the maximum system pressure that could be expected.

In the event that pressure relief is required in the lines, an on-the-water operation of the isolation valve or the thrusters is being considered.

This anomaly is open.

#### 14.1.19 Water/Glycol on Command Module Floor

During postflight operations, residue from approximately one teaspoon of water/glycol was found on the command module floor in front of the environmental control unit. A trace was also noted on the lower front edge of the suit heat exchanger and on the coolant control panel side of the environmental control unit.

Subsequent proof pressure and pressure decay tests conducted on both the primary and secondary coolant circuits were satisfactory. The coolant panel was cut away as required to visually observe possible leakage in the suspected area of the primary suit heat exchanger diverter valve. No leaking was observed and the torque stripe was intact on all B-nuts in that area.

During the helium pressure decay check, a leak of  $255 \times 10^{-7}$  scc/s was observed during repositioning of the suit heat exchanger bypass valve. A fiber was found under the two O-ring seals on the control key shaft when the valve was disassembled (see fig. 14-24). The valve is motor driven between two positions. The O-rings around each of the four openings (fig. 14-24) in the valve body normally maintain a seal at the selector and valve body interface, i.e., when the selector is in either position. During the movement of the selector from one position to the other, which requires about 20 seconds, system integrity through the valve is maintained by the two O-rings on the key shaft. Although the only time this valve is moved during the mission is just before entry into the earth's atmosphere, it is activated numerous times during spacecraft testing after the system is filled with water/glycol and pressurized.

The environmental control unit area, i.e., the bypass valve, B-nut connections, and cabin floor will be inspected for glycol leak prior to launch on subsequent missions.

This anomaly is closed.

#### 14.1.20 Oxidizer Deservicing Tank Failure

An explosive failure of a ground support equipment decontamination unit tank occurred during the postflight deactivation of the oxidizer (nitrogen tetroxide) portion of the Apollo 16 command module reaction control system.

The command module reaction control system is emptied of all remaining propellant using ground support equipment designed to provide an acid/base neutralization of the propellant in both the liquid and gaseous phases so that it may be disposed of safely. During the deactivation operation of the oxidizer from the Apollo 16 command module on May 7, 1972, the scrubber tank of the decontamination unit exploded, destroying the ground support equipment unit and damaging the building that housed the operation. Only minor injuries were received by the personnel in the area and the command module was not damaged. More detailed information concerning the incident is given in reference 7.

Test results show that the failure was caused by an insufficient quantity of neutralizer for the quantity of oxidizer. This insufficiency lead to exothermic nitration-type reactions which produced large quantities of gas at a very high rate and failed the decontamination tank.

Recommendations of the Apollo 16 Deactivation Investigation Board will be implemented for Apollo 17 and following missions (ref. 8).

This anomaly is closed.

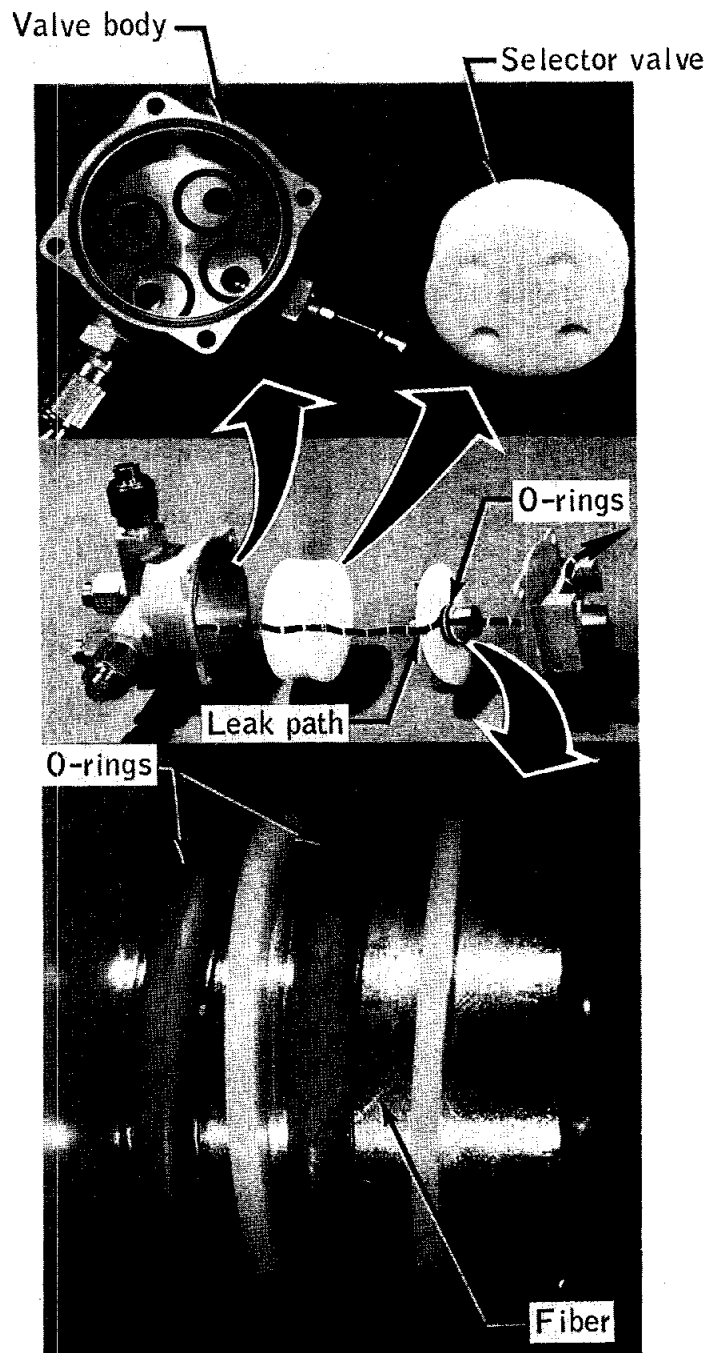


Figure 14-24.- Disassembled heat exchanger bypass valve.

## 14.1.21 Reaction Control System Regulator Inlet Filter Failure

As a result of the Apollo 16 lunar module reaction control system regulator anomaly, the command module reaction control system regulators were removed for postflight testing and examination. A visual examination showed two of the regulator cylindrical-inlet-filter assemblies were deformed in the area of the end screen (fig. 14-25). On one filter, the end screen was bulged out about 0.060 inch. The visual examination also revealed that these two filters have either a wire separation or crack in the end screen near the peripheral weld area. Tests showed that the bubble point on the worst-case filter had increased to 100 microns (specification is 25 microns). The filters on the other two regulators were essentially normal, and testing on these two regulators showed completely normal characteristics.

The deformed filters are being evaluated. This evaluation includes retesting the filters for bubble point and performing a microscopic examination and a metallurgical examination in the areas of the wire separation. The objective of this investigation is to establish if the deformation is a normal condition resulting from system activation or if a unique condition occurred on Apollo 16.

This anomaly is open.

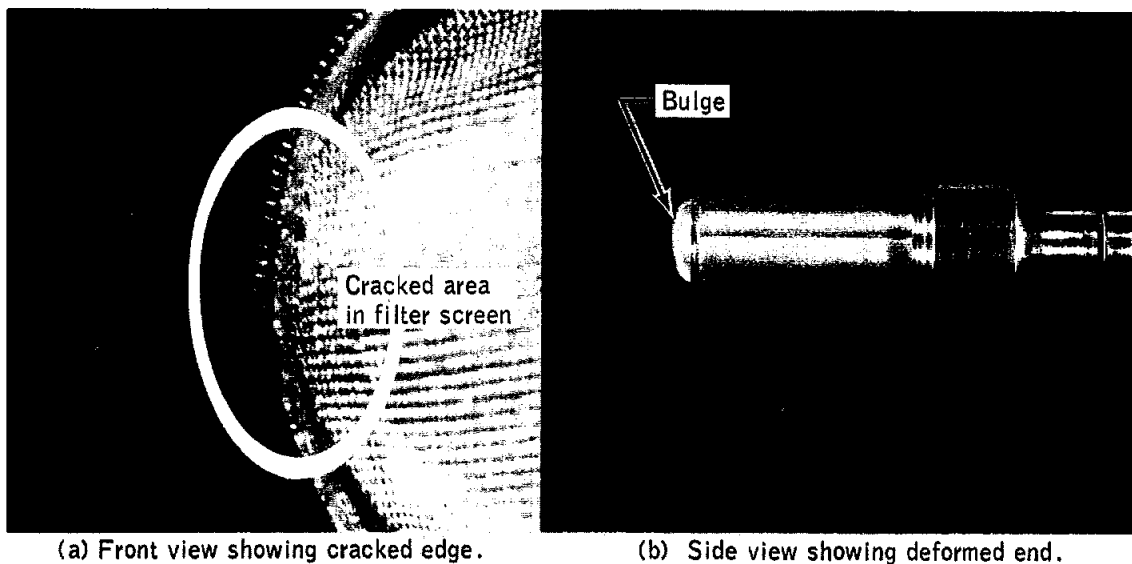


Figure 14-25.- Reaction control system regulator filter.

## 14.2 LUNAR MODULE ANOMALIES

### 14.2.1 Paint Flaking From Thermal Shield Panels

Just prior to transposition and docking, particles were coming off the thermal shield panels on the minus Y side of the ascent stage. The particles caused the panels shown in figure 14-26 to have a shredded appearance. (The aft equipment rack thermal shields and the insulation dangling from the bottom of the ascent stage shown in figure 7-1 are discussed in section 14.2.2.) The paint flakes interfered with star sightings and were potential optical surface contaminants. Thermal tests conducted on specimens removed from a lunar module panel demonstrated that the paint on the panels starts to peel at approximately minus 120° F. The predicted minimum temperature of the panels during the mission is minus 270° F.

Effective with the Apollo 15 spacecraft, changes were made to the vehicle to minimize the reaction control system propellant temperatures for the 72-hour lunar stay design case. One change was that 16 panels on the ascent stage were painted white. Subsequently, a more effective change was made by the addition of tank insulation. The effect of total loss of the paint on the panels results in a maximum reaction control system propellant temperature increase of approximately 2° F.

The corrective action for Apollo 17 will be to remove the paint from the panels since the paint has little thermal value.

This anomaly is closed.

### 14.2.2 Aft Equipment Rack Panels Torn Loose

At lunar lift-off, four vertical thermal shields (fig. 14-26) on the aft equipment rack were torn loose from the lower standoffs and remained attached only at the upper standoffs. This occurrence was observed from the lunar-based television.

The most probable cause of the failure was ascent engine exhaust entering the cavity behind these thermal shields. A cross section of the lower edge of the shields is shown in figure 14-27. Analysis shows that the thermal shield which extends below the support tube allows a pressure buildup on the closure shield which exceeds its capability. Once the closure shield failed, the exhaust entered the cavity behind the shield, resulting in a pressure buildup exceeding the capability of the vertical thermal shields. The detailed flight configuration in this area was not tested.



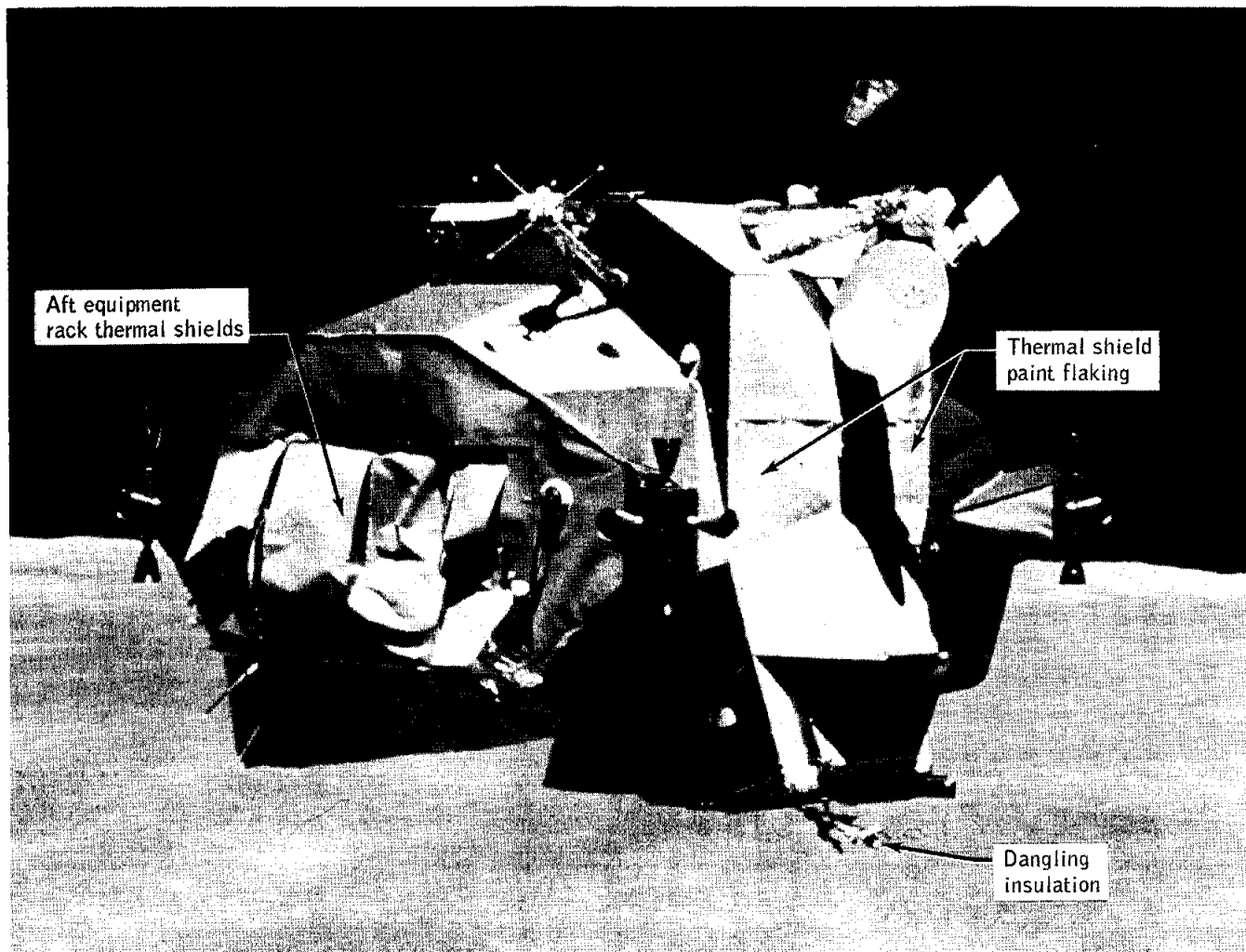
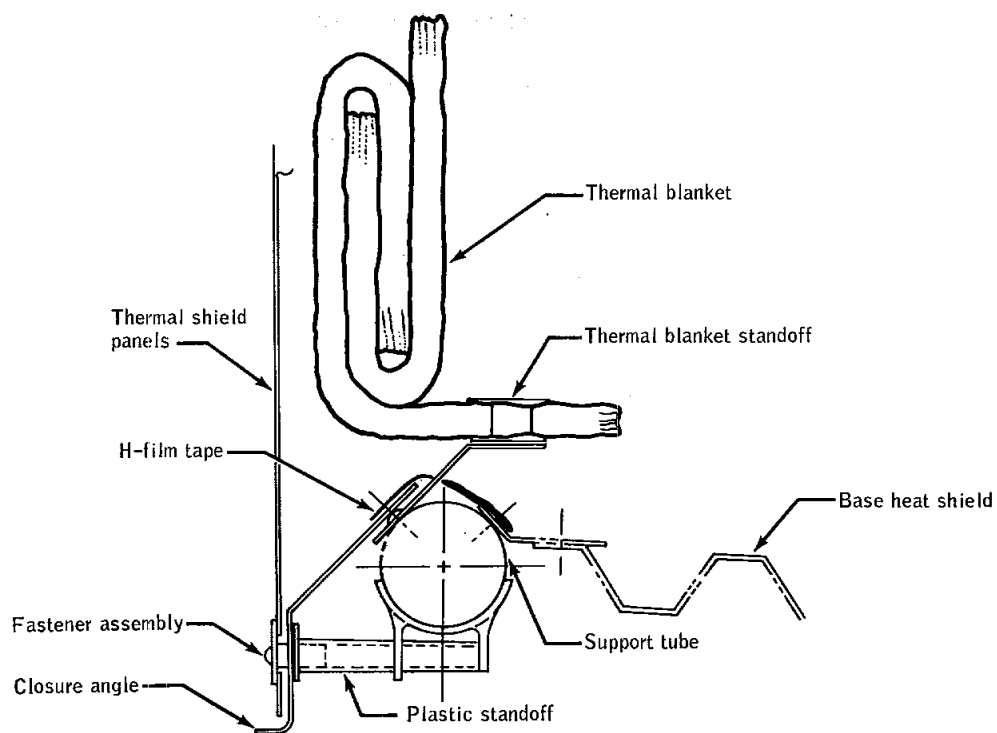
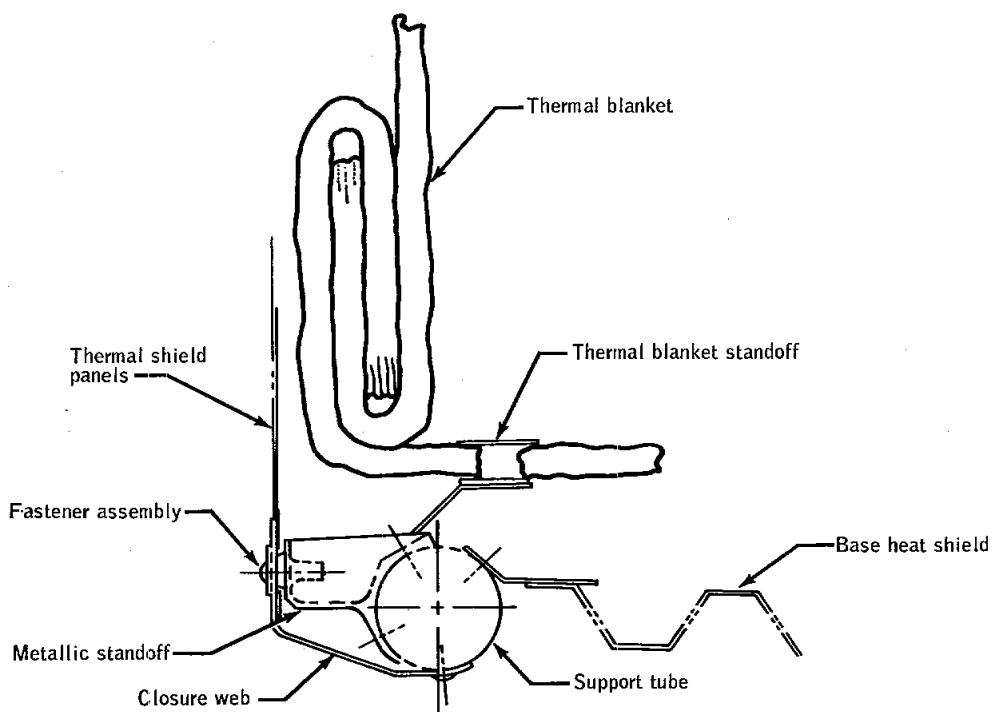


Figure 14-26.- Paint flaking and damaged thermal shield panels.



(a) Existing thermal shield configuration.



(b) Proposed thermal shield configuration.

Figure 14-27.- Aft equipment rack thermal protection configuration.

In the lunar surface photographs taken prior to lift-off, some of the shields appear to have come loose from the center standoff (fig. 14-28). Excessive gaps between some of the panels are evident. Both conditions could be caused by excessive pressure in the thermal blanket due to insufficient venting during boost.

The corrective action will include a redesign of the thermal shield to eliminate the projection below the support tube, as shown in figure 14-27, and to provide additional venting to the blankets as well as additional standoffs.

This anomaly is closed.

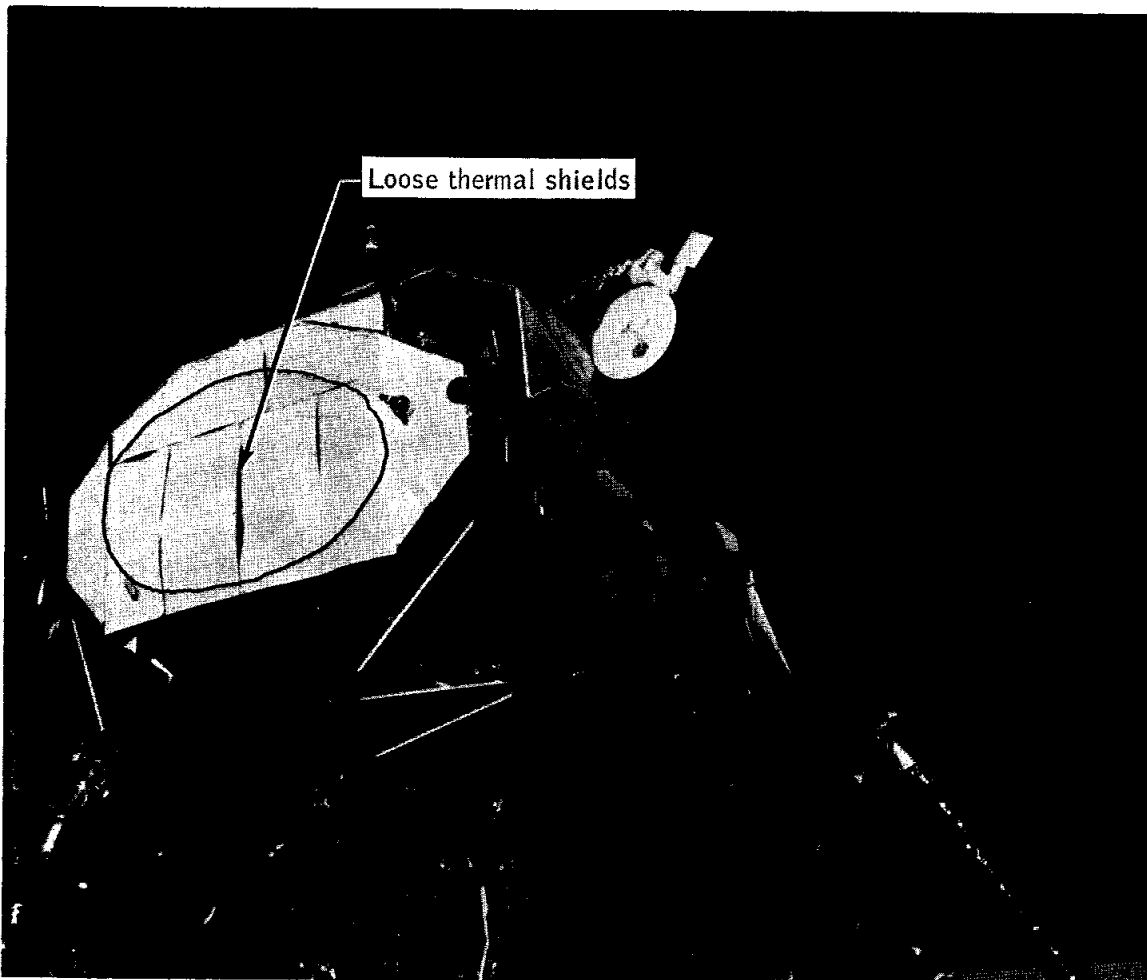


Figure 14-28.- Aft equipment rack thermal shields loose at center standoff.

### 14.2.3 Steerable Antenna Inoperative In Yaw Axis

The S-band steerable antenna (fig. 14-29) would not move in the yaw axis during initial activation. Several unsuccessful attempts were made to operate the unit using both the manual slew and auto track modes. Photographs and inflight test data show that the problem was caused by failure of the mechanical stow latch to release.

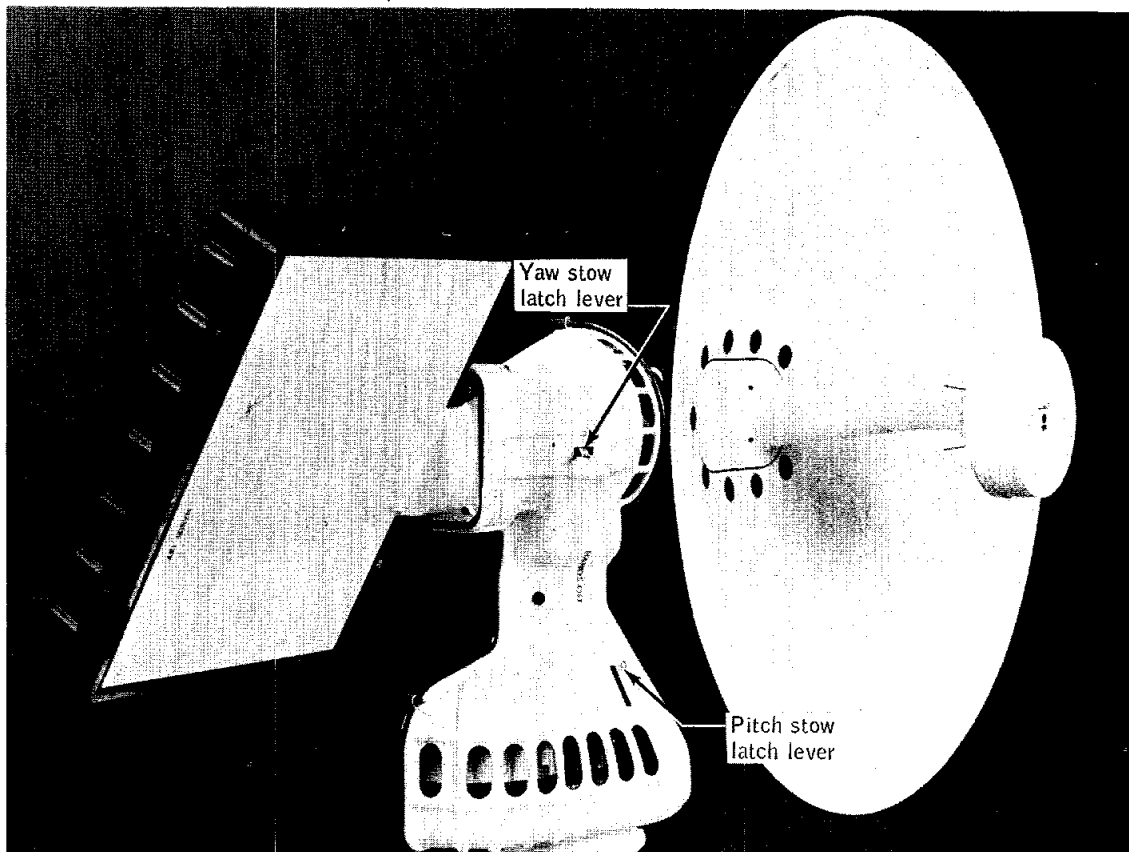


Figure 14-29.- Lunar module S-band steerable antenna.

Functionally, the stow latch restrains the antenna during launch. Figure 14-30 shows the functional operation of the latch. The lock pin, when extended, holds the antenna in the stowed position. A spring is held under compression by a sleeve which is constrained to the latch housing by a shoulder soldered to the sleeve. Melting the solder allows the spring to push the sleeve which, in turn, raises the lock pin out of the retainer. A manual mode is provided for checkout purposes. The lever (fig. 14-30)

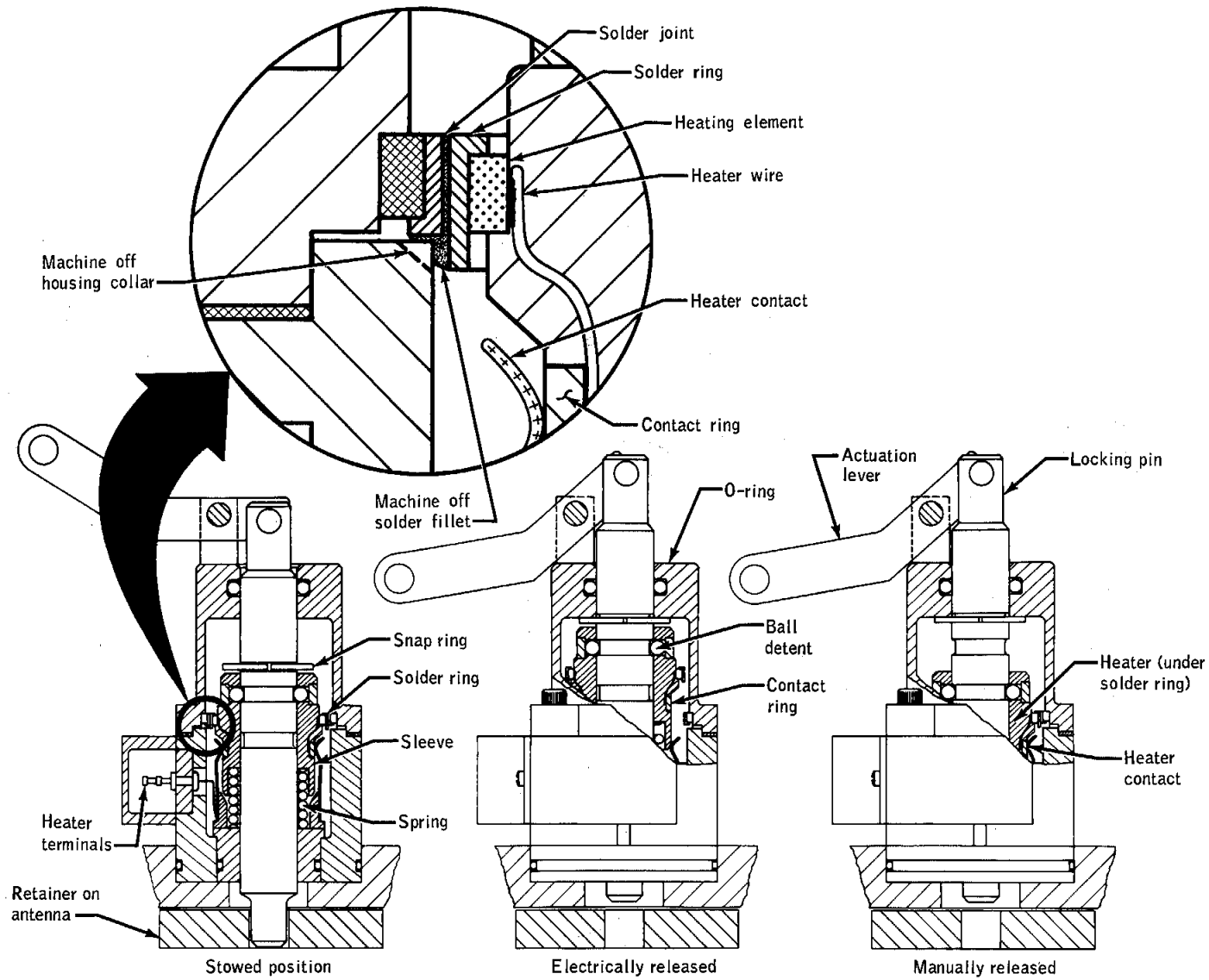


Figure 14-30.- Antenna stow latch mechanism.

will pull the lock pin past the ball detent, thus releasing the antenna without disturbing the spring-sleeve-solder configuration.

Antenna photographs taken on the lunar surface and in lunar orbit prior to docking indicate that the lever for the yaw axis latch was still in the locked position. The crew noted a 2- to 3-degree movement of the yaw indicator during activation attempts. Ground tests have shown that the tolerances in the antenna retainer/locking mechanism will allow a slight movement of the antenna dish even though the pin is locked.

There are several areas in the electrical circuitry which could have caused the problem. One is that one contact in the safe/arm switch (figure 14-31) did not make. The second is that an open may have existed downstream of the safe/arm switch, either in the solder-melting element or in the wiring back through ground. A resistance measurement is made across the two parallel solder-melting elements prior to flight. About a 3-ohm increase in resistance was found at the last check. This change is equivalent to a possible 10-ohm increase in one of the elements which could have reduced the power dissipation below that required to melt the solder. Allowable tolerances on mechanical drawings and tests on sample latches have shown that it is possible for a solder fillet extending below the ring to make physical contact with the housing (fig. 14-30). The

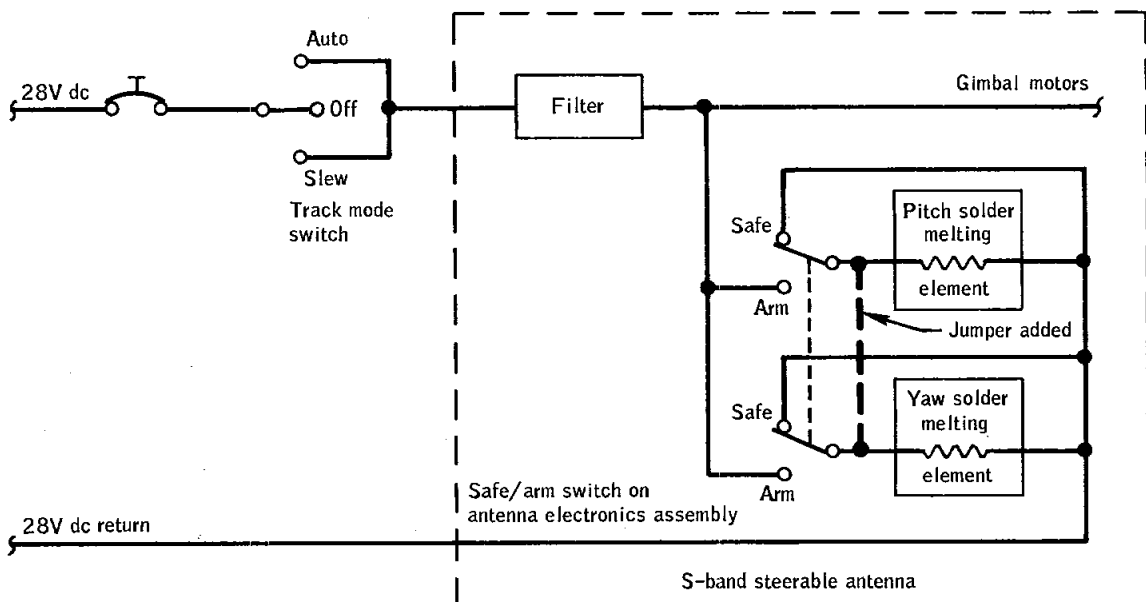


Figure 14-31.- Lunar module steerable antenna stow-latch circuit.

contact allows the housing to act as a heat sink and, under marginal electrical conditions, draw off sufficient heat to prevent melting of the ring.

Several corrective actions are planned for Apollo 17 to cover all reasonable possibilities of failure. These include:

- a. Machining off the exposed solder fillet and a portion of the housing to eliminate possible contact.
- b. Inspect 100 percent of the heating wire of the solder assemblies.
- c. X-raying latch assemblies to insure proper assembly.
- d. Measuring the circuit resistance of both the antenna and associated wiring on the vehicle.
- e. Adding wiring to the circuit to provide redundant paths through the safe/arm switch to the solder melting elements.

This anomaly is closed.

#### 14.2.4 Reaction Control System Helium Regulator Leakage

During pressurization of the system at about 95 hours, the regulator outlet pressure in system A (fig. 14-32) increased above regulator lockup pressure. The normal pressurization is characterized by a sharp increase from the nominal pad pressure, in the interval of 1 to 2 seconds, to the normal regulator outlet pressure. The outlet pressure of system A, after reaching the normal value of 184 psia, continued to rise at approximately 10 psi/minute, a condition which clearly indicated the existence of internal leakage in the regulator assembly.

Approximately 3 minutes after pressurization, the first of four propellant transfer operations was performed (fig. 14-33) to lower the ullage pressure and to create a larger pressurant volume in the propellant tanks, thereby obtaining a blowdown capability for expulsion of the remaining propellant in case of total loss of system A pressurization gas through the relief valves. The helium leakage continued throughout the mission, although the leakage rate varied from essentially zero to a maximum of about 1100 scc/min (figs. 14-34 and 14-35). The regulator outlet pressure eventually increased to about 237 psia at which time the relief valves of system A started to periodically relieve the pressure to about 232 psia.

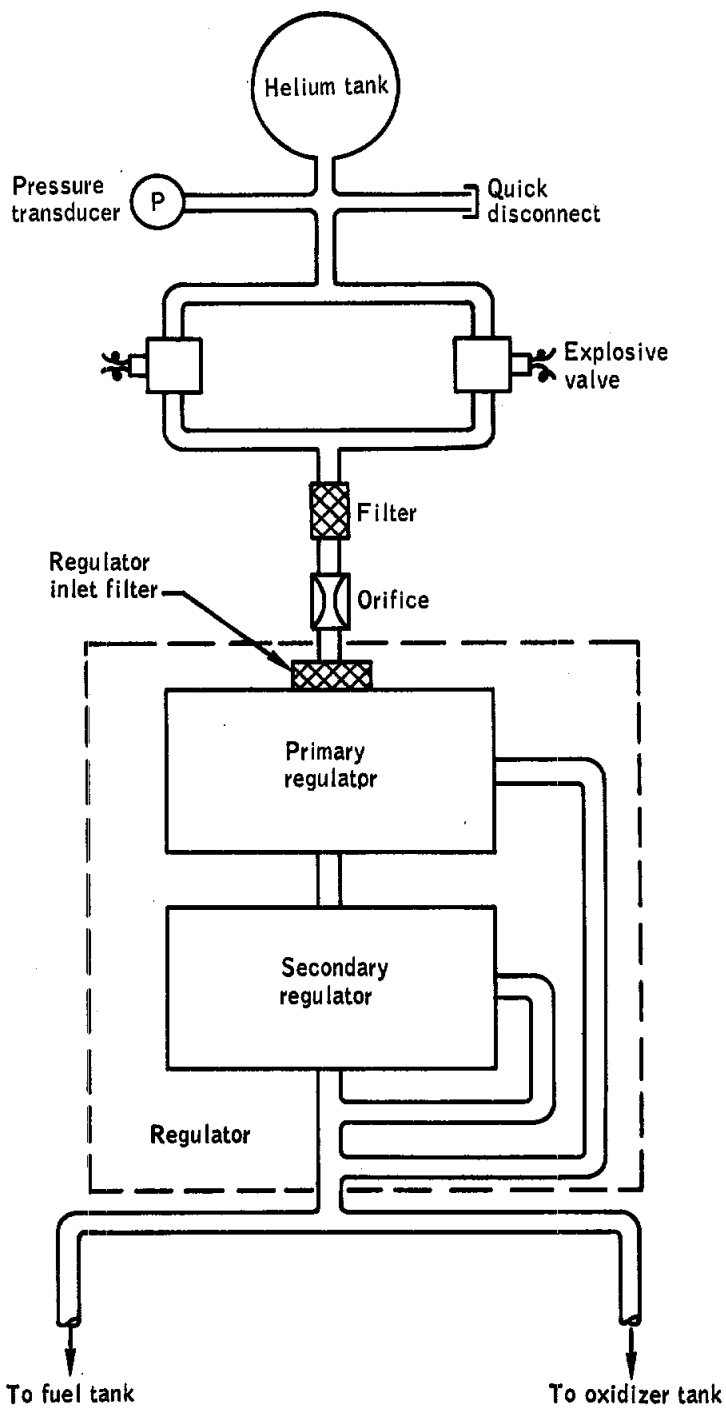


Figure 14-32.-- Reaction control system pressurization system.



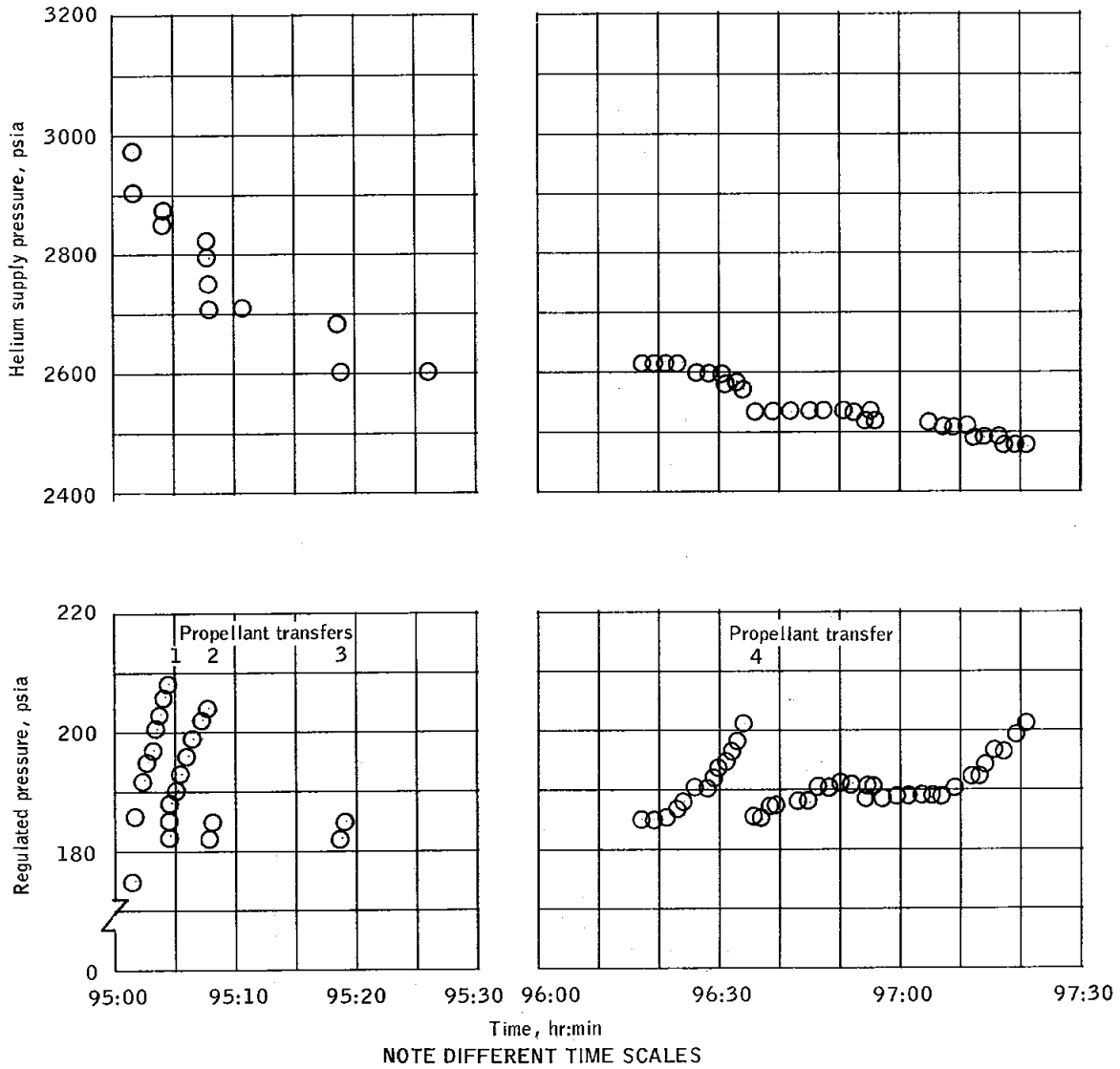


Figure 14-33.- Comparison of helium supply pressure and regulator outlet pressure following reaction control system pressurization.

The helium regulator assembly consists of two series regulators (figure 14-36). The unit immediately exposed to the high pressure source is designated as the primary regulator and the downstream unit as the secondary regulator. Both units are identical in configuration with the exception of shims which are used to determine their pressure settings. The primary unit is set to regulate at  $181 \pm 3$  psia; the secondary, at  $185 \pm 3$  psia.

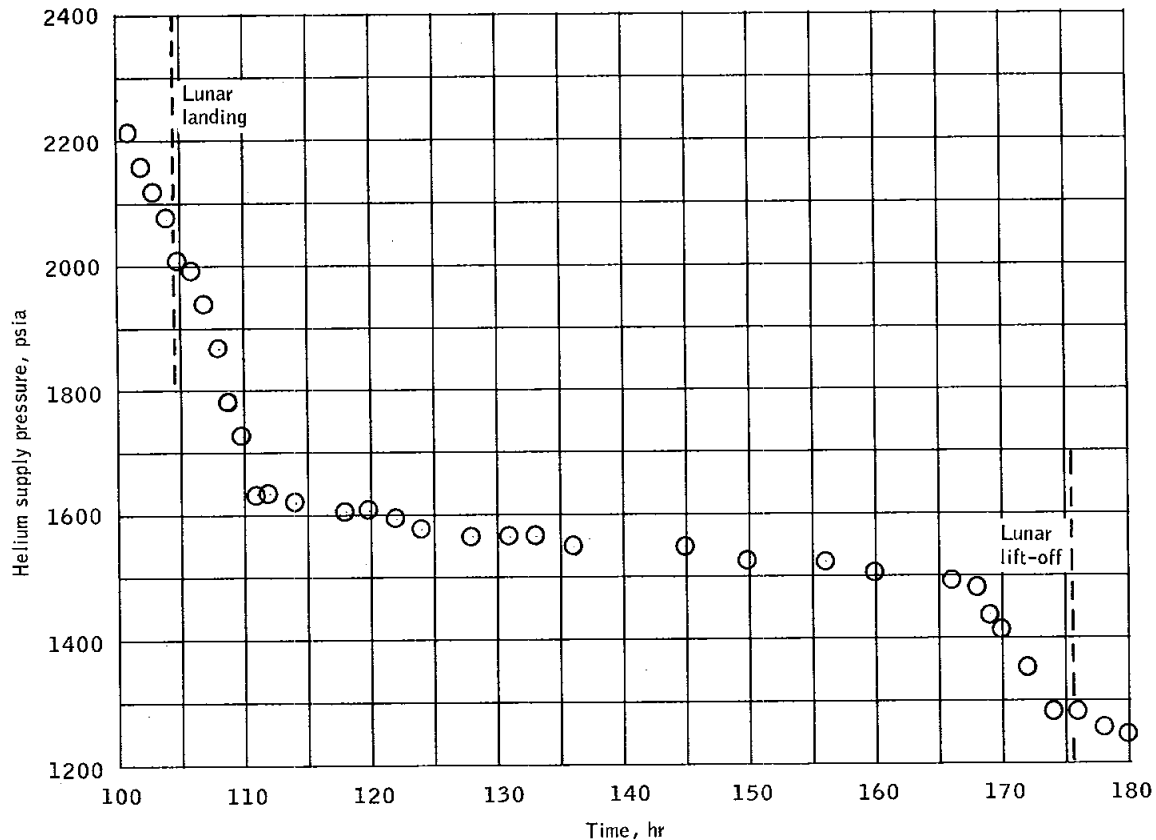


Figure 14-34.- Helium supply pressure for reaction control system during lunar stay.

A series of tests was performed to determine lockup characteristics of nine spare regulators under small differential pressure conditions. The tests showed that a design deficiency in the secondary regulator does not exist, but did not eliminate the possibility of a weak poppet spring or sticky poppet in the Apollo 16 regulators since they were not tested under the same conditions. Further, the test demonstrated that the flight anomaly was the result of two discrepancies within the regulator assembly. A matrix of the possible leakage paths is shown in table 14-I. As can be seen from the matrix, there are 15 possible double-failure combinations which can result in the anomalous condition observed during the flight. Of these, the four involving only the poppets are considered probable since the leakage was variable. A variable leak path is usually caused by particulate contamination on a poppet seat. The particulate contamination could have been inside the regulator assembly during ground tests, but located in such a manner that it was not dislodged by the gas flow under 1-g conditions. In a weightless condition, the contamination could have moved and deposited between any of the poppets and their seats.

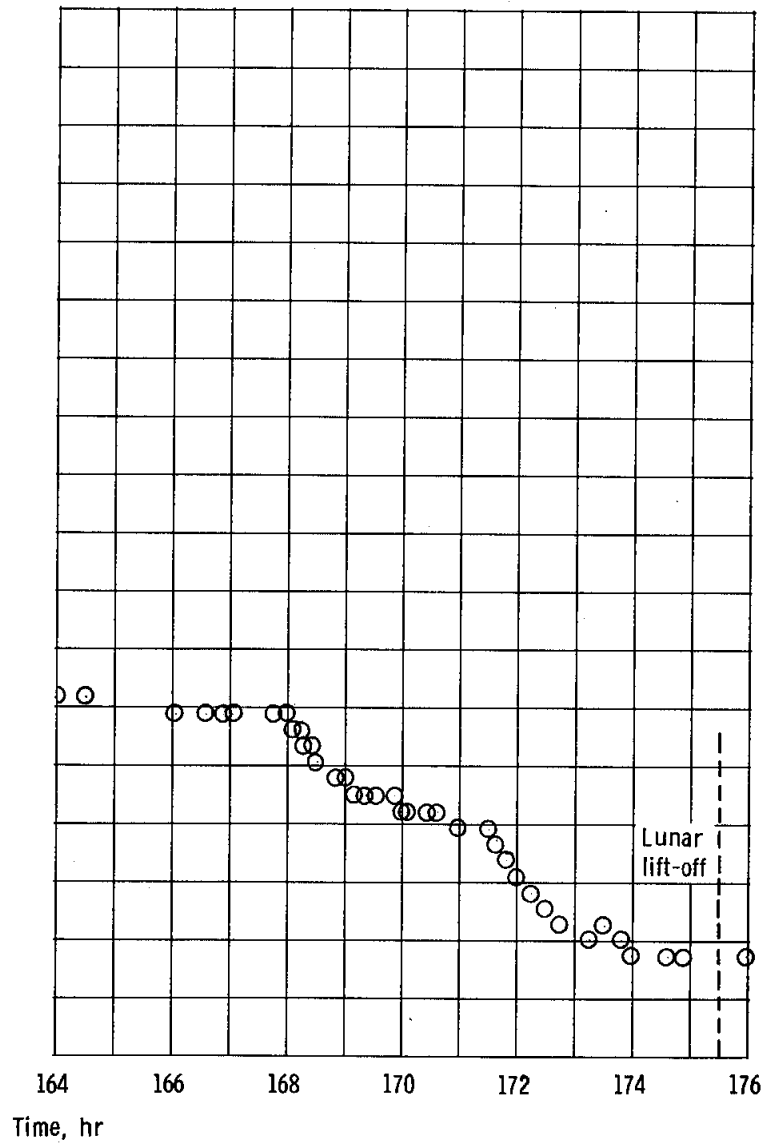
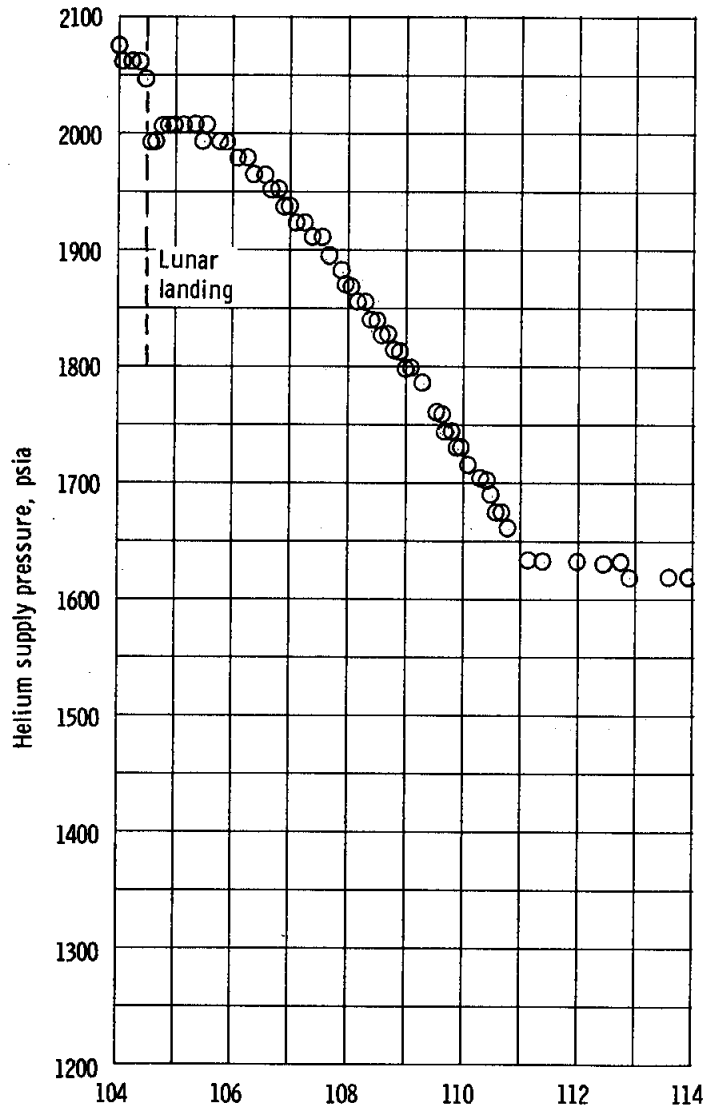
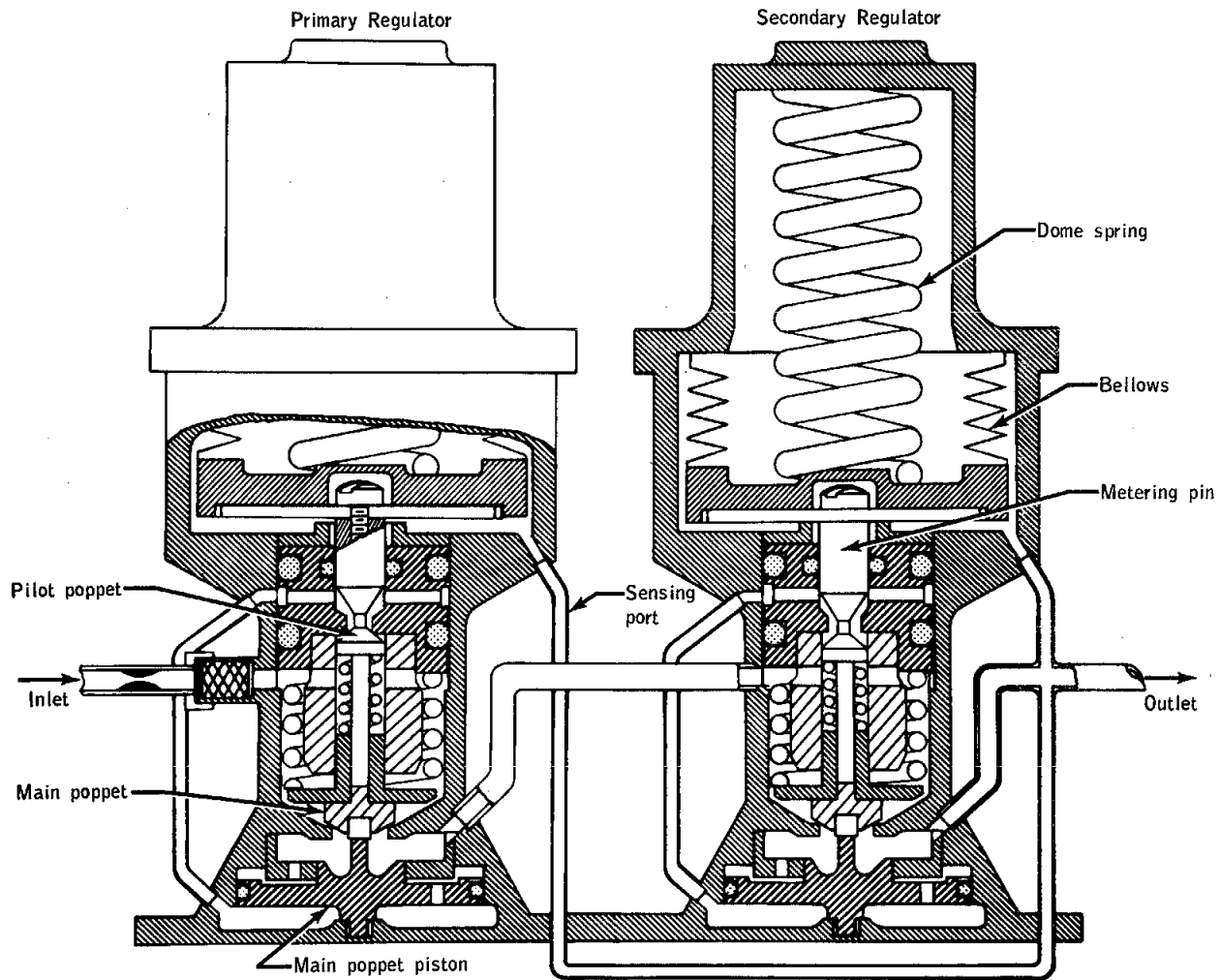


Figure 14-35.- Expanded plot of helium supply pressure during two periods on lunar surface.



Note: Normal pressurized configuration:  
 Primary main and pilot poppets closed  
 Secondary main poppet closed  
 Pilot poppet-open responding to  
 pressure demand

Figure 14-36.- Cross-section of reaction control regulator.

TABLE 14-I.- MATRIX FOR POSSIBLE HELIUM REGULATOR  
INTERNAL LEAKAGE

	Secondary regulator pilot poppet	Secondary regulator main poppet	Secondary regulator guide primary O-ring	Primary regulator guide secondary O-ring	Primary regulator metering pin O-ring
Primary regulator pilot poppet	X	X	X	X	X
Primary regulator main poppet	X	X	X	X	X
Primary regulator guide primary O-ring	X	X	X	X	X

Because contamination during manufacture was considered to be a possibility, two regulator assemblies were disassembled and examined. Approximately 90 pieces of material over 100 microns in size (fibers and particles) were found in the first regulator assembly. Over 50 of these were found in the lubricant (Dri-lube 822) adhering to the poppets and poppet guide assembly of the primary regulator. The rest were in the sensing tubes and transfer tubes. The secondary regulator poppets were not checked. Contamination consisted of about 50 fibers (paper and nylon) and some metallic, plastic and unidentified hard particles. The cleanliness specification used by the manufacturer does not allow any particles in excess of 100 microns; however, a hard particle less than 100 microns in diameter, if located on a poppet seat, would cause that poppet to leak in excess of specification. The origin of the contamination could not be established. However, since the regulator was not tested after delivery, the contamination must have been built into the component. Examination of the second regulator assembly showed similar contamination.

A squib valve pressurization shock wave could damage or distort the regulator inlet filter and allow upstream contamination to enter the regulator. A test was conducted to determine the effect of the pressure shock on the inlet filter and an examination of the filter showed no deformation

or damage. During the disassembly of the Apollo 16 command module regulators, lubricant was found on the main poppet and corresponding pilot poppet in one of the four regulators. In addition, all regulators showed grease in the area of the main poppet spring assembly. If grease from this area was transported to the poppet surfaces of the Apollo 16 regulators, it could have acted as a trap for holding contaminants, thereby causing leakage.

During buildup of the Apollo 16 reaction control system module, a quick disconnect (fig. 14-37) located directly downstream of the regulator outlet was replaced three times. During one change a five-legged fitting (fig. 14-37) required replacement. The repairs required seven brazing operations in an area which is directly above the regulator outlet when installed in the vehicle. Any contaminants introduced during these operations would be trapped in the volume downstream of the regulator by various filters (fig. 14-37). These contaminants could have been moved around during reaction control system module installation or when the lunar module ascent stage was rotated during the cleaning process. During these operations, any contaminants present could have been transported to the area directly downstream of the secondary regulator primary poppet. This volume has many areas where contaminants can be trapped (fig. 14-36).

On four occasions during quad check valve tests at the launch site, the regulators were subjected to 5-psi backpressure with the pilot poppets open. Backflowing the regulators has had a history of causing leakage due to contamination. These tests were done for the first time for this mission at the launch site. Also, there may have been reverse pressurization during checkout at the launch site. If any contamination were present at the regulator outlet, it could have been transported into the regulator assemblies during these tests.

The most probable cause of the leakage is contamination introduced during component replacement and, subsequently, swept into the regulator outlet by backflow. There is also the possibility that lubricant existed on the sealing surfaces to capture the contaminants.

No components have been replaced downstream of the Apollo 17 lunar module regulators. Also, the following changes will be made to the launch site testing to eliminate regulator backflow.

a. A quad check valve cracking test will be performed by pressurizing through the quick disconnect upstream of the regulator rather than downstream.

b. A caution and warning limits test will be performed prior to the regulator functional test and with the secondary regulator locked up.

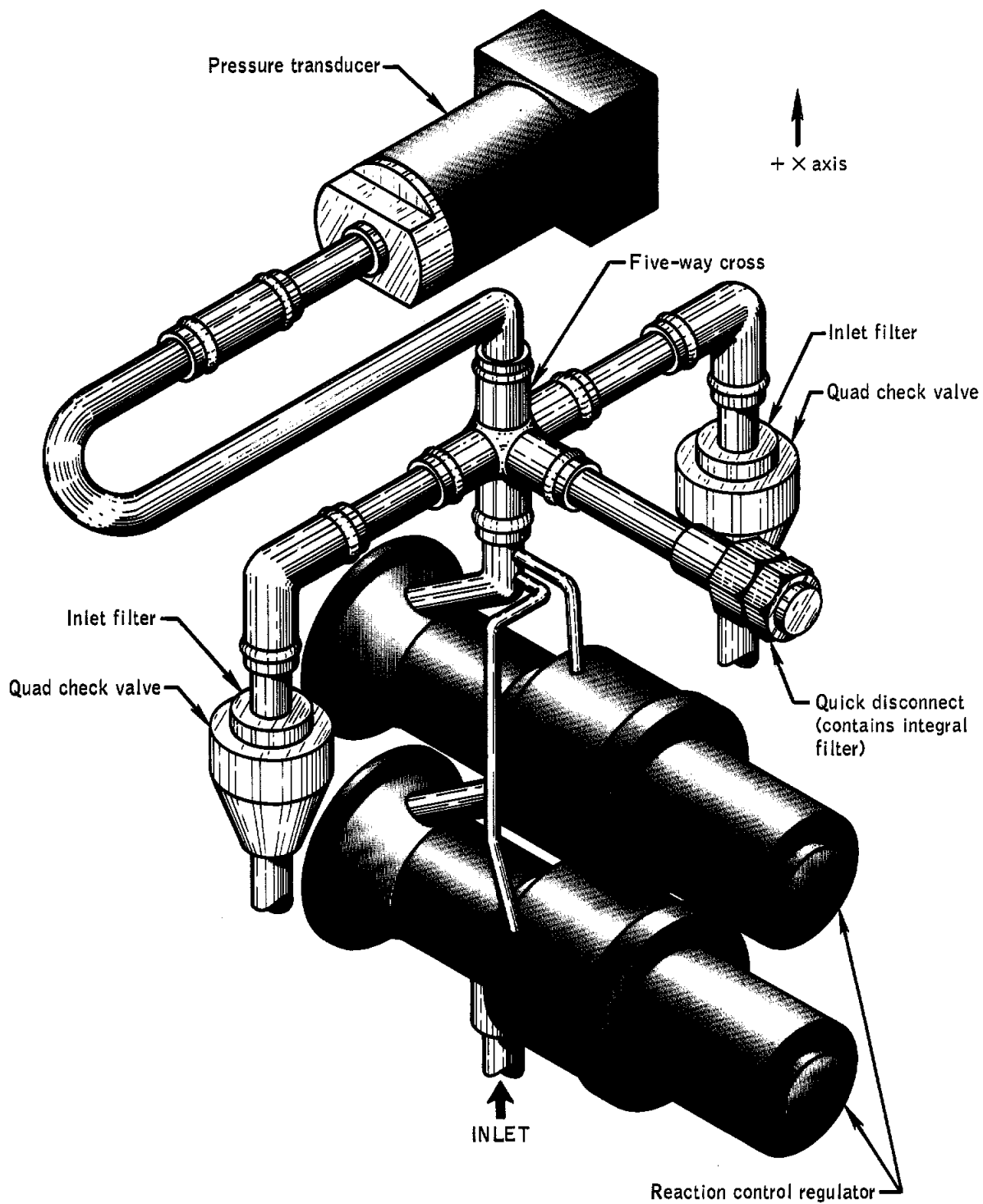


Figure 14-37.- Repaired reaction control system module area.

c. A test will be added to assure that the secondary regulator poppets seat at low differential pressures.

This anomaly is closed.

#### 14.2.5 Apparent Sticking Of Cabin Gas Return Valve

The crew reported hearing a chattering noise and experiencing a pulsating, insufficient flow in the suit circuit at 95:47 while configured to the cabin mode of operation (fig. 14-38). Data indicate that the cabin mode flow was normal at system activation (93:41), and this was confirmed by the crew after the mission. The pulsing and chattering occurred again after the demand regulator check (95:55) and after lunar landing (105:57).

The problem was traced to the cabin gas return valve which apparently failed to open in the "automatic" position, thus blocking the cabin gas from returning to the suit circuit. This results in "deadheading" of the suit fan, thereby causing the downstream check valve to chatter and pulsate due to the small amount of flow drawn through the suit gas diverter valve in the cabin position. The manual "open" and "closed" positions of the cabin gas return valve were used for the remainder of the mission. The "automatic" position was selected later during the lunar stay and operated normally (good flow, no chatter).

Since the valve functioned properly upon activation and again late in the lunar stay, the apparent cause of the problem was contamination. There are two possible areas of contamination: material on the inlet screen or residue on the flapper seal (fig. 14-39). A suspected source of residue is the orange juice that leaked from the drink bags.

Alternate procedures are available to assure suit circuit flow if a malfunction should occur in the cabin gas return valve. Liquid entering the suit circuit through the cabin gas return valve should not cause a further problem since it would be absorbed in the lithium hydroxide canister.

A test will be performed on the Apollo 17 lunar module to check the force needed to open the cabin gas return valve flapper in the "automatic" position, thus increasing confidence in the ground checkout of the valve.

This anomaly is closed.



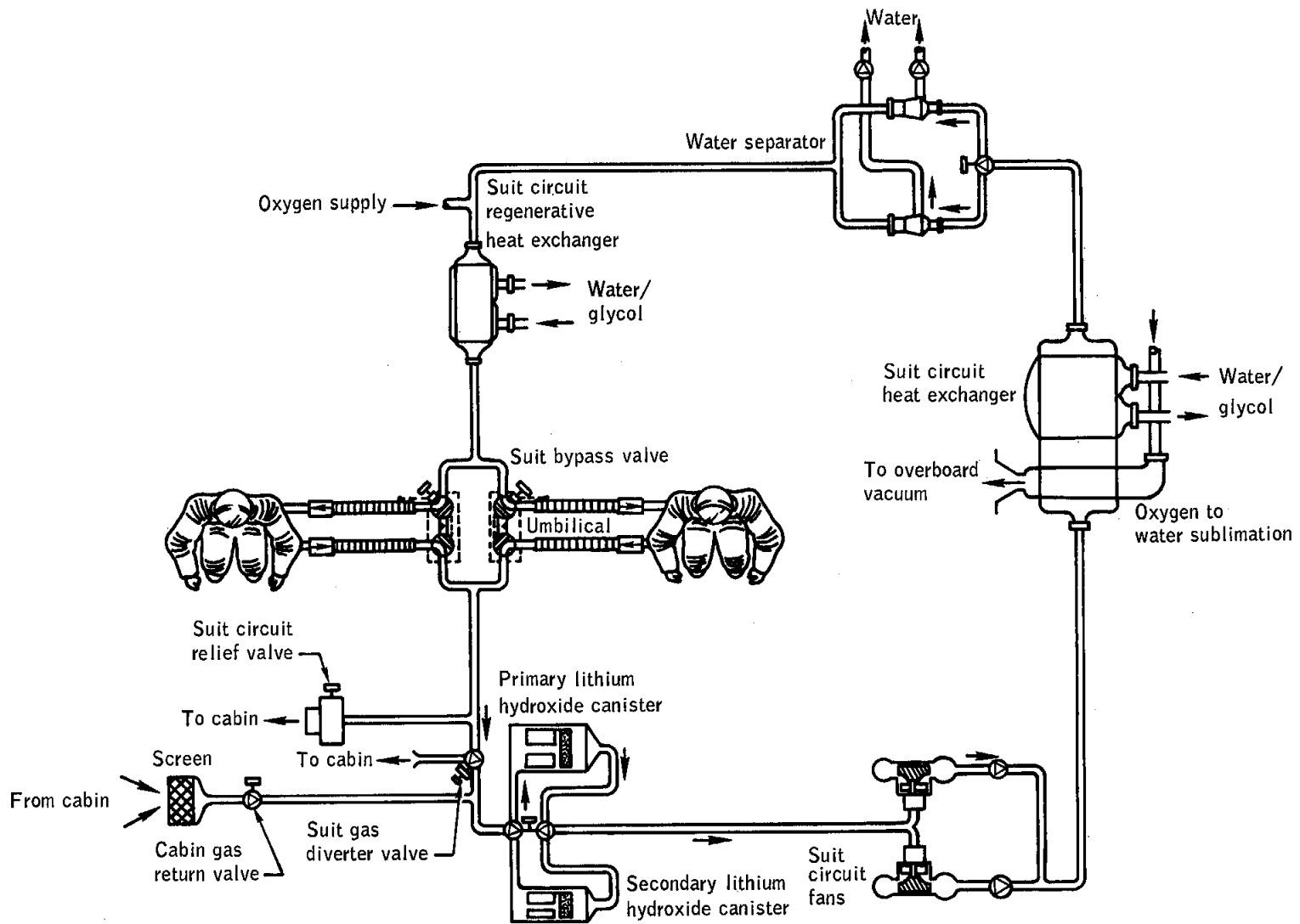


Figure 14-38.- Atmosphere revitalization section.

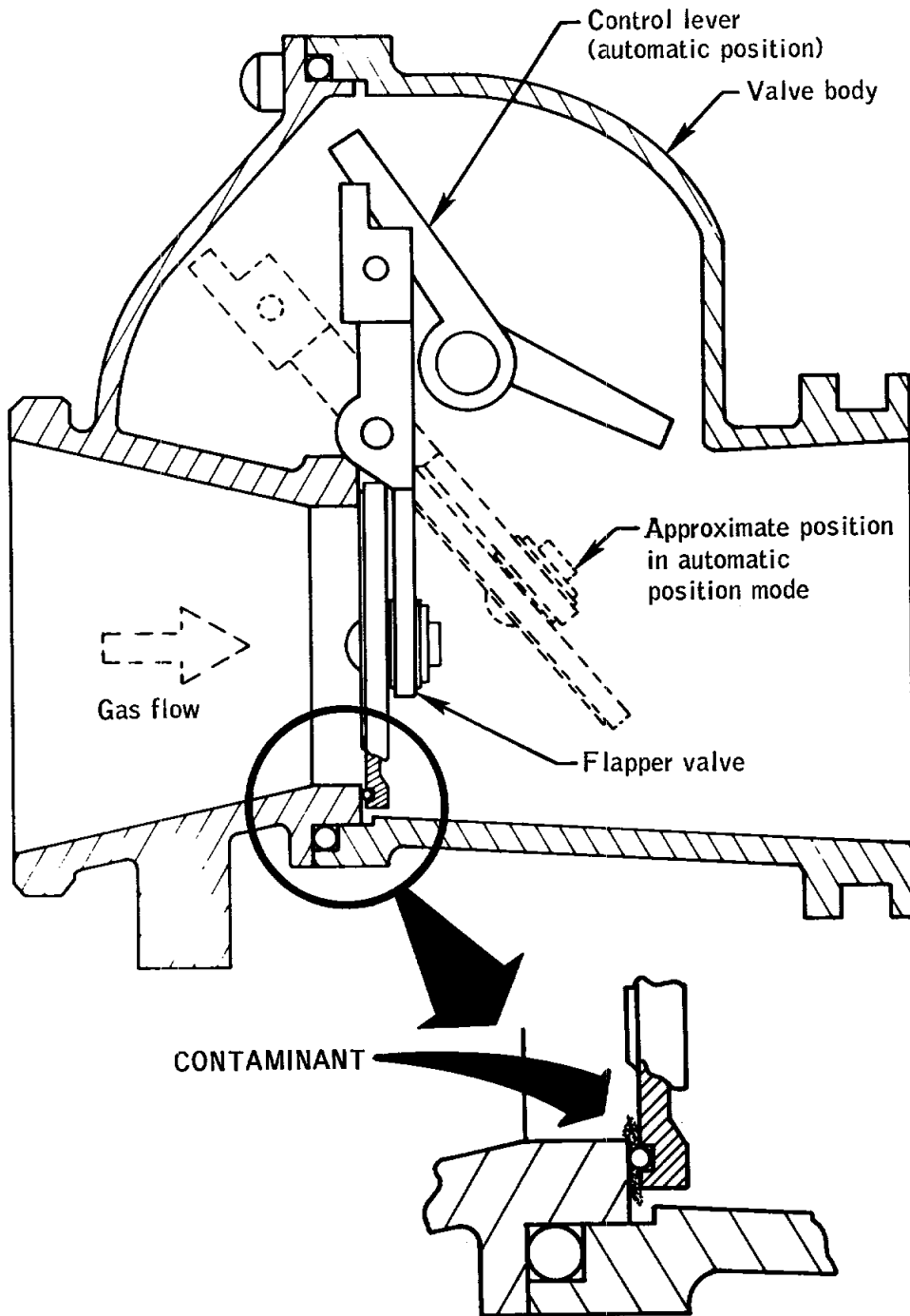


Figure 14-39.- Cabin gas return valve.

## 14.2.6 Loss Of Lunar Module Attitude Control After Jettison

Lunar module attitude control was lost immediately after the lunar module was jettisoned from the command and service module at 195:00:12. The lunar module was to be controlled between jettison and lunar surface impact (including the deorbit firing) with the digital autopilot of the primary guidance system (fig. 14-40). After jettison, telemetry showed that the autopilot was properly issuing error signals to the attitude and translation control assembly primary preamplifiers; however, no engine driver commands were being issued by the attitude and translation control assembly, as indicated by telemetry.

Any of the following conditions could have caused the problem (refer to fig. 14-40):

- a. The circuit breaker which provides the 28-volt-dc enabling voltage to the primary preamplifiers may have closed mechanically but not electrically.
- b. The guidance control switch may have failed.
- c. The primary guidance mode control switch may have failed.
- d. The in-line filter could have failed.
- e. An open or short-to-ground may have occurred in the spacecraft wiring or associated connectors.
- f. The circuit breaker may have opened because of current loads in excess of 2 amperes.
- g. The circuit breaker could have been left open by the crew.

Review of flight data and failure histories has been performed and the following conclusions reached:

- a. A circuit breaker on Apollo 15 failed to make electrical continuity when mechanically latched due to non-conductive contaminant between the contacts.
- b. The switches in items b and c in the preceding paragraph have been X-rayed and no conductive contaminants observed. The toggle switches have no failure history of non-conductive contaminants. The guidance control switch was not changed from the position it was in during rendezvous and docking when the primary control system performed as expected.
- c. Only one failure has been recorded for the in-line filter.

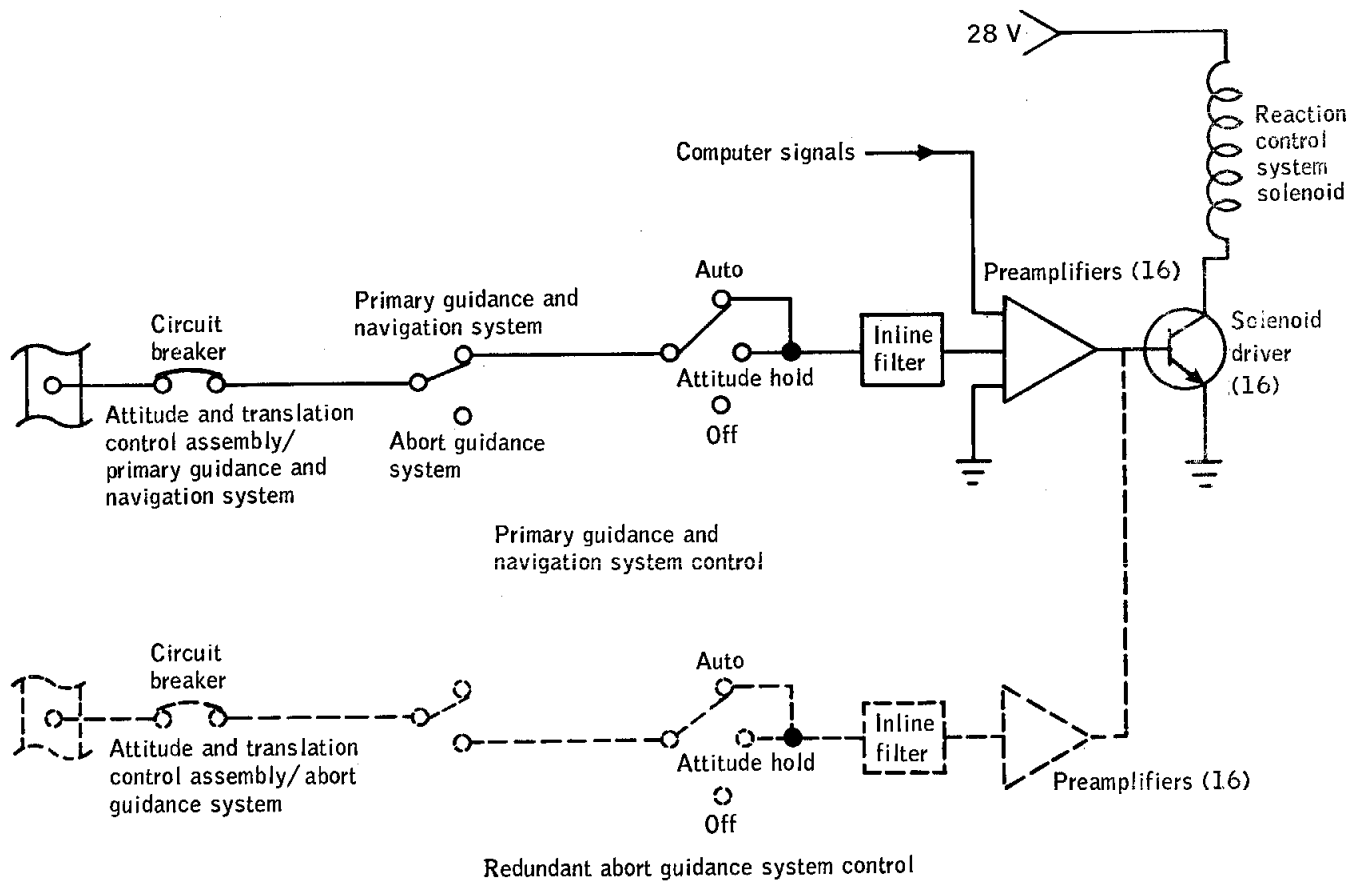


Figure 14-40.- Reaction control system control schematic.

d. Opens or shorts-to-ground may have occurred and a short may have popped the circuit breaker, but it is unlikely that such an event occurred during this time.

e. The most probable cause of the problem is that the circuit breaker which provides 28 volts to the primary preamplifier either did not make electrical contact (similar to Apollo 15) or was inadvertently left open.

Extensive changes to the flight plan and attendant procedural changes were communicated to the crew. The procedural changes were correct and were copied correctly. If the procedures for an engine hot-fire test had been required by the ground before the crew left the lunar module, an open circuit breaker or a system malfunction would have been detected. If a system malfunction had occurred, however, the deorbit maneuver could not have been executed. The deorbit maneuver can only be executed with the primary guidance system. If a system malfunction had occurred during the manned portion of the flight, adequate system redundancy is available for attitude control (fig. 14-40).

No corrective action is required.

This anomaly is closed.

#### 14.2.7 Abort Guidance System Out-Of-Plane Velocity Error Larger Than Expected

Abort guidance system data during descent revealed two abnormal conditions. First, the out-of-plane component of velocity, when compared to the primary guidance system, increased to a maximum of 28 ft/sec near lunar touchdown. Second, the roll axis was misaligned after touchdown by 0.47 degree when compared to the primary guidance system roll axis. Both of these errors are within acceptable performance limits, but they are larger than expected and are the largest seen on any Apollo flight.

Figure 14-41 is a time history of the difference between the abort guidance system and the primary guidance system X-axis attitude reference during descent. The rapid error buildup during the first 2 minutes indicates drift rates of up to 19 degrees per hour. No reason can be given for these high drift rates; however, a change in the X-axis gyro performance characteristics obviously took place. The steady drift rate of 2 degrees per hour during the last 8 minutes is believed to have been caused by a shift in a mass unbalance along the X gyro spin reference axis. Drift caused by this mass unbalance was also apparent in the data for the lunar surface calibration (due to gravity) and during ascent (due to the ascent engine thrust).

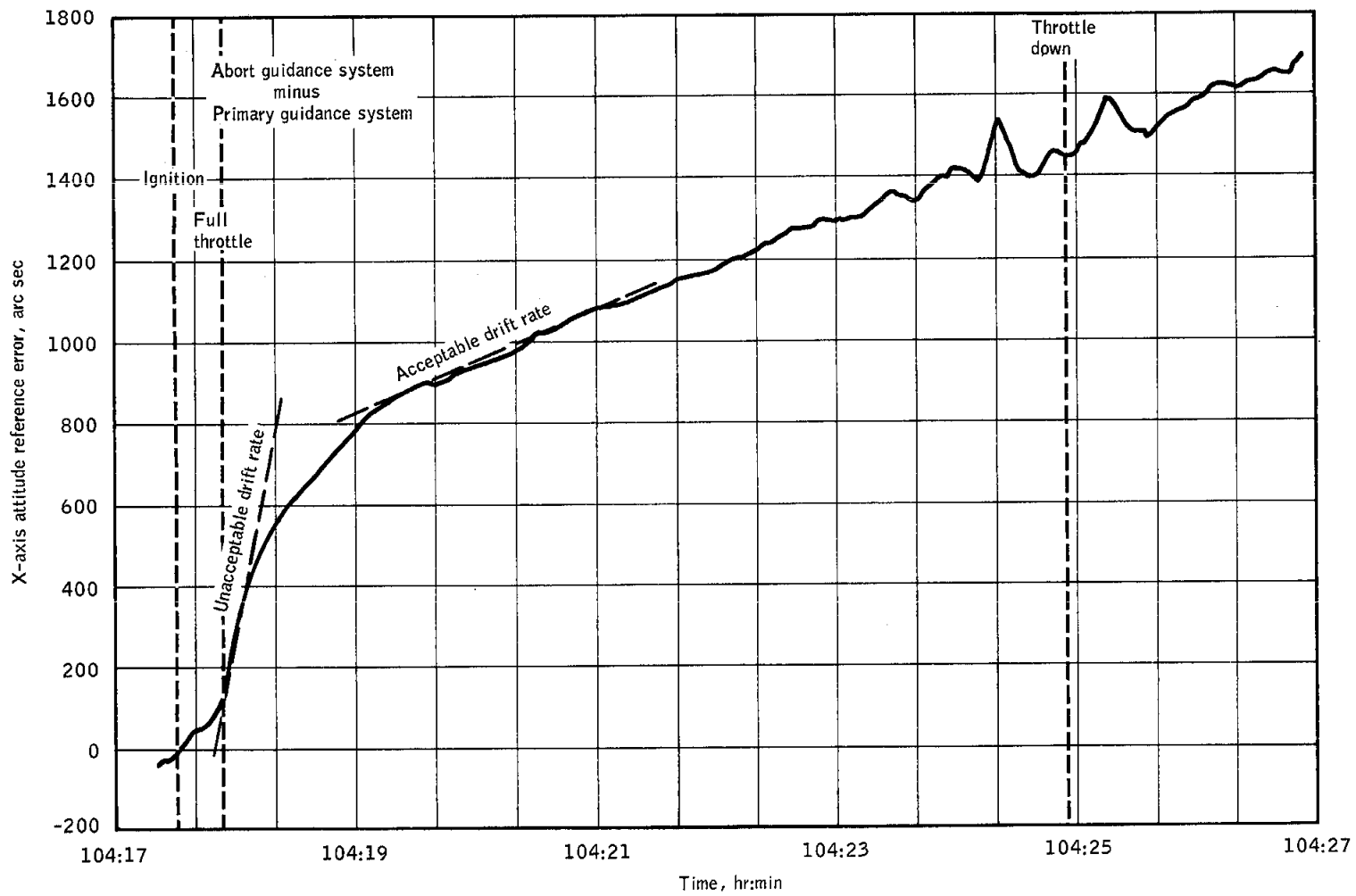


Figure 14-41.- Attitude reference error during descent.

The roll axis misalignment is accounted for by the higher-than-normal drift rates during descent.

No indication of a problem existed before launch. Hardware malfunctions of the gyro and associated electronics have been hypothesized in an attempt to construct a model which would reproduce the error curve shown in figure 14-41. The worst-case electronics failure would only produce drift rates of 1 degree per hour compared to the 19 degrees per hour observed. Mechanical failures within the gyro which would duplicate flight results have a very low probability of occurrence. Therefore, the most likely cause is contamination or an air bubble in the fluid between the gyro float and case.

Settling tests have been performed on abort sensor assemblies to detect contamination or air bubbles and determine the best unit to install in the Apollo 17 lunar module. No evidence of contamination or air bubbles was found.

This anomaly is closed.

#### 14.2.8 Ascent Propulsion Chamber Pressure Increase and Decay During the Ascent Firing

Approximately 157 seconds into the lunar orbit insertion firing, the telemetry indication of the ascent propulsion engine chamber pressure reflected an abrupt 10-psi rise followed by a slow decay to its initial value in 10 seconds (fig. 7-3). The phenomenon was repeated 11 seconds after the initial pressure rise.

In order for the indicated pressure rise to be real, the mass flow rate into the engine and the vehicle acceleration must change. Examination of the engine inlet pressure measurements and the acceleration data from the guidance and navigation system at the time of the pressure rises did not show any change. Based upon these data and analyses, it is concluded that the observed thrust chamber pressure increases were not in the engine, and that the indication of the pressure increase was due to instrumentation.

Analyses and tests of the transducer did not reveal any failure mode which would cause the transients observed in the data. The only method by which the transducer could be forced to produce similar transients was by heating the internal strain gage diaphragm.

The diaphragm heating could not have been caused by a leak in the sense line or transducer since such a leak would not have sealed itself. The heating, therefore, must have been caused by a mechanism occurring

inside the sense line, such as decomposition of small quantities of explosive compounds deposited in the line by normal engine operation.

When the engine is fired, oxidizer flow starts at the injector about 50 milliseconds before fuel flow. At the start of the fuel flow on Apollo 16, oxidizer vapor was in the transducer and sense line at 3 to 6 psi pressure. Since the sense line was near 70° F (based on ground tests) and the oxidizer (nitrogen tetroxide) boils at 70° F, a film of liquid oxidizer could have been on the sense line walls and in the transducer sense cavity.

When fuel flow was initiated, the indicated pressure increased to the normal value of 125 psi. Since the transducer sense port is located in an area which is cooled by a fuel vapor barrier, the sense line was then pressurized with fuel (aerozine 50). The fuel could have then been nitrated by the nitrogen tetroxide depositing solid explosive compounds (such as hydrazine nitrate) on the transducer diaphragm.

The transducer temperature increases during the engine firing and stabilizes at about 130° F after 2 1/2 minutes. At 157 seconds, when the first pressure transient occurred, the deposits could have decomposed and provided the necessary heat input into the strain gage diaphragm. Calculations show that decomposition of less than 2 milligrams of such compounds would cause the transients seen on the data.

Two to three milligrams of oxidizer can be introduced into the sense line before fuel flow starts. Since this amount of oxidizer will not generate sufficient explosive compounds to damage the transducer or sense line, no corrective action is required.

This anomaly is closed.



## 14.3 GOVERNMENT FURNISHED EQUIPMENT ANOMALIES

14.3.1 Malfunction of Television Camera Monitor  
In Command Module

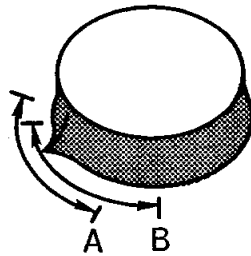
The command module television camera monitor exhibited horizontal bars during the initial usage. This condition cleared and performance of the monitor was normal until the press conference telecast during the transearth coast phase. At that time, the monitor had the same horizontal lines reported during the initial usage. The horizontal-hold control adjustment would not correct the horizontal line condition. The monitor was turned off for approximately 5 minutes, then turned back on, after which the monitor picture was normal.

Since the downlink television video signal was not affected, the malfunction was isolated to the monitor and associated cable.

Postflight testing of the flight unit has shown the following:

- a. Horizontal synchronization may be maintained for 90 degrees of the 300-degree rotation range of the horizontal synchronization control.
- b. The 90-degree picture synchronization range shifts as much as 30 degrees counterclockwise in the 300-degree rotation range when the unit is heated from ambient to 130° F, or when operated in a vacuum where it heats up due to lack of convection.
- c. The location of the 90-degree synchronization range within the possible 300-degree rotation range varies as much as 10 degrees from system activation to system activation. This condition is inherent in the design of the monitor and was known prior to flight.
- d. The optimum horizontal control knob setting is 110 degrees from the maximum counterclockwise knob position. Synchronization is lost and horizontal bars appear when the control knob is turned 60 degrees counterclockwise or 30 degrees clockwise from the optimum position (fig. 14-42).

If the horizontal synchronization control is set within 30 degrees of the clockwise end of the 90-degree stable synchronization range at ambient temperature and then the unit is heated up, synchronization will be lost. Synchronization may be reacquired by repositioning the horizontal synchronization control; however, the repositioning must be done slowly or the horizontal circuit does not have an opportunity to stabilize. These conditions could have occurred in flight.



Ranges for maintaining horizontal synchronization on the horizontal control knob at ambient turn-on conditions is shown by line A and after monitor warmup is shown by line B.

Figure 14-42.- Horizontal synchronization knob operational range.

Thermal testing from minus 30° F to plus 132° F and vacuum testing from  $10^{-3}$  mm Hg to  $10^{-6}$  mm Hg has not disclosed any failures in the unit.

Circuit analysis has shown that the failure of any one of 3 components in the horizontal hold (synchronization) circuit could have caused the failure. These off-the-shelf commercial components are 2 dual diodes, and one potentiometer that is the horizontal synchronization control. The operating flight television monitor will be vibrated to search for any possible intermittent condition.

History has shown fractures and contamination failures in similar components. No corrective action will be taken. Prior to flight, it was known that this was a commercial monitor with known contamination and drift problems.

For Apollo 17, the television monitor controls will have warm optimum-setting marks applied to the television monitor case.

This anomaly is closed.

#### 14.3.2 Oxygen Purge System Antenna Broke

Following ingress after the second extravehicular activity, the crew reported that approximately 2 inches had been broken off the tip of the antenna on the Commander's oxygen purge system (fig. 14-43). The antenna had inadvertently been left unstowed while ingressing and it is believed that the antenna was broken when it struck the ascent propulsion system engine cover as the Commander was entering through the hatch.

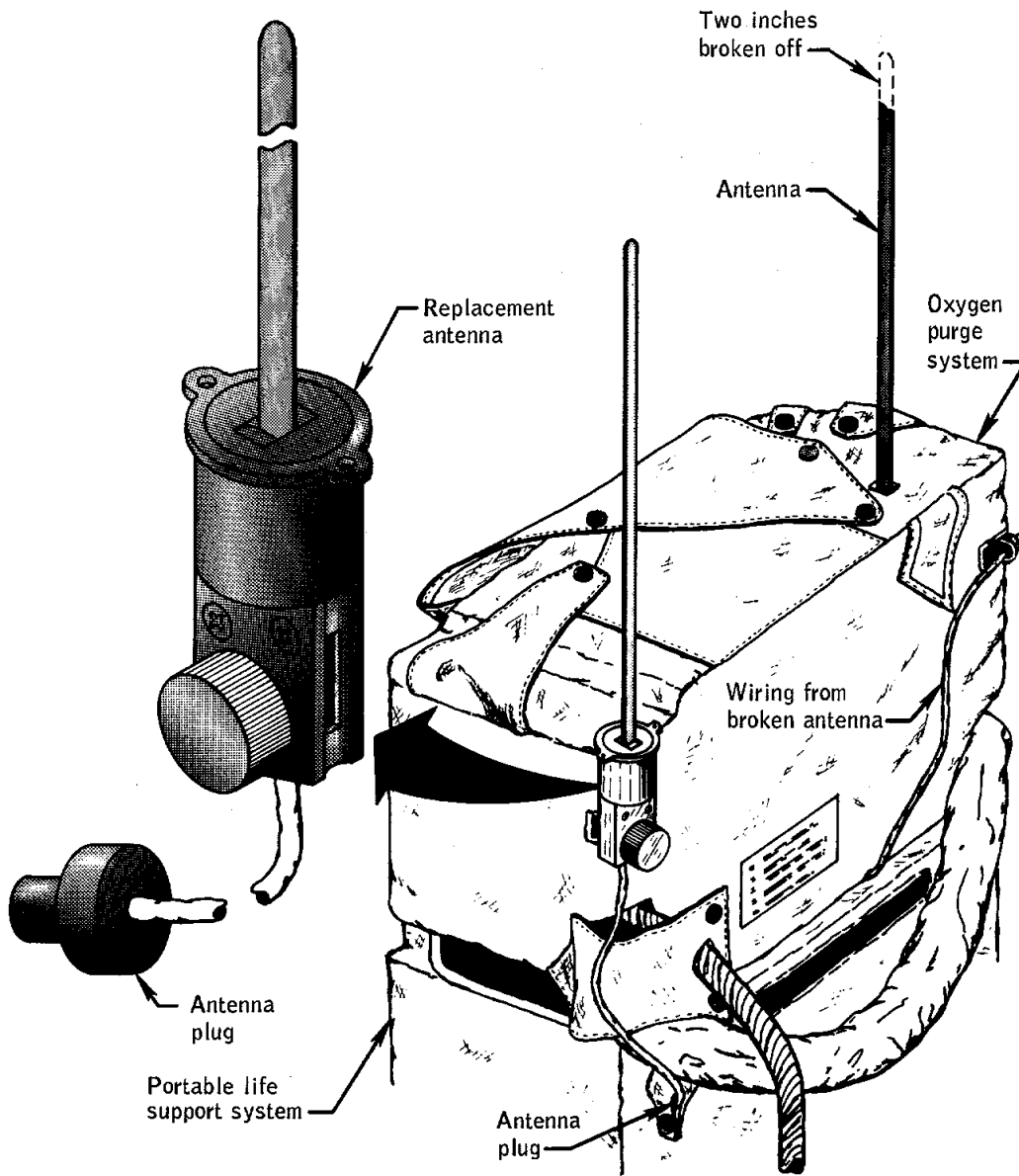


Figure 14-43.- Oxygen purge system antenna.

One spare oxygen purge system antenna will be carried on Apollo 17 and will be stowed in the buddy secondary life support system bag on the lunar roving vehicle.

Installation of the spare antenna is accomplished by clamping the antenna adapter to the oxygen purge system right-hand D-ring and connecting the spare antenna coaxial connector in place of the broken antenna's connector (fig. 14-43).

The installation will be made by the other crewman when operating in the pressurized suit condition.

This anomaly is closed.

#### 14.3.3 Experimental Gas/Water Separator Leakage

The experimental gas/water separator was cracked and leaking; therefore, it was not used.

Postflight inspection showed that the fracture occurred at the base of the threaded section of the lid (fig. 14-44) which is made of plexiglass. The unit was made of plexiglass for demonstration purposes. There was no fillet radius provided in this area which results in a stress concentration point highly susceptible to cracking. The load which caused cracking could have been induced preflight or possibly when the device was initially installed on the food preparation port by the crew.

No corrective action is required since this device will not be flown on future missions.

This anomaly is closed.

#### 14.3.4 Wrist Disconnects Difficult to Rotate

After exposure to the lunar surface environment, the wrist ring disconnects on the Commander's and the Lunar Module Pilot's suits were hard to rotate to the locked position and, once locked, were very difficult to rotate out of the locked position. Lunar soil contamination is suspected as the causes of this problem.

The wrist disconnect attaches the glove to the suit sleeve (fig. 14-45) and is covered by a gauntlet on the glove. The gauntlet is loose fitting around the suit sleeve and dirt can get to the wrist disconnect. Small tolerances between the sliding surfaces are inherent in the design to make it impossible to accidentally unlock the wrist disconnects.

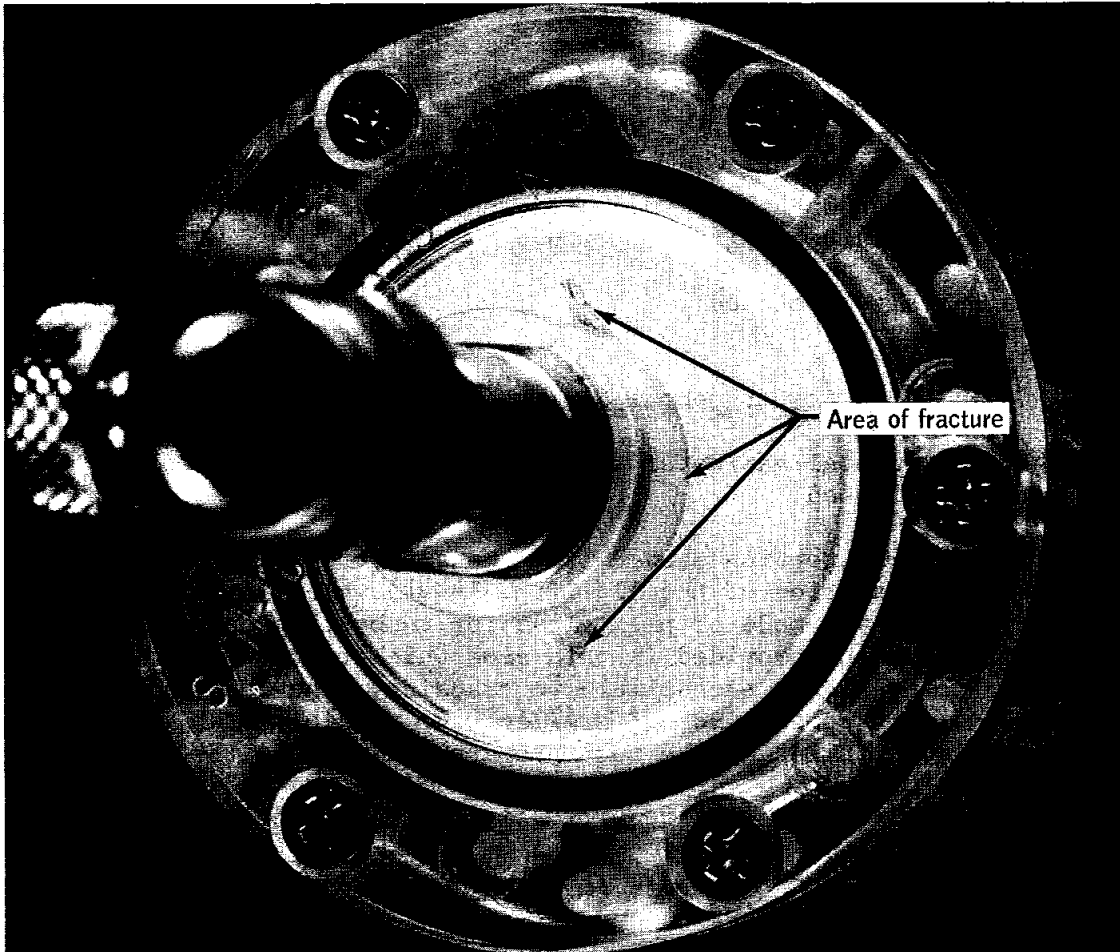
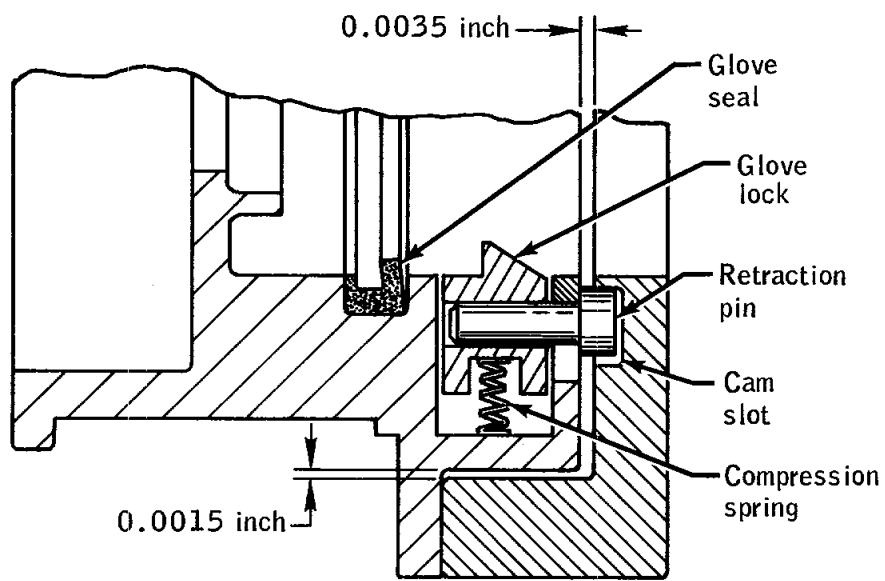
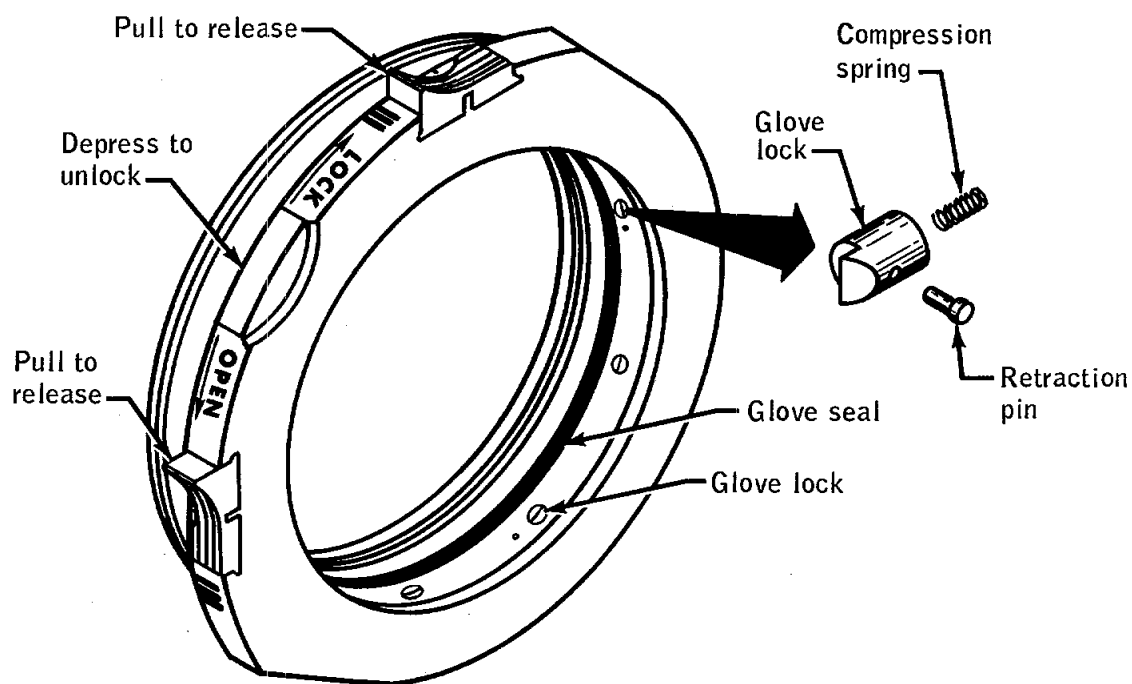


Figure 14-44.- Gas/water separator failure.

Postflight inspection of the wrist disconnects showed that lunar dust in the clearance areas caused the problem. Rubber dust covers for the ring disconnects which will afford better protection from contamination will be added for Apollo 17.

This anomaly is closed.



Section through ring (typical eight places)

Figure 14-45.- Wrist disconnect.

#### 14.3.5 Communications Carrier Microphone Boom Tip Loose

During the communications check prior to the first extravehicular activity, the microphone audio signal from the Lunar Module Pilot's headset was too weak to operate the voice-operated keying circuitry in his extravehicular communications system. This failure was attributed to a loose end cap on the right hand acoustic tube assembly (microphone boom), plus orange juice blockage of the left-hand acoustic tube (fig. 14-46). The problem was cleared during flight by pushing the right-hand boom tip back into place and sucking out the orange juice from the left-hand boom.

Postflight inspection of the right-hand boom by the manufacturer showed an insufficient amount of adhesive had been applied during fabrication of the tip to the acoustical tube.

Corrective action consists of a pull test to assure that sufficient adhesive has been used in attaching the tip to the tube.

This anomaly is closed.

#### 14.3.6 Communication Carrier Intermittent

During the transearth coast phase, the Lunar Module Pilot experienced intermittent operation of his communications carrier headset earphone circuit. This condition was cleared by flexing the constant wear garment harness near the 21-pin connector (fig. 14-47).

Postflight testing involving the communications carrier umbilical and control head, the constant-wear garment harness, and the communications carrier headset showed no hardware problem. However, a condition was found wherein the microphone was active but the earphone was dead if the 21-pin connector was not mated securely. The Lunar Module Pilot stated that he had disconnected the 21-pin connector several times during the transearth coast phase.

Indications are the problem was caused because the connector was not fully seated and the flexing of the harness seated the connector.

This anomaly is closed.

#### 14.3.7 Retractable Tether Would Not Fully Retract

The Commander's tether would not fully retract during lunar surface operations.

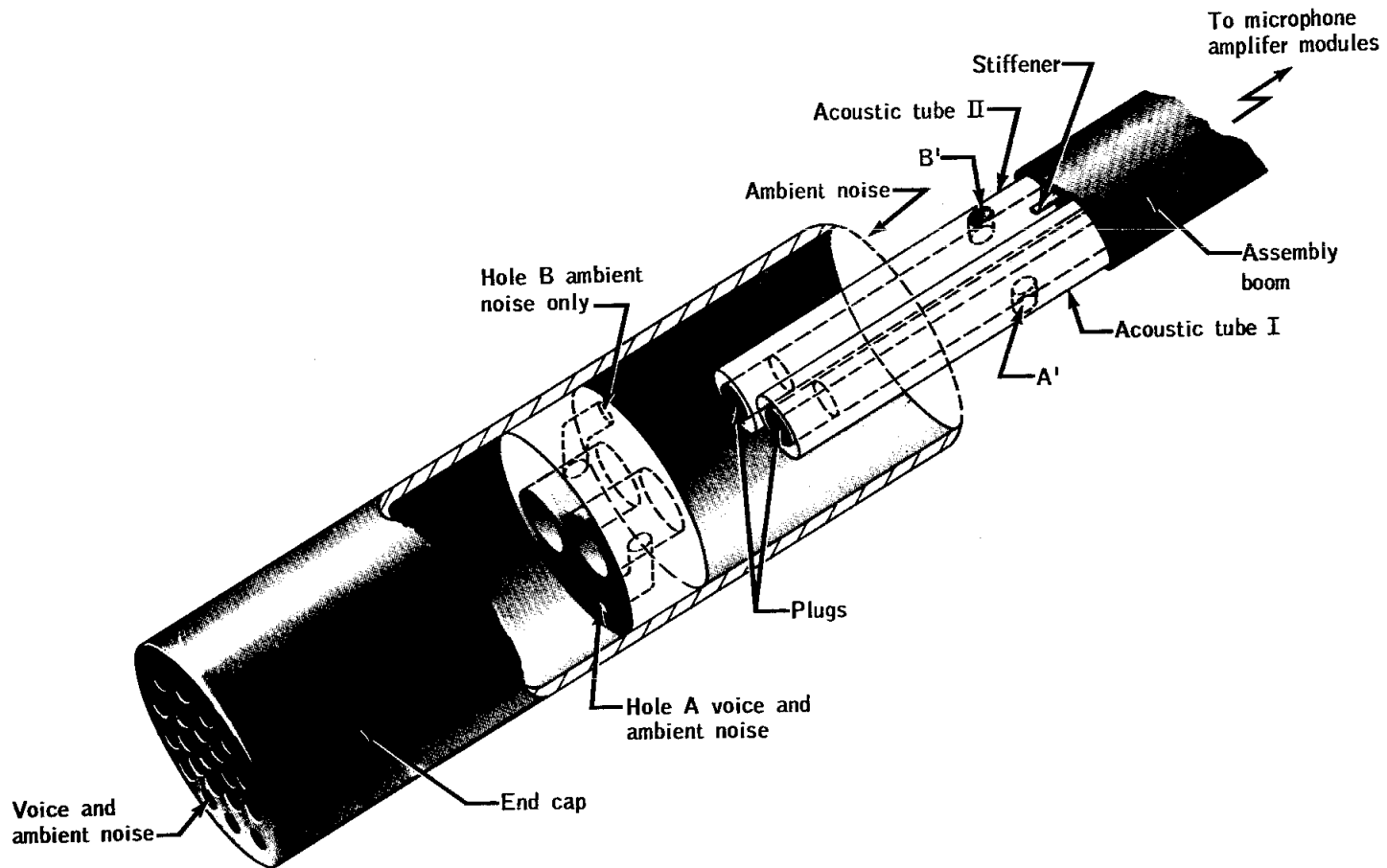


Figure 14-46.- Communication carrier microphone boom (exploded view).



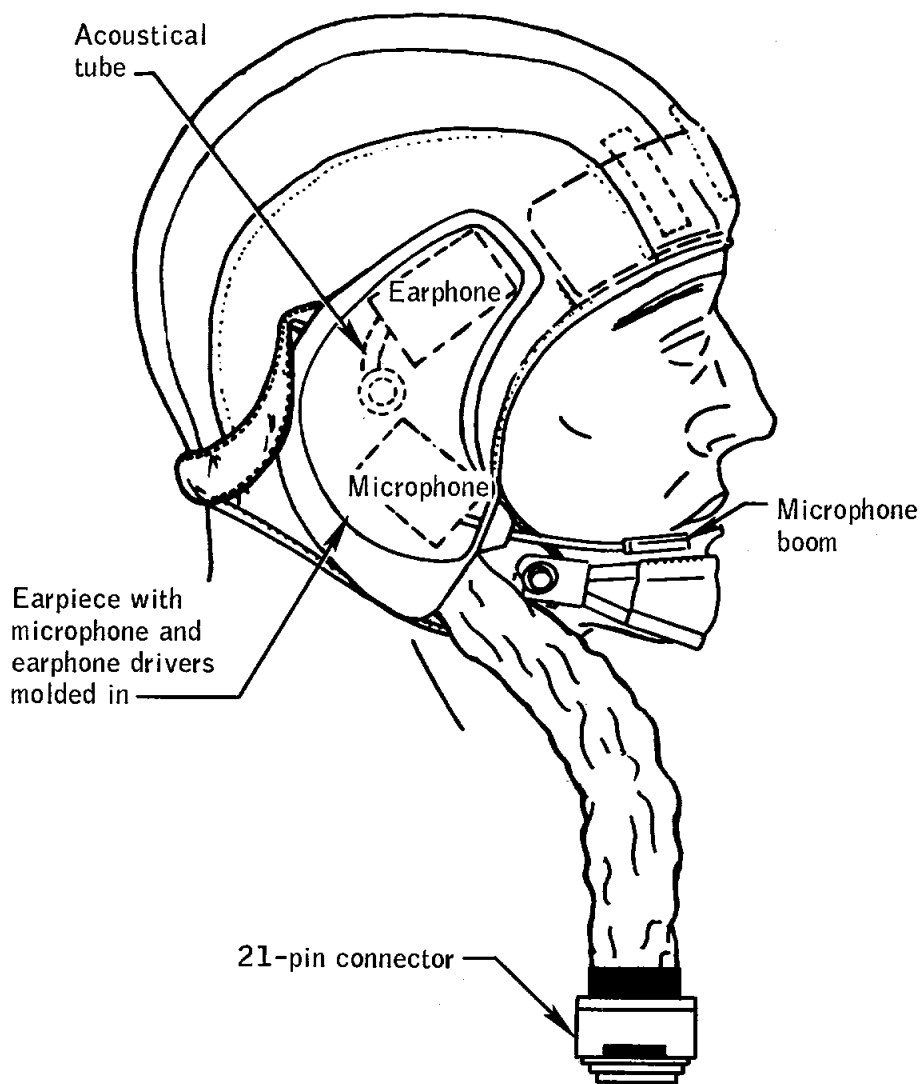


Figure 14-47.- Communications carrier.

Postflight inspection indicates that the tether is now operating; however, there is a noticeable increase in friction (fig. 14-48) during the retraction cycle. A thread sealant (loctite) was found on the spool shaft, which increased the friction.

Future units will be tested for friction buildup prior to flight.

This anomaly is closed.

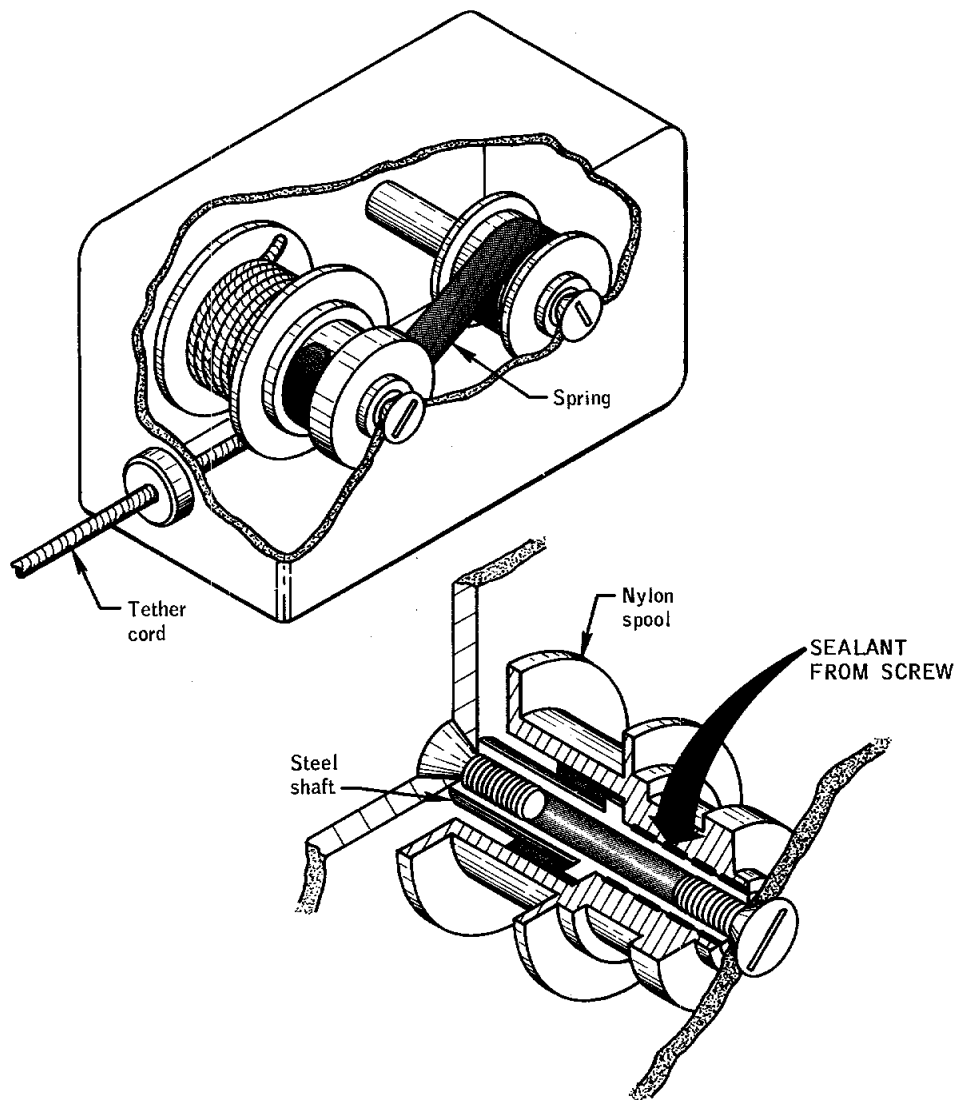


Figure 14-48.- Retractable tether.

#### 14.3.8 Commander's and Lunar Module Pilot's Cuff Gage Readings Different During Transearth Extravehicular Activity

The Commander reported that his cuff gage indicated a different pressure from that of the Lunar Module Pilot during the transearth extravehicular activity. The Commander's gage indicated approximately 3.5 psia, whereas the Lunar Module Pilot's gage indicated approximately 3.9 psia. The normal suit pressure should have been approximately 3.8 psia. During the previous suit integrity check, the cuff gages indicated approximately the same. The crew did not read the gages again after the reported problem.

The cuff gage (fig. 14-49) is a bellows-actuated aneroid-type mechanical gage which indicates differential pressure and has an accuracy of  $\pm 0.1$  psia. The gage opening to the outside of the gage is protected by a centered plug. When the bellows is pressurized, it lifts the rocker arm, rotating the rocker in its pivots. The other arm on the rocker then rotates the rack assembly, causing the pinion gear and pointer to rotate.

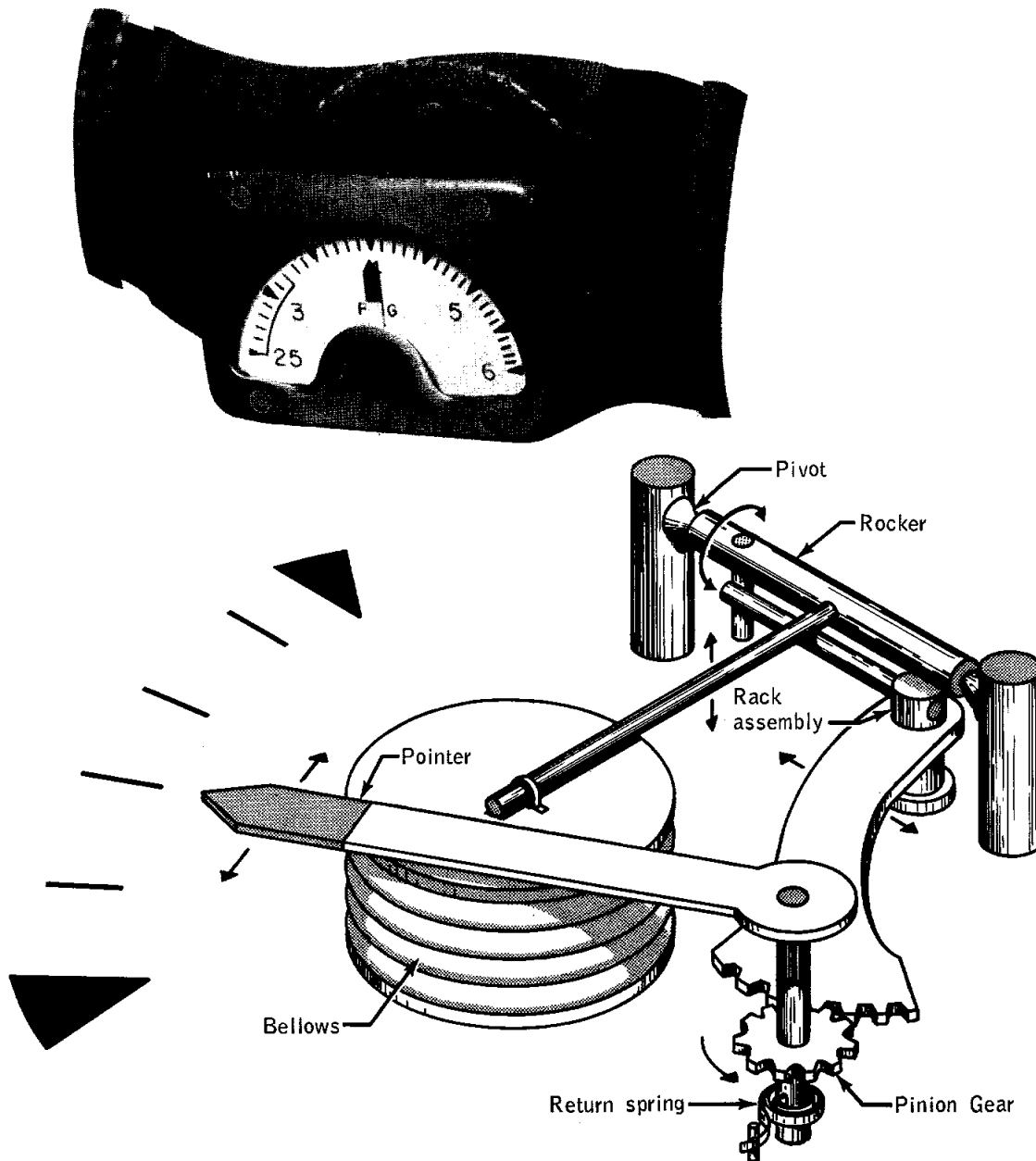


Figure 14-49.- Cuff gage mechanism.

During postflight testing at ambient and vacuum conditions, both the Commander's and the Lunar Module Pilot's gages read well within 0.1 psi of the 4.0 psi to which they were pressurized.

Both gages were disassembled and inspected. No discrepancies were found. Minor contamination was found, some particles as large as 0.001 to 0.002 inch, but none were large enough to interfere with the operation of the gage mechanism. Leak tests on the bellows were also performed and the results were well within specification.

There are two possible explanations for the low reading. The first is that a contaminant particle large enough to resist the movement of the mechanism temporarily became caught in the gear train. The particle could have been lost during disassembly. The second possibility is that the gage was misread.

Before final assembly, the gage is completely cleaned with freon and dried. Since the cleanliness procedure is satisfactory and no anomaly could be found in the flight gage, no corrective action is required.

This anomaly is closed.

#### 14.3.9 Extravehicular Mobility Unit Maintenance Kit In Command Module Expanded

The crew commented that the kit in the command module appeared to have expanded more than the kit in the lunar module, and that the wet wipes were the items which had expanded. This condition made it more inconvenient to handle the kit.

Two extravehicular mobility unit maintenance kits are carried aboard the spacecraft: one is stowed in a rigid locker in the command module and one in a Beta cloth helmet stowage bag in the lunar module. Three flat pockets, each containing two wet wipes for visor anti-fog treatment, are provided in each kit. Before placing in the kit, the wet wipes packets are evacuated to 1.5 psia and the packet is double heat-sealed. This is done to reduce the size for packing and to reduce ballooning.

The individual packets are vacuum checked for leaks which would allow the wipes to dry out. This check has also indicated that packet pressure is approximately 7 psia as a result of film permeability, outgassing, etc. Therefore, some expansion can be expected at 5 psia.

The Apollo 17 crew has been familiarized with the expansion to be expected. Some variation in expansion can be expected. Expansion does not create a problem, so no corrective action is required.

This anomaly is closed.

## 14.3.10 Purge Valve Pin Came Out

On three occasions during the first extravehicular activity, the pin assembly (red apple) of the Commander's purge valve was accidentally removed while ingressing or egressing the lunar roving vehicle. Each time, the assembly was found and reinserted. During subsequent extravehicular activities, the crew wore their purge valves rotated from the recommended position to prevent the pin from being pulled out.

Testing indicates that the lunar rover lap belt buckle could be the cause of the purge valve pin being accidentally removed.

A modification has been made to eliminate the barrel actuator spring in the purge valve and to shorten and stiffen the pin assembly lanyard. This modification will require manual pull-out of the purge valve barrel, and will provide less chance of the red apple and lanyard being snagged.

This anomaly is closed.

## 14.3.11 Tool Carrier Fell Off Portable Life Support System

During the preparation inside the lunar module for the first extravehicular activity, the tool carrier harness became disconnected and fell off the portable life support system.

The harness is held together by a quick-disconnect snap buckle which has a spring-loaded release pin (fig. 14-50). Only a small force (5 lb) on the release strap is required to move the pin. The pin was inadvertently pulled during the cabin activity.

The pin spring has been changed to increase the pull force required to between 10 and 20 pounds so as to avoid inadvertent actuation.

This anomaly is closed.

## 14.3.12 Watch Crystal Missing

At depressurization, just prior to the third lunar extravehicular activity, the Lunar Module Pilot noted that his chronograph crystal was gone. The chronograph hands and face were not hit. However, about 12 minutes later the movement stopped. Most likely, warpage caused by thermal cycling allowed the differential pressure across the acrylic crystal to pop it out of the case. The exposure to and penetration of lunar dust contamination about the Lunar Module Pilot's sleeves probably caused the failure of the chronograph movement.

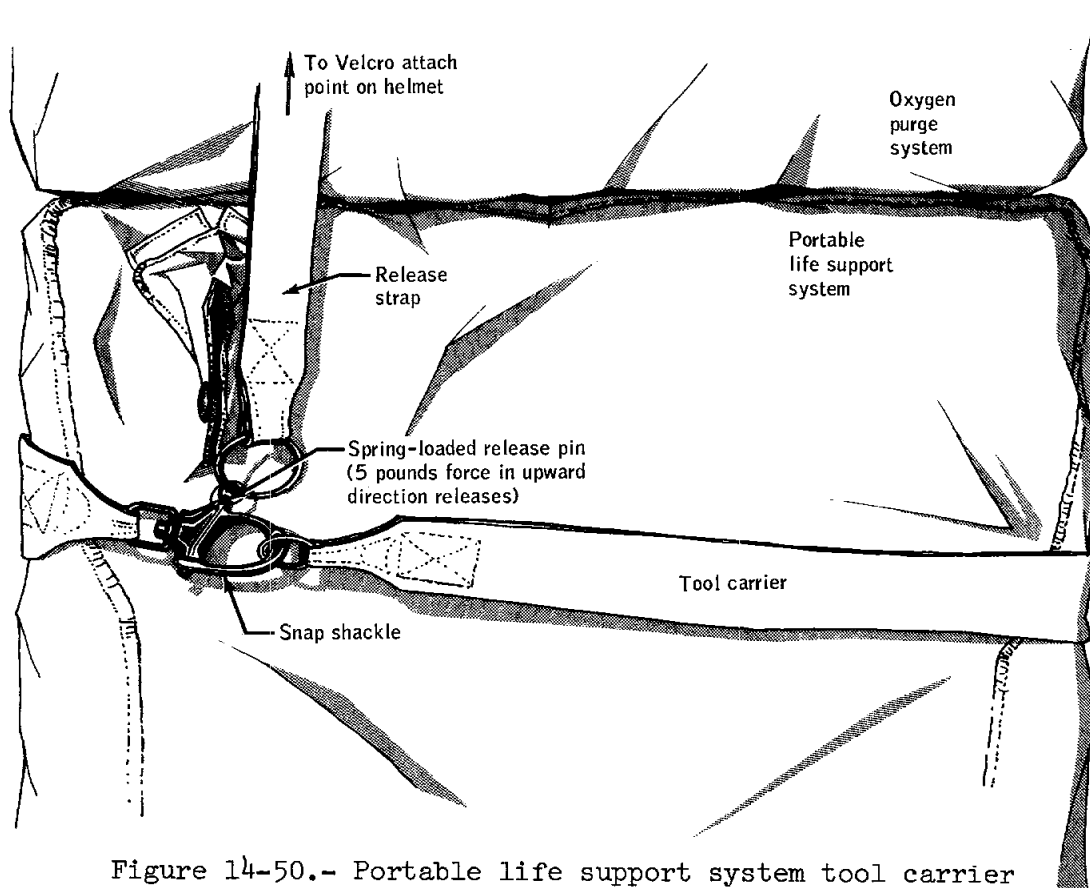


Figure 14-50.- Portable life support system tool carrier spring-pin shackle connection.

These chronographs are certified to a maximum temperature of 160° F. Testing has demonstrated that in the range of 190° F, the crystal is weakened to the point where internal pressure can push the crystal off. For the chronograph to reach a temperature of 190° F, direct continuous exposure to incident solar radiation normal to its surface is required for approximately 12 minutes.

These chronographs are tested at the Manned Spacecraft Center when received, again before shipment to the Kennedy Space Center and again just prior to flight. The Apollo chronograph is a secondary timing device and is not critical to mission success or crew safety. There are no plans for corrective action.

This anomaly is closed.

#### 14.4 LUNAR SURFACE EXPERIMENTS EQUIPMENT ANOMALIES

##### 14.4.1. Heat Flow Experiment Cable Broke

The Commander's legs became entangled in the heat flow experiment cable near the central station and his movements resulted in the cable breaking at the connector to the central station (at the connector board solder joints); however, the central station did not move. Loss of the connection to the central station resulted in loss of the heat flow experiment.

The heat flow experiment is stowed on subpackage 2. Upon arrival at the Apollo lunar surface experiments package deployment site, the experiment is removed from the subpackage and the electrical ribbon cable is connected to the central station by an Astromate connector (fig. 14-51). The cable is bonded and soldered to a printed circuit board which is clamped in a connector. The cable-to-board joint is reinforced by two to four thicknesses of 0.5-mil Kapton tape.

Pull tests performed on the cable/Astromate connector configuration indicate the strength at the cable/board interface was 31 pounds. A modified joint assembly (fig. 14-52) which provides for strain relief and has a pull strength of over 100 pounds will be used for the heat flow experiment connector and similar connectors on Apollo 17.

This anomaly is closed.

##### 14.4.2 One Stake on Mortar Package Did Not Deploy

The lanyard pulled the release pins from three of the four spring-loaded hinged stakes on the mortar package pallet and these three deployed normally. The release pin for stake 3 was bent and jammed so that it could not be pulled out. The pallet was emplaced with the three stakes pressed into the lunar surface, and the crew reported the complete mortar package and pallet assembly was stable.

The mortar package pallet assembly includes four 7-inch long stakes (fig. 14-53) which deploy normal to the pallet when the release pins are removed. When the pallet is properly positioned, the stakes are pressed into the lunar surface to provide additional stability to the platform.

Tests performed during the development of the pallet assembly showed three deployed stakes are adequate to provide stability.

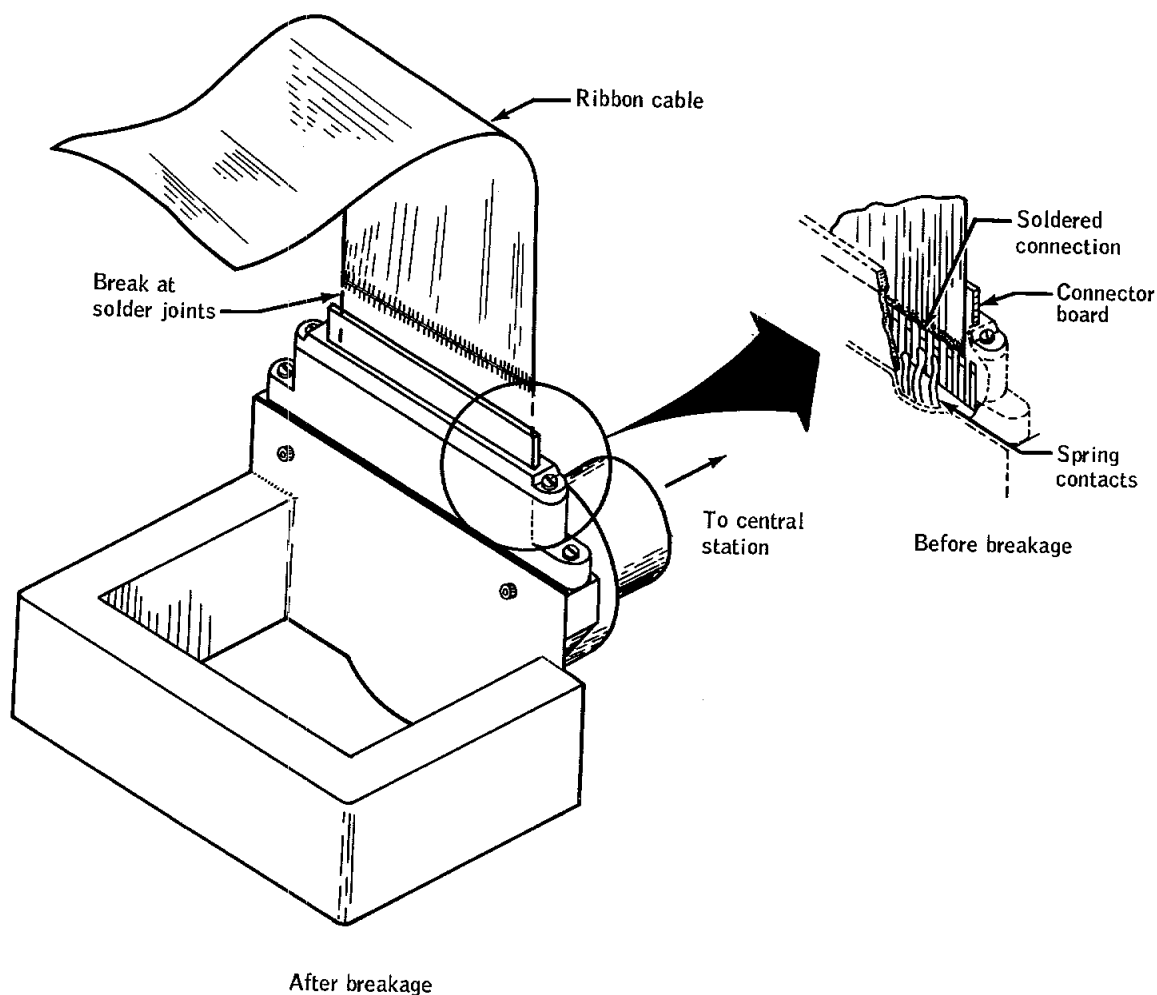


Figure 14-51.- Heat flow experiment connector.

No corrective action is required as the experiment is not scheduled for another mission.

This anomaly is closed.

#### 14.4.3 Mortar Box Roll Angle Telemetry Indicated Off-Scale High

The telemetry indication of the active seismic experiment mortar box roll angle has been off-scale high since initial activation of the telemetry high-bit-rate mode after turn-on. The indication suggests the package rolled to the right between 25° and 145°. However, the position of



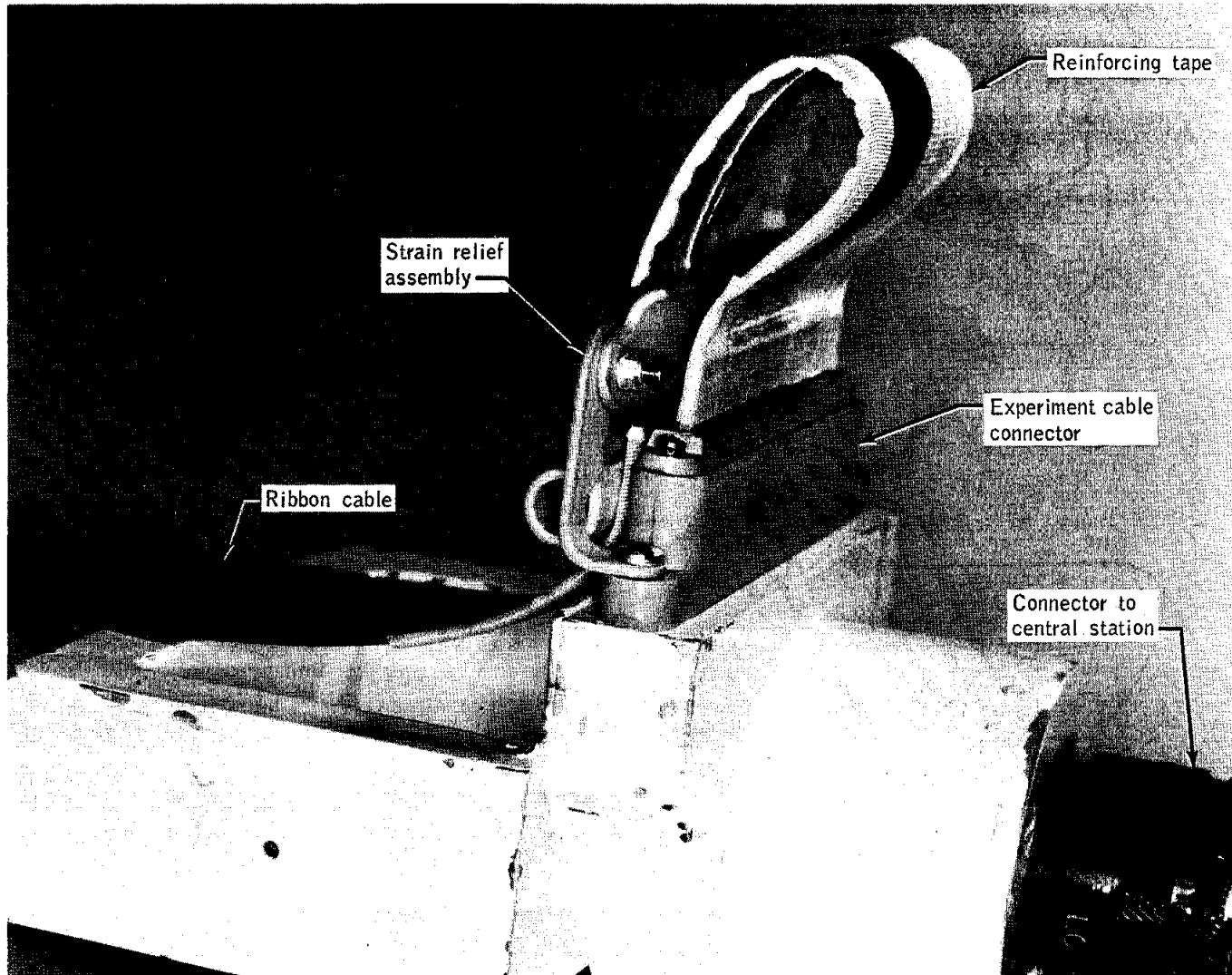


Figure 14-52.- Modified heat flow experiment connector assembly.

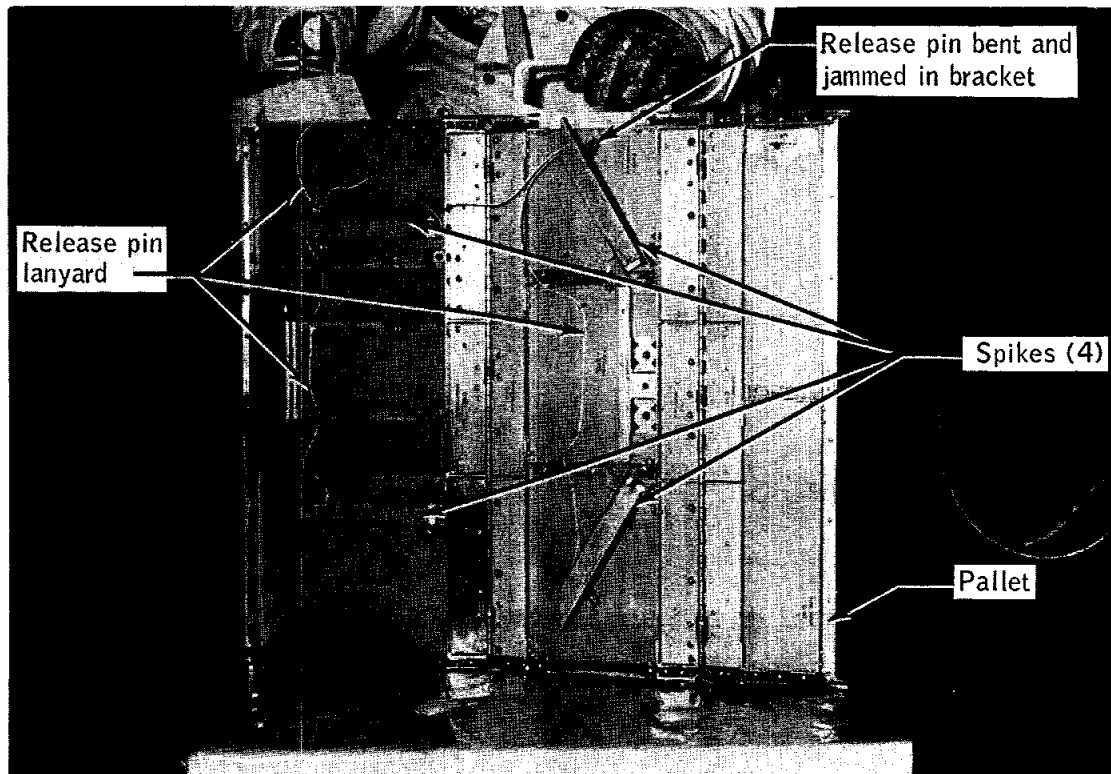


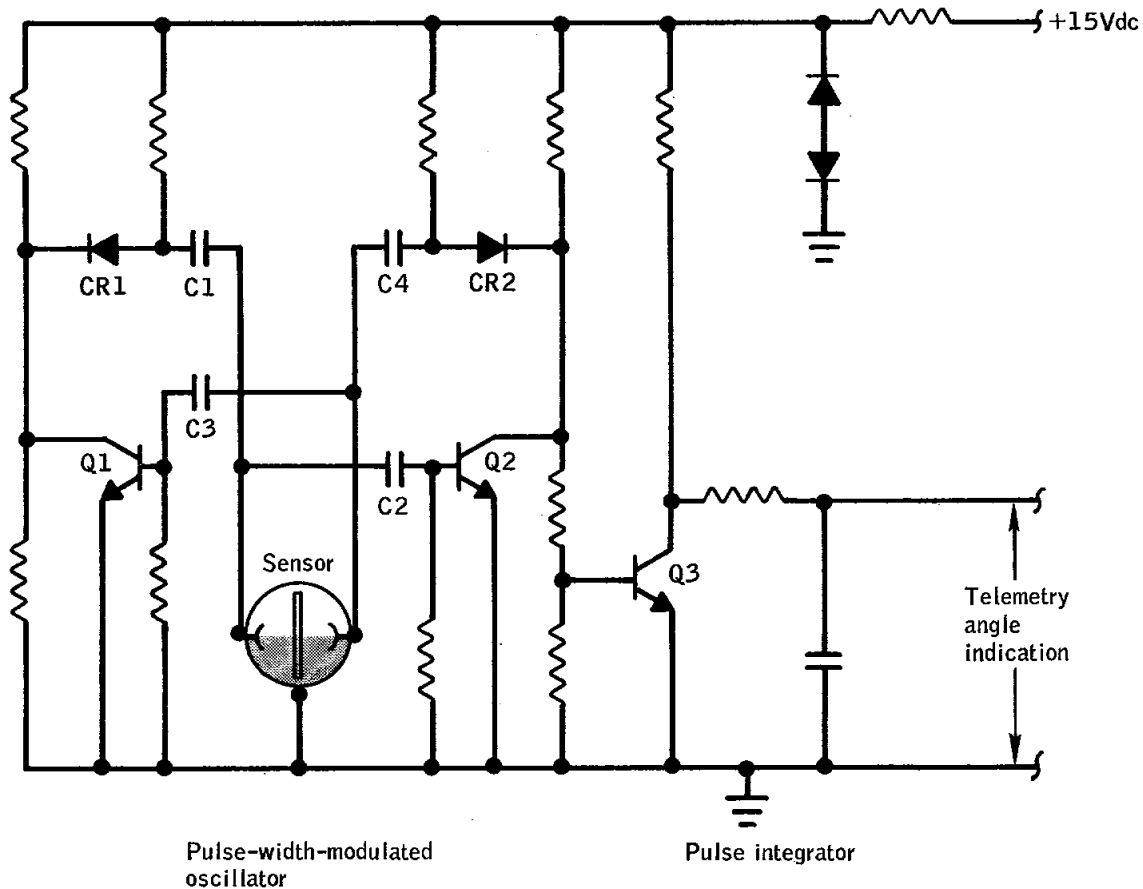
Figure 14-53.- Bottom view of active seismic experiment mortar package pallet.

the bubble in the level indicator observed by the crew showed that the mortar package was less than  $5^\circ$  off the nominal in combined pitch and roll. The pitch angle sensor data indicated a pitch angle of minus  $2.7^\circ$  and photography confirms that the alignment was satisfactory. The off-scale reading therefore indicates a failure of the sensor circuit.

The sensor circuitry includes a free-running multivibrator, with the pulse-width ratio controlled by the sensor which functions as a potentiometer (fig. 14-54). Numerous failure possibilities in the circuit, such as open transistors, shorted capacitors, and open solder joints could have caused failure of the multivibrator and the off-scale high reading.

No corrective action is required as the experiment is not scheduled for another mission.

This anomaly is closed.



Note: An open in any component in the pulse-width-modulated oscillator (CR1, CR2, C1, C2, C3, C4, Q1 and Q2) is a single-point failure, or an open in the pulse integrator (Q3) is a single-point failure.

Figure 14-54.- Roll or pitch angle sensor electronics.

#### 14.4.4 Cosmic Ray Detector Panel 4 Shade Partially Deployed and Lanyard Broke

The Commander pulled the red-ring lanyard to shift the shade in panel 4. The shade moved only 1 inch instead of about 3.5 inches and the lanyard broke.

A movable platinum shade (fig. 14-55) covers the top half of panel 4 during translunar flight and until after the radioisotope thermoelectric generator is removed from the area during lunar surface operations. The

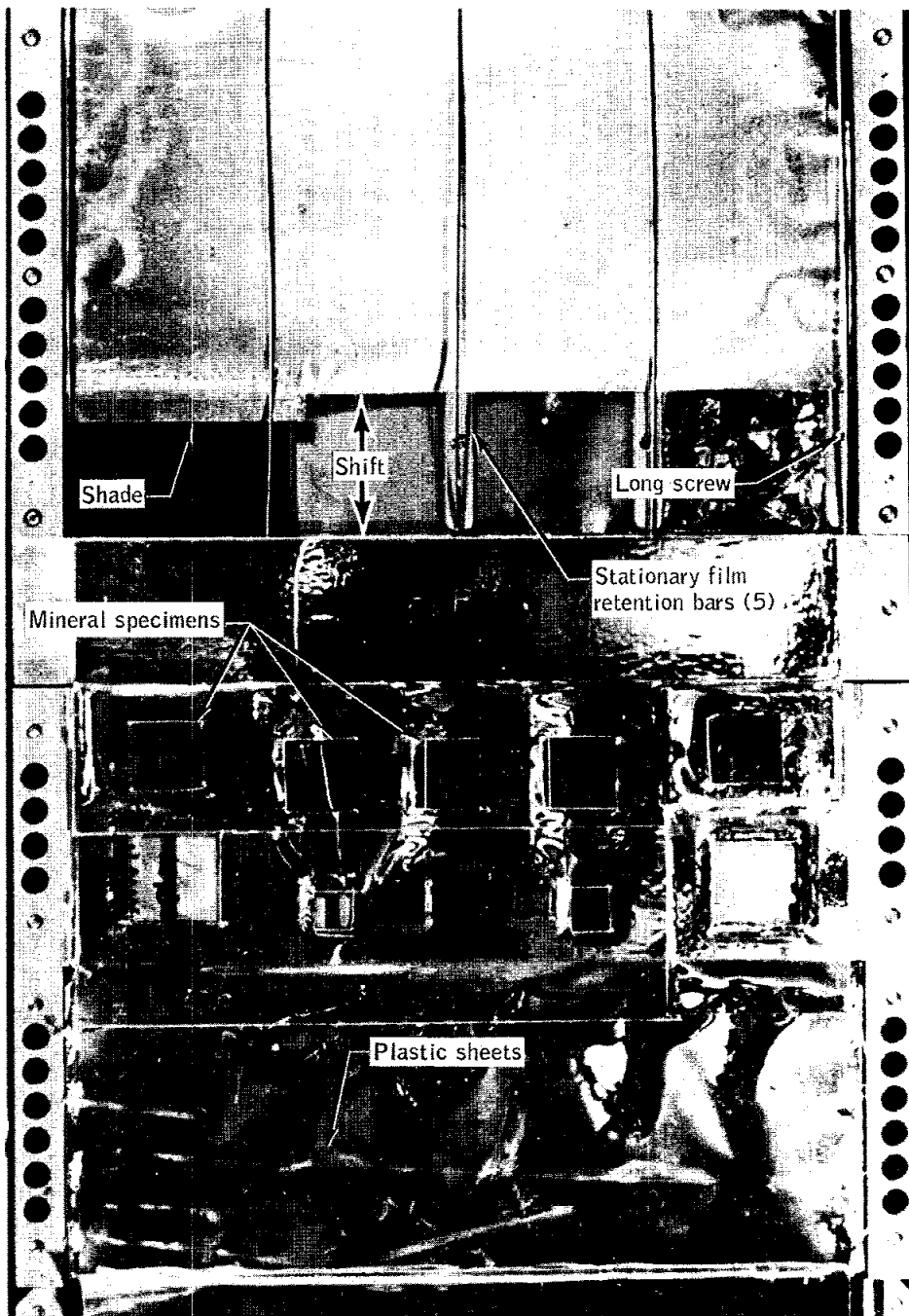


Figure 14-55.- Panel 4 with partially deployed shade.

shade passes over a round guide bar at the top of the instrument (see fig. 14-56) and is connected in the back of the panel to the movable target plate. The red-ring lanyard is attached to the bottom edge of the target plate and, passing behind panels 1, 2, and 3, it extends from the bottom of panel 1. When the lanyard is pulled down, the target plate moves down and the platinum foil moves upward over the round guide bar. This exposes material mounted on the stationary backplate.

Examination of the panel assembly has shown that the failure of the shifting mechanism was caused by a clamping of the target plate by two retention bar screws which projected past the backplate into the target plate, and effectively locked it in place (fig. 14-57).

Figure 14-56 shows the panel 4 assembly with the target plate and shade fully deployed after having backed off the two projecting screws. Note the rub mark from the screws on the target plate.

The assembly performed satisfactorily when deployed during the pre-flight fit and function check. However, it was necessary to refurbish the hardware after this operation, and the screw clearances may have changed as a result of the refurbishment.

This experiment is not scheduled for another mission.

This anomaly is closed.

#### 14.4.5 Vertical Staff of Gnomon Separated From Leg Assembly

When the gnomon (fig. 14-58) was being unstowed from its stowage bag during the second extravehicular activity, the leg assembly remained in the bag, and the vertical staff came out separately. The leg assembly, because of its color scale, was used during the rest of the lunar surface photographic operations. The primary function of the complete gnomon is to indicate the local vertical in lunar surface geology photographs.

The staff can be separated from the leg assembly by backing out the gimbal pivot screws. However, all four screws must be backed out (fig. 14-59). There was no indication in the photographs of any screws backing out. During ground operations, a staff separated from the leg assembly by breaking the inner gimbal pivot pins. The break occurred where the 0.040-inch-diameter pivot pin is pressed into the pivot screw.

The pivot assembly consists of standard high-speed steel reamer blank material pressed into a stainless steel adjusting screw or retainer. The reamer blank material provides the high strength and hardness required,

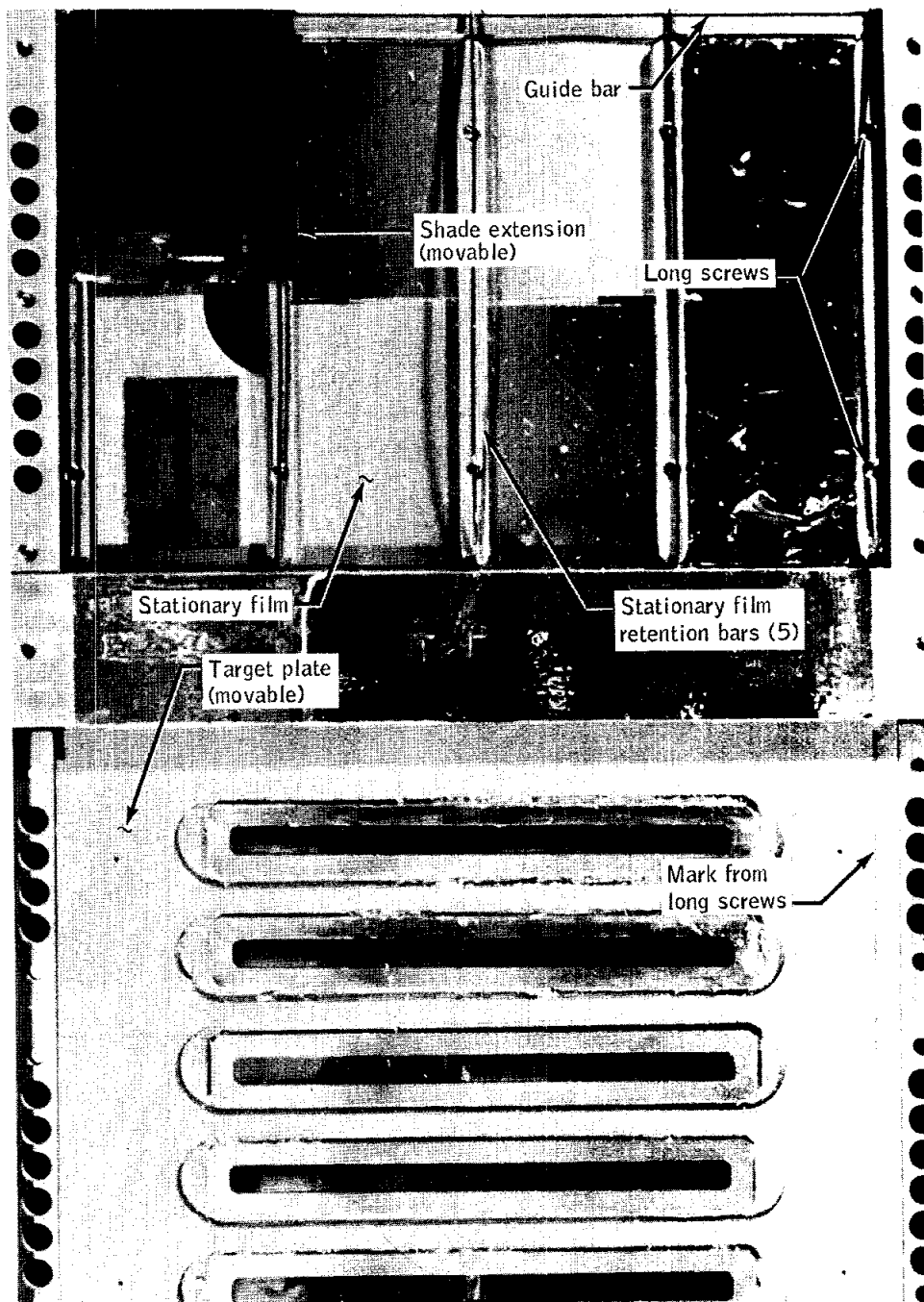


Figure 14-56.- Panel 4 target plate and fully deployed shade.

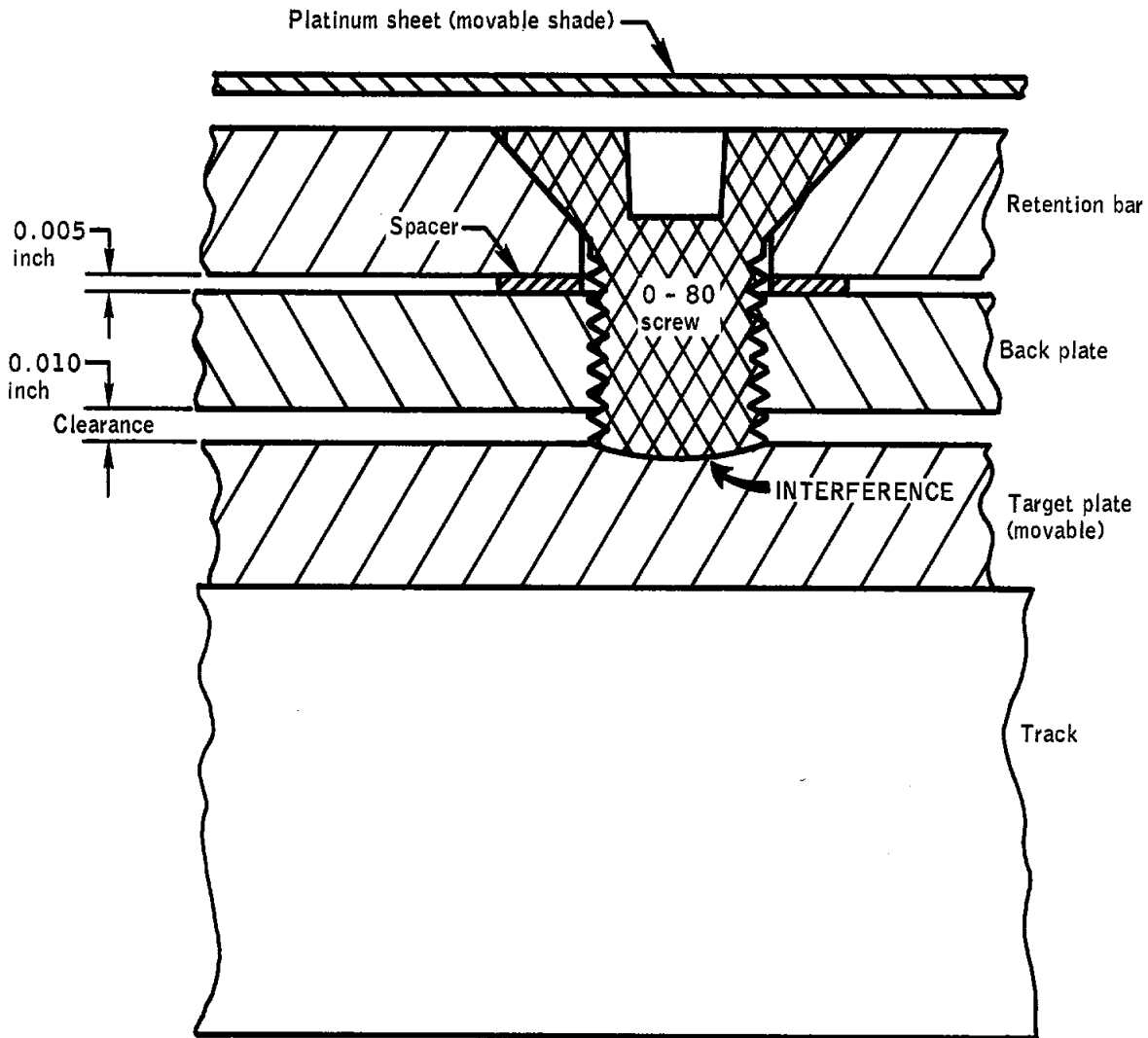


Figure 14-57.- Panel 4 screw interference

but has a tendency to be brittle without additional tempering. In addition, the combination with stainless steel can be conducive to stress corrosion. Either, or a combination, of the two conditions is considered as the most likely cause of the anomaly.

Pivot pins for the Apollo 17 gnomon will be given the additional tempering required for greater toughness, and a thin film of oil will be applied for protection against corrosion. Ground tests have shown the

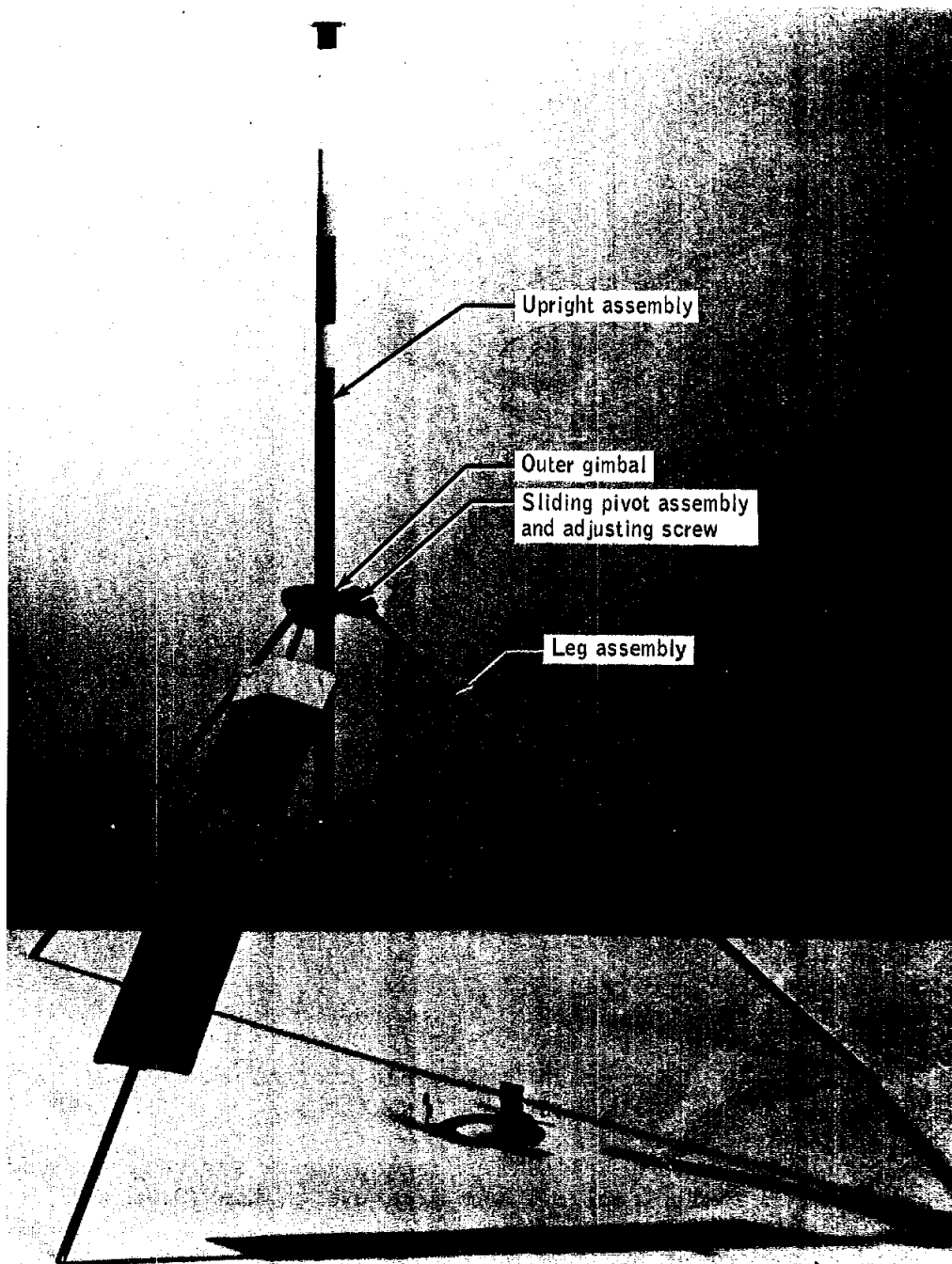


Figure 14-58.- Gnomon assembly.



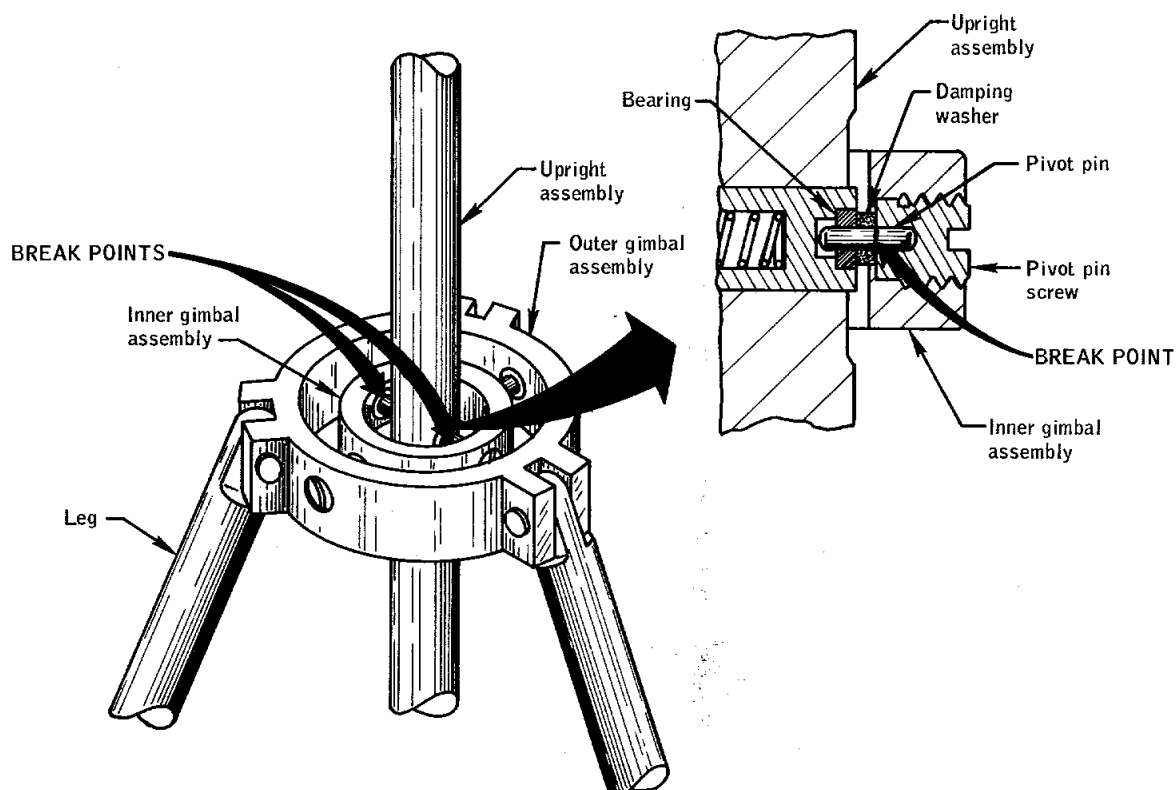


Figure 14-59.- Gnomon gimbal assembly

damping will be unaffected. Assembly of the pin in the screw will be delayed until as late as possible before launch so as to reduce the time for possible stress corrosion to occur.

This anomaly is closed.

#### 14.4.6 Documented Sample Bag Dispensers Fell Off 70-mm Camera Brackets

During the geology activities on the lunar surface, the bag dispenser assemblies repeatedly fell off the brackets on the 70-mm cameras.

The dispenser is mounted on an adapter (fig. 14-60) which is inserted in the ring-sight tee-slot bracket on the camera. The adapter-to-tee slot interface is horizontal and depends on springs in the tee slot to hold the adapter in the latched position. This latching method is inadequate.

The adapter has been redesigned so as to provide a positive lock in the installed position as shown in figure 14-60.

This anomaly is closed.

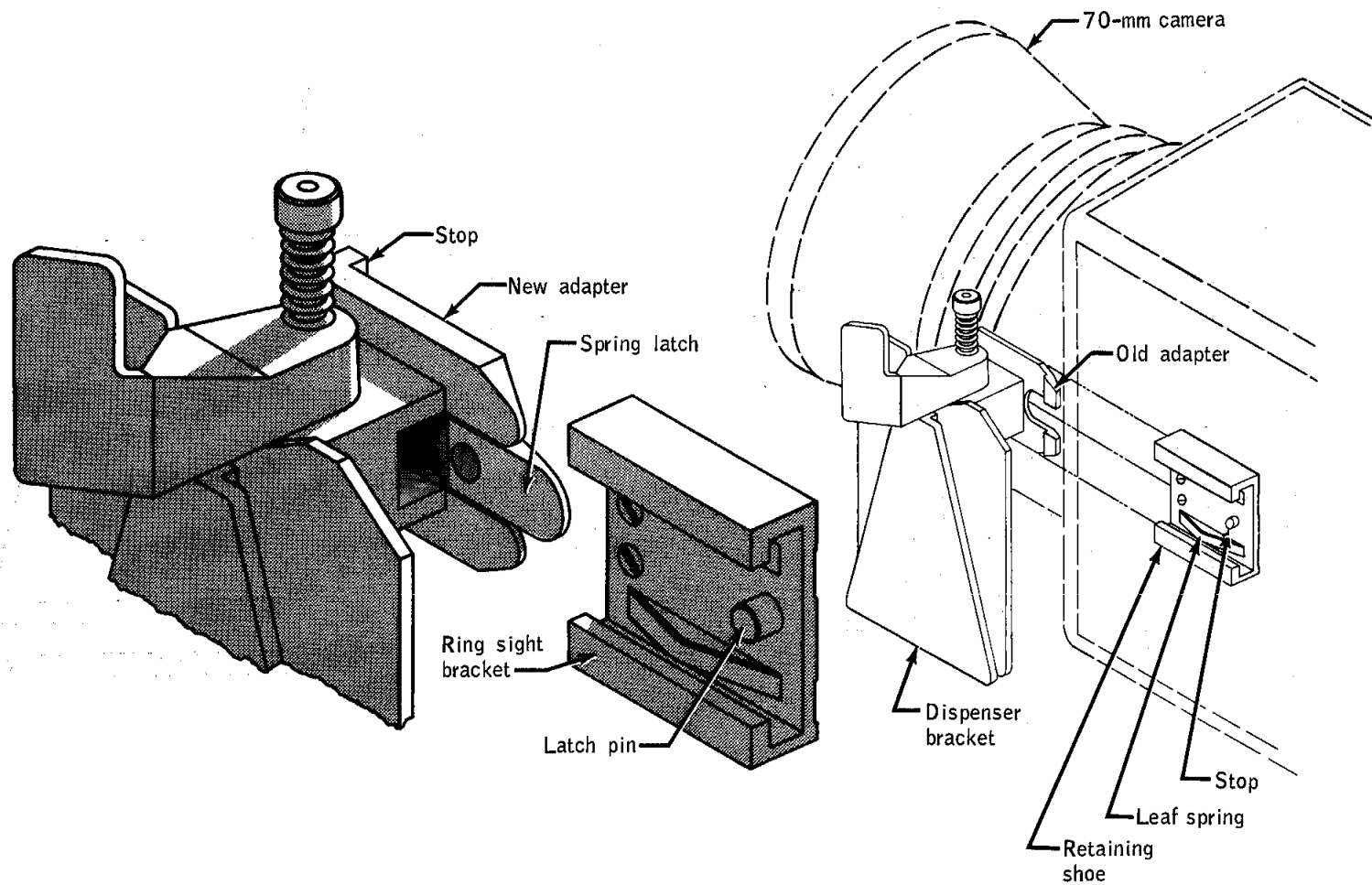


Figure 14-60.- Sample bag dispenser retention.

#### 14.4.7 Screws and Holding Ring Came Off One of the Documented Sample Bag Dispensers

The three screws which fasten the bag ring to the bracket plate had come out on one of the documented sample bag dispensers and consequently came apart when unstowed.

The three flat-headed stainless steel screws mate with threads in the aluminum ring (fig. 14-61). The heads are staked to the aluminum bracket plate. Thread sealant materials are not permitted because of the possibility of lunar sample contamination.

The Apollo 17 dispensers will be re-inspected to assure proper staking of the screws and tightness of the threads in the aluminum ring.

This anomaly is closed.

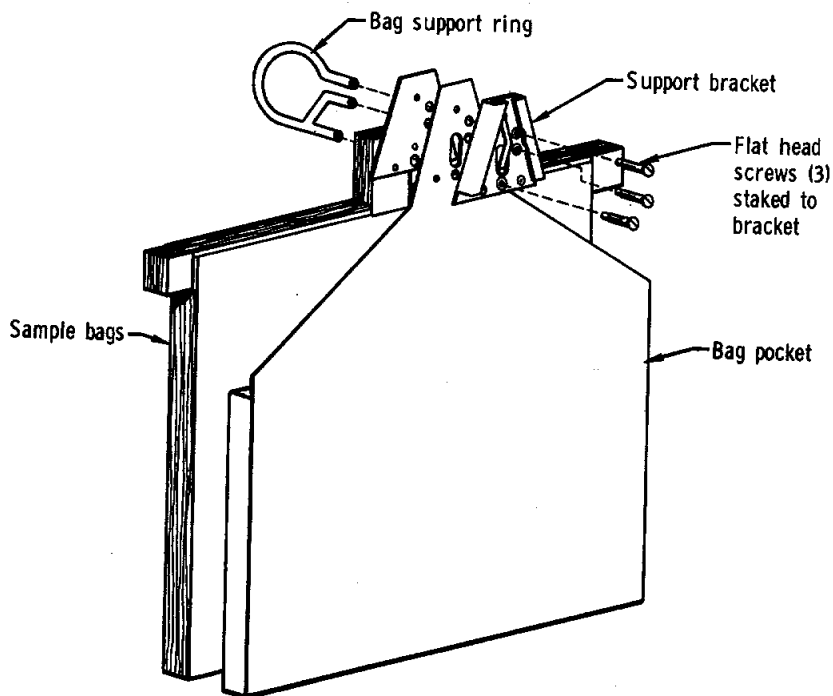


Figure 14-61.- Documented sample bag dispenser assembly.

#### 14.4.8 Sample Collection Bag Fell Off the Portable Life Support System Tool Carrier

During lunar surface operations, the Commander's sample collection bag came loose from the portable life support system tool carrier several times and fell off once.

The sample collection bag essentially consists of a Teflon bag on a metal frame (fig. 14-62). The bag opening is covered by a Teflon lid on a hinged metal frame. Attached to the metal frame on one side of the bag, about 2 inches below the lid, is a 3/8-inch-wide stainless steel strap with offsets to accommodate the two hooks on the tool carrier. About 1 inch from the bottom of the same side is a 1-inch-wide Teflon band, sewn to the bag, with an offset loop approximately 1 inch by 5 inches to accommodate the Velcro strap from the bottom of the tool carrier. The Velcro strap, when tightened down, keeps the bag from floating or bouncing off the hooks. During the lunar roving vehicle operations, the Velcro strap sometimes loosened because of the entrapped lunar dust so that the bag could come off.

For Apollo 17, the sample container bag hooks that are attached to the portable life support system tool carrier have been redesigned to prevent the bag from floating or bouncing off the portable life support system. The new hook design consists of a flat spring and a stop so that the same force is required to install and remove the bag.

This anomaly is closed.

#### 14.4.9 Lunar Surface Far Ultraviolet Camera Azimuth Adjustment Became More Difficult

Rotating the camera assembly for each azimuth setting was more difficult than expected, and became progressively difficult during the lunar stay.

To adjust the azimuth to the proper dial reading, the camera is rotated on a 12.5-inch diameter ball-bearing ring (fig. 14-63). The bearing is not sealed; however, the crew did not observe any lunar dust on the bearing.

The azimuth ring bearing was packed with a waxy, low-outgassing grease which stiffens appreciably at temperature below 50° F. This grease is normally used as a sealant rather than a lubricant. The camera was intentionally kept in the shade to protect the film from high temperatures. As a result, the grease stiffened. The manual azimuth adjustment operation was not included in cold chamber tests with other operations of the camera.

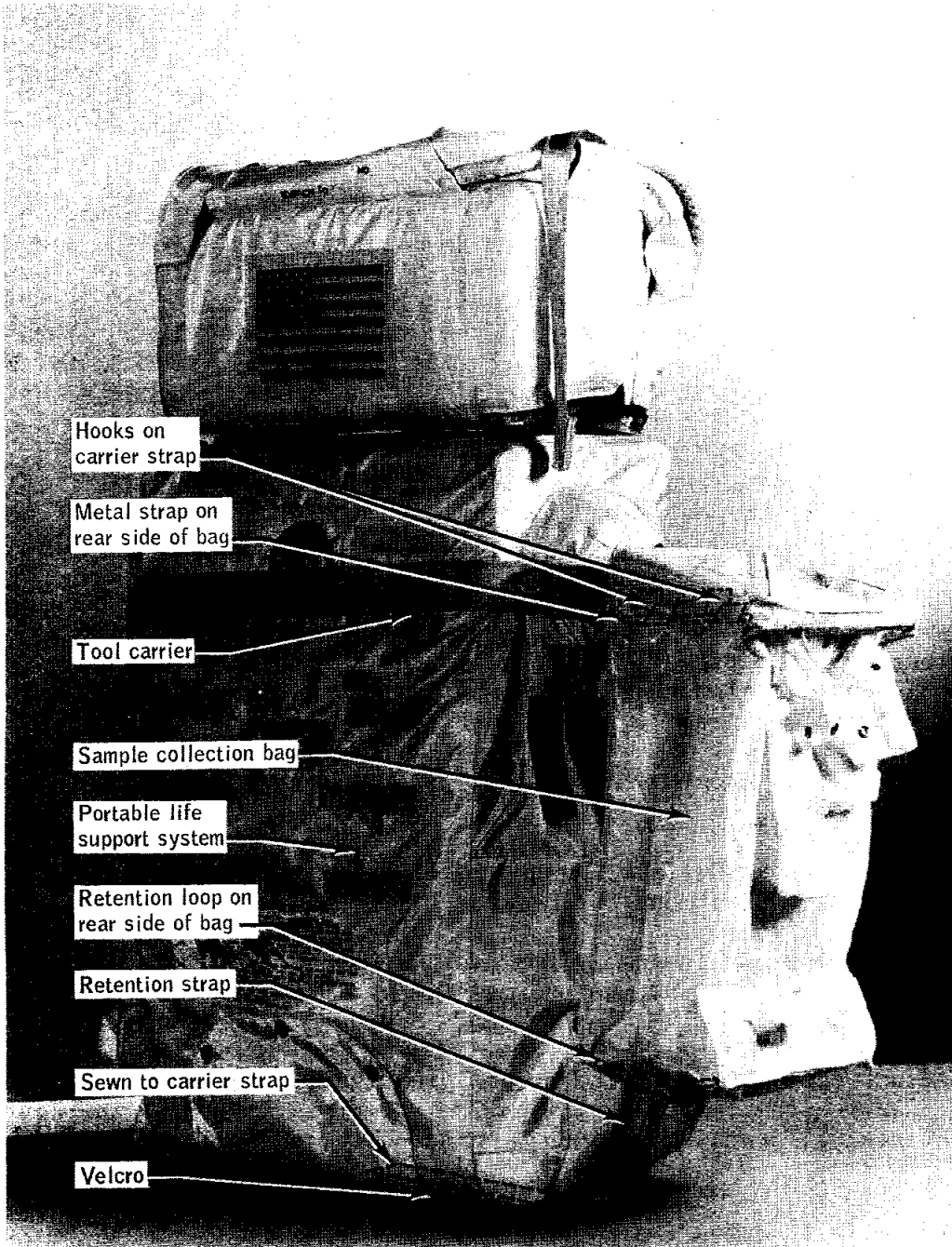


Figure 14-62.- Sample collection bag on portable life support system tool carrier.

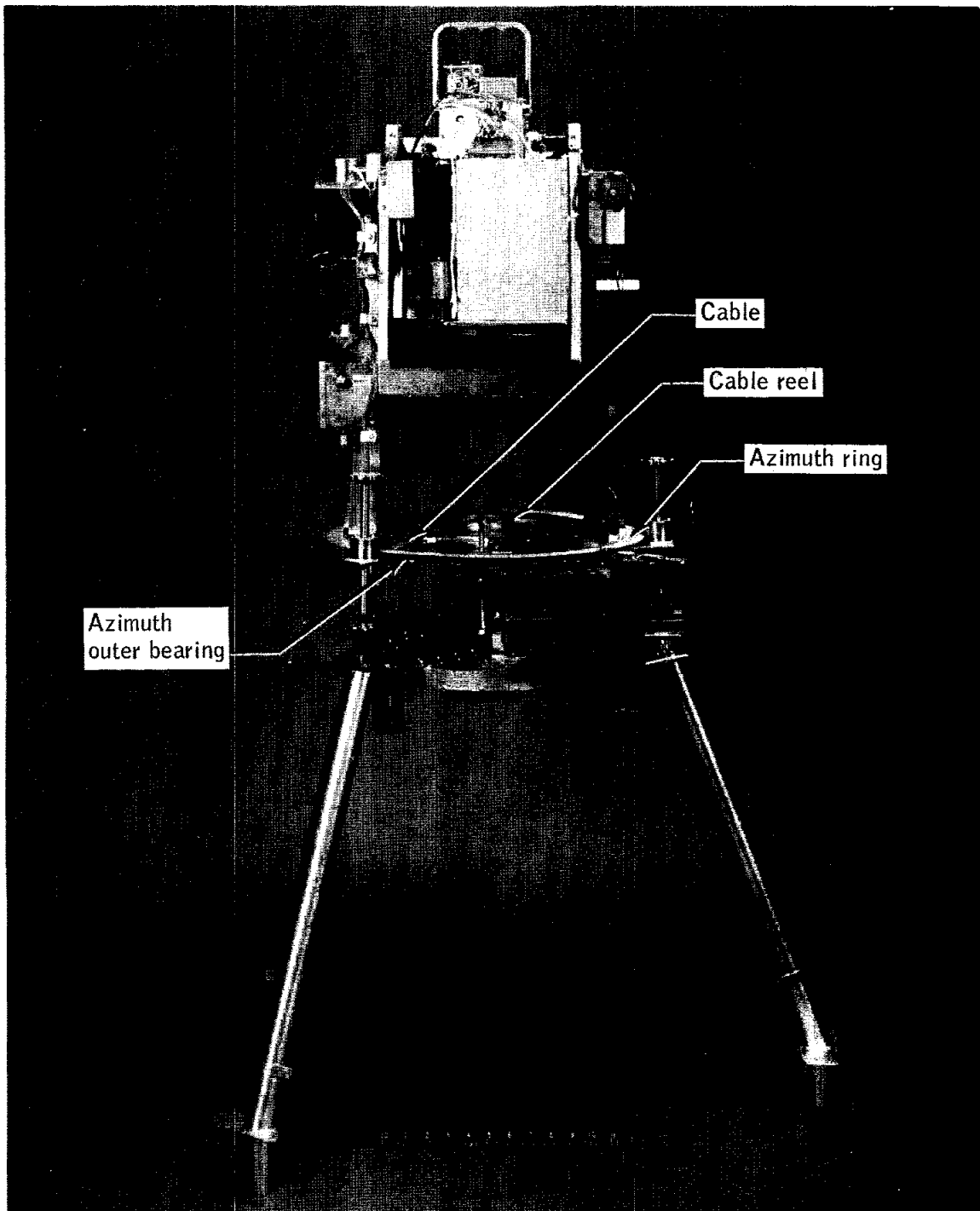


Figure 14-63.- Far ultraviolet camera.

The difficulty was caused by the use of the wrong type of grease in the azimuth ring bearing.

The experiment is not scheduled for another flight, and no further action is required.

This anomaly is closed.

#### 14.4.10 Velcro Patch Came Off Both Padded Sample Bags

When the crew wrapped the Velcro strap around each of the padded sample bags to further secure them, the Velcro attachment patches came off the bags and the straps were ineffective.

A 20-inch-long wrap-around Velcro pile strap is provided to hold the bag closed in addition to the usual tab closure (fig. 14-64). One end of the strap is bonded with a fluorel adhesive to an etched Teflon patch which

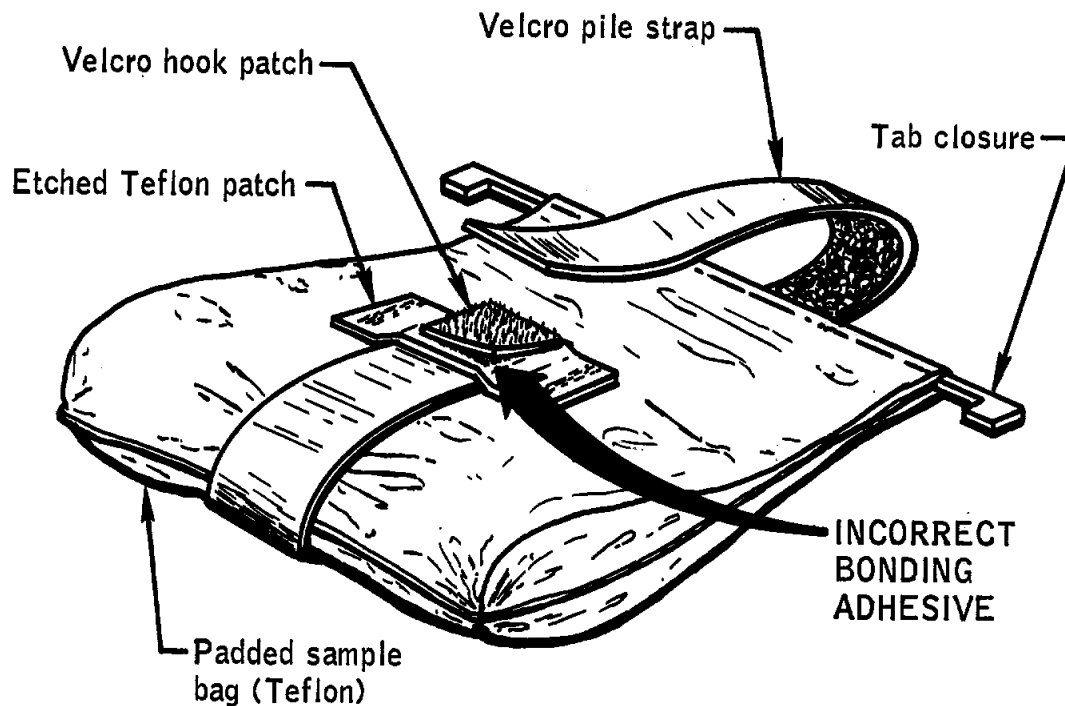


Figure 14-64.- Padded sample bag.

is heat-sealed to the Teflon bag. A Velcro hook patch is bonded to the etched Teflon patch with a pressure-sensitive adhesive and provides the attach point for the other end of the strap. The peel strength of the pressure-sensitive bond was less than that of the Velcro pile-to-hook connections. Consequently, when the Velcro strap was adjusted to the proper tension, the hook patch came off the bag.

The problem resulted from using the improper bond material for the Velcro hook patch.

This equipment is not scheduled for another flight and no further action is required.

This anomaly is closed.

#### 14.4.11 Loop Came Off Lanyard for Penetrometer Stowage Release Pin

When the Commander was unstowing the penetrometer, the end of the lanyard loop pulled out of the swaged joint. The pin was pulled by wrapping the wire around the gloved hand.

There were 71 lanyard assemblies on the lunar module, of which nine were made with 3/64-inch cable, and the rest with 1/16-inch cable. The lanyard with the pulled-out loop was made with 3/64-inch cable.

A condition similar to the one experienced by the Commander was simulated by utilizing a 3/64-inch cable, a 3/64-inch-diameter sleeve, and a 1/16-inch-diameter crimping device.

The nine lanyards made with 3/64-inch cable are to be changed to 1/16-inch cable and pull-tested. The existing 1/16-inch-cable lanyards will also be pull-tested in cases where the pull pin cannot be pulled without the lanyard.

This anomaly is closed.

#### 14.4.12 Active Seismic Experiment Pitch Sensor Indicated Off-scale High After Launching the Third Grenade

Immediately prior to launching the third grenade, the pitch sensor indicated that the mortar package assembly was pitched down about 8° from the nominal plus 45° elevation (fig. 14-65). Within 2 seconds after firing the mortar, the sensor indication was off-scale-high and has remained off-scale-high.



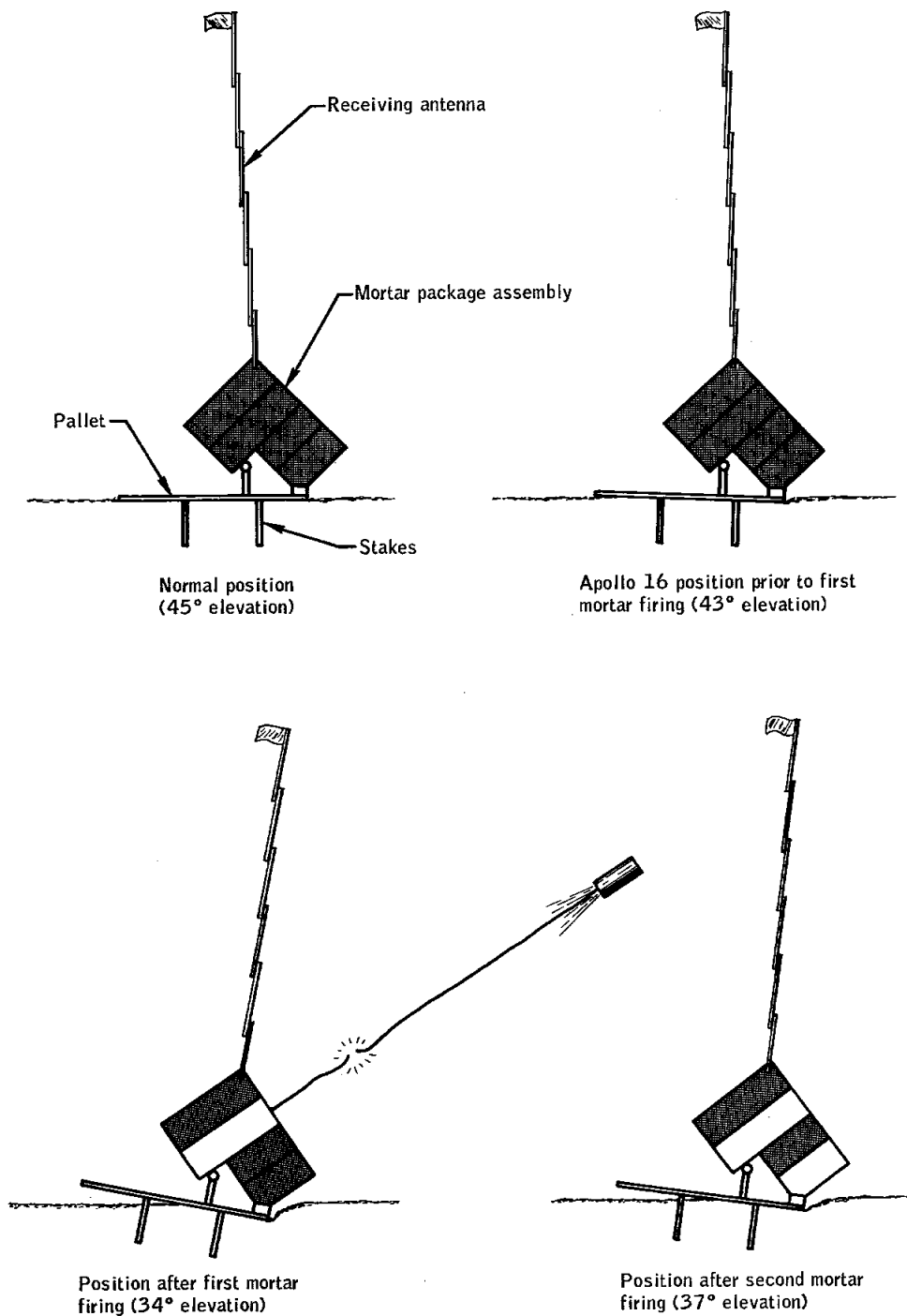


Figure 14-65.- Pitch movement of mortar package assembly.

Based on ground tests during which the assembly was rotated through 360°, an off-scale-high indication means either that the mortar package assembly is pitched up between 25° and 155° above the normal plus 45° elevation, or that the sensor has failed. There are two stable positions of the mortar package and pallet assembly between these two points: (1) pitched up 30° above normal (75° elevation), and (2) pitched up 135° above normal (180° elevation). The temperature profiles for the two temperature sensors on the mortar package assembly, when compared with the calculated temperature profiles for elevations of 45° and 75°, indicated that the mortar package assembly was not in the 75° elevation position. In the 180° elevation position, the receiving antenna would have been broken off or badly bent and lying on the ground. In this case, complete real-time event data would not have been received during the flight of the third grenade. However, complete real-time event data were received during the entire 19-second flight, indicating that the mortar package assembly was not in the 180° elevation position.

The pitch and roll sensor circuits are identical (sec. 14.4.3), and there are numerous failure possibilities in the circuit (such as open transistors, shorted capacitors, and open solder joints) which can cause failure of the multivibrator, and result in the off-scale-high indication.

It is most likely that there is a failure in the pitch sensor circuit, and the orientation of the mortar package is unknown.

No corrective action is required as the experiment is not scheduled for another mission.

This anomaly is closed.

## 14.5 ORBITAL EXPERIMENT EQUIPMENT ANOMALIES

14.5.1 Mapping Camera Extend/Retract Times  
Were Abnormally Long

The first mapping camera extension was normal, but the retraction required 2 minutes and 54 seconds. The normal time for extension or retraction is approximately 1 minute and 20 seconds. The second and third extensions and retractions required about 3 minutes, but the fourth retraction and fifth extension were both normal at 1 minute and 18 seconds. The fifth (final) retraction time was 1 minute and 34 seconds.

This anomaly is similar to the Apollo 15 problem in that the times of the first extension and retraction were normal and subsequent times were excessive, with some in excess of 4 minutes. In addition, the Apollo 15 camera would not retract after the final (15th) deployment. Subsequent investigations did not isolate a probable cause of that anomaly.

Deployment rails attached to the bottom of the camera slide through ball-bushings that are part of the deployment mechanism (fig. 14-66). Deployment of the camera is accomplished by the drive screw turning within the drive nut, which is bolted to the camera. Friction in this screw-nut drive is minimized through the use of recirculating streams of ball bearings riding between the threads of the nut and screw.

Two redundant motors, each capable of deploying the camera should the other fail, power the drive screw via a drive train consisting of clutches, gearing, and a "no-back" device that locks the deployment mechanism when power is removed from the motors. The motors, clutches, and most of the gearing are contained within the gear box. Two clutches are used, one with each motor. Their design is such that, should a motor seize, its clutch will decouple from the drive train. The clutches contain bearings that are lubricated with a mixture of silicone oil and grease; therefore, a test was conducted to determine the effect of contamination of the friction surfaces by the lubricant. The result was that lubricant applied directly to the friction elements did not significantly affect the clutch performance.

Preflight deployment operations had disclosed a chattering noise in the mechanism when the retraction was aided by the pull of the cable harness to the camera. An analysis of the drive train indicates that a state of dynamic instability may exist in a zero-g environment because of the resultant loss of the damping provided by the deployment rail friction. Simulated zero-g tests are being conducted by suspending the camera with a long cable in order to remove the weight from the rails while maintaining the inertial properties of the camera during the deployment.

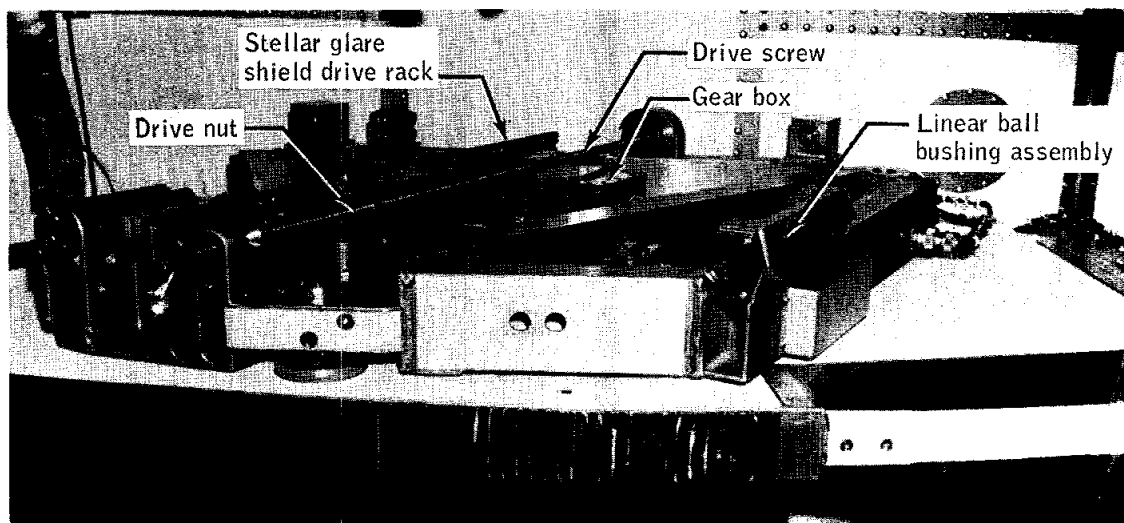


Figure 14-66.- Mapping camera deployment mechanism.

A separate anomaly report will be published upon completion of analysis and testing.

This anomaly is open.

#### 14.5.2 Mapping Camera Stellar Glare Shield Failed to Retract

The Command Module Pilot observed that the glare shield for the stellar camera was jammed against the handrail paralleling the scientific instrument module bay (fig. 14-67) during the transearth extravehicular activity. In the 16-mm photography of the extravehicular activity, the outermost edge of the folding tip of the glare shield is visible above the handrail, in the fully-extended position as shown in figure 14-64.

Scientific instrument module bay photographs taken from the lunar module indicate that the glare shield was properly retracted at rendezvous; therefore, the failure to retract occurred at the third, fourth, or fifth (last) camera retraction. A review of the stellar film indicates that this anomaly did not affect the stellar photography.

Glare shield deployment is accomplished by a rack-and-pinion mechanism that is connected by gearing to a rack on the camera deployment

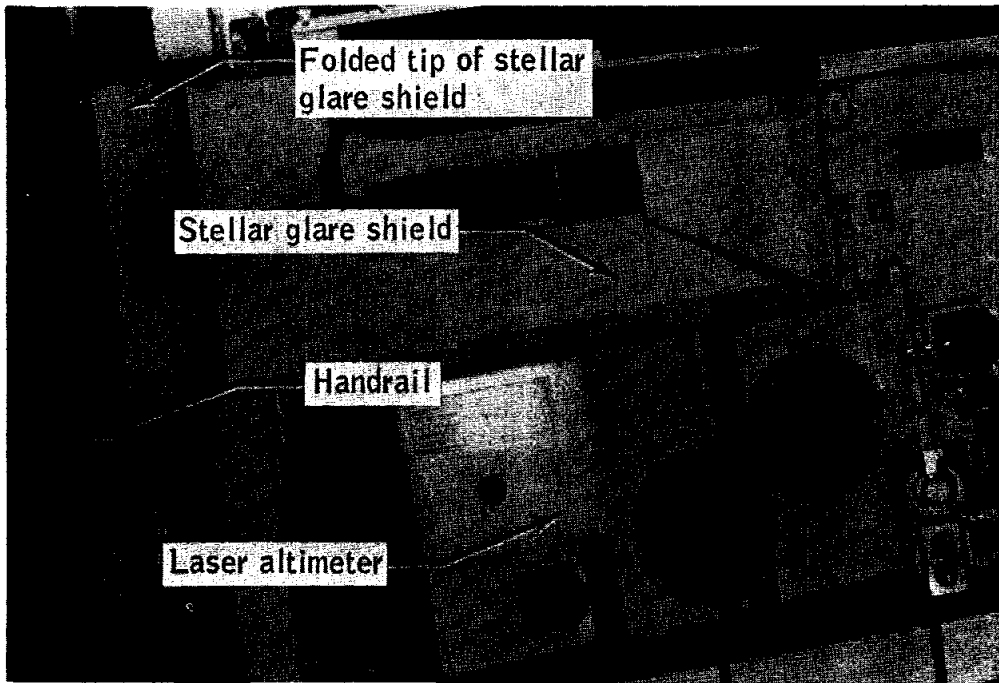


Figure 14-67.- Mockup photograph of glare shield handrail.

mechanism (fig. 14-66). As the camera is deployed from the scientific instrument module bay, the glare shield is automatically extended outward from the stellar camera. Two sets of miter gears are utilized. Both sets are located within the camera body. Each set contains a steel gear and an aluminum gear.

During the inspection of the exposed film prior to processing, numerous aluminum particles were found wound up with the film. Analysis of the chips indicated they were 6061 alloy rather than the 2024 alloy of the gears, showing a source other than the gears.

Since the glare shield deployment mechanism is driven by the camera extend/retract action, useful information related to this anomaly may be obtained from the camera zero-g tests being performed.

A separate anomaly report will be published upon completion of analysis and testing.

This anomaly is open.

### 14.5.3 Laser Altimeter Output Power Degraded

The laser altimeter performed normally during its first operating period - 41 minutes during lunar revolutions 3 and 4. Evidence of laser degradation began to appear early in the second operating period (revolution 16). The pulse forming network voltage controller began stepping to voltage position 1 (step 0 is the initial setting), and the laser output power, when in step 0, was occasionally too low for ranging - as manifested by altitude readings of zero meters and an overflowing range counter. For this period, altitude data validity was about 68 percent; i.e., approximately 32 percent of the data was "zero".

The degradation rate appeared to be rather constant during the next three operating periods, with voltage step 4 appearing near the end of the fifth period (revolution 47). During the sixth operating period (revolution 60), the degradation appeared to accelerate and the pulse forming network voltage controller reached step 5, the highest available step, by the end of this run. In step 5, maximum voltage is delivered to the flashlamps which "pump" the laser ruby. During the last scheduled operating period (revolution 63), laser output degraded to the point that no further altitude data were obtained.

There were approximately 2400 laser operations (firings) during the mission. The laser output appeared to degrade more rapidly than during the Apollo 15 mission (fig. 14-68) but was compensated by the action of the pulse forming network voltage controller added for this purpose as a result of the Apollo 15 anomaly. The voltage controller consists of a laser power status sensor (photodiode) located inside the laser module and associated circuitry to increase the output of the pulse forming network power supply if the sensed laser power is lower than a pre-established threshold.

Compensation was sufficient until the last 40 minutes of the final scheduled operating period. After this time, laser output was apparently too low for ranging against the sunlit lunar surface. One consequence of the pulse forming network controller operation was some loss of altitude data on alternate laser firings; therefore, data validity was only about 70 percent during most of this mission. Had the controller not been added to this unit, the amount of valid data obtained would have been significantly less. An estimate of the data that would have been obtained is shown in figure 14-68. The controller operates to increase input power to the laser if the laser output on the preceding operation was low, and to decrease input if the output was high. It appears that the threshold may have been low, or the voltage steps too large, so that inadequate output was obtained on the lower step, resulting in loss of altitude data. This was particularly true on illuminated portions of the lunar surface where background radiance decreases receiver sensitivity.

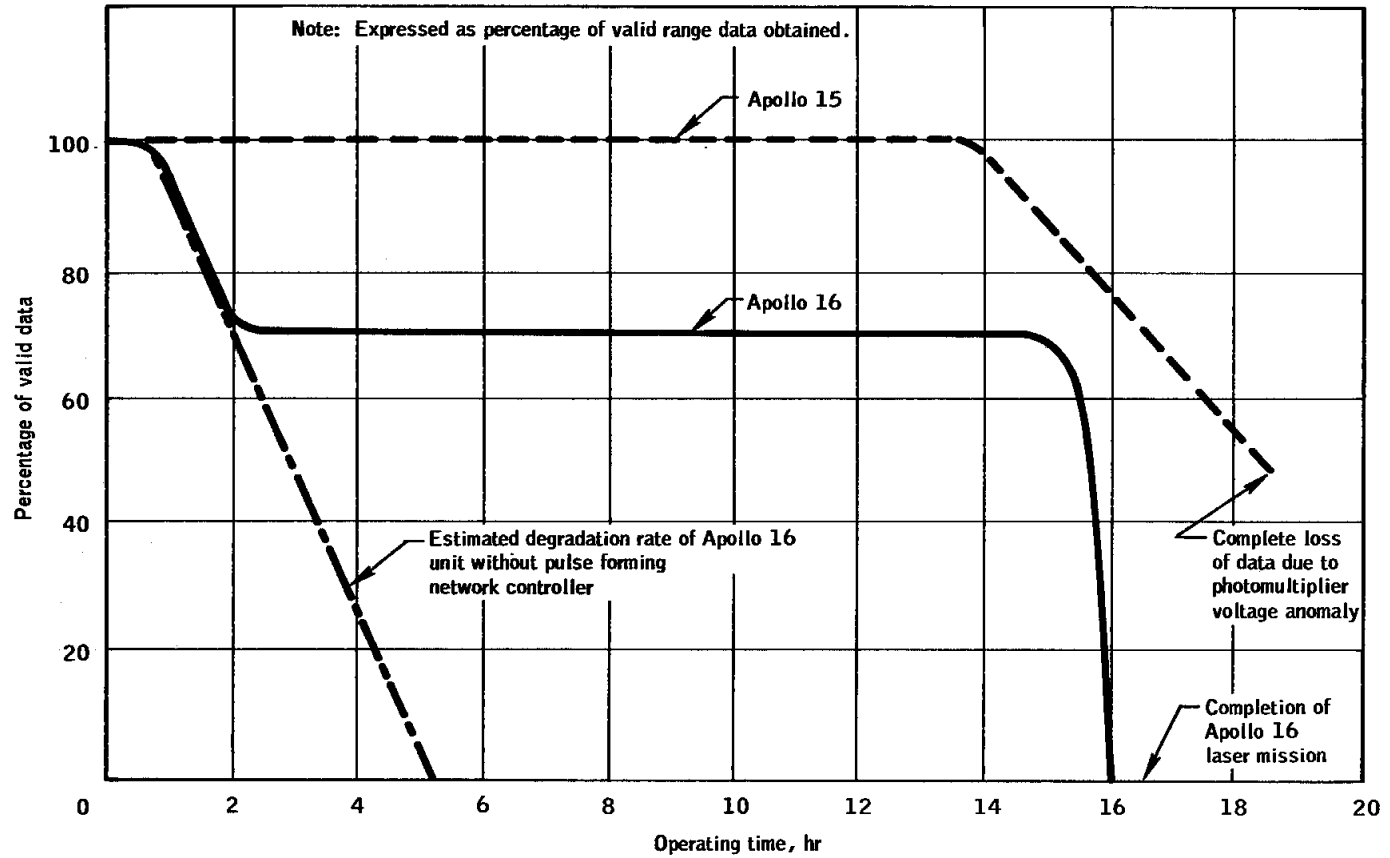


Figure 14-68.- Laser degradation versus operating time.

Analysis of the Apollo 15 failure indicated that the most probable cause was contamination of the internal optical surfaces by oil from the Q-switch bearings (fig. 14-69). Consequently, a delta qualification test was performed on a laser module, using new bearings incorporating oil-retainer shields. The qualification test consisted of a 220-hour thermal vacuum test which included a 50.5-hour mission operation timeline. Over 9000 laser firings were performed and the voltage controller had only reached step 4 by the end of the test.

Since the Apollo 16 laser also incorporated these new bearings, similar improved performance was expected during the mission. The number of prelaunch discharges was limited, however, to conserve laser life so the rapid laser degradation was not detected before launch.

The plots of data validity versus operating time in figure 14-68 are approximate in that the effects of laser module temperature and lunar surface illumination have been averaged out. During the first 11 hours of laser operation during Apollo 15, the command and service module was in a highly eccentric orbit which, due to the range limitations of the laser altimeter, caused the loss of approximately 50 percent of the altitude data. Since the data loss was not due to a hardware malfunction, the curve for Apollo 15 is drawn at 100 percent during this period.

Contamination of the optical surfaces within the laser module is considered to be the most likely cause of the degradation. A secondary cause is the degradation of the flashlamps because of discoloration of the lamp quartz as the result of the repeating high intensity light flashes and impurities in the quartz. The lubricant in the Q-switch motor and rotor bearings is apparently the principal source of contamination. Bearing life tests indicated that elimination of the oil reservoir in the bearings by the use of oil-impregnated bearings does reduce oil migration. Consequently, the Apollo 17 laser module will be modified to incorporate Q-switch bearings with oil-impregnated ball retainers and selection of flashlamps using a high purity quartz which is not as subject to degradation. Cover plates, installed over both access openings to the motor coupling, will complete the enclosure of the motor bearing.

This anomaly is closed.

#### 14.5.4 Panoramic Camera Automatic Exposure Control Indicated Low Light Levels

The panoramic camera contains a light sensor and associated circuitry that determines the film exposure. As the scene luminance decreases, the output from the sensor decreases; the resulting signal delivered to the slit width servo causes the exposure slit to widen, thereby automatically increasing the film exposure. The slit width and the light sensor output are both telemetered (fig. 14-70).



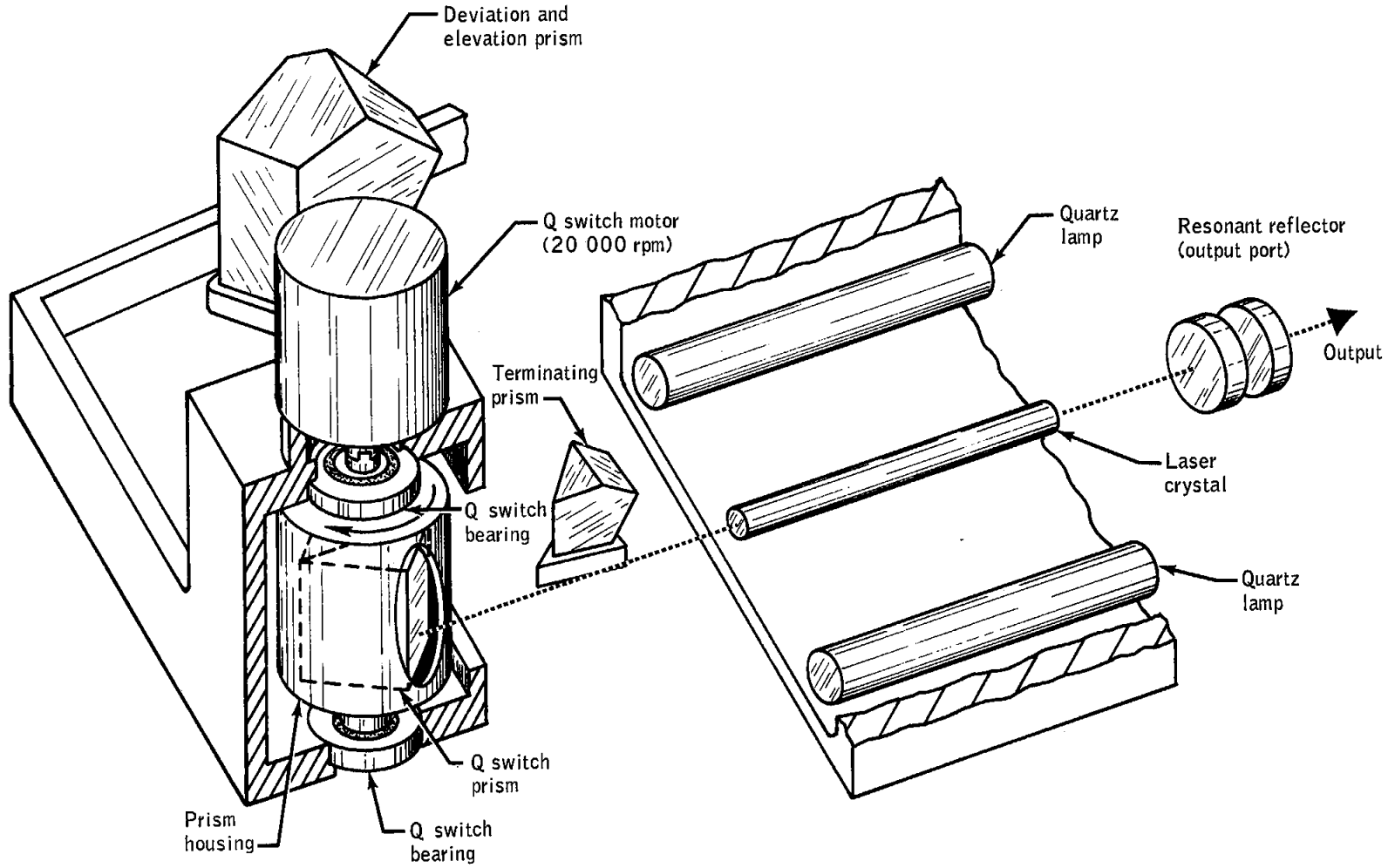


Figure 14-69.- Laser altimeter module light reflection components.

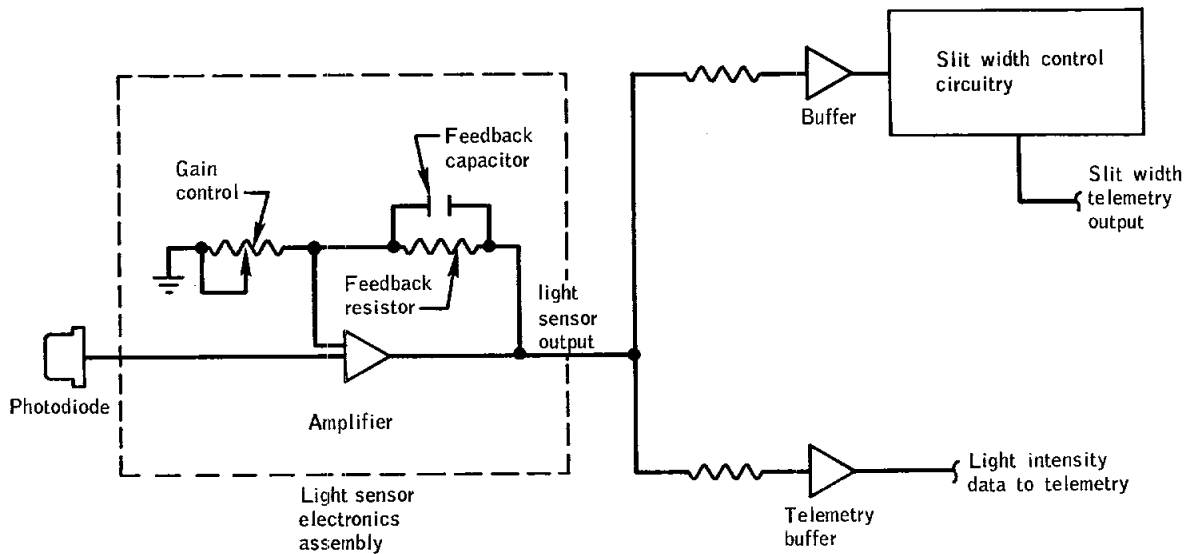


Figure 14-70.- Block diagram of panoramic camera automatic exposure control.

Throughout the mission, telemetry indicated that the sensor output was too low, resulting in a slit width that was too wide. Consequently, an overexposure of the film occurred. Based upon preflight brightness calculations and real-time mapping camera exposure data, the degree of overexposure was estimated to be approximately 1-1/2 to 2 f-stops. As a consequence, the film processing was modified to compensate for this degree of overexposure.

The problem could have been the result of contamination on the sensor optics or a failure in the light sensor or its associated circuitry (fig. 14-71). Analyses and tests have shown that component open or short circuit failures could not have caused the problem since the amount of overexposure could not be duplicated. Feedback capacitor leakage (equivalent to about 6 megohms leakage resistance), or a decrease in the gain of the photodiode input amplifier (an integrated circuit), or a decrease in photodiode sensitivity, shown in figure 14-70, could have caused the problem. These components, however, have no previous history of these types of failures; therefore, no corrective action will be taken.

A review of data indicates that the problem occurred preflight, at some time between January 5, 1972, and February 25, 1972. The failure was not detected because the test merely ascertained that the light sensor responded to stimulation (a light source placed in front of the sensor). Although sensor output voltage was recorded, no voltage tolerances had been established for the test.

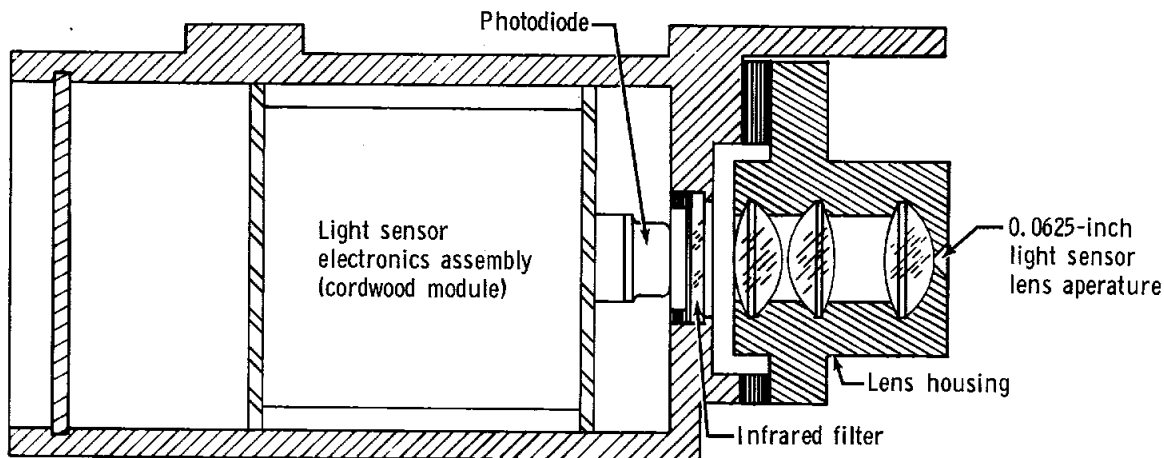


Figure 14-71.- Panoramic camera light sensor assembly.

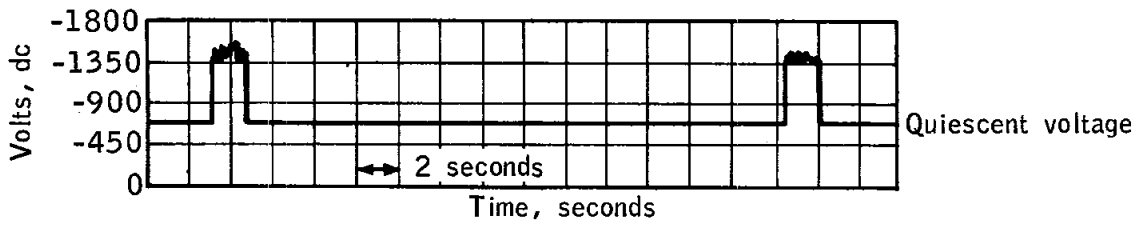
To preclude a similar problem not being detected in ground testing, sensor output voltage limits have been added to the test procedure.

This anomaly is closed.

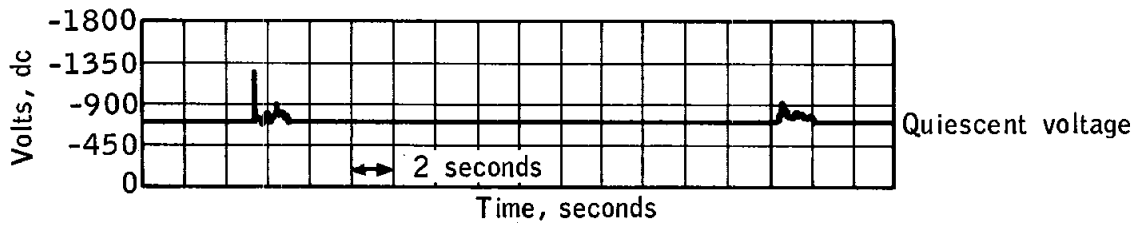
#### 14.5.5 Erratic Laser Altimeter Photomultiplier Tube Voltage

During the revolution-60 operation of the laser altimeter, the high voltage supply for the photomultiplier tube was occasionally erratic. During the next operating period (revolution 63) the erratic behavior became more pronounced (fig. 14-72), and there were several instances when the voltage failed to rise from the quiescent (idling) level.

The photomultiplier tube power supply idles at approximately minus 700 volts during the periods between laser firings. About three-fourths of a second before the laser fires, the power supply is commanded to increase its voltage to the value required for proper photomultiplier tube operation. This value is determined by automatic gain control circuitry (fig. 14-73) that senses the background illumination from the lunar surface. As a result of the automatic gain control action, the photomultiplier tube voltage varies during the mission and appears somewhat noisy, as evidenced by the normal trace (revolution 38) shown in figure 14-72. The revolution-63 trace is unusually erratic, however, and failure to rise from the quiescent level is indicative of anomalous operation.



(a) Revolution 38



(b) Revolution 63

Figure 14-72.- Laser altimeter photomultiplier voltages.

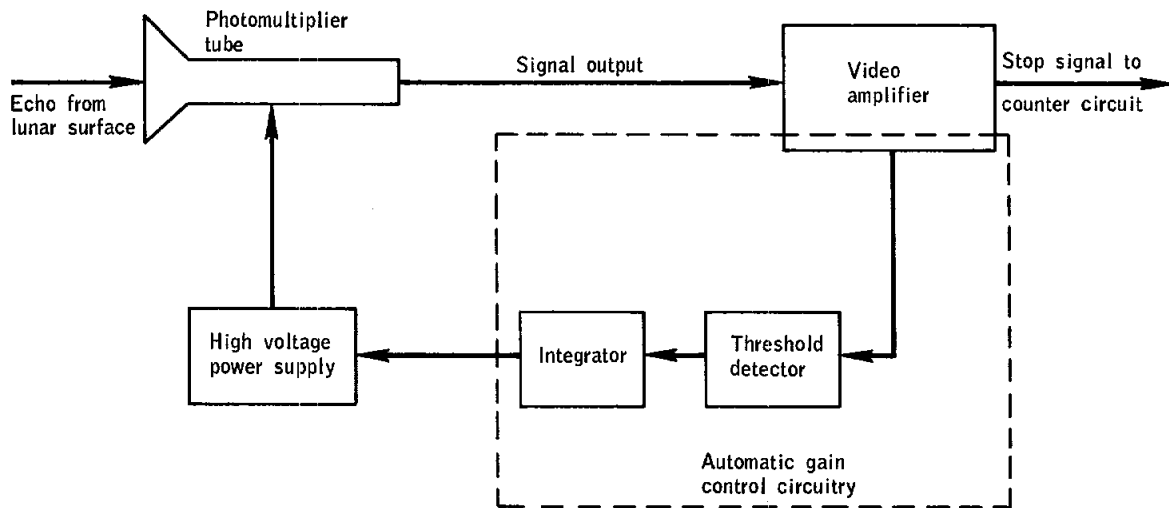


Figure 14-73.- Laser receiver circuitry.

Some of the anomalous voltages which occurred during revolution 60 were probably caused by sunlight reflecting off the deployed spectrometers. Although the spectrometers were not in the field of view of the altimeter receiver optics, reflections from the spectrometers may have been reflecting from the altimeter's gold-plated lens barrel and, thence, into the photomultiplier tube, thereby unduly affecting the automatic gain control action. This does not, however, explain the revolution-63 performance, because the mass spectrometer had been jettisoned and the gamma-ray spectrometer was not deployed.

A number of intermittent conditions are possible that could either increase the gain of the photomultiplier amplifier or couple electrical noise into the amplifier's input. Either of these occurrences could cause the effects observed in the data. An intermittent condition could have been caused by the cyclic thermal environment that occurs as a result of lunar orbit operation. Since qualification test results and acceptance tests are considered to be adequate for this equipment, no corrective action will be taken.

This anomaly is closed.

#### 14.5.6 Overexposure of Nine Frames of Mapping Camera Metric Photographs

Nine frames of mapping camera metric photography were overexposed. The overexposures were single events dispersed throughout the film. Most overexposures occurred when the shutter was being commanded to a slower speed by the automatic exposure control because of decreasing scene luminance. Instead of going to the next slower speed, the shutter would drop to an even slower rate for one frame and then return to the proper rate for the remainder of the frames.

Shutter speed is controlled by a photo cell which senses the light level in the camera's field of view. The photocell operates in a servo system which controls shutter speed. The photocell servo system consists of the photocell, a comparator, a voltage reference, and a seven-stage shift register, as shown in figure 14-74.

The complete operational sequence of the photocell servo is as follows: Assume that the reflected lunar surface light level is decreasing, thus, the photocell output voltage is less than the reference voltage. The comparator supplies a continuously decreasing signal to the shift register, thus enabling the register to shift the "on stage" toward the slower shutter speed. A group of six clocking pulses are supplied to the register once before each film exposure (about every 20 seconds). When the first clocking pulse appears, the on condition is shifted one

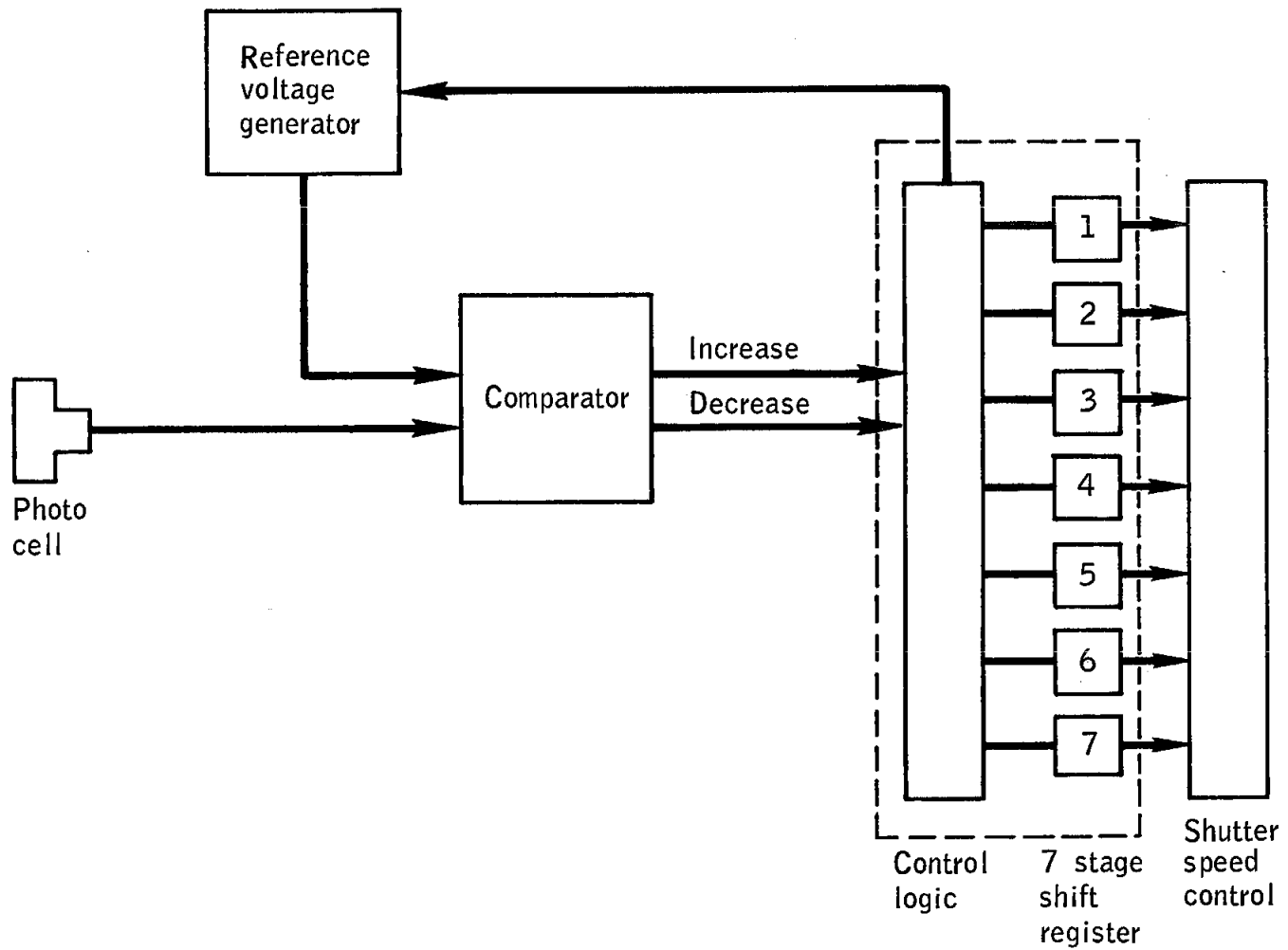


Figure 14-74.- Photocell servosystem.

stage. The register then causes the reference voltage to decrease one step. If the photocell output is still less than the new reference voltage, the second clocking pulse will shift the on condition to the next lower stage in line in the shift register. This sequence will continue until the difference between the photocell output voltage and the reference voltage is within the dead band of the comparator, at which time the comparator output signal to the shift register will disappear and the register will stop shifting. The shutter speed will then be determined by which stage of the shift register is in the on condition.

The seven shift-register stages correspond to seven shutter speeds with the first corresponding to the fastest speed, and the seventh corresponding to the slowest speed. The logic is designed such that at initial camera turn-on or whenever either of two invalid logic conditions exist (all stages off or more than one stage on), the fifth stage is turned on and all others are turned off.

Noise voltage pulses can set or reset (turn on or off) any stage in the register regardless of the condition of any other stage. Thus, more than one stage could be on at the same time, and, in this condition, when the first clocking pulse occurs, the logic would turn stage five on and all other stages off. The remaining five clocking pulses then could still shift to the on stage required by the light level seen by the photocell and no anomalous operation would result. Should the noise pulse occur during the clocking cycle, however, there may not be enough clocking pulses left to shift the on condition back to the required stage. Since the effect of the noise pulse is to shift the on condition to stage five, slow shutter speed and overexposure can be expected to occur more often than fast shutter speed and underexposure.

Noise voltage on the power supplied to the register or generated by some intermittent condition in the camera must have switched one or more stages in the shift register on or off. The camera qualification test results and acceptance tests are adequate. No corrective action is necessary.

This anomaly is closed.

#### 14.5.7 Contaminated Mapping Camera Film

A considerable amount of contamination was found throughout the metric and stellar film from the mapping camera during the pre-processing inspection. Special cleaning procedures were developed and successfully used in removing a majority of these particles prior to film development. Consequently, the photography was not compromised.

The contamination included many types of particles, most of them being metal chips of various sizes and shapes (fig. 14-75). There were also a few particles which appeared to be paint chips.

Analysis of several of the metallic chips with a scanning electron microscope indicated that the chips were an aluminum alloy.

The camera frame and cover are aluminum; however, consideration of the camera and cassette mechanisms plus visual examination of the particles indicate that the contamination was not caused by wear in the camera

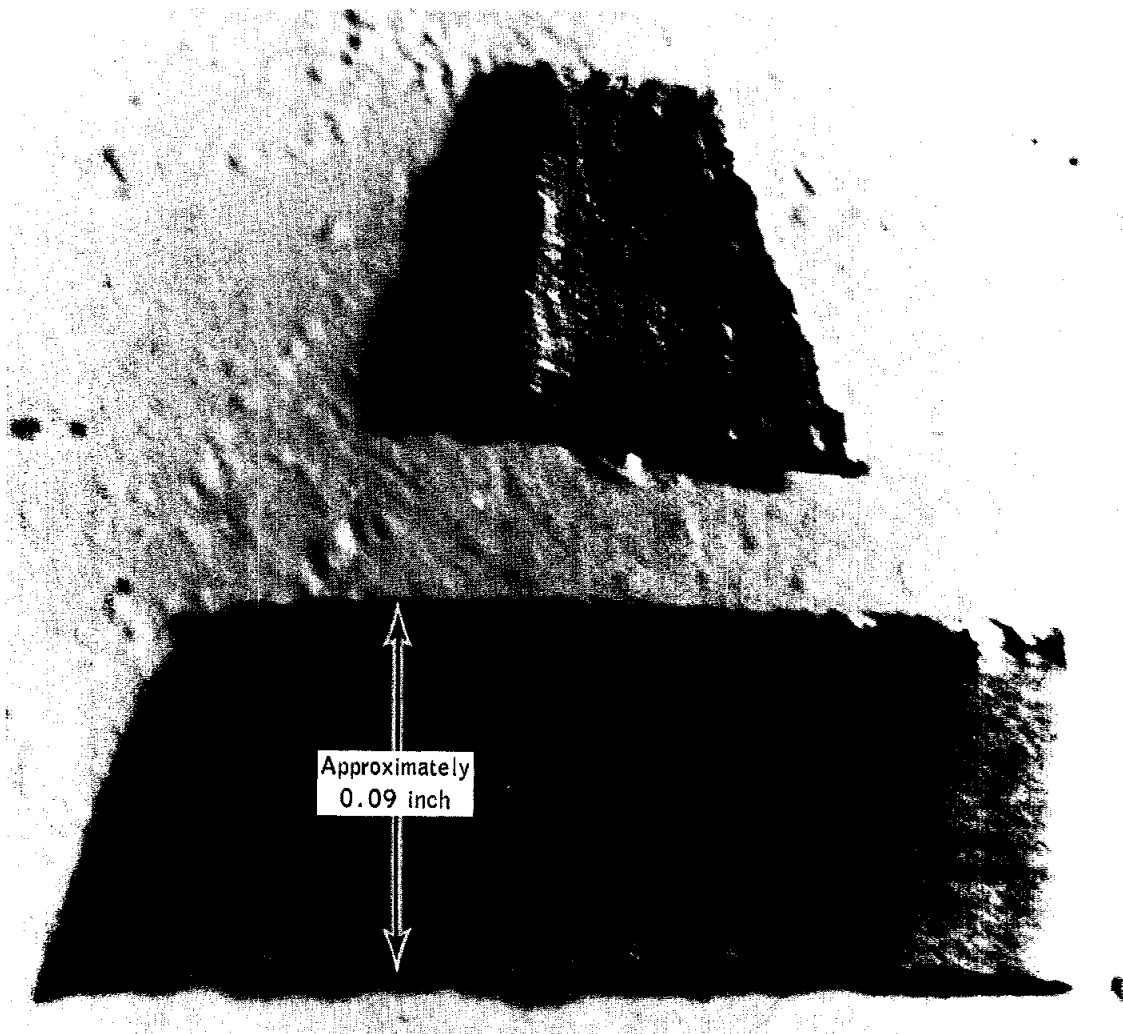


Figure 14-75.- Metal particles found on mapping camera film.



or cassette, but was more likely, either residue from manufacturing or introduced from some outside source.

The Apollo 16 camera and cassette were tumbled and cleaned at the contractor's facility, and the camera again tumbled and cleaned at the Kennedy Space Center. Contaminate particles were removed in each case. It is possible that some additional particles remained entrapped until the prolonged exposure to the zero-g environment during the mission.

More thorough cleaning and inspection procedures are being implemented for Apollo 17. In addition, the special cleaning procedures which were developed for the Apollo 16 film will again be used with the Apollo 17 film.

This anomaly is closed.

## 14.6 LUNAR ROVING VEHICLE ANOMALIES

### 14.6.1 Electrical System Meter Anomalies

The lunar roving vehicle experienced the following electrical system meter anomalies at initial powerup during the first extravehicular activity:

- a. Battery 2 voltmeter indicated off-scale low.
- b. Battery 2 ampere-hour meter indicated off-scale low.
- c. Battery 1 and 2 temperature meters indicated off-scale low.

Later, during the second and third extravehicular activities, anomalous conditions were experienced. The battery 2 ampere-hour meter showed an increase in ampere-hours and the battery 1 temperature meter showed a decrease in temperature to off-scale low.

The circuitry associated with the electrical system meters is shown in figure 14-76. Note the multiple wire-crimp splices in the system. The return for the volt/ampere meter is connected to the battery return with a five-wire crimp splice containing one 12-gage wire, one 20-gage wire, and three 22-gage wires. This splice was associated with the electrical modification made on the Apollo 16 lunar roving vehicle at the launch site. An intermittent connection at this splice would explain the volt meter reading off-scale low and then later reading properly. An open connection at this splice would reverse the polarity on the ampere-hour integrator sense line and give a false indication of battery 2 charging as observed during the second and third extravehicular activities (see fig. 14-77). Also, the battery 1 ampere-hour meter indicated a 20-ampere-hour decrease rate which was greater than predicted. However, a review of the data shows that the current readings taken during this period of time were correct and a 20-ampere load was present. Therefore, the ampere-hour integrator for battery 1 was working properly.

Both battery temperatures reading off-scale low and then reading properly could be caused by an intermittent connection at the four-wire splice (fig. 14-76). However, this would require a simultaneous open circuit at two splices initially, which later corrected themselves, and finally, failure of a single splice in the battery 1 temperature circuit.

The second possibility is that two circuit breakers were not closed electrically, resulting in no power to the temperature meter circuits and ampere-hour integrators. This would also explain the battery 2 ampere-hour integrator reading off-scale low, but would not explain the battery 1

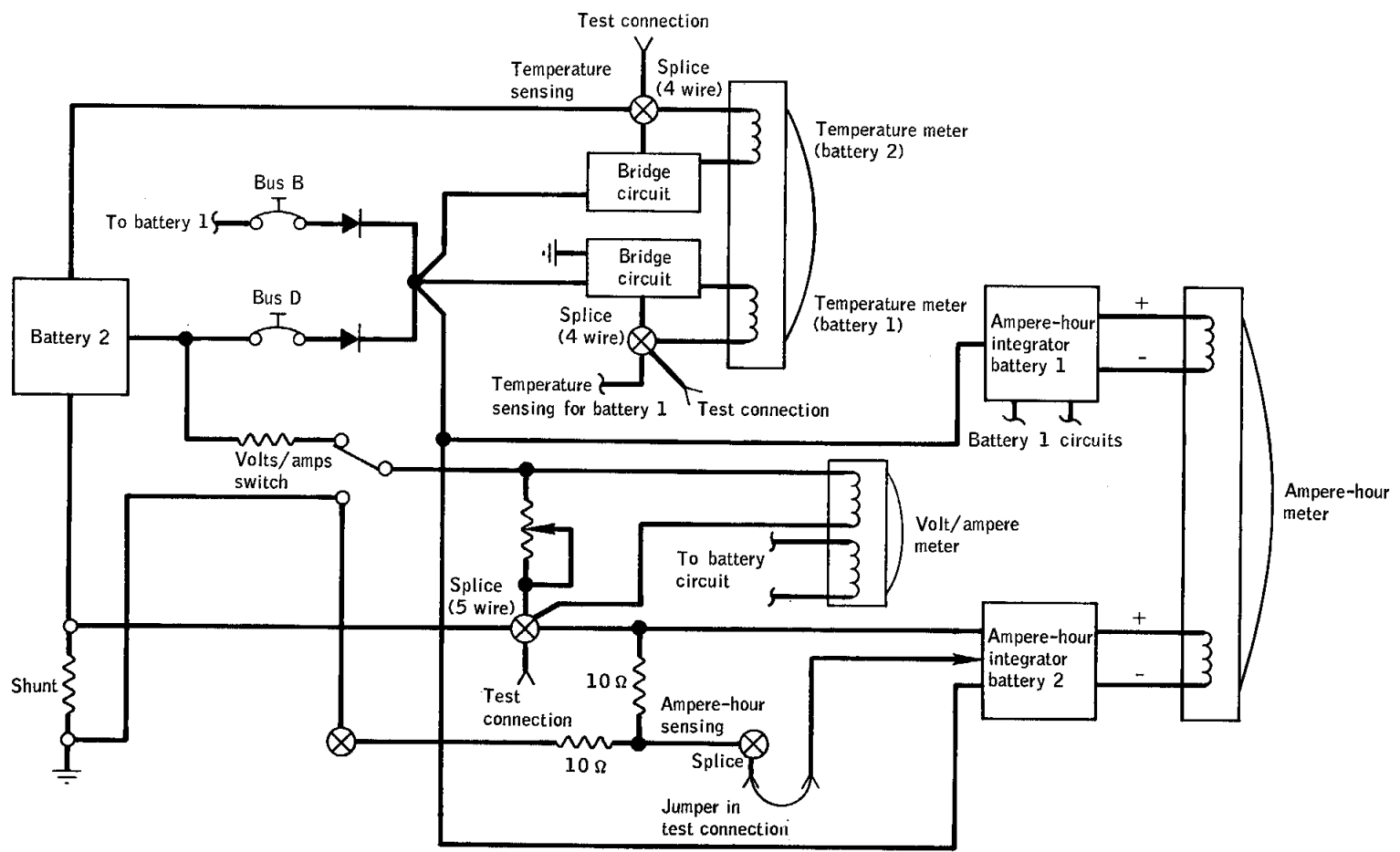


Figure 14-76.- Lunar roving vehicle electrical meter circuitry.

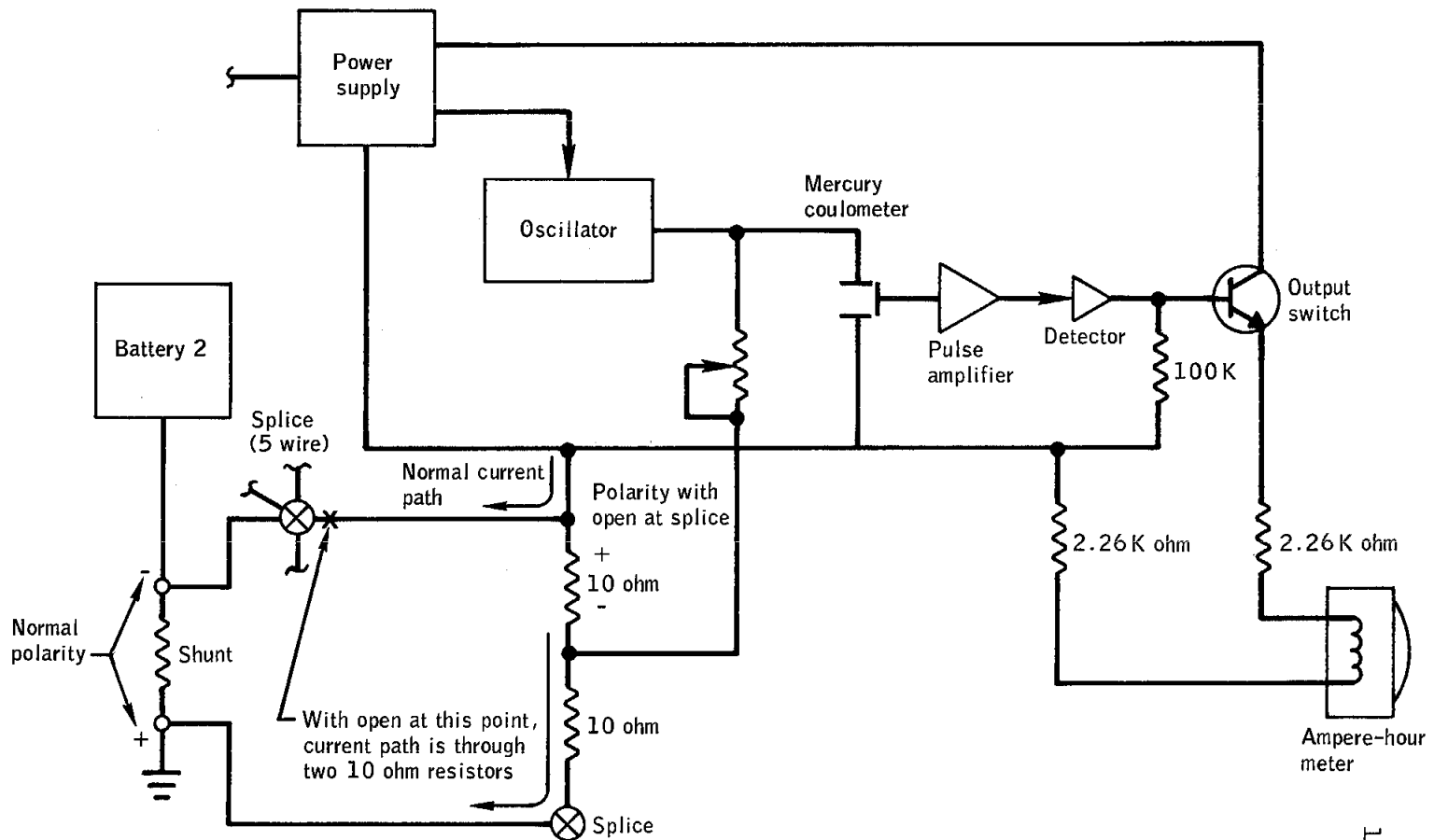


Figure 14-77.- Battery 2 ampere-hour integrator circuit.

ampere-hour integrator reading full-scale, unless a sneak circuit existed. This sneak circuit must result from an open circuit at the five-wire splice in the battery 2 volt and ampere-hour meter circuit.

If no sneak circuit can be identified, the most likely cause of temperature meter anomalies would be the four-wire splice in the temperature meter circuits.

This anomaly is open.

#### 14.6.2 Rear Steering Inoperative

On the initial drive to the modular equipment stowage assembly, the crew reported that the rear steering was inoperative; however, upon leaving that stop, both the front and rear steering systems were operational and functioned normally for the remainder of the mission.

Analysis of troubleshooting procedures initiated by the crew and a review of the switch- and circuit-breaker configuration timeline suggests that no intermittent hardware malfunction existed. An intermittent condition in the rear steering electrical system would explain the anomalous operation, but this is very unlikely because the system exhibited normal performance for the balance of the lunar activity.

Figure 14-78 shows that switch 10, circuit breaker 10, and circuit breakers 3 or 4 must be closed to provide power to the rear steering system. In addition, circuit breakers 3 or 4 must be closed to provide  $\pm 15$  Vdc for the drive as well as steering control electronics. Since the vehicle had both mobility and forward steering, at least one of these breakers made contact. Switch 10 was cycled after vehicle motion; however, the rear steering remained inoperative. Circuit breaker 10 could possibly have been open due to some contaminate existing in the breaker.

Another possible cause of the anomalous condition is in the steering servo system (fig. 14-79). A signal generated by the hand controller is coupled to the input servo amplifier as an error signal across a bridge. This signal is amplified and applied to the steering motor field coils in a direction determined by the polarity of the input signal which depends upon the direction of the hand controller deflection. The feedback potentiometer is driven by the steering motor in a direction to balance the bridge, thus cancelling the original error signal. A non-conductive lubricant (DC 40), is applied to the wiper and resistive element of the potentiometers to produce smooth operation and reduce noise. At low temperatures, this lubricant could become more viscous and insulate the wiper

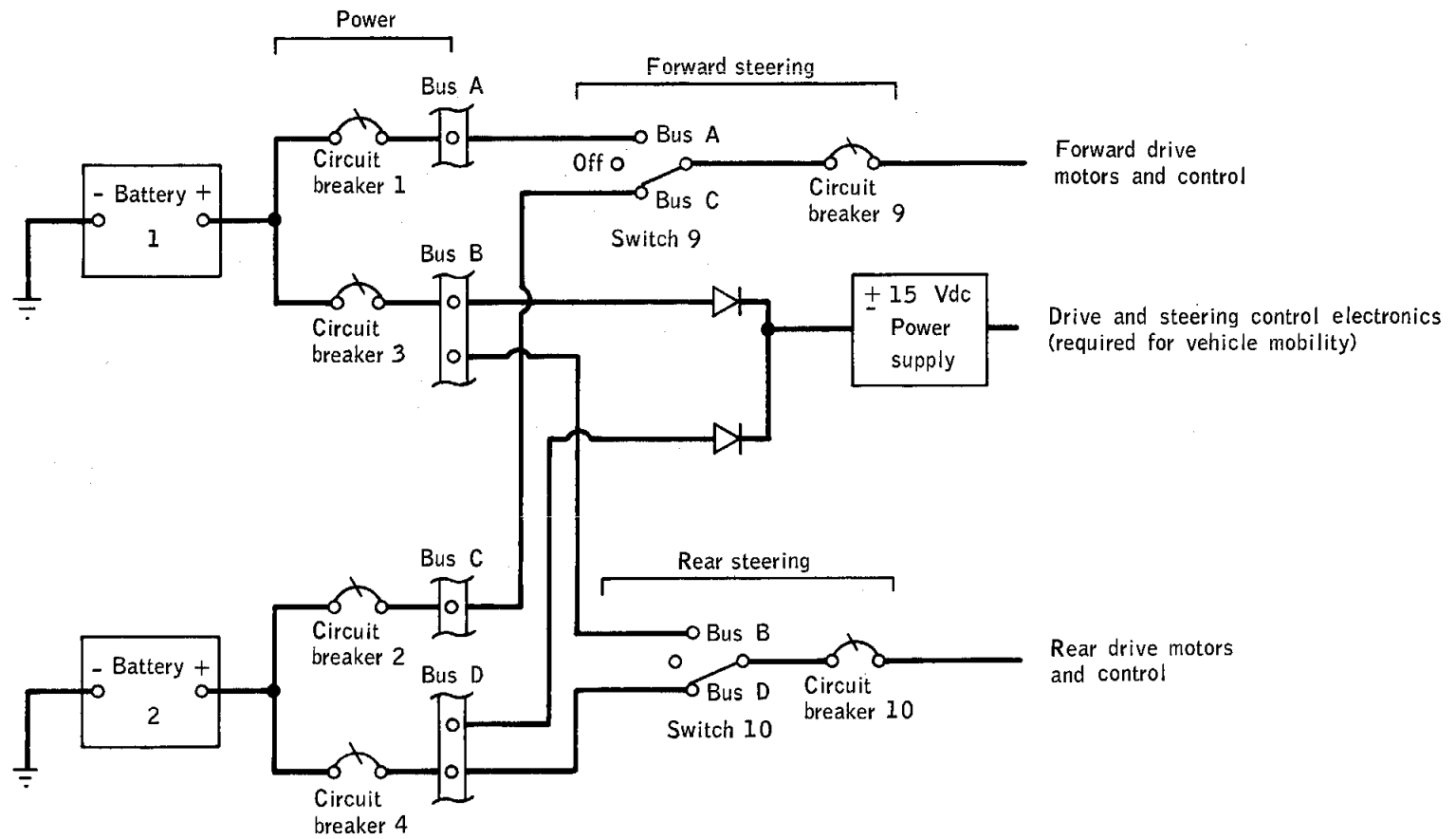


Figure 14-78.- Lunar roving vehicle steering power schematic.

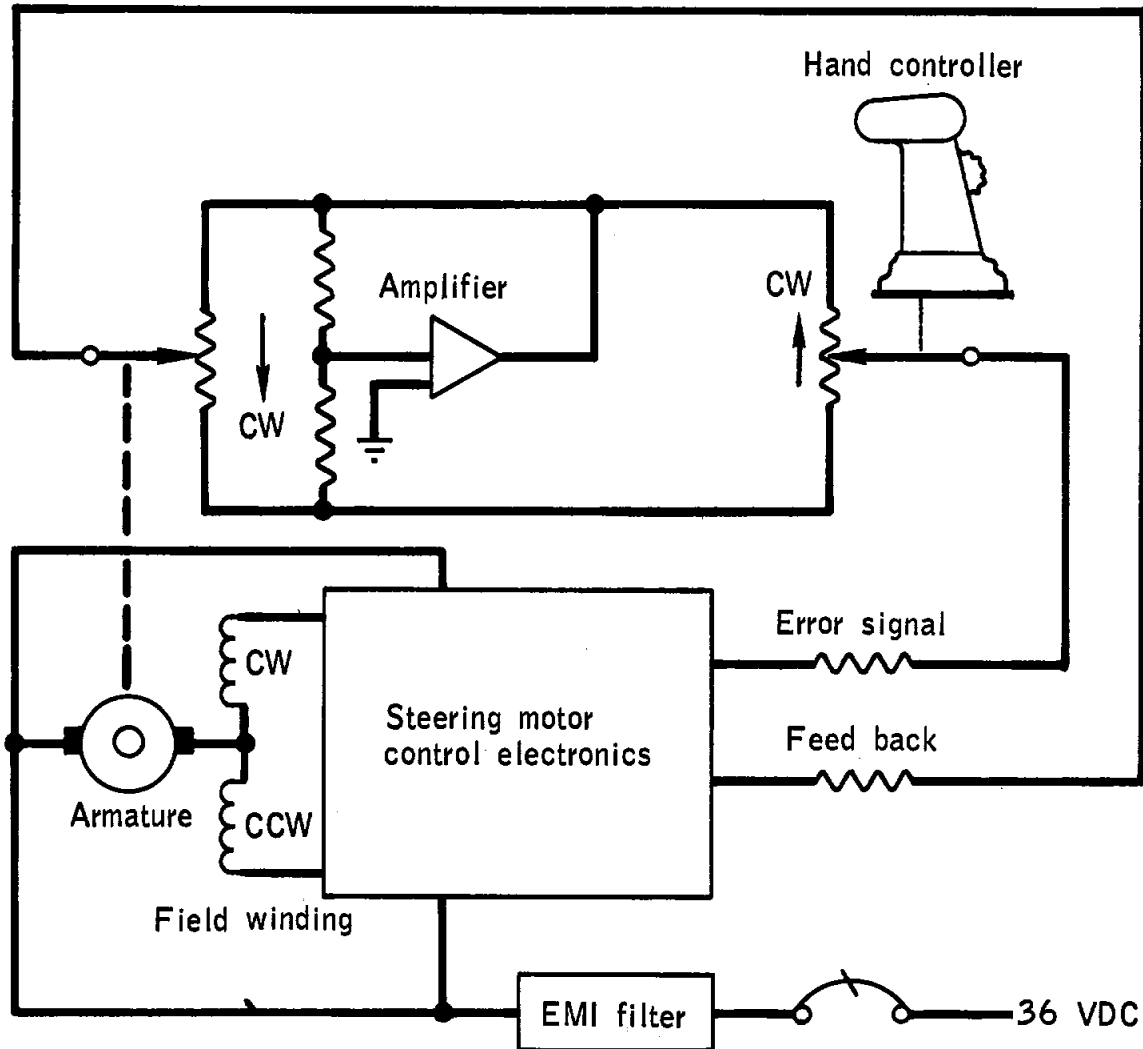


Figure 14-79.- Steering system electrical.

from the resistive element. No error signal would then be present at the input to the servo amplifier, although the hand controller was deflected. As the steering electronics heat up, the lubricant becomes less viscous. Exercising the hand controller then cleans the lubricant from the wiper and resistive element, allowing contact to be made. This would account for the anomalous condition. Tests will be conducted to determine the effect of the lubricant on the potentiometers at low temperatures.

This anomaly is open.

### 14.6.3 Navigation System Computed Parameters Not Updating

After leaving station 9 during the second extravehicular activity, the crew reported that the computed parameters of bearing, distance, and range were not being updated by the navigation system. The heading and speed indicators, however, were operating normally. In reviewing the navigation data reported at stations 8 and 9, the distance and bearing data are incompatible with the time and direction of travel, respectively, from station 8 to station 9. This indicates the navigation system also failed to operate properly between stations 8 and 9. Again, the system did not update the computed parameters between stations 9 and 10. At station 10, the navigation system logic and displays were reset to zero and the system functioned normally during the third extravehicular activity.

The navigation system is functional with the bus B (battery 1), bus D (battery 2), and navigation circuit breakers closed. In this configuration, the gyro operates and the heading is displayed. In addition, with the right rear motor-drive power switch to either bus B or bus D position, the speed indicator will register. In order to compute and display distance, bearing, and range data, and to update these data, at least three of the four motor-drive power switches must be positioned to an active bus.

At station 8, after the navigation readouts, the vehicle was moved while attempting to determine the cause of the rear drive loss between stations 6 and 8. Several switch configurations were attempted which accounts for the subsequent incompatible navigation readouts at station 9. The readouts had the bearing and distance indicating a northeasterly direction, although the crew reported that travel was in a northerly and northwesterly direction. Also, during the traverse from stations 9 and 10, the crew reported that the navigation system was not updating bearing, range, and distance. This condition will occur with the loss of power to two drive motors. From the battery and motor temperature data in figure 14-80, battery 1 temperature shows an increase while the battery 2 temperature did not rise, indicating little or no load on battery 2. Also, the rear motor temperature shows an increase while the forward motor remains constant. Thus, the navigation had no inputs from the forward wheels and could not update.

At station 10, the digital displays and internal registers were reset to zero and the circuit breakers and switches were returned to the normal configuration. The navigation system then performed normally throughout the third extravehicular activity.

No corrective action is required.

This anomaly is closed.



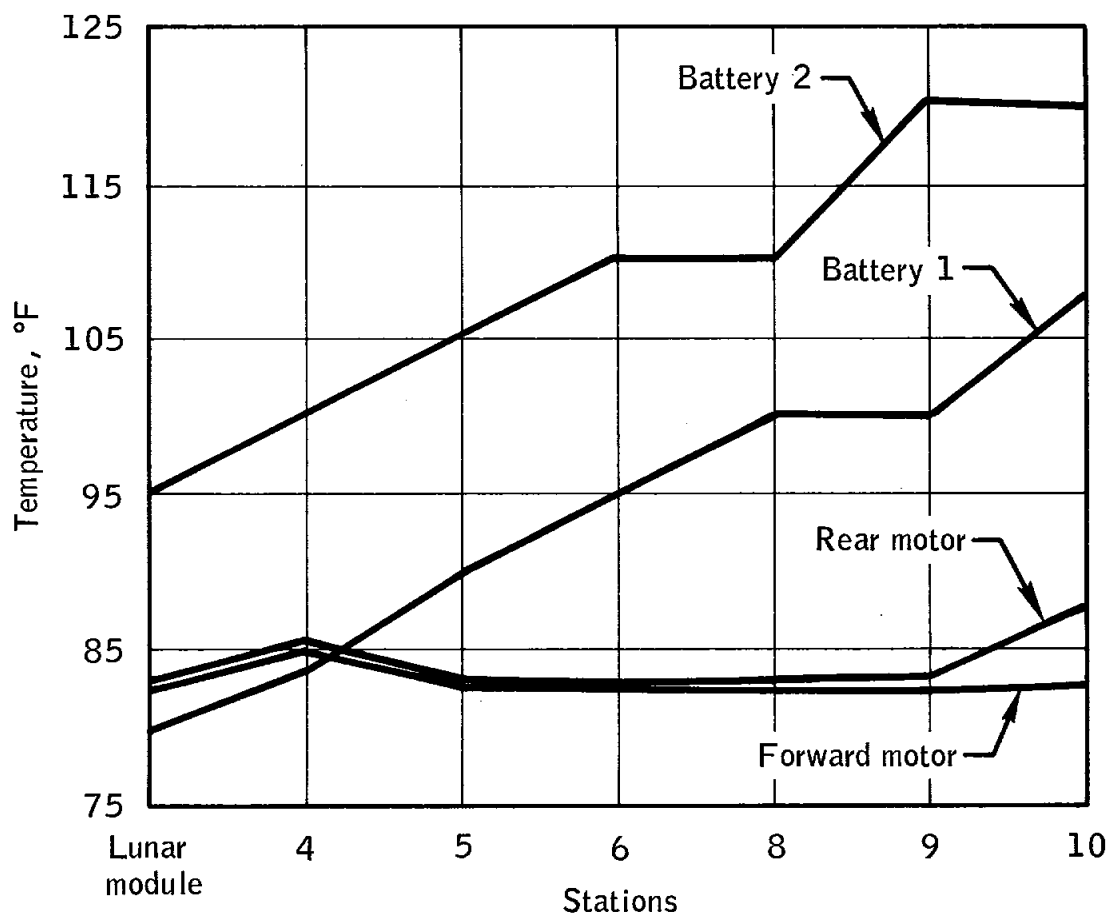


Figure 14-80.- Battery and motor temperatures during second extravehicular activity.

#### 14.6.4 Scale Debonded from Pitch Attitude Indicator

During the second extravehicular activity, the crew reported that the lunar roving vehicle pitch attitude indicator scale had fallen off. The indicator provides a vehicle pitch reference between plus and minus 20 degrees. The loose pitch scale did not impact the mission because the pointer for the indicator continued to work properly and the crew could adequately estimate the vehicle pitch from the pointer position.

The pitch attitude indicator scale is bonded to a bracket (fig. 14-81) which is attached to the indicator case. The scale is constructed of 2024T3

aluminum and the bracket is 6/6 nylon. A comparison of the coefficients of thermal expansion of the materials indicate approximately a 4-to-1 ratio for nylon-to-aluminum. With this expansion ratio, stress factors of safety for an ideal bond are 3 and 4 at temperatures of minus 100° F and plus 250° F, respectively. Although a review of the bonding procedures did not reveal any problems, a flaw most probably existed in the bond and this allowed stress buildup which caused the scale to become unbonded. The crew experienced no difficulty in estimating the pitch angle after the scale became unbonded. The back of the meter case must be machined off to gain access to the scale, and special handling permits must be obtained before working on the meter because of the radioactive materials within the case. For these reasons, no hardware changes will be made for Apollo 17.

This anomaly is closed.

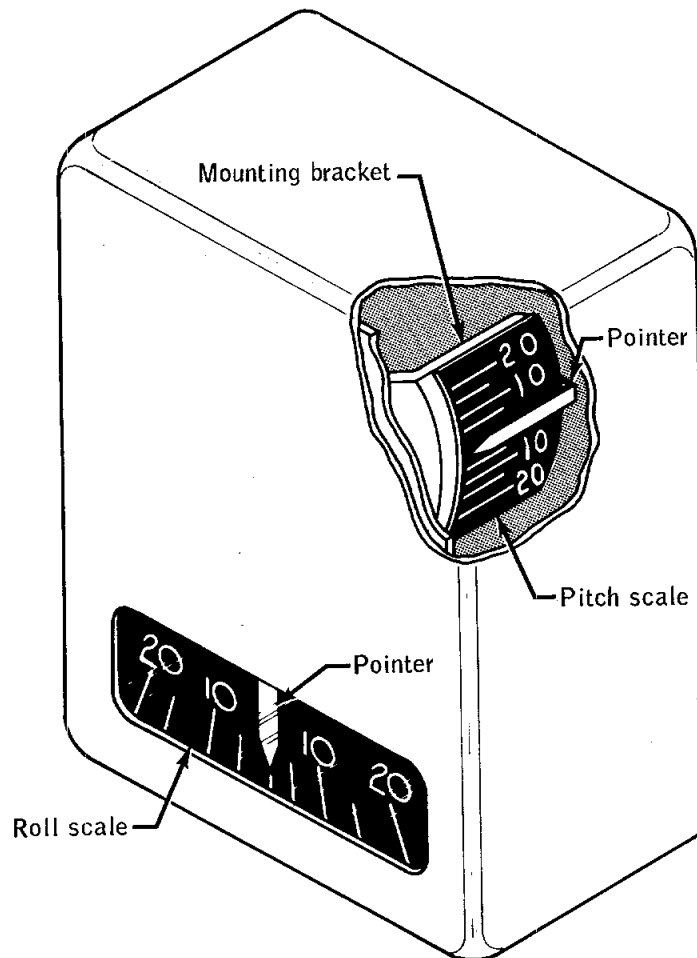


Figure 14-81.- Pitch attitude indicator.

## 15.0 CONCLUSIONS

The overall performance of the Apollo 16 mission was excellent with all of the primary mission objective and most of the detailed objectives being met, although the mission was terminated one day earlier than planned. Experiment data were gathered during lunar orbit, from the lunar surface, and during both the translunar and transearth coast phases for all detailed objectives and experiments except subsatellite tracking for autonomous navigation and the heat flow experiment. Especially significant scientific findings of the mission were the first photography obtained of the geocorona in the hydrogen (Lyman alpha) wavelength from outside the earth's atmosphere and the discovery of two new auroral belts around the earth.

Lunar dust and soil continues to cause problems with some equipment although procedural measures have been taken and equipment changes and additions have been made to control the condition.

Loss of the heat flow experiment emphasizes that all hardware should be designed for loads accidentally induced by crew movements because of vision and mobility constraints while wearing the pressurized suits.

The capability of the S-band omnidirectional antenna system to support the overall lunar module mission operations was demonstrated after the failure experienced with the S-band steerable antenna.

The performance of the Apollo 16 particles and fields subsatellite showed that the lunar gravitational model was not sufficiently accurate for the orbital conditions that existed to accurately predict the time of impact.

The absence of cardiac arrhythmias on this mission are, in part, attributed to a better physiological balance of electrolytes and body fluids resulting from an augmented dietary intake of potassium and a better rest-work cycle that effectively improved the crew's sleep.

The ability of the crew and the capability of the spacecraft to land safely in the rough terrain of a lunar highlands region without having high resolution photography prior to the mission was demonstrated. Further, the capability of the lunar roving vehicle to operate under these conditions and on slopes up to 20° was demonstrated.

## APPENDIX A - VEHICLE AND EQUIPMENT DESCRIPTION

This Appendix discusses the configuration changes to the spacecraft, the extravehicular systems, and the scientific equipment since Apollo 15. In addition, equipment flown for the first time in the Apollo Program is described.

The Apollo 16 command and service module (CSM-113) was of the block II configuration, but was modified to essentially the same configuration as Apollo 15 to carry out a greater range of lunar orbital science activities than had been programmed on missions prior to Apollo 15. The lunar module (LM-11) was modified, as was the Apollo 15 lunar module, to increase the lunar surface stay time and return a larger scientific payload. The launch escape system was unchanged. The potting material around the pyrotechnic panel-separation devices in the spacecraft/launch vehicle adapter was changed from an air-drying type to a catalyst-curing type to prevent acetic acid, that is produced during the curing of the air-drying material, from reacting with the lead sheath of the pyrotechnic device. The Saturn V launch vehicle used for this mission was AS-511, and the significant configuration changes for that vehicle are given in reference 2.

Many minor changes were made because of problems which occurred during the Apollo 15 mission. These are briefly discussed in this section of the report. The Apollo 15 mission report (reference 4) contains detailed discussions of these modifications and should be used if the detailed information is required.

### A.1 COMMAND AND SERVICE MODULES

The mass spectrometer and gamma ray spectrometer booms in the scientific instrument module bay were modified to improve the extension and retraction operations. Two proximity switches were added to the spectrometer booms along with telemetry measurements to provide the crew and ground personnel an improved indication of the boom position during the extension and retraction cycles. The service module auxiliary battery was modified in the same manner as the lunar module descent batteries. These changes are discussed in paragraph A.2.

A large heater was installed in the removable eyepiece assembly used with the scanning telescope. The heater prevents moisture condensation and eyepiece fogging, which was experienced on Apollo 15.

The mode IA abort sequence was extended from 42 to 61 seconds to preclude the possibility of a land landing with full command module reaction control system propellant tanks. The sequence timer which inhibits the

firing of the pitch control motor in the launch escape system and the command module reaction control system propellant dump was changed from 42 to 61 seconds. In the event of a pad or early abort, the pitch control motor will fire to provide a further downrange landing point and the reaction control system propellant will dump through the command module blow-out plugs to reduce impingement of propellant on the parachutes.

As a product of improvement, the parachute riser link material was changed from 4130 steel to Inconel 718. This eliminated the need for a plating operation on the 4130 which could possibly cause a hydrogen embrittlement problem.

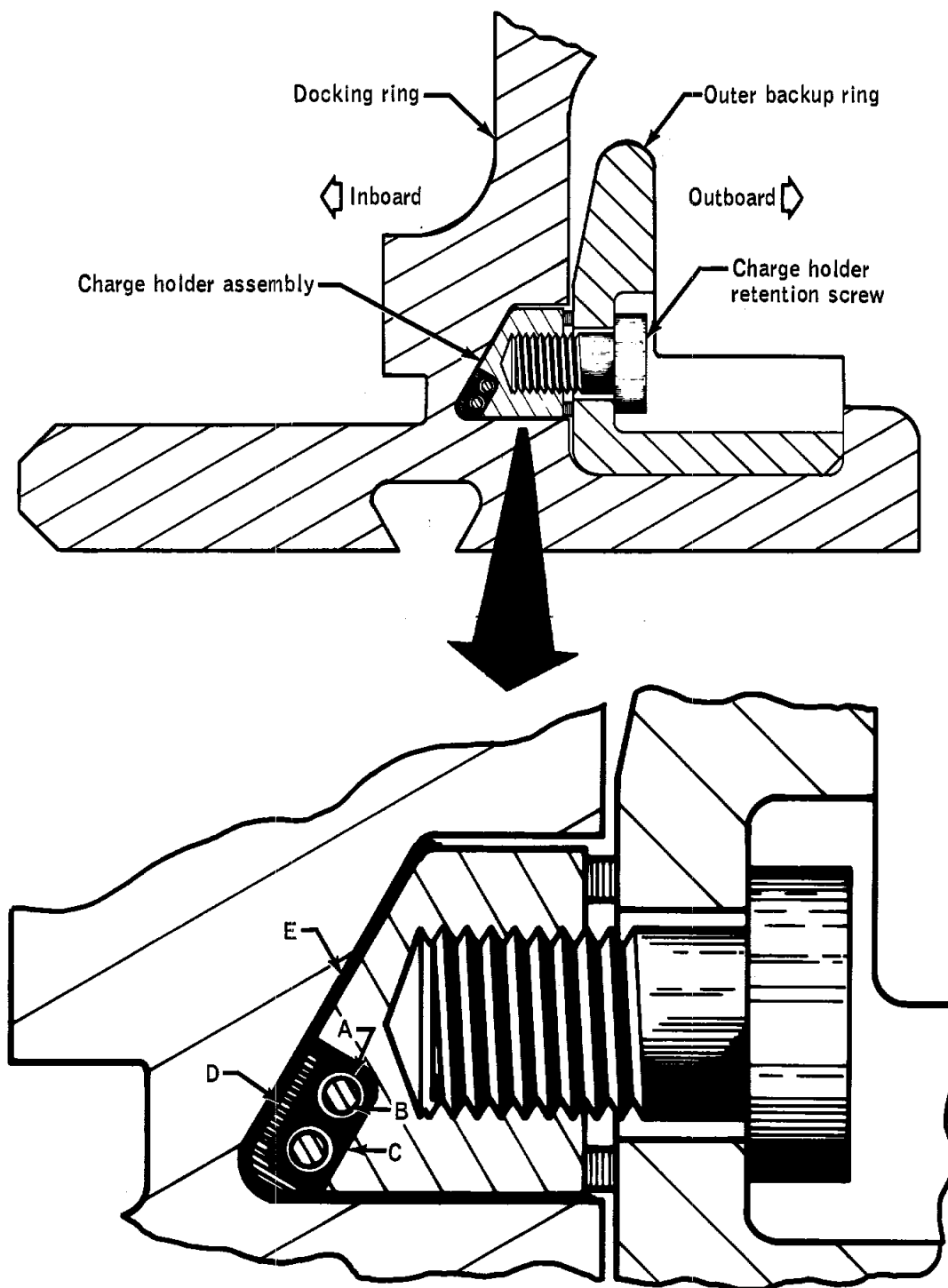
Undervoltage alarms and the loss of lighting for some controls and displays during Apollo 15 were caused by a short circuit in the mission timer. For Apollo 16, a fuse has been added in the numerics power line to each timer; if a failure of this type should recur, the fuses will prevent other systems from being affected.

A potential single-point failure was found during analysis of the Apollo 15 mission data. As a result, two circuit breakers were added in series with the command and service module/lunar module final separation switches and a lanyard-operated actuating device was added to the circuit breakers to enable the crew to actuate the circuit breakers while strapped in their couches during launch.

Broken glass on the range/rate meter in the Apollo 15 lunar module resulted in glass applications being reviewed in both vehicles. As a result, transparent Teflon shields were added to the flight director attitude indicators, the service propulsion gimbal position and launch vehicle propellant tank pressure indicator, the service propulsion oxidizer unbalance indicator, the fuel oxidizer quantity indicators, and the entry monitor roll indicator.

The configuration of the docking ring separation system was modified to insure single-cord cutting capability, thus insuring redundancy in the separation system (fig. A-1). This modification eliminated free volume between the explosive charge and docking ring, thus enhancing the energy transfer from the explosive charge to the docking ring.

The plastic insert within the quick disconnect on the water gun, used to attach the bacteria filter, was modified because of breakage during the Apollo 15 mission. The plastic material was changed to steel.



- A. Silver sheath of mild detonating fuse
- B. Explosive core of mild detonating fuse
- C. Room temperature vulcanizing material filled during mild detonating fuse location molding.
- D. Room temperature vulcanizing material filled during charge holder flush molding.
- E. Room temperature vulcanizing material filled during charge holder installation operation.

Figure A-1.- Modifications to docking ring separation system.

## A.2 LUNAR MODULE

The lunar module batteries were modified to prevent the case-cracking and low-capacity problems experienced with previous flight batteries. These modifications included the installation of Teflon sheet separators between the battery case and the end shells. Also, the limits of the vent system were changed and the plate tabs were strengthened. Manufacturing processes were altered and additional flight battery cells were fabricated for use in ground tests to refine battery ampere-hour capacity predictions.

A manual descent battery coolant flow shutoff valve was installed to provide control of the descent battery temperatures, thereby increasing the battery capacity capabilities. The use of this coolant flow shutoff valve was constrained because of temperature limitations on the two descent electrical control assemblies which were on the same coolant loop. Therefore, transducers were added for monitoring each electrical control assembly to verify that the temperature limits were not exceeded.

The plastic insert in the quick disconnect between the water gun and bacteria filter broke during the Apollo 15 mission when subjected of excessive torque. As a result, the insert material was changed from plastic to steel.

During Apollo 15, electromagnetic interference caused numerous abort guidance system master alarms and warnings. The cause of these alarms was traced to a buffer within the warning system which was not properly grounded. A ground has been added for Apollo 16 and 17 to prevent voltage spikes from initiating an alarm.

The broken glass of the range/rate meter during the Apollo 15 mission resulted in a glass doubler being placed on the meter and tape or shields being placed over other indicators. The flight director attitude indicators were taped and a glass shield was installed over the crosspointer indicator.

### A.3 LUNAR SURFACE MOBILITY SYSTEMS

#### A.3.1 Extravehicular Mobility Unit

The extravehicular mobility unit was modified to improve its operational capability, safety, and to provide increased dust protection. Significant changes were as follows:

- a. A red stripe was added to the back of the Commander's oxygen purge system to aid in personnel identification.
- b. Beta cloth flaps were added on the top of each oxygen purge system to cover those portions of the stowed antenna that were not covered previously.
- c. Dust protectors were added to the oxygen purge system gas connectors and portable life support system water connectors.
- d. Anti-peel patches were added to the gloves to protect the gusset between the thumb and palm.
- e. A secondary restraint was added to the knee convolute in case of cable failure.
- f. The insuit drinking device soft valve seat was removed to increase the flow rate.
- g. The length of the water transport hoses between the portable life support system and suit was increased 4 inches to improve donning characteristics.

The cord within the retractable tethers, worn by the crew while on the lunar surface, was changed from a 30- to 50-pound test cord. The terminating knots were changed to an improved clinch type which is normally used with monofilament line. Also, the knots were dipped in cement to prevent them from slipping or becoming untied.

#### A.3.2 Lunar Roving Vehicle

Minor changes were made to the lunar roving vehicle, these changes were:

- a. The internal circuitry of the ammeter was modified to register from 0 to 50 amperes, but the meter face remained scaled from 0 to 100 amperes. The true value of the readout was one half that indicated on the meter face.



b. Velcro was added to the battery covers to provide increased protection against dust. Reflective tape was added to provide more radiative cooling.

c. New underseat stowage bags with dust covers were provided.

d. The gnomon stowage bag strap was modified for more positive retention.

e. Stiffened seat belts with over-center tightening mechanisms were added, and stowage loops for the belts were attached to the low-gain antenna and the camera staffs.

f. The auxiliary power circuit breaker was changed from 7.5 to 10 amperes. A switch was also added to bypass the circuit breaker and prevent loss of power after lunar module ascent.

### A.3.3 Extravehicular Communications

The lunar communications relay unit and associated hardware were modified for better operation and increased reliability. The changes were:

a. Redesigned elevation and azimuth clutches were incorporated to insure proper camera response to elevation and azimuth commands.

b. Optical sight earth image intensity was increased by a factor of 3 by removing an aperture restriction and the associated baffling.

c. Fifteen square inches of mirror were added to the top of the color television camera to alleviate thermal problems. Also, the black paint on the exposed upper surfaces of the television control unit was changed to white for thermal considerations.

d. A higher torque elevation drive motor was incorporated to provide increased margin for operation at higher temperatures.

e. Velcro strips added to lunar communications relay unit thermal blanket to permit covering of lunar communications relay unit control panel for additional post-extravehicular activity thermal protection (lunar roving vehicle was left in different parking attitude than on Apollo 15).

## A.4 EXPERIMENT EQUIPMENT

### A.4.1 Lunar Surface Science Equipment

Two lunar surface experiments, which have not been flown previously, were added to the Apollo 16 complement. These include the cosmic ray detector (sheets) experiment and the far ultraviolet camera/spectroscopy experiment. One new tool, the lunar surface sampler, was also flown for the first time on Apollo 16. The remaining Apollo 16 lunar surface experiments and tools have been flown previously and their descriptions are found in references 4 and 9 through 13.<sup>1</sup> Table A-1 lists the lunar surface experiments and identifies the previous missions on which these experiments were conducted.

In addition to the normal repackaging of the central station (fig. A-2) to accommodate the specific experiments for Apollo 16, one minor change was made. This change consisted of increasing the rear-curtain-retainer release-pin lanyard strength from 50-pound test material to 180-pound test material to prevent the breakage problem experienced on the previous mission. Also, the lunar dust detector was removed from the central station.

Modifications were made to the heat flow experiment bore stems and to the lunar surface drill to improve the penetration ability and resolve problems that were experienced during Apollo 15. The bore stem tapered joints with diminished external flutes were changed to titanium threaded joints with the external flute depth maintained. The titanium joints were bonded to the boron-fiberglass bore-stem body. Bore stem lengths were also changed so that one 54-inch long stem and two 28-inch long stems were used for each hole instead of six 22-inch long stems. The drill spindle was modified to accept the bore stem threaded joints. The spindle adapter assembly previously used with the bore stem, was replaced with a reducer for use with the core stem. The core stem wrench was modified so that it can also be used for separating both the bore and core stems. A core stem extractor was also provided for use with the treadle (fig. A-3) to assist the crew in removing the core stems from the lunar surface.

The active seismic experiment mortar box cable was lengthened from 10 feet to 50 feet for greater separation distance from the central station. Also, a subpallet was added for the mortar box (fig. A-2) to provide greater stability during firings and for ease of alignment when initially erecting the experiment. The thumper selector switch was modified to provide a more positive detent and all openings around the thumper selector knob and arming and firing knob were covered with dust protectors.

<sup>1</sup>Although some changes have been made to the science hardware since its initial configuration, they are minor in nature and do not alter the descriptions previously provided.

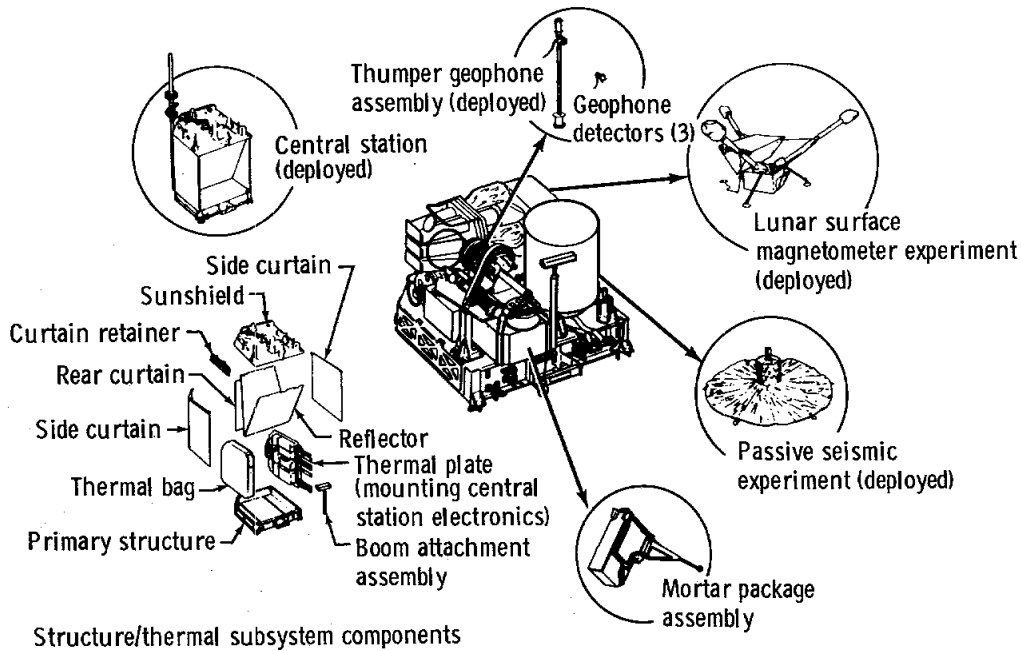
TABLE A-I.- LUNAR SURFACE SCIENCE EXPERIMENTS

Experiment	Experiment number	Previous Apollo missions on which conducted
Apollo lunar surface experiment package:		
(1) Fuel capsule for radioisotope thermoelectric generator		12, 14, 15
(2) Subpackage 1:		
(a) Passive seismic experiment	S-031	12, 14, 15
(b) Active seismic experiment	S-033	14
(c) Lunar surface magnetometer experiment	S-034	12, 14, 15
(d) Central station for command control		12, 14, 15
(3) Subpackage 2:		
(a) Heat flow experiment	S-037	(a), 15
(b) Radioisotope thermoelectric generator		12, 14, 15
Lunar field geology	S-059	11, 12, 14, 15
Far ultraviolet camera/spectroscope equipment	S-201	
Solar wind composition experiment	S-080	11, 12, 14, 15
Lunar soil mechanics	S-200	11, 12, 14, 15
Portable magnetometer experiment	S-198	14
Cosmic ray detector (sheets) experiment	S-152	

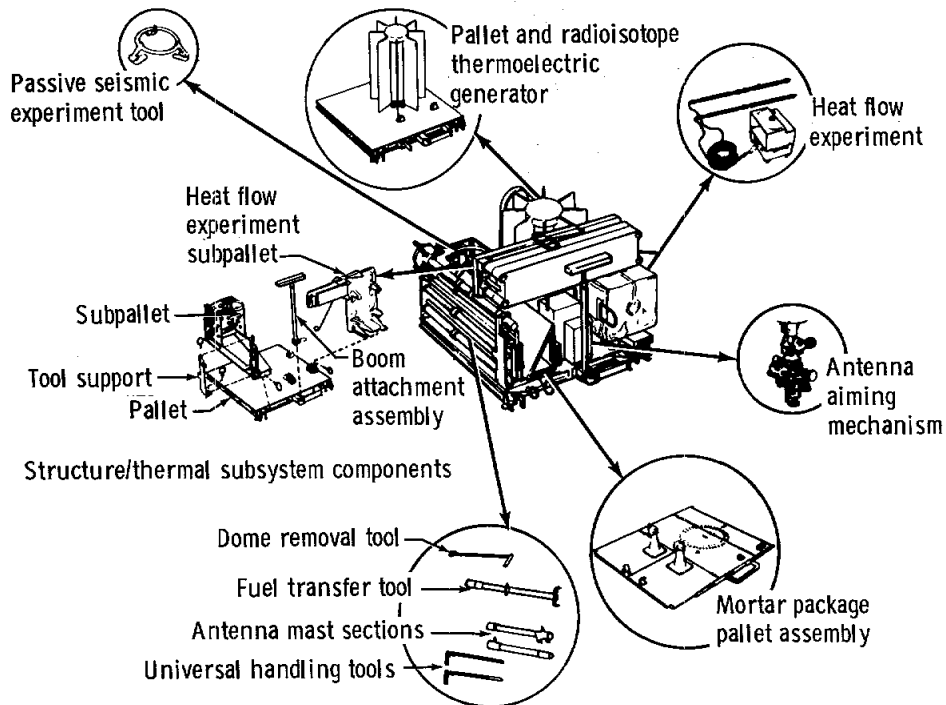
The operational measurement range of the lunar portable magnetometer was increased from  $\pm 100$  gamma to  $\pm 250$  gamma. The motor-type gages used to readout the measurements were changed to a solid-state digital readout. Also, a ratchet was added to the cable reel to ease rewinding of the cable.

Cosmic Ray Detector (Sheets) Experiment.- The purpose of the cosmic ray detector (sheets) experiment, shown in figure A-4, is to:

- a. Measure the charge, mass, and energy spectrum of heavy cosmic ray and solar wind particles in the energy ranges from 0.5 to 10 kiloelectron volts/nucleon and from 0.2 to 200 million electron volts/nucleon.
- b. Provide calibration data for glass detectors, including tektite glass.



(a) Subpackage 1.



(b) Subpackage 2.

Figure A-2.- Apollo lunar surface experiments package.

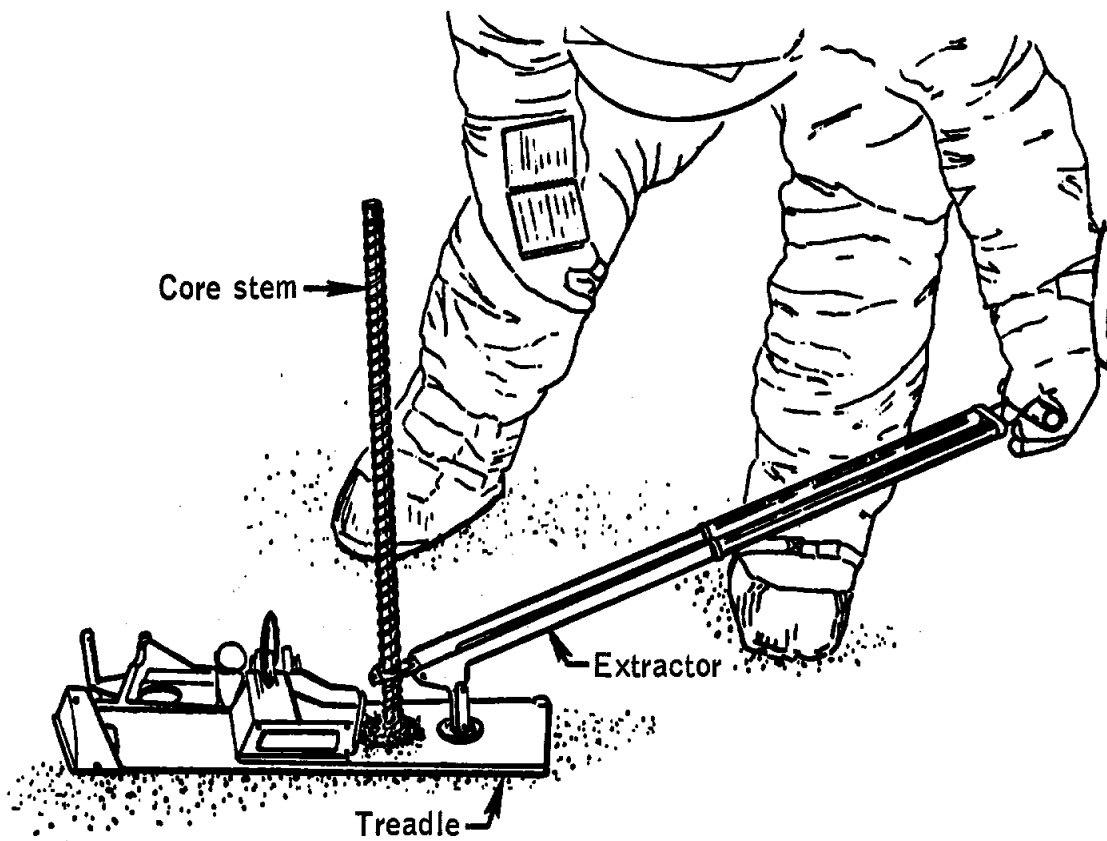


Figure A-3.- Core stem extractor.

- c. Measure the thermal neutron flux at the lunar surface.
- d. Assess the problem of  $\text{Ar}^{40}$  implantation.

The cosmic ray detector experiment consists of a four-panel foldable detector array. This array, which is mounted on the outside of the lunar module descent stage, is directly exposed to cosmic ray and solar wind particles from spacecraft/launch vehicle adapter separation through lunar landing. During the initial phases of the first lunar surface extravehicular activity, a hidden surface of the number 4 detector panel is uncovered by a crewman, and this exposes the surface to the lunar surface cosmic ray and solar wind environment.

Near the end of the last extravehicular activity, the detector panels will be retrieved and stowed in a special bag, equipped with temperature indicators, for return to earth. When the panels are folded, half of the

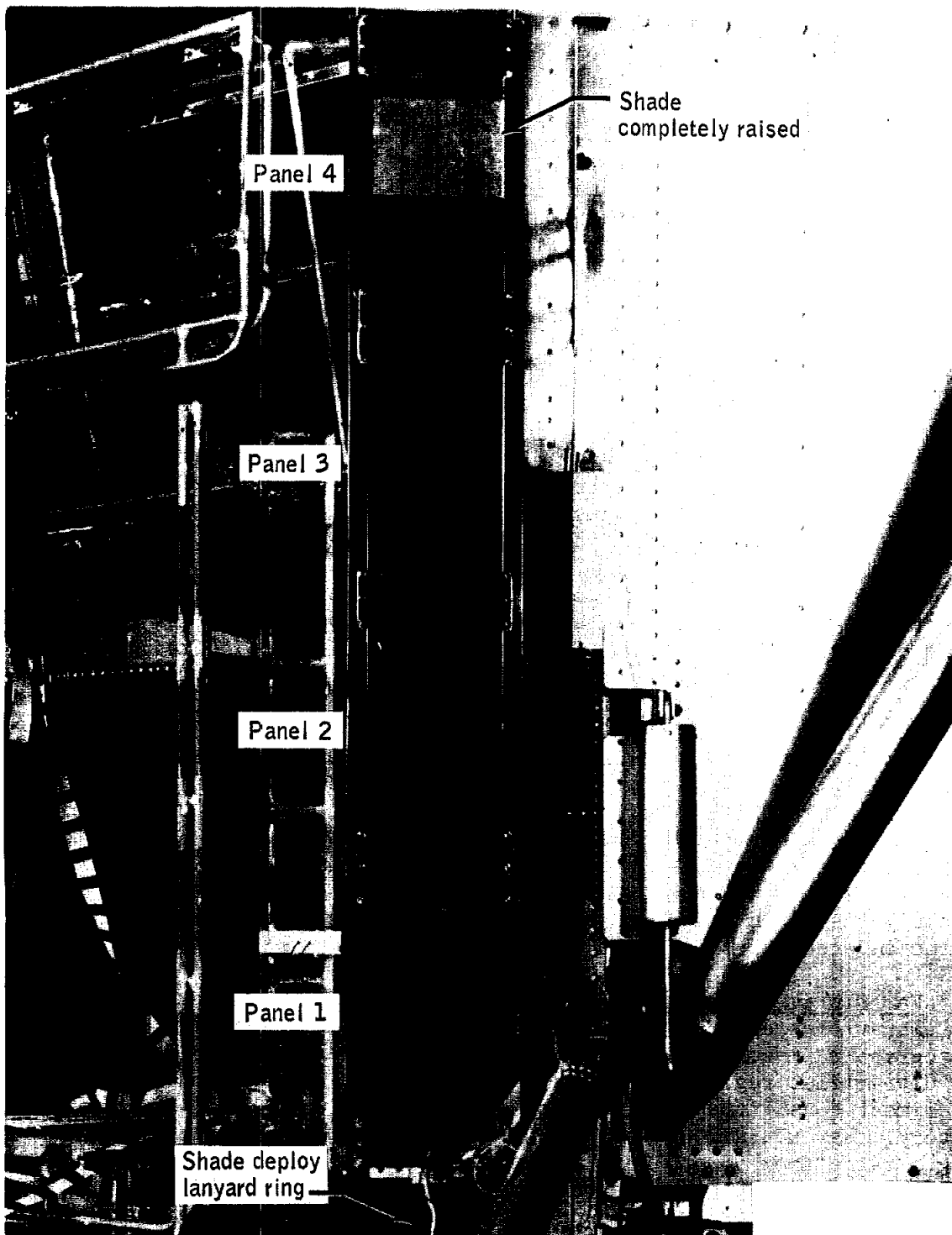


Figure A-4.- Fully deployed cosmic ray detector experiment.

detector sheets are automatically shifted relative to the other half, allowing the detection of particles which strike the panels during trans-earth coast while the experiment is stowed within the command module. Photographs of the experiment on the lunar surface will be taken with the 70-mm electric data camera (60-mm lens).

The number 1 detector panel is composed of 31 sheets of Lexan plastic, 0.025-centimeter thick, that are covered by perforated aluminized Teflon. Two temperature indicators of the color-changing type are located within the panel.

The number 2 detector panel is similar to the number 1 panel with the exception that it has within its two samples, a pre-irradiated plastic for postflight data analysis purposes.

The number 3 detector panel is composed of a stack of 40 0.20-centimeter-thick Kodacel cellulose triacetate sheets, with a stack of ten, 5-micron-thick, Lexan plastic sheets bonded to the upper half of the panel. Five glass specimens of various sizes and shapes are placed within the lower portion of the panel.

The number 4 panel, the most complex panel of all, contains a variety of particle-detecting materials. The main detector sheets are Lexan and cellulose triacetate, laminated as previously described. The plastic sheets composing the lower portion of the panel require shifting, but those of the upper portion of the panel do not. The lowest quarter of the panel is covered with a 0.076-centimeter-thick piece of aluminum to which small pieces of mica, glass, and various naturally occurring crystals are attached. The next highest quarter of the panel is covered with 2-micron-thick foil bonded to the adjacent plastic sheet. The number 4 panel also contains two temperature indicators. The upper half of the number 4 panel is covered with 5-micron-thick aluminum foil bonded to a base of platinum. The action of a crewman pulling a lanyard moves this assembly inside the panel to expose another piece of aluminum foil bonded to the adjacent plastic sheet.

Far Ultraviolet Camera/Spectroscope Experiment.- The purpose of the far ultraviolet camera/spectroscope experiment (fig. A-5) is to provide photographic imagery and spectroscopic data on celestial objects in the far ultraviolet region (principally at the Lyman-alpha wavelength). This experiment constitutes the first planetary-based precursor astronomy laboratory. Far ultraviolet spectroscopic data are obtained in the wavelength range from 500 to 1550 angstroms with a resolution of 30 angstroms. Imagery data are obtained in the wavelength ranges from 1050 to 1260 angstroms and from 1200 to 1500 angstroms. Difference techniques are performed on these imagery data to identify characteristic Lyman-alpha radiation at 1216 angstroms, which will identify hydrogen gas clouds. Special targets of interest included the geocorona, earth's atmosphere, solar

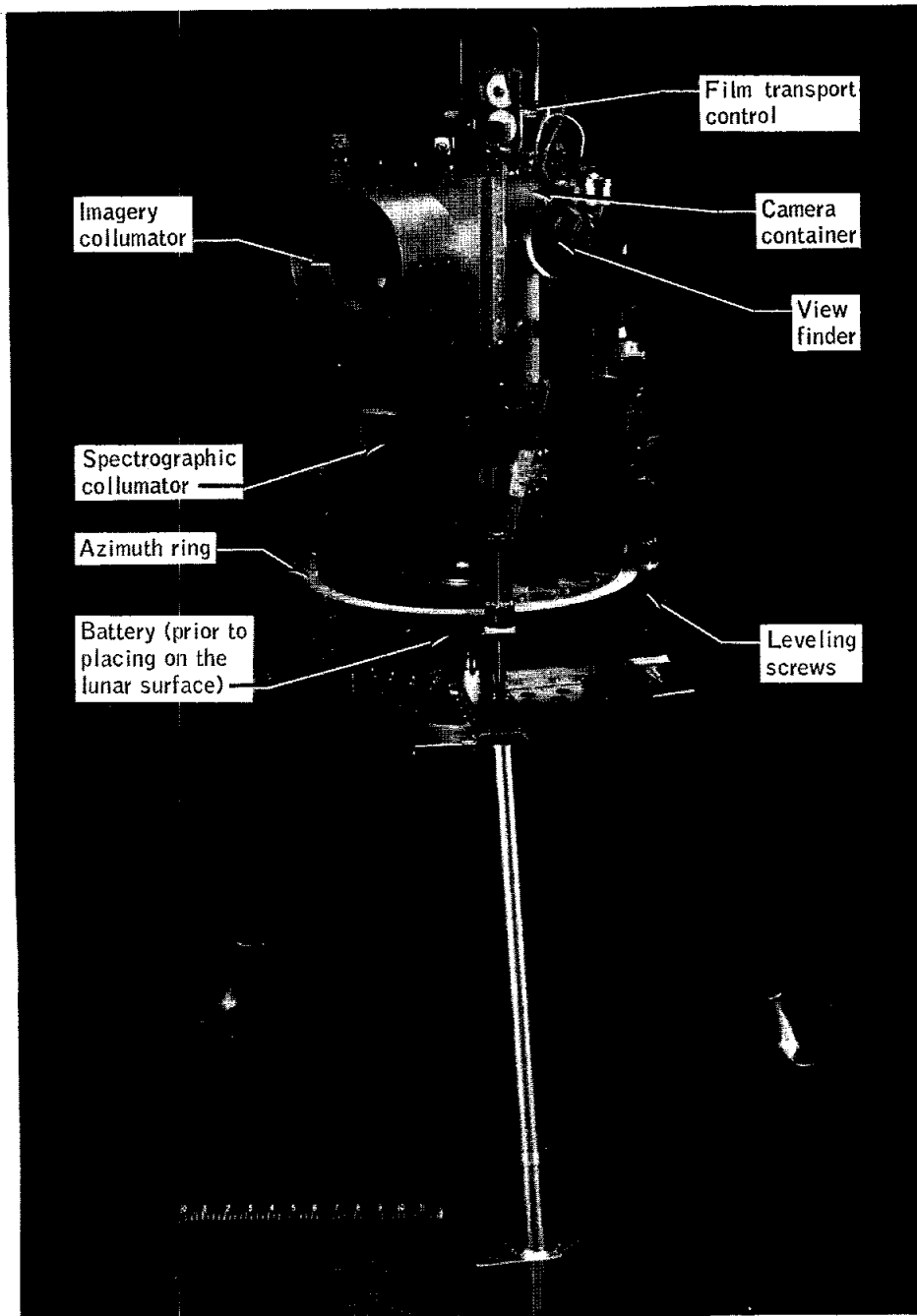


Figure A-5.- Far ultraviolet camera deployed on lunar surface.



wind, various nebulae, star clouds (Milky Way), galaxy clusters and other galactic objects, intergalactic hydrogen, the solar bow cloud, lunar atmosphere, and lunar volcanic gases.

The equipment for the far ultraviolet camera/spectroscope experiment consists of a 3-inch electronographic camera with a Cesium iodide (CsI) cathode and film transport device (containing 35-mm film). While operating, it is tripod mounted in the lunar module shadow. Lithium fluoride (LiF) and Calcium fluoride (CaF<sub>2</sub>) filters are used to obtain the imagery difference necessary to identify hydrogen Lyman-alpha radiation at the 1216 angstroms wavelength. No filters are used to obtain the required spectroscopic data.

The crew deploys the tripod-mounted camera in the lunar module shadow and adjusts the camera to the specified level and alignment tolerances, pointing the camera at the required targets by means of the elevation and azimuth adjustments, and activates the automatic exposure sequencer. At the end of the last extravehicular activity, the crew removes the film transport device from the camera, places it in a special stowage bag, and returns it to the lunar module ascent stage for subsequent return to earth. Orientation photographs of the deployed camera assembly are taken by the crew with the 70-mm electric data camera (60-mm lens).

Lunar Surface Sampler Tool.- The lunar surface sampler tool is used to collect undisturbed lunar soil samples (fig. A-6). The sampler consists of two major subassemblies; a 100-square-centimeter surface sampler plate and a container assembly. Two of these units are used on Apollo 16 - one having Beta cloth covering the sampler plate, and the other having deep-pile nylon velvet over the sampler plate. The Beta-cloth covered sampler plate is used to pick up an undisturbed surface layer about 0.5-millimeter thick and the nylon-velvet covered plate is used to pick up an undisturbed surface layer about 1-millimeter thick.

The universal hand tool is used in conjunction with the sampler for ease of placing the sampler on the surface. The samplers are stowed on the lunar roving vehicle pallet.

#### A.4.2 Inflight Science Experiments

The inflight science equipment within the command and service modules for the Apollo 16 mission is the same as that flown on Apollo 15 (reference 4). Table A-II shows on which missions the equipment were flown and in which reports the experiment is described; therefore, no overall descriptions will be presented in this report. However, as a result of a problem with the panoramic camera during the Apollo 15 mission, a modification was made to the camera control circuitry. A switch was provided to manually override the automatic operation of the velocity/altitude sensor, should sensor operation become erratic.

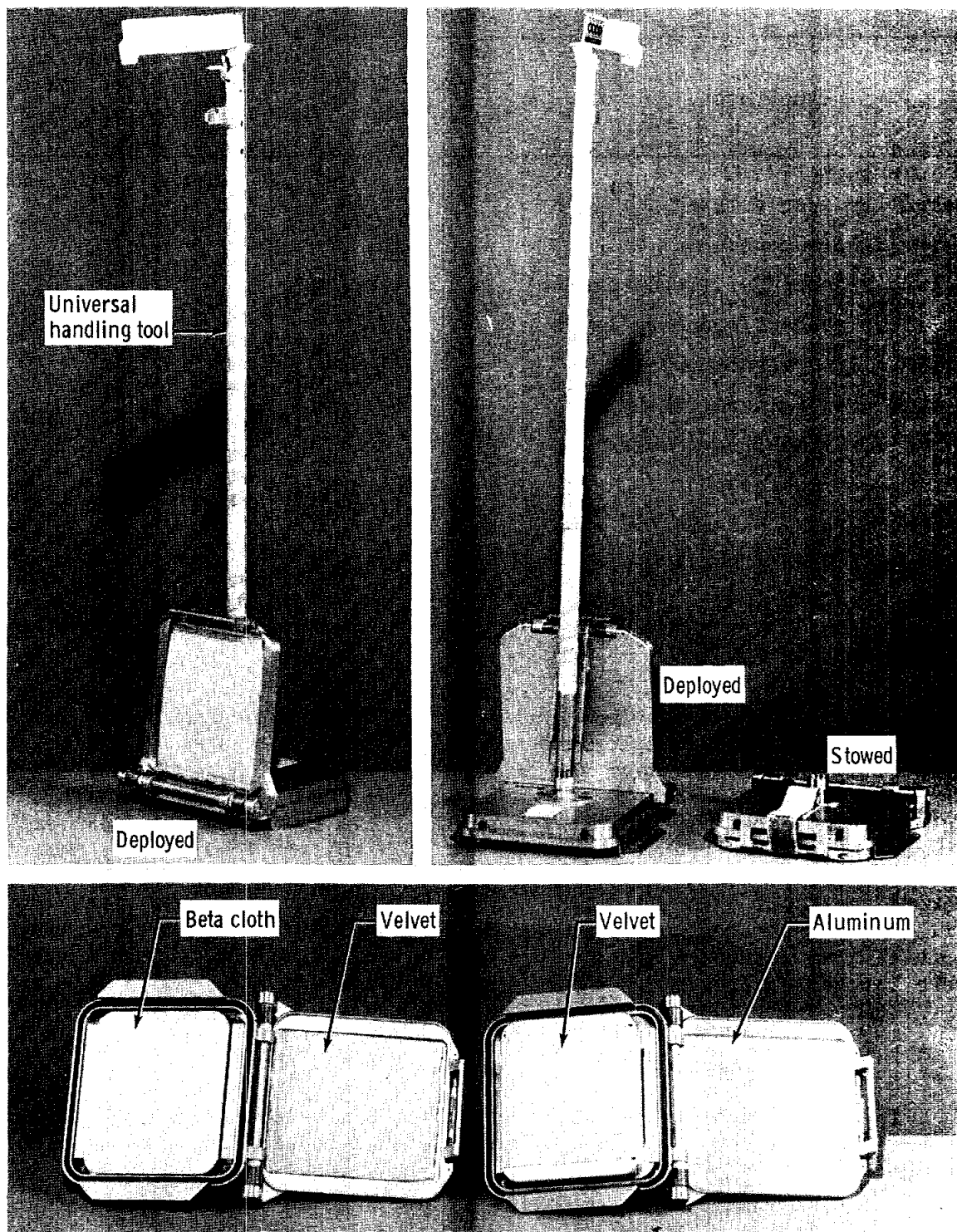


Figure A-6.- Lunar surface sampler tool.

TABLE A-II.- LUNAR INFLIGHT SCIENCE EXPERIMENTS

Experiment	Experiment Number	Previous Apollo Missions on which conducted or Deployed
Gamma-ray spectrometer	S-160	15
X-ray fluorescence	S-161	15
S-band transponder (subsattellite)	S-164	15
Particle shadows/boundary layer	S-173	15
Subsattellite magnetometer	S-174	15
S-band transponder (CSM-LM)	S-164	14, 15
Alpha particle spectrometer	S-162	15
Mass spectrometer	S-165	15
UV photography - earth and moon	S-177	15
Gegenschein from lunar orbit	S-178	14, 15
Bistatic Radar	S-170	14, 15

Also, as a result of problems during Apollo 15, minor changes were made to the mapping camera deployment mechanism and to the laser altimeter. The deployment mechanism of the mapping camera operated sluggishly, so the lubrication was changed from a molybdenum disulfide dry film lubricant to a vacuum compatible oil and grease mixture. In the laser altimeter, compensation circuitry was added in the high voltage power supply to automatically increase the voltage to the laser module should the power output become degraded. Also, the bearing seals in the Q-switch motor were modified to prevent contamination of the optical surfaces within the laser module. Two resistors and a relay that were included for ground safety, were removed to prevent possible corona problems.

#### A.4.3 Photographic Tasks and Equipment

The photographic tasks for the Apollo 16 mission are divided between cameras located in the service module, command module, lunar module, and on the lunar surface.

Service module photographic tasks.- The photographic tasks for the cameras operated in the service module are as follows:

- a. Obtain high-resolution panoramic photographs of the lunar surface using stereoscopic and monoscopic techniques.
- b. Obtain stellar photographs and high-quality lunar surface metric photographs with simultaneous exposures.
- c. Obtain data on the altitude of the command and service modules above the lunar surface.

Command module photographic tasks.- The photographic tasks for the cameras operated in the command module are as follows:

- a. Obtain photographs of diffuse galactic light of selected celestial subjects.
- b. Obtain photographs of solar corona after spacecraft sunset and prior to spacecraft sunrise.
- c. Obtain photographs of a comet, if appropriate trajectory and celestial conditions exist.
- d. Obtain photographs of zodiacal light as the spacecraft approaches sunrise.
- e. Obtain photographs of lunar surface areas of prime scientific interest.

Lunar surface and lunar module photographic tasks.- The photographic tasks for the cameras operated on the lunar surface are as follows:

- a. Obtain documentary metric and stereo photographs of each emplaced lunar surface experiment, showing the relationship to other experiments. Also, document all experiment operations while on the lunar surface.
- b. Obtain documentary metric and stereo photographs of collected samples and their initial relationship to the surrounding area. Also, document all geological investigations.
- c. Obtain 360-degree panoramic photographs of the landing site area.
- d. Obtain motion picture photography as the lunar roving vehicle moves during the three traverses.
- e. Obtain lunar module descent and ascent sequence photography and lunar module and service module inspection photography.

Photographic equipment.- The majority of the experiments and detailed objectives associated with lunar orbital and lunar surface operations require photographic data for evaluation or validation. The photographic equipment required with these operations has been described in conjunction with the applicable experiments in previous sections or previous mission reports. However, for convenience, a complete listing of the equipment and film is provided in table A-III.

A problem with the 70-mm camera while operating on the lunar surface necessitated minor modifications to the camera mechanism. Two surface flats were ground on the motor shafts for more positive retention of the drive pinion set screws.

## A.5 MEDICAL EXPERIMENTS

Two medical experiments are being flown for the first time on Apollo 16. They are the biostack experiment (M-211), and microbial response in space environment experiment (M-191).

### A.5.1 Biostack Experiment (M-211)

The biostack experiment (fig. A-7) is designed to obtain information on the biological effects of high-atomic high-energy ions or particles of the cosmic radiation environment on selected biological systems. The high-atomic (number) high-energy particles are not yet obtainable from earth-based radiation sources. Therefore, information pertaining to the biological effects of these particles can only be obtained from experiments conducted in space. Such information is required to determine the nature and extent of this type radiation hazards to future manned space missions.

The biostack experiment hardware consists of four types of biological systems interlayered with nuclear radiation detectors and encased in a hermetically sealed aluminum cylinder.

The biological materials selected for this experiment are *Bacillus Subtilis* spores (hay bacillus), *Arabidopsis thaliana* seeds (mouse-ear crest), *Vicia Faba* (broad bean roots), and *Artemia Salina* eggs (brine shrimp). The materials are prepared and embedded in monolayers in water-soluble foils of polyvinyl alcohol. These are interlayered between cosmic ion track detectors, i.e., nuclear emulsions (Ilford K2 and K5) and plastic (cellulose nitrate and polycarbonate). The plastic detectors, which have different energy thresholds, facilitate determination of the charge and energy characteristics of the high-atomic high-energy particles. The techniques developed for assembly and processing permit accurate correlation of incident high-atomic, high-energy particles with individual biological objects.

TABLE A-III.- PHOTOGRAPHIC EQUIPMENT

Experiment or objective	Camera type <sup>a</sup>	Lens	Film type <sup>b</sup>
Experiments			
In flight:			
Gamma ray spectrometer	PC	24-inch	LBW (3414)
X-ray fluorescence	MC	3-inch	BW (3400)
Alpha particle spectrometer			BW (3401)
S-band transponder			
Mass spectrometer			
Subsatellite (launch)	DAC	75-mm	CEX (SO-368)
Mass spectrometer	DAC	18-mm	BW (SO-164)
Ultraviolet photography	HEC	105-mm	I1a-0, CEX (SO-368)
		UV transmitting	
Lunar surface:			
Lunar geology			
	HEDC	60-mm	BW (3401)
	HEDC	60-mm	HCEX
	LDAC	10-mm	CEX
	HEDC	500-mm	TED
Apollo lunar surface	HEDC	60-mm	HCEX (SO-168)
Experiments package	LDAC	10-mm	CEX (SO-368)
Far UV camera/spectroscope	LSUV	Electrono- graphic Schmidt	NTB-3
	HEDC	60-mm	HCEX (SO-168)
Solar wind composition	HEDC	60-mm	HCEX (SO-168)
			BW (3401)
Soil mechanics	HEDC	60-mm	BW (3401)
	LDAC	10-mm	CEX (SO-168)
Portable magnetometer	HEDC	60-mm	HCEX (SO-168)
Cosmic ray detector (sheets)	HEDC	60-mm	HCEX (SO-168)
			BW (3401)
Detailed objectives			
In flight:			
Service module orbital	PC	24-inch	LBW (3414)
Photographic tasks	MC	3-inch	BW (3400)
	SC	3-inch	BW (3401)
Command module	35	55-mm	VHBW (2485)
Photographic tasks	HEC	80-mm	VHBW (2485)
	HEC	250-mm	CEX (SO-368)
			VHBW (2485)
	DAC	18-mm	VHBW (2485)

<sup>a</sup>Camera nomenclature:

DAC 16-mm data acquisition camera  
 LDAC 16-mm lunar surface data acquisition camera (battery operated)  
 HEC 70-mm electric camera  
 HEDC 70-mm electric data camera (with reseau)  
 35 35-mm camera  
 MC 3-inch mapping camera  
 SC 3-inch stellar camera  
 PC 24-inch panoramic camera  
 LSUV Electronographic camera

<sup>b</sup>Film nomenclature:

CEX Color exterior (SO-368)  
 HCEX High speed color exterior (SO-168)  
 BW Medium speed black and white (3400, 3401, and SP-164)  
 LBW Low speed black and white (3414)  
 VHBW Very high speed black and white (2485)  
 I1a-0 Ultraviolet (UV) spectroscopic  
 NTB-3 Far UV spectroscopic

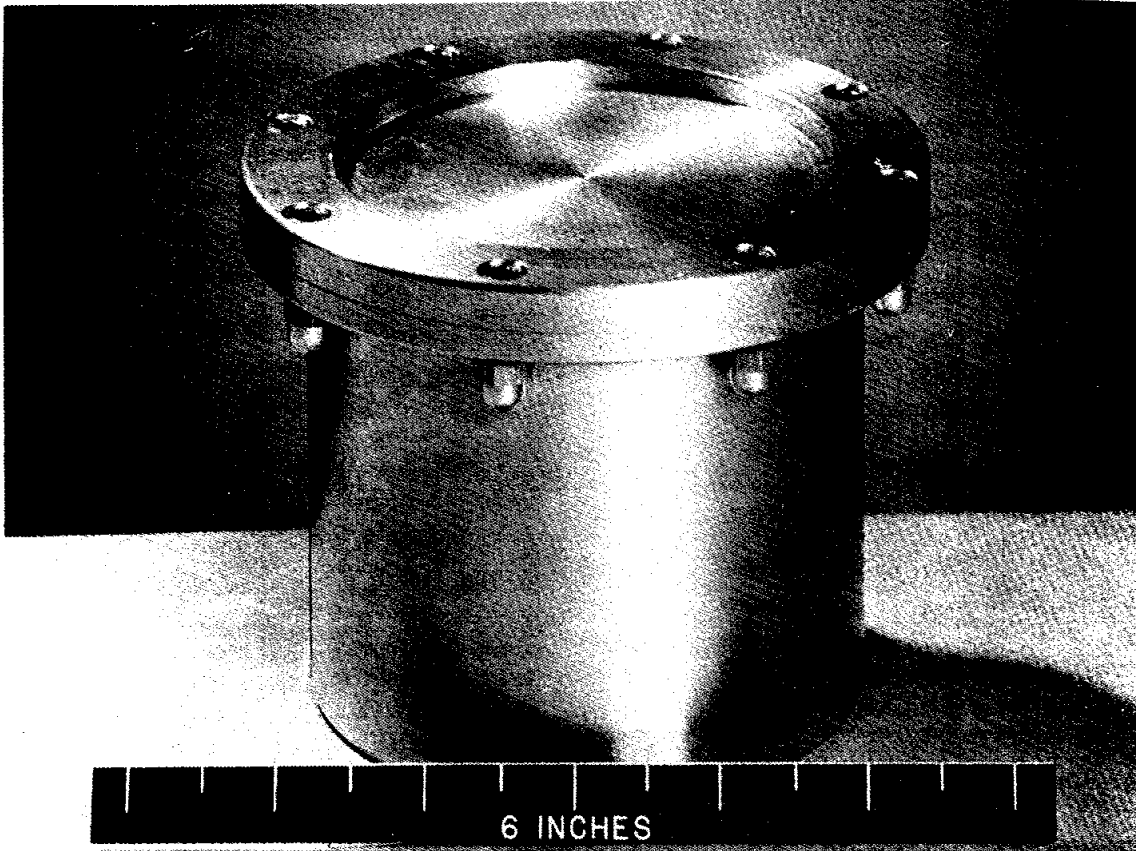


Figure A-7.- Biostack experiment hardware.

The experiment is stowed in the command module, is completely passive, and requires no life support or crew participation.

#### A.5.2 Microbial Response in Space Environment Experiment (M-191)

The microbial response in space environment experiment (fig. A-8) is designed to quantitatively measure the effects of certain space flight environmental parameters on nine different microbial systems and to evaluate the consequence of genetic and responsive alteration in these test systems. To obtain data of medical importance, model test systems were selected which demonstrated disease-associated phenomena, but were not pathogenic to man. By separating the test systems into 840 individual compartments, each containing an average of ten thousand microorganisms, selective evaluations of the alterations influenced by space vacuum,

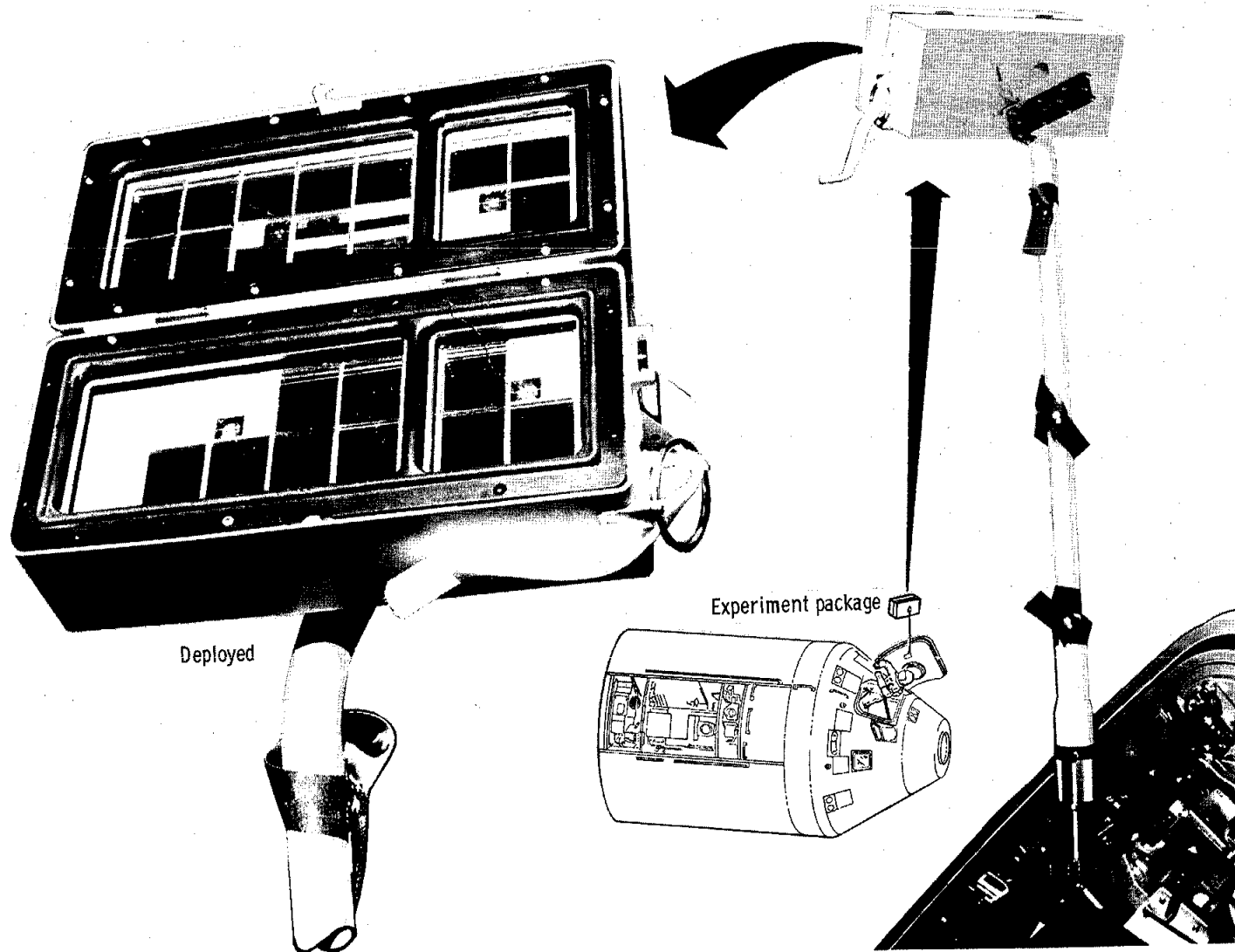


Figure A-8.- Microbial response in space environment experiment hardware.



changes in oxygen partial pressure, lowered gravity states, and cosmic radiation, as well as the total space flight environment are made possible. The unusually fine sensitivity, made possible by the large sample sizes, is further increased by manipulation of the mutation rate. This is made possible through the use of selected components of the solar ultraviolet spectrum, controlled by a series of optical filters. The flight hardware consists of a microbial ecology evaluation device which is exposed to solar radiation and space vacuum during the transearth coast extravehicular activity. In addition to the microbial test systems, this hardware contains two types of ultraviolet measuring systems, a compound high energy-multicharged article dosimeter package, and recording thermometers. These systems provide the measurement data required for interpretation of the biological results.

#### A.6 MASS PROPERTIES

Mass properties for the Apollo 16 mission are summarized in table A-IV. These data represent the conditions as determined from postflight analyses of expendable loadings and usage during the flight. Variations in command and service modules and lunar module mass properties are determined for each significant mission phase from lift-off through landing. Expendables usage are based on reported real-time and postflight data as presented in other sections of this report. The weights and center-of-gravity of the individual modules (command, service, ascent stage, and descent stage) were measured prior to flight and inertia values calculated. All changes incorporated after the actual weighing were monitored, and the mass properties were updated.

TABLE A-IV.- MASS PROPERTIES

Event	Weight, lb	Center of gravity, in.			Moment of inertia, slug-ft <sup>2</sup>			Product of inertia, slug-ft <sup>2</sup>		
		X	Y	Z	I <sub>XX</sub>	I <sub>YY</sub>	I <sub>ZZ</sub>	I <sub>XY</sub>	I <sub>XZ</sub>	I <sub>YZ</sub>
Command and service module/lunar module										
Lift-off	116 393	843.4	3.0	2.5	73 561	1 240 951	1 241 242	3741	10 697	2617
Earth orbit insertion	107 226	804.5	3.3	2.6	72 679	767 814	768 124	6559	11 528	2606
Transposition and docking: Command & service modules	66 923	933.8	5.0	4.7	36 440	80 316	81 940	-2095	329	2260
	Lunar module	36 252	1238.2	-0.7	0.8	25 898	26 177	27 117	-519	203
Total docked	103 175	1040.8	3.0	3.3	62 580	576 734	579 385	-11 409	-5484	1934
Lunar orbit insertion	102 642	1041.3	3.0	3.4	62 114	575 152	577 930	-11 220	-5728	2066
Descent orbit insertion	77 595	1081.2	2.1	1.9	49 096	450 349	457 001	-9172	-1127	-936
Separation	76 590	1083.9	2.1	1.9	49 925	446 004	452 325	-8624	-1392	-1012
Command and service module circularization	39 595	942.6	4.3	3.2	22 210	60 398	65 668	-2469	1416	-504
Command and service module plane change	38 994	942.9	4.3	3.1	21 881	60 271	65 383	-2477	1438	-481
Docking: Command & service modules	38 452	943.2	4.2	3.1	21 590	60 203	65 079	-2457	1435	-501
	Ascent stage	5866	1165.6	4.5	-2.5	3298	2312	2677	-113	-8
Total after docking: Ascent stage manned	44 318	972.7	4.2	2.4	24 923	116 885	122 091	-2496	44	-880
	Ascent stage unmanned	44 298	970.7	4.1	2.4	24 839	112 588	117 804	-2825	258
After ascent stage jettison	38 992	944.0	4.3	2.9	21 698	60 225	65 073	-2337	1264	-527
Subsatellite jettison	38 830	944.3	4.2	3.1	21 581	59 974	64 861	-2257	1153	-479
Transearth injection	38 697	944.3	4.2	3.1	21 463	59 886	64 793	-2258	1159	-446
Transearth extravehicular activity	27 490	968.2	1.4	3.8	15 826	47 705	47 245	-898	864	-1125
Command and service modules prior to separation	27 225	968.8	1.3	4.0	15 523	47 253	46 846	-823	860	-1024
After separation: Service module	14 199	904.4	2.4	2.2	9536	15 336	15 488	-427	520	-987
	Command module	13 026	1039.1	0.1	5.9	5958	5308	4762	55	-388
Entry	13 015	1039.1	0.1	5.9	5952	5301	4761	54	-386	-23
Main parachute deployment	12 442	1037.5	0.1	6.0	5746	4900	4401	56	-334	-21
Landing	11 995	1035.6	0.1	6.0	5680	4607	4090	52	-339	-20
Lunar module										
Lunar module at earth launch	36 255	184.1	0.4	-1.0	25 903	27 362	26 147	85	547	188
Separation	36 743	185.1	0.4	-0.5	27 348	28 594	27 243	84	834	180
Powered descent initiation	36 617	184.9	0.5	-0.5	27 280	28 294	26 927	184	830	166
Lunar landing	18 208	208.6	0.8	-0.8	15 709	16 580	17 894	128	877	178
Lunar lift-off	10 949	243.7	0.4	2.7	6762	3390	5976	95	178	-35
Orbit insertion	6001	256.6	0.7	5.0	3365	2896	2114	84	95	-37
<sup>a</sup> Terminal phase initiation	5972	256.4	0.6	5.0	3353	2888	2097	80	96	-36
Docking	5866	256.2	0.1	5.1	3298	2866	2030	64	99	-30
Jettison	5306	255.1	0.0	3.1	3142	2762	1975	75	79	-30

<sup>a</sup>Post ullage

APPENDIX B - SPACECRAFT HISTORIES

The history of command and service module (CSM-113) operations at the manufacturer's facility, Downey, California, is shown in figure B-1, and the operations at Kennedy Space Center, Florida in figure B-2.

The history of the lunar module (LM-11) at the manufacturer's facility, Bethpage, New York, is shown in figure B-3, and the operations at Kennedy Space Center, Florida, in figure B-4.

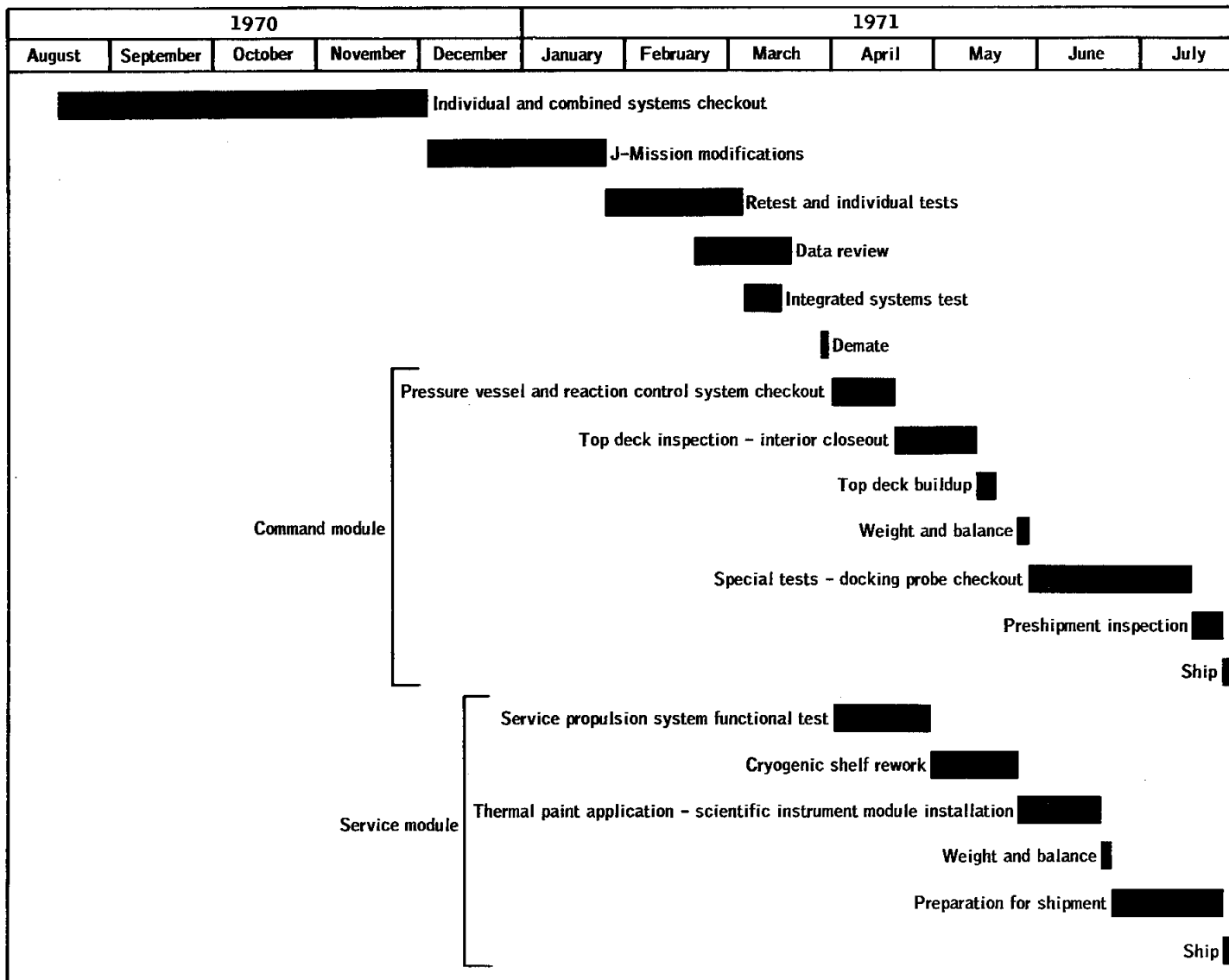


Figure B-1.- Checkout flow for command and service module 113 at contractor's facility.

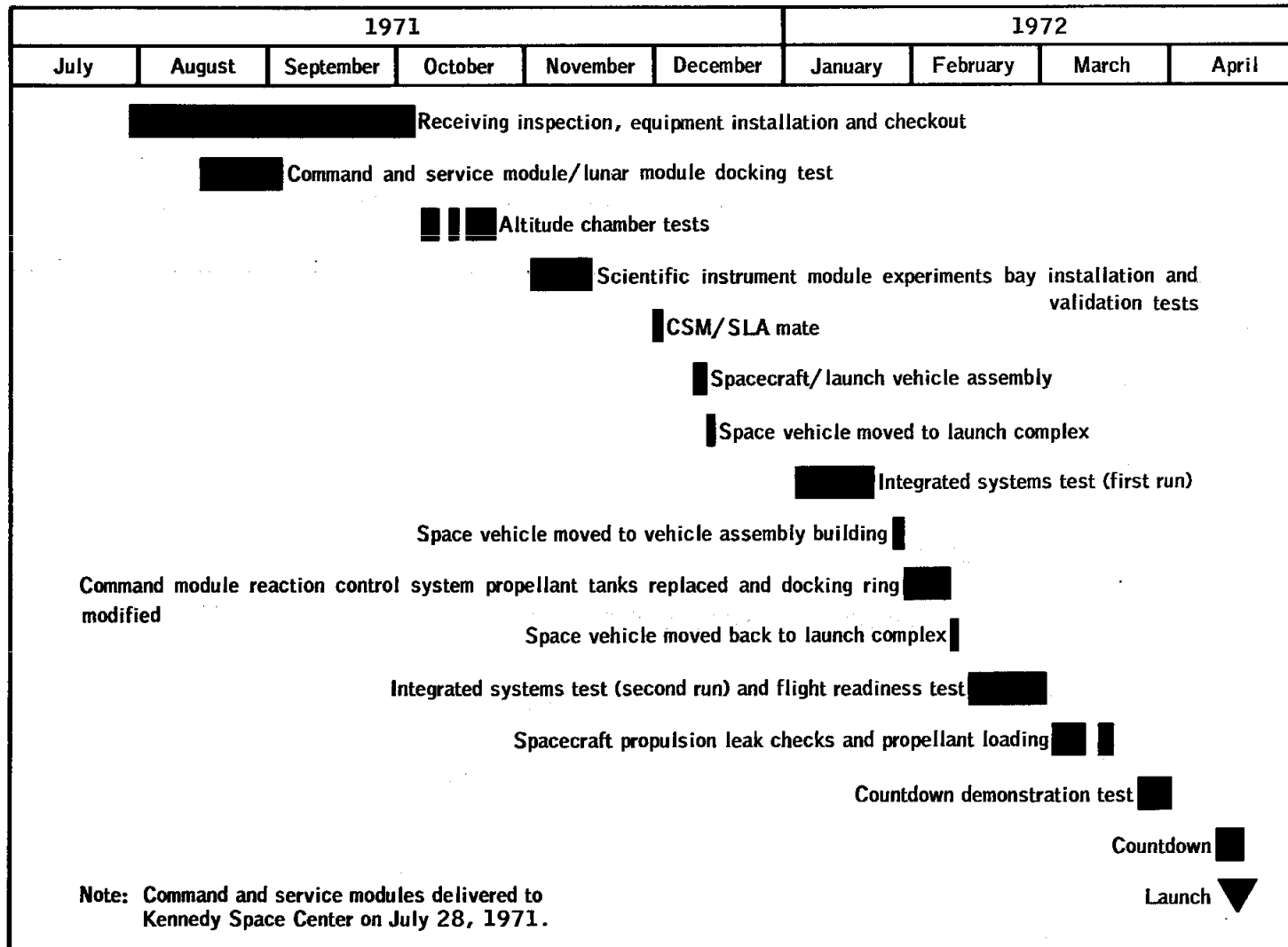


Figure B-2.- Command and service module 113 checkout history at Kennedy Space Center.

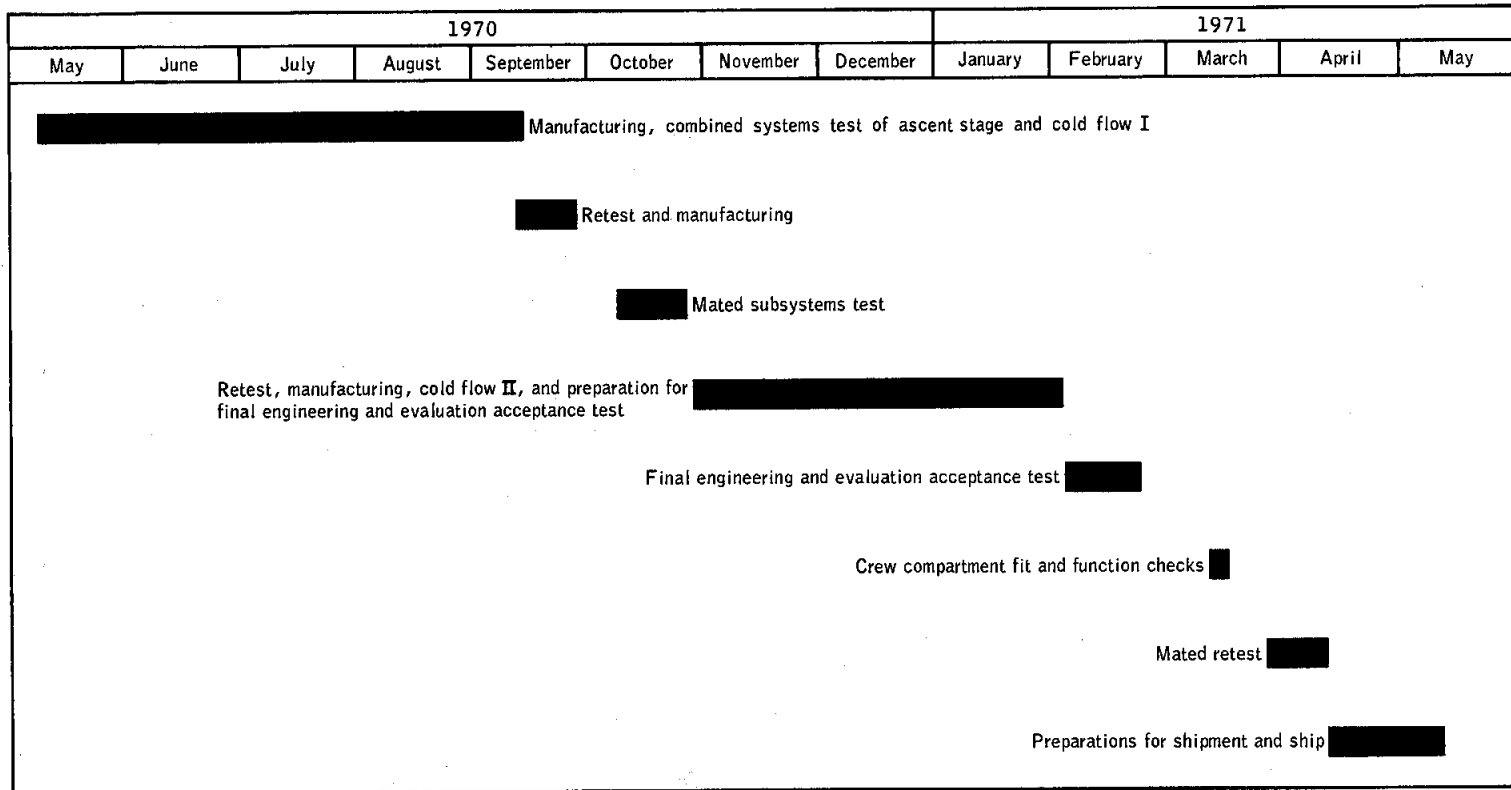


Figure B-3.- Checkout flow for lunar module 11 at contractor's facility.

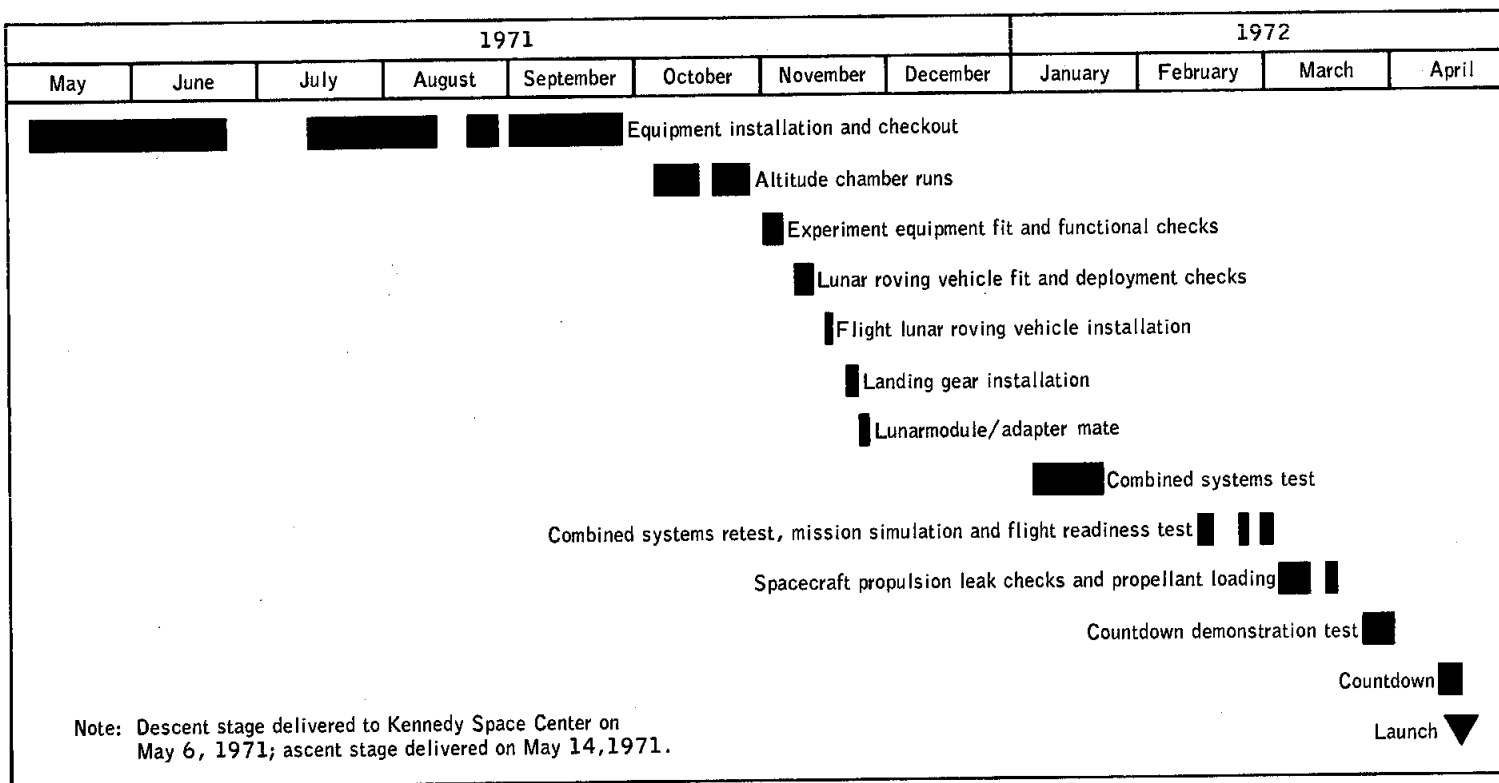


Figure B-4.- Lunar module 11 checkout history at Kennedy Space Center.

APPENDIX C - POSTFLIGHT TESTING

Postflight testing and inspection of the command module and crew equipment for evaluation of the inflight performance and investigation of the flight irregularities were conducted at the contractor's and vendor's facilities and at the Manned Spacecraft Center in accordance with approved Apollo Spacecraft Hardware Utilization Requests (ASHUR's). The tests performed as a result of inflight problems are described in table C-I and discussed in the appropriate systems performance section of this report. Tests being conducted for other purposes in accordance with other ASHUR's and the basic contract are not included.



TABLE C-I.- POSTFLIGHT TESTING SUMMARY

ASHUR no.	Purpose	Tests performed	Results
Guidance and Navigation			
113007	Investigate cause of false gimbal lock.	Perform resistance, power and coolant-on, and bench tests	Contact bounce in the thrust vector control enable relay caused the anomaly.
113007	Determine cause of 8 occurrences of inertial coupling data unit failure indications.	Perform resistance, power and coolant-on, and bench tests.	See sec. 14.1.4.
113017	Investigate cause for secondary yaw actuator servo assembly oscillations.	Perform analysis, inspection, and electrical checks.	See sec. 14.1.10.
113007	Investigate cause of uneven drive rates of scanning telescope shaft axis	Perform analysis, inspection, and operational checks.	See sec. 14.1.14.
Electrical, Batteries, and Cryogenics			
113021	Determine cause of erratic digital event timer behavior.	Conduct spacecraft test, disassemble, and inspect.	Paint particle caused intermittent contact.
113019	Investigate cause for high battery manifold pressure.	Pressure check manifold, and conduct mission profile on batteries and charger.	Manifold was tight and batteries functioned normally.
113023	Investigate cause for hydrogen tank 3 heat leak to be excessive.	Conduct analysis and review records.	See sec. 14.1.5.
Communications			
113024	Investigate loss of spacecraft up-link command capability.	Integrity verification, and perform system and bench testing.	See sec. 14.1.6.
113042	Determine why the high-gain antenna would not acquire.	Perform analysis, systems verification, and bench testing.	See sec. 14.1.16
Crew Equipment			
113006	Investigate gas/water separator leakage.	Perform inspection and analysis.	See sec. 14.3.3
113020	Determine cause of monitor loss on color television.	Perform thermal and vibration testing.	See sec. 14.3.1
113032	Investigate cause for poor fit of Lunar Module Pilot's pressure garment assembly.	Perform analysis.	Fit was satisfactory after garment was pressurized.
113045	Investigate weak signal from Lunar Module Pilot's headset.	Perform analysis and component testing.	Microphone boom tips were loose.
Propulsion			
113508	Determine leakage and contamination in support of lunar module problem.	Disassemble regulators, inspect for damage and contamination.	Regulators were normal. See sec. 14.1.21
113511	Determine cause for forward heat shield thruster leakage.	Perform visual examination.	Apparent leakage was normal.

TABLE C-I.- POSTFLIGHT TESTING SUMMARY (Concluded)

ASHUR no.	Purpose	Tests performed	Results
Structures			
113509	Determine why mass spectrometer and gamma ray booms failed to retract.	Examine flight data and perform analysis.	See sec. 14.1.8 and 14.1.9.
113510	Determine source of fibers found in command module.	Examine and analyze fibers.	Source and quantity of fibers were normal.
113034	Determine why Y-Y strut was difficult to extend.	Inspect strut clearances and evaluate ease of operation.	Improper adjustment of set screw deformed strut barrel.
Environmental Control			
113014	Investigate water/glycol mixing valve fluctuations.	Perform operational tests and analysis to isolate cause.	See sec. 14.1.1.
113011	Determine cause of chlorine injector leakage.	Inspect and perform pressure and leak tests on returned ampules.	Sixty percent had loose base plates excessive bonding, and one leaked.
113015	Determine why lithium hydroxide canister was difficult to remove.	Inspect and perform analysis.	Canister swells due to water accumulation during solo operation.
113010	Determine cause of cabin fan moaning.	Inspect and activate cabin fans.	No damage. See sec. 14.1.11.
113012	Investigate apparent vacuum cleaner failure.	Inspect, operate, and analyze.	Excessive dust deposits caused impeller jamming on restart.
113013	Determine why suit loop pressure was not higher than expected.	Perform recalibration, disassembly, and analysis of suit pressure transducer.	Three pieces of lunar soil got inside the sense cavity and affected the variable reluctance element.
113512	Locate source of water/glycol spill found on cabin floor.	Inspect and perform pressure and leak tests.	Suit heat exchanger bypass valve stem seal leaked.

APPENDIX D - DATA AVAILABILITY

Tables D-I and D-II are summaries of the data made available for systems performance analyses and anomaly investigations. Table D-I lists the data for the command and service module, and table D-II, the lunar module. The following table contains the times that experimental data were made available to the principal investigator for scientific analyses.

Time, hr:min		Time, hr:min	
From	To	From	To
70:00	93:30	169:03	172:16
105:00	113:35	174:15	175:16
113:54	115:32	176:57	194:02
115:50	150:34	195:13	218:38
152:32	168:23	219:35	261:10

For additional information regarding data availability, the status listing of all mission data in the Central Metric Data File, building 12, should be consulted.

TABLE D-I.- COMMAND AND SERVICE MODULE DATA AVAILABILITY

Time, hr:min		Data Source (a)	Bandpass plots or tabs	Bilevels	Computer word tabs	Oscillo-graph records	Brush records	Special plots or tabs	Special programs
From	To								
-04:00	00:30	ALDS	X	X					
00:00	00:08	MIL	X	X	X	X	X	X	
00:04	00:14	BDA	X	X	X	X			
00:04	03:30	STDN	X	X	X				
01:48	01:56	GDS	X			X	X		
02:30	02:40	GDS	X	X	X	X	X	X	
02:50	05:50	GDS	X	X	X	X			
08:30	11:30	STDN	X	X	X				
12:00	13:00	GDS	X	X					
23:00	24:00	MAD	X	X					
27:00	80:00	STDN	X						
29:39	31:38	GDS	X	X	X	X			
37:00	39:00	STDN	X	X	X				
37:30	38:31	GDS	X	X	X	X			X
41:30	42:58	MAD		X			X	X	
42:00	43:00	STDN	X	X	X				
42:56	46:58	MAD		X			X	X	
58:04	59:00	GDS	X	X					
60:00	70:00	STDN	X						
69:38	73:05	STDN	X	X	X				
69:50	70:00	MAD	X	X		X			
73:05	76:15	STDN	X	X	X				
73:18	74:19	MAD	X	X	X	X		X	
74:22	74:36	GDS	X	X	X	X	X	X	
75:47	76:18	GDS	X	X					
76:00	81:00	STDN	X	X	X				
76:17	77:01	GDS	X	X	X				
78:00	79:11	GDS	X	X	X	X	X	X	
80:03	80:07	GDS	X						
80:16	84:52	STDN	X	X	X				
80:19	81:02	GDS	X	X	X				
81:03	82:12	GDS		X					
82:29	83:08	GDS	X	X	X				
82:44	85:03	GDS		X					
84:00	89:00	STDN	X	X	X				
84:24	85:03	GDS		X	X				
85:08	85:56	GDS	X	X					
86:17	86:56	GDS			X				
86:18	89:38	HSK		X					
89:27	92:46	STDN	X	X	X				
90:06	90:45	MAD		X	X				
90:40	91:40	MAD		X					
91:35	92:26	MAD	X	X					
92:28	93:30	MAD	X	X	X				
92:46	96:43	STDN	X	X	X				
94:25	96:11	MAD		X					
96:11	96:16	MAD	X	X	X	X		X	X
96:15	97:00	MAD		X	X				
97:31	97:41	MAD	X	X	X				X
98:11	100:54	STDN	X	X	X	X			X
98:30	101:13	GDS	X	X	X				
100:38	104:58	STDN	X	X	X				
101:57	102:47	GDS		X					X
103:14	103:27	GDS	X	X	X	X		X	
103:19	108:53	STDN	X	X	X				
105:13	106:28	GDS	X	X	X				
107:05	108:50	GDS			X				
108:53	112:46	STDN	X	X	X				
110:45	111:38	HSK			X				
111:58	115:32	HSK			X				
112:46	116:51	STDN	X	X	X				
116:07	119:43	MAD			X				
116:51	120:48	STDN	X	X	X				
120:06	121:35	MAD			X				
120:48	124:49	STDN	X	X	X				

TABLE D-I.- COMMAND AND SERVICE MODULE DATA AVAILABILITY (Continued)

Time, hr:min		Data Source (a)	Bandpass plots or tabs	Bilevels	Computer word tabs	Oscillo-graph records	Brush records	Special plots or tabs	Special programs
From	To								
122:54	126:35	GDS			X				
124:49	128:46	STDN	X	X	X				
127:00	127:38	GDS	X	X	X				
127:08	132:40	STDN	X	X	X				
127:35	129:36	GDS			X				
130:45	131:40	GDS			X				
132:40	136:22	STDN	X	X	X				
132:51	134:15	GDS			X				
134:59	140:07	HSK			X				
135:06	144:21	STDN	X	X	X				
140:44	144:35	MAD			X				
144:21	148:21	STDN	X	X	X				
144:34	148:38	MAD			X				
148:30	149:20	GDS		X	X				
148:32	152:29	STDN	X	X	X				
150:33	152:53	GDS		X	X				
153:16	156:20	STDN	X	X	X				
153:30	156:28	GDS			X				
156:20	160:11	STDN	X	X	X				
156:41	159:25	GDS			X				
160:11	164:10	STDN	X	X	X				
160:16	164:11	HSK			X				
164:10	169:03	STDN	X	X	X				
164:20	165:08	MAD	X	X	X		X		
165:08	166:12	HSK	X	X	X				
166:14	168:23	MAD			X				
168:17	172:15	STDN	X	X	X			X	
168:58	169:07	MAD	X	X	X	X			
169:22	172:16	MAD			X				
173:02	176:12	STDN	X	X	X				
173:49	174:12	GDS			X				
176:32	181:03	STDN	X	X	X				
176:57	177:49	GDS	X	X	X	X			
177:48	178:51	GDS	X		X				
179:05	179:11	GDS	X		X				
179:09	180:05	GDS		X	X				
180:03	180:40	GDS	X	X	X				
181:20	184:59	STDN	X	X	X				
182:01	182:49	GDS			X				
183:59	184:46	HSK			X				
184:08	188:50	STDN	X	X	X				
185:05	186:46	HSK			X				
187:05	189:01	HSK			X				
188:35	192:48	STDN	X	X	X				
189:57	190:43	MAD		X	X				
190:51	193:33	MAD		X	X				
191:59	192:35	MAD		X	X				
192:48	193:33	MAD			X				
192:48	196:47	STDN	X	X	X				
193:22	193:49	MAD	X		X				
193:32	194:02	MAD		X	X				
195:22	196:06	MAD	X	X	X	X			
196:42	197:58	MAD		X	X				
197:05	200:52	STDN	X	X	X				
200:13	200:26	GDS	X	X	X	X		X	
200:13	204:57	STDN	X	X	X				
200:29	201:28	GDS	X	X	X	X			
201:27	202:27	GDS			X	X			
205:14	209:03	STDN	X	X	X				
206:30	209:24	HSK		X			X	X	
209:03	212:15	STDN	X	X	X				
209:24	214:16	HSK		X			X	X	
212:15	214:28	STDN	X	X	X				
214:14	215:08	HSK	X	X	X	X			

TABLE D-I.- COMMAND AND SERVICE MODULE DATA AVAILABILITY (Concluded)

Time, hr:min		Data Source (a)	Bandpass plots or tabs	Bilevels	Computer word tabs	Oscillo-graph records	Brush records	Special plots or tabs	Special programs
From	To								
218:10	220:10	STDN	X	X	X				
220:36	222:38	MAD			X				
221:50	224:32	STDN	X	X	X				
222:34	226:30	GDS			X				
225:45	229:48	STDN	X	X	X				
226:28	227:29	GDS			X				
227:30	227:35	GDS	X						
235:13	235:15	HSK						X	
239:06	241:08	MAD	X	X	X	X			
242:06	243:08	MAD			X				
242:14	245:54	STDN	X	X	X				
243:06	246:08	MAD			X				
248:31	256:07	GDS			X				
248:40	251:25	STDN	X	X	X				
256:18	260:12	HSK			X				
259:27	265:49	STDN	X	X	X				
260:10	265:30	HSK	X	X	X	X		X	
265:22	265:52	DSE	X	X	X	X	X		X

TABLE D-II.- LUNAR MODULE DATA AVAILABILITY

Time, hr:min		Data Source (a)	Bandpass plots or tabs	Bilevels	Computer word tabs	Oscillo-graph records	Brush records	Special plots or tabs	Special programs
From	To								
-04:00	00:00	ALDS	X	X					
34:02	34:07	GDS	X	X					
53:30	53:45	STDN	X	X					
93:17	96:43	STDN	X	X	X				
94:20	95:13	MAD	X	X	X			X	X
95:12	95:29	MAD	X	X					X
96:16	96:58	MAD	X	X	X	X		X	X
96:43	100:37	STDN	X	X	X				
96:44	96:54	MAD		X		X			
96:57	99:15	MAD	X	X	X				X
99:08	101:02	MAD	X	X		X			
100:05	104:30	GDS			X				X
100:38	104:58	STDN	X	X	X				
101:02	103:06	GDS	X	X					
103:19	108:53	STDN	X	X	X				
103:50	104:31	GDS	X	X	X	X	X	X	
104:28	105:27	GDS	X	X	X	X			
108:53	116:51	STDN	X	X	X				
116:08	118:07	MAD	X	X				X	
116:51	120:48	STDN	X	X					
124:49	152:29	STDN	X	X					
152:32	155:30	GDS	X	X					
153:16	169:03	STDN	X	X					
165:00	166:24	MAD	X					X	
165:43	165:52	HSK	X	X				X	
166:22	168:00	MAD	X					X	
168:17	172:15	STDN	X	X	X				
171:07	172:23	MAD	X	X				X	
173:02	176:12	STDN	X	X	X				
174:00	176:14	GDS	X	X	X	X	X	X	
176:32	181:03	STDN	X	X	X				
176:57	177:49	GDS	X	X	X	X	X	X	
192:48	196:47	STDN	X	X					
194:43	195:15	MAD	X	X	X	X		X	
195:00	195:58	MAD		X		X	X		
210:32	210:55	HSK	X	X			X		

<sup>a</sup>Data sources:

STDN - Spacecraft Tracking and Data Network

STDN station call letters and location:

BDA - Bermuda Islands  
GDS - Goldstone (California)  
HSK - Honeysuckle (Canberra, Australia)  
MAD - Madrid (Spain)  
MIL - Merrit Island (Florida) - launch area

## Other:

ALDS - Apollo launch data system (Kennedy Space Center, Florida)  
DSE - Spacecraft data storage equipment

APPENDIX E - MISSION REPORT SUPPLEMENTS

Table E-I contains a listing of all reports that supplement the Apollo 7 through Apollo 16 mission reports. The table indicates the present status of each report not yet completed and the publication date of those which have been published.



TABLE E-I.- MISSION REPORT SUPPLEMENTS

Supplement number	Title	Publication date/status
Apollo 7		
1	Trajectory Reconstruction and Analysis	May 1969
2	Communication System Performance	June 1969
3	Guidance, Navigation, and Control System Performance Analysis	November 1969
4	Reaction Control System Performance	August 1969
5	Cancelled	
6	Entry Postflight Analysis	December 1969
Apollo 8		
1	Trajectory Reconstruction and Analysis	December 1969
2	Guidance, Navigation, and Control System Performance and Analysis	November 1969
3	Performance of Command and Service Module Reaction Control System	March 1970
4	Service Propulsion System Final Flight Evaluation	September 1970
5	Cancelled	
6	Analysis of Apollo 8 Photography and Visual Observations	December 1969
7	Entry Postflight Analysis	December 1969
Apollo 9		
1	Trajectory Reconstruction and Analysis	November 1969
2	Command and Service Module Guidance, Navigation, and Control System Performance	November 1969
3	Lunar Module Abort Guidance System Performance Analysis	November 1969
4	Performance of Command and Service Module Reaction Control System	April 1970
5	Service Propulsion System Final Flight Evaluation	December 1969
6	Performance of Lunar Module Reaction Control System	August 1970
7	Ascent Propulsion System Final Flight Evaluation	December 1970
8	Descent Propulsion System Final Flight Evaluation	December 1970
9	Cancelled	

TABLE E-I.- MISSION REPORT SUPPLEMENTS (Continued)

Supplement number	Title	Publication date/status
10	Stroking Test Analysis	December 1969
11	Communications System Performance	December 1969
12	Entry Postflight Analysis	December 1969
Apollo 10		
1	Trajectory Reconstruction and Analysis	March 1970
2	Guidance, Navigation, and Control System Performance Analysis	December 1969
3	Performance of Command and Service Module Reaction Control System	August 1970
4	Service Propulsion System Final Flight Evaluation	September 1970
5	Performance of Lunar Module Reaction Control System	August 1970
6	Ascent Propulsion System Final Flight Evaluation	January 1970
7	Descent Propulsion System Final Flight Evaluation	January 1970
8	Cancelled	
9	Analysis of Apollo 10 Photography and Visual Observations	August 1971
10	Entry Postflight Analysis	December 1969
11	Communications System Performance	
Apollo 11		
1	Trajectory Reconstruction and Analysis	May 1970
2	Guidance, Navigation, and Control System Performance Analysis	September 1970
3	Performance of Command and Service Module Reaction Control System	December 1971
4	Service Propulsion System Final Flight Evaluation	October 1970
5	Performance of Lunar Module Reaction Control System	December 1971
6	Ascent Propulsion System Final Flight Evaluation	September 1970
7	Descent Propulsion System Final Flight Evaluation	September 1970
8	Cancelled	
9	Apollo 11 Preliminary Science Report	December 1969

TABLE E-I.- MISSION REPORT SUPPLEMENTS (Continued)

Supplement number	Title	Publication date/status
10	Communications System Performance	January 1970
11	Entry Postflight Analysis	April 1970
Apollo 12		
1	Trajectory Reconstruction and Analysis	September 1970
2	Guidance, Navigation, and Control System Performance Analysis	September 1970
3	Service Propulsion System Final Flight Evaluation	December 1971
4	Ascent Propulsion System Final Flight Evaluation	Publication
5	Descent Propulsion System Final Flight Evaluation	Publication
6	Apollo 12 Preliminary Science Report	July 1970
7	Landing site Selection Processes	Final Review
Apollo 13		
1	Guidance, Navigation, and Control System Performance Analysis	September 1970
2	Descent Propulsion System Final Flight Evaluation	October 1970
3	Entry Postflight Analysis	Cancelled
Apollo 14		
1	Guidance, Navigation, and Control System Performance Analysis	January 1972
2	Cryogenic Storage System Performance Analysis	March 1972
3	Service Propulsion System Final Flight Evaluation	May 1972
4	Ascent Propulsion System Final Flight Evaluation	May 1972
5	Descent Propulsion System Final Flight Evaluation	Publication
6	Apollo 14 Preliminary Science Report	June 1971
7	Analysis of Inflight Demonstrations	January 1972
8	Atmospheric Electricity Experiments on Apollo 13 and 14 Launches	January 1972

TABLE E-I.- MISSION REPORT SUPPLEMENTS (Concluded)

Supplement number	Title	Publication date/status
Apollo 15		
1	Guidance, Navigation and Control System Performance Analysis	Preparation
2	Service Propulsion System Final Flight Evaluation	Preparation
3	Ascent Propulsion System Final Flight Evaluation	Preparation
4	Descent Propulsion System Final Flight Evaluation	Preparation
5	Apollo 15 Preliminary Science Report	April 1972
6	Postflight Analysis of the Extravehicular Communications System - Lunar Module Communications Link	January 1972
7	Analysis of Command Module Color Television Camera	Preparation
Apollo 16		
1	Guidance, Navigation and Control System Performance Analysis	Preparation
2	Service Propulsion System Final Flight Evaluation	Preparation
3	Ascent Propulsion System Final Flight Evaluation	Preparation
4	Descent Propulsion System Final Flight Evaluation	Preparation
5	Apollo 16 Preliminary Science Report	Preparation
6	Microbial Response and Space Environment Experiment (S-191)	Preparation
7	Analysis of Fluid Electrophoresis Demonstration	Preparation

APPENDIX F - GLOSSARY

Albedo	Relative brightness, defined as the ratio of radiation reflected from a surface to the total amount incident upon it.
Afterglow	The glow that persists after the source of excitation is no longer present.
Anisotropic	Having different optical or other physical properties along axes in different directions.
Auroral belts	Approximately circular bands around the earth's geomagnetic poles resulting from interaction of high-energy electrons and protons of solar origin with the upper atmospheric gases. The bands are located about $10^{\circ}$ to $15^{\circ}$ from the poles and broaden toward the equator during periods of intense activity.
Bilirubin	A red bile pigment that causes variations in the color of the bile.
Breccia	A rock consisting of sharp fragments embedded in a fine-grained matrix.
Bungee	Elasticized cord used as a fastener.
Cirrus	Clouds formed in the highest cloud region and composed of ice crystals. They are usually thin and wispy in appearance.
Clast	A discrete fragment of rock or mineral included in a larger rock.
Double umbra	When the umbra of a satellite is within the umbra of a planetary body around which it is orbiting.
Earthshine	Illumination of the moon's surface by sunlight reflected from the earth's surface and atmosphere.
Ecliptic	The plane defined by the earth's orbit about the sun.
Endogenetic	Having to do with rocks formed by solidification from fusion, precipitation from solution, or sublimation.
Ephemeris	A table of the computed positions of celestial bodies at regular intervals.

## APPENDIX F - GLOSSARY - Continued

Fecal	Pertaining to body waste discharged through the anus.
Friable	Easily crumbled, pulverized, or reduced to powder.
Geocorona	The envelope of atomic hydrogen surrounding the earth.
Germicide	An agent that destroys pathogenic micro-organisms.
Hummocky	Descriptive of an area having many low, rounded hills or knolls.
Limb	The outer edge of the apparent disc of a celestial body, or a portion of the edge.
Magnetic equator	The line on the surface of the earth that connects all points at which the magnetic inclination is zero.
Maria	Large, dark, flat areas of the lunar surface.
Pathogenic microflora	Disease producing organisms.
Polarimetric	Relating to the measurement of the amount of polarization of light in a partially polarized ray.
Radial sample	Material taken from a crater's ejecta field at the crater's rim, at a distance equal to the crater's radius, and at a distance equal to the crater's diameter.
Ray	Bright material extending radially outward from a crater and composed of ejecta from the formation of the crater.
Regolith	The surface layer of unsorted fragmented material on the earth or moon that overlies solid material.
Reseau plate	A glass plate containing a grid of fine lines of a standard size that is photographed with an object or scene to aid in measurement.
Reticle	A pattern of very fine lines in the focus of the eyepiece of an optical instrument.
Seconal	A proprietary medicine used to induce sleep.

## APPENDIX F - GLOSSARY - Concluded

Selenodetic	Relating to the branch of applied mathematics that determines by observation and measurement the positions of points on the moon's surface and the size and shape of the moon.
Sinkhole	A hollow or hole worn through a rock.
Solar corona	The outer visible envelope of the sun.
Stereobase	A type of photography in which photographs taken of the same area from different angles are combined to produce visible features in three-dimensional relief.
Stratigraphy	That branch of geology that deals with the origin, composition, distribution and succession of strata.
Substellar point	A point at which a star is vertically overhead.
Terra	Large areas of the lunar surface that are lighter in color than the adjacent maria.
Umbra	The conically-shaped shadow projecting from a planet or satellite on the side opposite the sun.
Unipole	The pole fastened to the side hatch of the command module and upon which devices such as cameras are mounted during transearth extravehicular operations.
Vignetting	Pertaining to the progressive reduction in the intensity of illumination falling on a photographic film toward the edges of the picture due to the obstruction of oblique light beams.
Zap pits	Small glass-lined depressions in rocks caused by impacts from particles travelling at extremely high speeds.
Zero phase	An orientation in which an area or object viewed is coplanar with the sun and observer, resulting in poor definition of features.

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8. Manned Spacecraft Center: Final Report of the Apollo 16 Deactivation Investigation Board. Rupture of S14-138 RCS Oxidizer Deactivation Unit, May 7, 1972, at North Island Naval Air Station. Unnumbered document. June 2, 1972.
9. Manned Spacecraft Center: Apollo 11 Mission Report. MSC-00171. November 1969.
10. Manned Spacecraft Center: Apollo 12 Mission Report. MSC-01855. March 1970.
11. Manned Spacecraft Center: Apollo 13 Mission Report. MSC-02680. September 1970.
12. Manned Spacecraft Center: Apollo 14 Mission Report. MSC-04112. May 1971.



APOLLO SPACECRAFT FLIGHT HISTORY  
(Continued from inside front cover)

<u>Mission</u>	<u>Mission report number</u>	<u>Spacecraft</u>	<u>Description</u>	<u>Launch date</u>	<u>Launch site</u>
Apollo 4	MSC-PA-R-68-1	SC-017 LTA-10R	Supercircular entry at lunar return velocity	Nov. 9, 1967	Kennedy Space Center, Fla.
Apollo 5	MSC-PA-R-68-7	LM-1	First lunar module flight	Jan. 22, 1968	Cape Kennedy, Fla.
Apollo 6	MSC-PA-R-68-9	SC-020 LTA-2R	Verification of closed-loop emergency detection system	April 4, 1968	Kennedy Space Center, Fla.
Apollo 7	MSC-PA-R-68-15	CSM 101	First manned flight; earth-orbital	Oct. 11, 1968	Cape Kennedy, Fla.
Apollo 8	MSC-PA-R-69-1	CSM 103	First manned lunar orbital flight; first manned Saturn V launch	Dec. 21, 1968	Kennedy Space Center, Fla.
Apollo 9	MSC-PA-R-69-2	CSM 104 LM-3	First manned lunar module flight; earth orbit rendezvous; extra-vehicular activity	March 3, 1969	Kennedy Space Center, Fla.
Apollo 10	MSC-00126	CSM 106 LM-4	First lunar orbit rendezvous; low pass over lunar surface	May 18, 1969	Kennedy Space Center, Fla.
Apollo 11	MSC-00171	CSM 107 LM-5	First lunar landing	July 16, 1969	Kennedy Space Center, Fla.
Apollo 12	MSC-01855	CSM 108 LM-6	Second lunar landing	Nov. 14, 1969	Kennedy Space Center, Fla.
Apollo 13	MSC-02680	CSM 109 LM-7	Aborted during trans-lunar flight because of cryogenic oxygen loss	April 11, 1970	Kennedy Space Center, Fla.
Apollo 14	MSC-04112	CSM 110 LM-8	Third lunar landing	Jan. 31, 1971	Kennedy Space Center, Fla.
Apollo 15	MSC-05161	CSM 112 LM-10	Fourth lunar landing and first extended science capability mission	July 26, 1971	Kennedy Space Center, Fla.
Apollo 16	MSC-07230	CSM-113	Fifth lunar landing and second extended science capability mission	April 16, 1972	Kennedy Space Center, Fla.