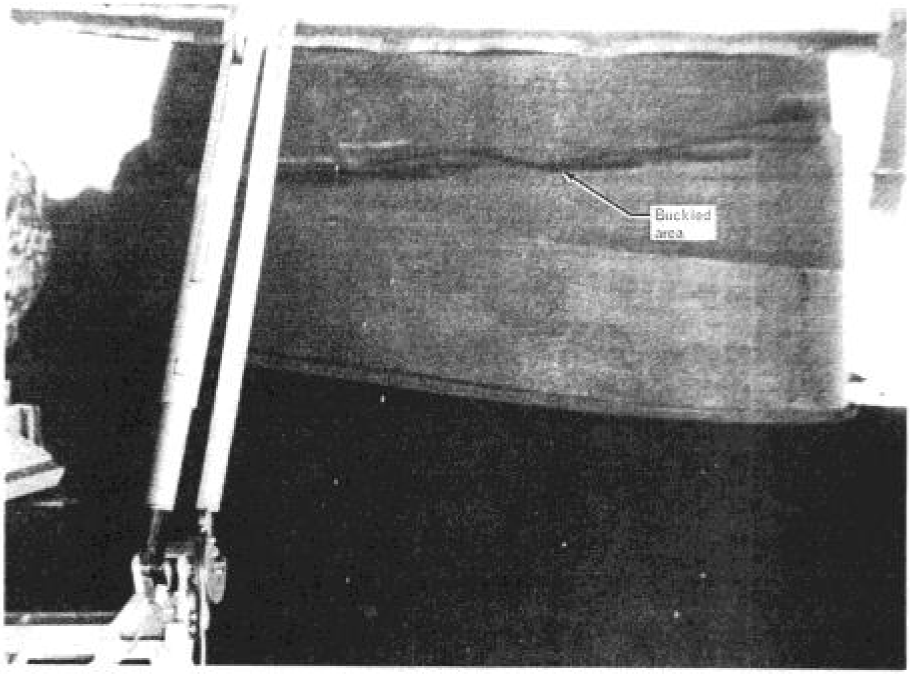


Figure 7-1.- Buckling of descent engine skirt.

The crew reported that there was a gap between the exit plane of the skirt and the lunar surface, indicating that buckling was probably caused by a buildup of pressure inside the nozzle due to proximity to the lunar surface, and not due entirely to contact of the nozzle skirt with the lunar surface. The crew also reported that the buckling seemed to be uniform around the skirt periphery and that the exit plane height above the surface was uniform.

The vehicle contact velocity and attitude data at touchdown show that the landing was very stable in spite of the relatively high lunar surface slope at the landing point. The plus-Z and plus-Y footpads contacted the lunar surface nearly simultaneously, providing a nose-up pitch rate of 17 deg/sec and a roll rate to the left of 15 deg/sec. Final spacecraft settling occurred 1.8 seconds later. The vehicle at-rest attitude, as determined from the gimbal angles, was 6.9 degrees pitch up and 8.6 degrees roll to the left, resulting in a vehicle tilt angle on the lunar surface of approximately 11 degrees from the horizontal (**Fig. 7-2**).

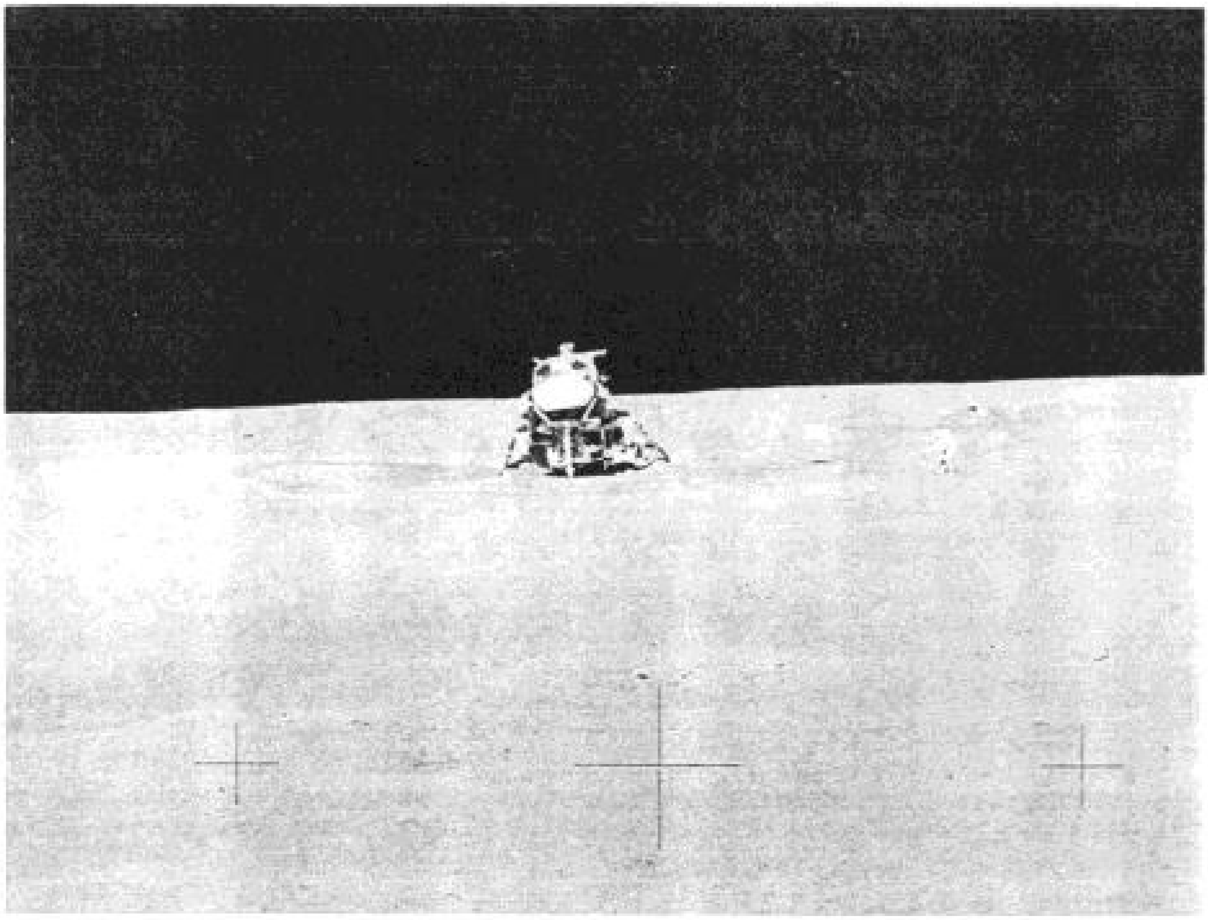


Figure 7-2.- Attitude of lunar module on lunar surface.

The performance of the electrical power distribution system and batteries was satisfactory. Descent battery management was performed as planned, all power svitchovers were accomplished as required, and parallel operation of the descent and ascent batteries was within acceptable limits. The d-c bus voltage was maintained above 28.9 volts, and the maximum observed current was 74 amperes, during powered descent. Electrical power used during the mission is given in section 7.9.6.

7.2 COMMUNICATIONS

The steerable antenna exhibited random oscillation characteristics identical to those experienced on previous missions, and resulted in three instances of temporary loss of voice and data. Also at random times, small oscillations were noted and were damped out. The problems with the antenna are discussed in section 14.2.4.

The lunar module did not receive VHF transmissions from the command module during the descent phase of the mission. The checklist erroneously configured the command module to transmit on 296.8 MHz and the lunar module to receive on 259.7 MHz.

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

7.3 RADAR

The landing radar acquisition of slant range and velocity was normal. The acquired slant range of 42,000 feet increased to about 50,000 feet in approximately 10 seconds. The indication of range increase may have been caused by blockage from a lunar mountain at initial acquisition. Velocity was acquired at an altitude of approximately 39 000 feet above the local terrain. Landing radar outputs were affected at an altitude of about 30 feet by moving dust and debris.

Rendezvous radar tracking operation during the rendezvous sequence was nominal. A lunar module guidance computer program was used after lunar orbit insertion to point the rendezvous radar antenna at the command and service module, thus enabling acquisition at approximately 109 miles. Two problems were noted during the mission and are as follows:

During the VHF ranging system/rendezvous radar comparison test after undocking and separation, a range difference of 2400 feet existed between the rendezvous radar and VHF ranging systems. This difference represents high-frequency ranging-tone cycle slippage in the rendezvous radar, probably caused by excessive phase shift. Range errors associated with cycle slippage, due to insufficient heater operation, have occurred during system checkout and have produced phase shifts. Downlink data at the time of the problem indicates that the rendezvous radar transponder heater was not in operation when the rendezvous radar checkout was first attempted; therefore, it is assumed that the phase shift was caused by low temperatures.

b. Acquisition with the rendezvous radar during ascent was unsuccessful. The radar antenna was pre-positioned prior to lunar lift-off to an approximate lunar-module guidance-computer designated position for acquisition following insertion. In this position, acquisition would have been accomplished when the command module came into the rendezvous radar antenna field of view. A review of lift-off television data revealed rendezvous radar antenna movement during the first 2 seconds of flight. Analysis has also shown that expansion of the ascent engine plume, after being deflected from the descent stage structure, exerts sufficient pressure on the antenna to overcome gimbal friction and move the antenna. Radar acquisition apparently was not accomplished because the radar antenna moved. Rendezvous radar tracking during ascent is not required.

7.4 CONTROLS AND DISPLAYS

The controls and displays performed normally. The range/range-rate tape meter glass was broken with about 20 percent of the glass missing; however, the meter operated satisfactory during the flight. Section 14.2.8 contains a discussion of this anomaly.

7.5 GUIDANCE, NAVIGATION, AND CONTROL

Guidance, navigation, and control system performance was satisfactory throughout the mission except for two anomalies. There was a simultaneous indication of an abort guidance system warning light and master alarm on two occasions (sec. 14.2.6), and no line-of-sight rate information was displayed on the Commander's crosspointers during the rendezvous braking phase (sec. 14.2-7). Neither anomaly affected overall systems performance.

The primary guidance system was activated at 98 hours 26 minutes, the computer timing was synchronized to the command module computer, and the lunar module platform was aligned to the command module platform. The crew had difficulty seeing stars in the alignment optical telescope while performing the docked realignment of the lunar module platform, but this is normal because of reflected light from the command-module structure. **Table 7-1** is a summary of all platform realignments of the primary guidance system, both in orbit and on the lunar surface. The calculated gyro drift rates compare well with the 1 sigma value of 2 meru and indicate good gyro performance. Accelerometer performance was equally good although shifts in the X- and Y-accelerometer bias of 0.39 and 0.46 cm/sec2, respectively, were detected while on the lunar surface. The shift resulted from removing and reapplying power to the inertial measurement unit and is not unusual. **Table 7-II** is a summary of preflight inertial component calibration data.

TABLE 7-I.- LUNAR MODULE PLATFORM ALIGNMENT SUMMARY

Time hr:min	Type alignment	Alignment mode						Star angle difference, deg	Gyro torquing angle, deg			Gyro drift, meru		
		Option[1]	Technique[2]	Detent[3]	Star	Detent[3]	Star		X	Y	Z	X	Y	Z
98:57	Docked	--	--	--	--	--	--	--	--	--	--	--	--	--
99:12	52	3	--	3	42 Peacock	1	37 Nunki	0.00	+0.171	-0.236	-0.663	--	--	--
101:16	52	3	--	2	41 Dabih	2	01 Alpheratt	0.01	-0.002	+0.076	-0.066	0.1	-2.4	-1.4
103:00	52	3	--	2	41 Dabih	2	01 Alpheratt	0.01	-0.010	+0.023	-0.34	0.4	-0.9	-1.3
105:07	57	3	1	--	--	--	--	0.03	-0.011	-0.041	-0.002	--	--	--
105:23	57	3	2	3	03 Navi	6	12 Rigel	0.01	-0.075	+0.058	-0.060	2.1	-1.6	-1.7
105:47	57	3	2	6	00 Planet	3	00 Planet	0.00	-0.008	-0.021	-0.033	--	--	--
169:38	57	4	3	3	05 Polaris	--	--	--	-0.083	-0.006	+0.028	--	--	--
170:59	57	4	3	3	05 Polaris	--	--	0.03	+0.021	+0.012	-0.057	-1.0	-0.6	-2.8

[1] 1 - Preferred; 2 - Nominal; 3 - REFSMMAT; 4 - Landing site.
[2] 0 - Stored attitude; 1 - REFSMMAT + g; 2 - Two body; 3 - One body + g.
[3] 1 - Left front; 2 - Front; 3 - Right front; 4 - Right rear; 5 - Rear; 6 - Left rear.

TABLE 7-II.- INERTIAL COMPONENT HISTORY - LUNAR MODULE

Parameter	Number of samples	Sample mean	Standard deviation	Countdown value	Flight load	Inflight performance		
						Power-up to surface	Surface power-up to lift-off	Lift-off to rendezvous
(a) Accelerometers								
X - Accelerometer								
Scale factor error (ppm)	5	-919	11.21		-980	--	--	--
Bias (cm/sec^2)	5	1.71	0.04		1.70	1.73	2.09*	2.04**
Y - Accelerometer								
Scale factor error (ppm)	5	-836	20.87		-990	--	--	--
Bias (cm/sec^2)	5	1.42	0.03		1.41	1.41	1.87*	1.78
Z - Accelerometer								
Scale factor error (ppm)	5	-1354	37.02		-1430	--	--	--
Bias (cm/sec^2)	5	1.42	0.00		1.42	1.31	1.29	1.26**
(b) Gyroscopes								
X - Gyro								
Null bias drift (meru)	5	3.30	0.18		3.2	+0.9	-1.0	--
ADSRA (meru/g)	5	-5.44	0.39		-6.0	--	--	--
ADIA (meru/g)	5	6.76	1.43		5.0	--	--	--
Y - Gyro								
Null bias drift (meru)	5	-1.94	1.21		-0.7	-1.6	-0.6	--
ADSRA (meru/g)	5	4.64	0.85		4.0	--	--	--
ADIA (meru/g)	10	-1.33	1.76		-2.0	--	--	--
Z - Gyro								
Null bias drift (meru)	5	0.96	0.43		1.4	-1.5	-2.8	--
ADSRA (meru/g)	5	-4.52	0.56		-4.0	--	--	--
ADIA (meru/g)	5	8.34	1.56		7.0	--	--	--

*X&Y flight load changed to 1.90 and 1.75
**X&Z flight load changed to 2.06 and 1.26

After a nominal separation from the command module, the abort guidance system was activated, initialized, and aligned to the primary guidance system. **Table 7-III** is a summary of preflight and inflight performance of the abort guidance system accelerometers and gyros.

TABLE 7-III.- ABORT GUIDANCE SYSTEM CALIBRATION HISTORY

(a) Accelerometers

Static bias, µg	Preflight performance				Inflight performance		
	Number of calibrations	Mean of calibrations	Standard deviation of calibrations	Flight load	System activation	Pre-descent	Post-ascent
X	12	-67	13.0	-48	-62	-95	+92
Y	12	+93	9.6	+107	+124	103	71
Z	12	-89	11.6	-84	-62	-100	-108

(b) Gyros

Gyro drift, deg/hr	Preflight performance				Inflight performance		
	Number of calibrations	Mean of calibrations	Standard deviation of calibrations	Flight load	System activation	Surface calibration no. 1	Surface calibration no. 2
X	12	-0.12	0.14	-0.02	-0.21	-0.14	-0.12
Y	12	-0.93	0.04	-0.90	-0.81	-0.81	-0.78
Z	12	+0.06	0.03	+0.07	+0.15	+0.06	+0.02

The powered descent to the lunar surface was initiated on time. **Table 7-IV** is a sequence of significant events during descent. A landing site update to move the targeted landing point 853 meters (2800 feet) downrange was made 95 seconds after ignition. The computer began accepting landing radar updates and began adjusting its estimate of altitude upward by 4800 feet. After enabling landing radar updates, the primary guidance altitude flattened out for approximately 70 seconds (**Fig. 7-3**). This resulted from the initial estimate of the slope stored in the computer being 1 degree; whereas, the true mare slope was zero. Convergence occurred rapidly once the lunar module was over the Apennine foothills where the computer-stored slope agreed more closely with the actual slope. Figure 7-3 is a time history of altitude from the primary and abort guidance systems. Data indicate that 18 separate deflections of the hand controller were made for landing point redesignations during the approach phase program. The total effect of the redesignations moved the landing site coordinates 338 meters (1110 feet) uprange and 409 meters (1341 feet) to the north. Touchdown disturbances were nominal despite the 11-degree slope upon which the landing occurred. **Figure 7-4** is a time history of spacecraft rates and attitudes at touchdown.

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

Elapsed time from lift-off, hr:min:sec	Time from ignition, min:sec	Event
104:25:13.0	-04:56.4	Landing radar on
104:30:02.0	-00:07.4	Ullage on
104:30:09.4	00:00.0	Ignition
104:30:35.9	00:26.5	Throttle to full throttle position
104:31:44.2	01:34.8	Manual target update (N69)
104:33:10.4	03:01.0	Yaw to face up
104:33:26.2	03:16.8	Landing radar range data good
104:33:38.2	03:28.8	Landing radar altitude data good
104:33:50.2	03:40.8	Enable landing radar updates (V57)
104:37:31.1	07:21.7	Throttle down
104:39:32.2	09:22.8	Approach phase program selected (P64)
104:39:39.0	09:29.6	Landing radar antenna to position 2
104:39:40.0	09:30.6	First landing point redesignation
104:40:13.0	10:03.6	Landing radar to low scale
104:41:08.7	10:59.3	Select attitude hold mode
104:41:10.2	11:00.8	Select landing phase program (P66)
104:42:28.6	12:18:2	Engine shutdown
104:42:29.3	12:19.9	Right side and forward foot pad contact
104:42:31.1	12:21.7	Final spacecraft settling

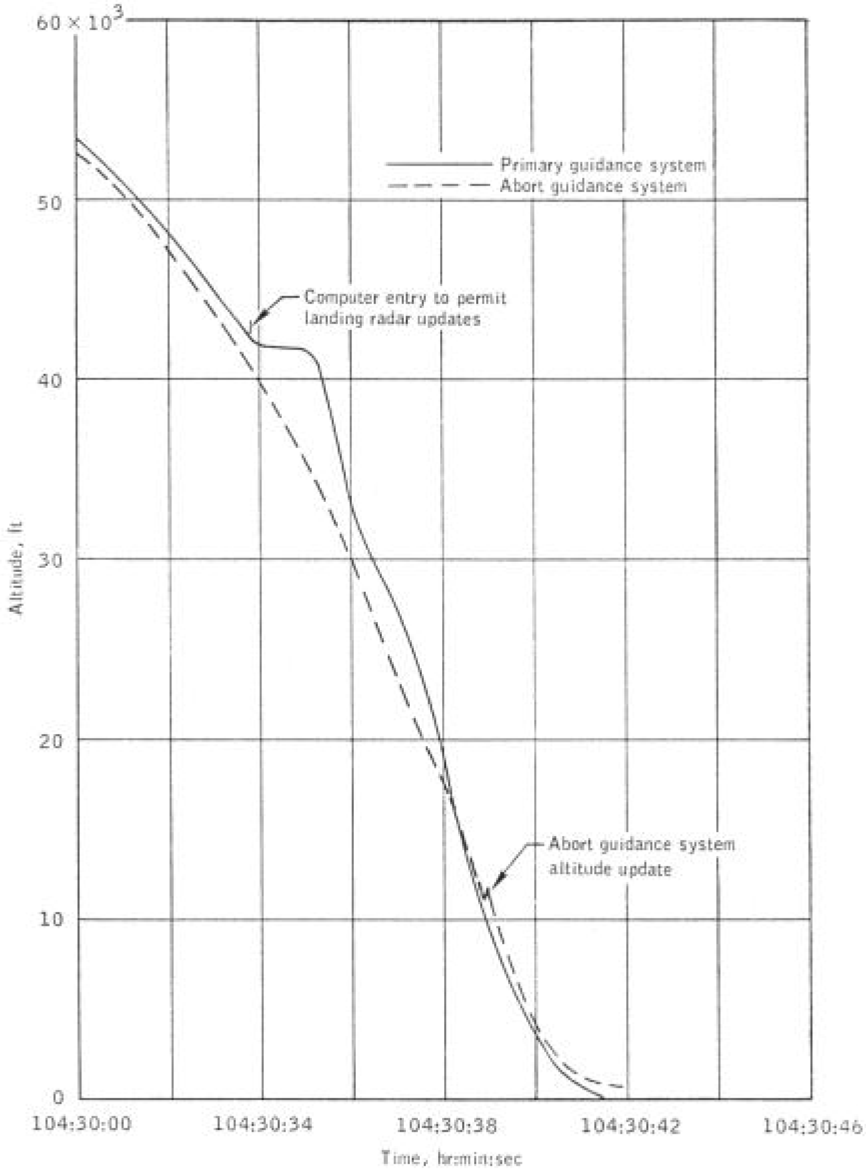


Figure 7-3.- Altitude comparison during lunar descent.

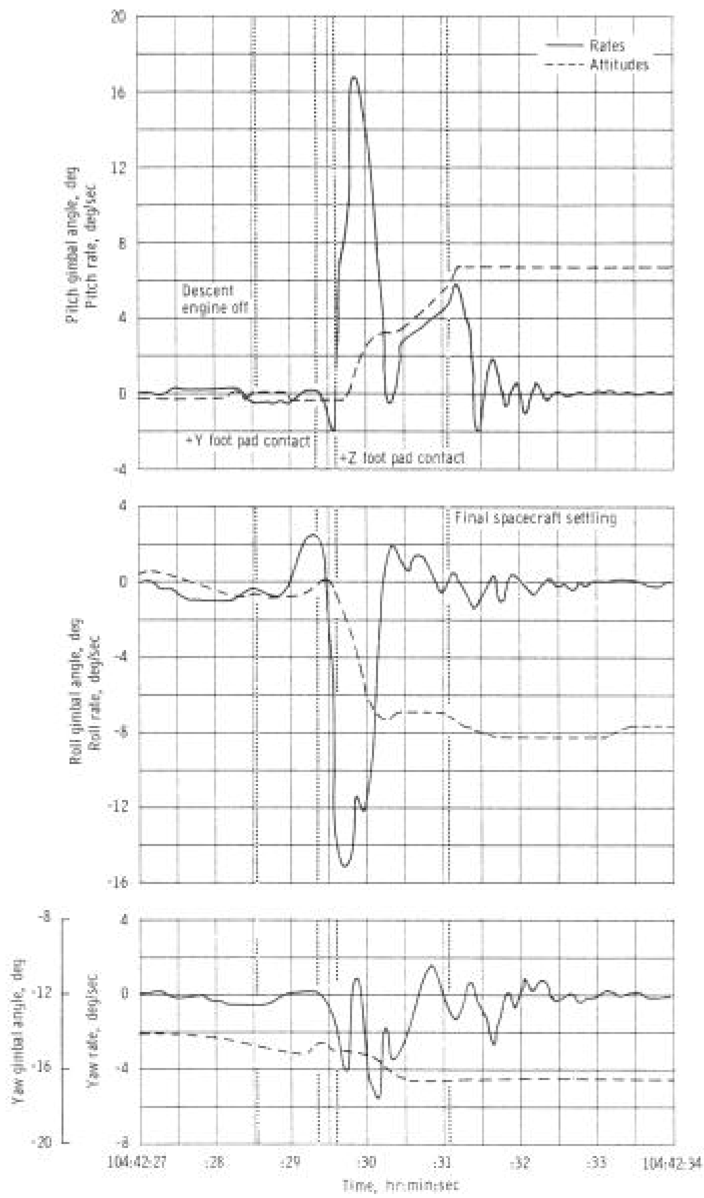


Figure 7-4.- Spacecraft dynamics during lunar touchdown.

Performance during ascent was nominal. For the first time, accelerometer biases were updated while on the lunar surface to correct for the small expected shifts experienced when the system was powered down. Since the lunar surface bias determination technique had not been totally proven, only half of the measured shift in the X accelerometer bias was corrected. As a result, some bias error existed during ascent and contributed about 2 ft/sec to the radial velocity error. Analysis is continuing to determine the cause of the remainder of the radial velocity error and possible causes will be discussed in a supplement to this report.

Because the primary guidance system radial velocity was greater than that from the powered flight processor and the abort guidance system, the velocity residuals at engine shutdown were trimmed using the abort guidance system solutions.

(Figure)

Source	Altitude, feet	Downrange velocity, ft/sec	Radial velocity, ft/sec
Primary guidance system	60 647	5531	32
Abort guidance system	59 417	5533	25
Power flight processor	58 645	5534	22

After trimming velocity residuals, an abort guidance system warning and master alarm occurred. They were reset by the crew and a computer self- test was performed successfully. System performance was nominal before, during, and after the warnings. See section 14.2.6 for further discussion of this anomaly. No vernier adjust maneuver was required, and the direct rendezvous was accomplished without incident. **Table 7-V** is a summary of rendezvous maneuver solutions.

TABLE 7-V.- RENDEZVOUS SOLUTIONS

Maneuver	Local vertical coordinates	Computed velocity change, ft/sec		
		Command module computer	Lunar module guidance computer	Abort guidance system
Terminal phase initiation	ΔV_x	-69.1	+70.3	+70.4
	ΔV_y	-6.1	+5.9	+5.9
	ΔV_z	+16.1	-17.7	-19.1
	Total	71.2	72.7	73.2
First midcourse correction	ΔV_x	+1.5	-1.1	-1.5
	ΔV_y	-0.2	0.0	0.0
	ΔV_z	+1.9	-1.1	-3.0
	Total	2.4	1.6	3.4
Second midcourse correction	ΔV_x	+2.8	-0.8	-1.4
	ΔV_y	-0.3	+0.6	+0.3
	ΔV_z	+6.2	-2.6	-4.1
	Total	6.8	2.8	4.3

The Commander reported that there were no line-of-sight rate data displayed on his crosspointers at a separation distance of 1500 feet. However, line-of-sight rates existed at this time because thrusting upward and to the left was required to null the -line-of-sight rates. Also, the Command Module Pilot verified the presence of line-of-sight rates. Section 14.2.7 contains a discussion of this anomaly.

After a successful docking, the lunar module was configured for the deorbit maneuver and jettisoned. The velocity changes observed at jettison in the X, Y, and Z axes were minus 1.24, minus 0.01, and minus 0.05 ft/sec, respectively. This is equivalent to a 206 lb-sec impulse. For comparison, the separation velocities observed at undocking prior to powered descent were minus 0.18, minus 0.02, and minus 0.04 ft/sec in the X, Y, and Z axes, respectively, or an impulse of 205 lb-see. The close agreement indicates the tunnel was completely vented and the impulse was due entirely to the separation springs. After jettison, the deorbit maneuver was accomplished and performance was nominal.

7.6 PROPULSION

7.6.1 Reaction Control System

The reaction control system performed satisfactorily throughout the mission with no anomalies. Skillful use of the system by the crew accounted for the propellant consumption being well below predicted levels. Section 7.9.3 contains a summary of the consumables usage during the mission.

7.6.2 Descent Propulsion System

Data analysis indicates that the descent propulsion system performed nominally during powered descent. The total firing time was 739.2 seconds . The propellant quantity gaging system indicated about 1055 Pounds of usable propellant remained at engine shutdown or about 103 seconds of hover time. The supercritical. helium system operated nominally. The skirt of the engine was buckled during landing (sec. 7.1). Section 7.9.1 contains a summary of the descent propulsion system consumables usage during the mission.

7.6.3 Ascent Propulsion System

The ascent propulsion system performance during the lunar ascent maneuver and the terminal phase initiation maneuver was satisfactory. The total engine firing time for the two maneuvers was 433.6 seconds. The ascent propulsion system consumables usage is summarized in section 7.9.2.

7.7 ENVIRONMENTAL CONTROL SYSTEM

The performance of the environmental control system was satisfactory throughout the mission. The waste management system functioned as expected; however, the urine receptacle valve was inadvertently left open for about 6 hours during the first lunar sleep period. This resulted in the loss of about 8 pounds of descent stage oxygen before the crew was awakened to close the valve.

The overspeed of the water separator which occurred on Apollo 14 during cabin-mode operation was not evident during this mission because of a decrease in flow with the helmet and gloves off that resulted from a reconfiguration of valves and hose connections. The only off-nominal performance of the water separator occurred following the cabin depressurization for the standup extravehicular activity when the speed decreased, causing a master alarm (see sec. 14.2.2).

After the first extravehicular activity, a broken quick disconnect between the water bacteria filter and the water drink gun resulted in spillage of about 26 pounds of water into the cabin (see sec. 14.2.3). The water was cleaned up by the crew before the second extravehicular activity.

Fluctuations in water/glycol pump differential pressure were noted following the cabin depressurizations for the standup extravehicular activity and the second extravehicular activity (see sec. 14.2.1). Otherwise, the heat transport system functioned normally.

On Apollo 15, the suits were removed and dried for more than 1 hour by connecting the oxygen umbilicals to the suits and allowing gas to flow through them. This was accomplished at the beginning of each rest period following the first two extravehicular activities.

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. (Figure)

Condition	Quantity, lb		
	Fuel	Oxidizer	Total
Loaded	7537.6	12 023.9	19 561.5
Consumed	7058.3	11 315.0	18 373.3
Remaining at engine cutoff:			
Total	479	709	1188
Usable	433	622	1055

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

Condition	Quantity, lb	
	Actual	Predicted
Loaded	51.2	51.2
Consumed	43.0	[a]44.9
Remaining at landing	8.2	6.3

[a]Adjusted to account for longer-than-predicted firing duration.

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. (Figure)

Condition	Propellant mass, lb			Predicted quantity, lb
	Fuel	Oxidizer	Total	
Loaded	2011.4	3225.6	5237.0	5242.9
Total consumed	1893.4	3052.6	4946.0	[a]4870.8
Remaining at lunar module jettison	118.0	173.0	291.0	372.1

[a]The propellant required for ascent was reduced by 51.5 lb 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. (Figure)

Condition	Actual quantity, lb
Loaded	13.8
Consumed	8.5
Remaining at ascent stage impact	5.3

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. (Figure)

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
Consumed to:				
Lunar landing			95	160
Docking			210	283
Impact			339	414
Remaining at lunar impact			292.2	217.2

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	47.7	
Tank 2	47.1	
Ascent stage		
Tank 1	2.4	
Tank 2	2.4	
Total	99.6	
Consumed		
Descent stage		
Tank 1	[a]26.5	22.8
Tank 2	[a]26.3	22.2
Ascent stage		
Tank 1	0	0
Tank 2	0	0
Total	52.8	45.0
Remaining in descent stage at lunar lift-off		
Tank 1	21.2	24.9
Tank 2	20.8	24.9
Remaining at docking (ascent stage)		
Tank 1	2.4	2.4
Tank 2	2.4	2.4
Total	4.8	4.8

[a]Oxygen leakage through the urine receptacle resulted in greater than predicted descent-stage oxygen consumption.

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	Predicted quantity, lb
Loaded (at lift-off)		
Descent stage		
Tank 1	205.0	
Tank 2	206.0	
Ascent stage		
Tank 1	42.5	
Tank 2	42.5	
Total	496.0	
Consumed		
Descent stage (lunar lift-off)		
Tank 1	[a]180.4	177.5
Tank 2	[a]189.7	178.5
Ascent stage (docking)		
Tank 1	6.1	6.8
Tank 2	6.1	6.8
Total	382.3	369.6
Ascent stage (impact)		
Tank 1	[b]24.9	17.3
Tank 2	[b]23.5	17.3
[c]Total consumed during flight	418.5	390.6
Remaining in descent stage at lunar lift-off		
Tank 1	24.6	27.5
Tank 2	16.3	27.5
Remaining in ascent stage at impact		
Tank 1	17.6	25.2
Tank 2	19.0	25.2
Total	36.6	50.4

[a]Water spillage in the cabin resulted in greater than predicted descent-stage water consumption.

[b]The extended lunar orbit time before lunar module jettison resulted in greater-than-predicted ascent stage water consumption.

[c]Both stages.

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	2075	1479	1648
Ascent	592	[a]455	387

[a]Lunar module jettison occurred one revolution later than planned.

8 LUNAR SURFACE OPERATIONAL EQUIPMENT

8.1 EXTRAVEHICULAR MOBILITY UNIT

Throughout the extravehicular activity, the new configuration of the pressure garment assembly provided good mobility and visibility, allowing the crew to perform their functions in an effective manner.

Checkout of the Commander's portable life support system prior to the first extravehicular activity was normal. Portable life support system startup for the Lunar Module Pilot was normal until the feedwater was turned on. The feedwater pressure increased faster and higher than expected. A warning tone and, a short time later, a vent flow flag was activated. The trouble was traced to a gas bubble trapped in the feedwater bladder during charging by the flight crew (**Fig. 8-1, Fig. 8-1, Con't**.). The gas bubble caused high feedwater pressure. Until the feedwater pressure had decayed to the suit pressure level, the condensate stowage volume was blocked by the feedwater bladder. This resulted in the water separator becoming saturated and allowing droplets of water to be carried over to the fan. This can reduce the fan speed, thereby activating the vent flow flag. Data confirmed the presence of current spikes which are a characteristic of water droplets hitting the fan.

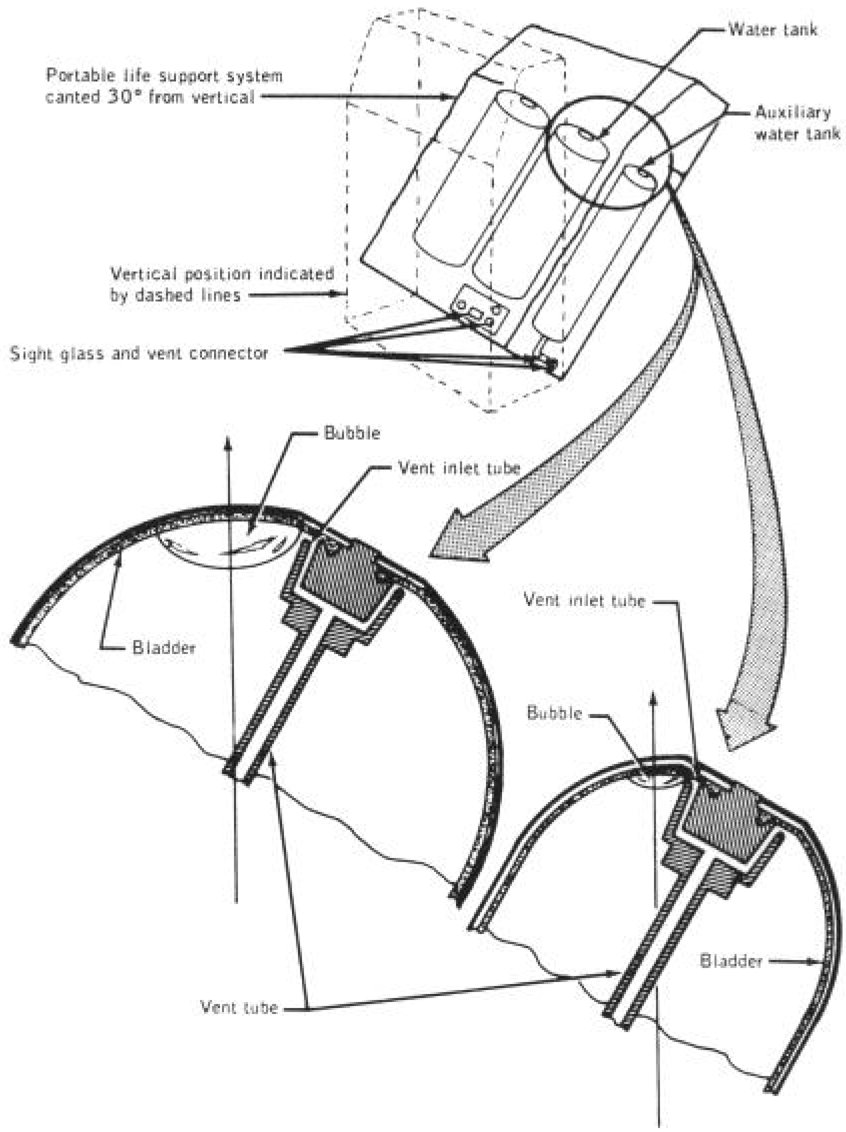


Figure 8-1.- Effect of tilt during water recharge

Subsequent to recharging the portable life support systems after the first extravehicular activity, the problem associated with the Lunar Module Pilot's water separator was found to have resulted from filling the portable life support system at a 30-degree tilt, and the unit was recharged thereafter while in the proper upright position.

Throughout the first extravehicular activity, the extravehicular mobility units maintained crew comfort as required. The feedwater was depleted in the primary tank of both the Commander and Lunar Module Pilot, and the auxiliary tank activation and sublimator repressurization were normal. During this period, the sublimator gas-outlet temperature on the Commander's extravehicular mobility unit ran slightly higher than expected. A comparative analysis of the extravehicular mobility unit parameters indicates that the condition was most likely caused by the cooling water flow running at a low-normal rate.

The first extravehicular activity was terminated about one-half hour earlier than planned because of a higher-than-expected oxygen usage by the Commander.

The communications check at the beginning of the second extravehicular activity was initially unsuccessful for the Lunar Module Pilot because his antenna was broken (sec. 14.5.6). The crewmen taped the antenna to the oxygen purge system in the stowed configuration and the communications check was successfully completed. In this configuration the limiting range is about 305 meters (1000 feet) between crewmen. The feedwater was depleted in the primary tank of both the Commander and the Lunar Module Pilot during the second extravehicular activity, and the auxiliary tank activation, the sublimator repressurization, and the sublimator gas-outlet temperature were normal.

During portable life support system activation for the third extravehicular period, the sublimator gas-outlet temperature and feedwater pressure of the Lunar Module Pilot's extravehicular mobility unit were both reading lower than expected. At lunar module depressurization, these parameters began an upward trend which led to normal readings by the time the Lunar Module Pilot reached the lunar surface.

Oxygen, feedwater, and power consumption of the extravehicular mobility units during the three extravehicular periods are shown in **Table 8-1**. For the Commander's first and second extravehicular activities, and the Lunar Module Pilot's first extravehicular activity, the oxygen redline limits were approached, indicating that the crew workload was approaching the portable life support system capability.

The only problems associated with the lunar module crew station equipment during the mission was that the Lunar Module Pilot could not get water from the insuit drinking device during the first and second extravehicular activities (see sec. 14.5-5), and the Commander's insuit drinking device mouthpiece became displaced during the second extravehicular activity. However, neither insuit drinking device problem constrained the extravehicular activities. The insuit drinking device was not used for the third extravehicular activity because of the short extravehicular activity time.

TABLE 8-I.- EXTRAVEHICULAR MOBILITY UNIT CONSUMABLES

Condition	Commander		Lunar Module Pilot	
	Actual	[a]Predicted	Actual	[a]Predicted
First extravehicular activity				
Time, min	392	420	392	420
[b]Oxygen, lb				
Loaded	1.80	1.734	1.78	1.734
Consumed	1.42	1.155	1.35	1.155
Remaining	0.38	0.579	0.43	0.579
Redline limit	0.37		0.37	
[b]Feedwater, lb				
Loaded	11.80	12.20	[c]11.94	12.20
Consumed	9.27	8.60	9.40	8.60
Remaining	2.53	3.60	2.54	3.60
Redline limit	0.91		0.91	
Battery, amp-hr				
Initial charge	25.7	25.7	25.7	25.7
Consumed	18.6	19.3	18.7	19.3
Remaining	7.1	6.4	7.0	6.4
Redline limit	3.1		3.1	
Second extravehicular activity				
Time, min	433	420	433	420
[b]Oxygen, lb				
Loaded	1.75	1.671	1.76	1.671
Consumed	1.36	1.155	1.12	1.155
Remaining	0.39	0.516	0.64	0.516
Redline limit	0.37		0.37	
[b]Feedwater, lb				
Loaded	12.50	12.50	12.50	12.50
Consumed	10.05	9.2	8.61	9.2
Remaining	2.45	3.3	3.89	3.3
Redline limit	0.91		0.91	
Battery, amp-hr				
Initial charge	25.7	25.7	25.7	25.7
Consumed	20.7	19.3	20.5	19.3
Remaining	5.0	6.4	5.2	6.4
Redline limit	3.1		3.1	
Third extravehicular activity				
Time, min	290	360	290	360
[b]Oxygen, lb				
Loaded	1.78	1.671	1.70	1.671
Consumed	1.02	1.056	0.77	1.056
Remaining	0.76	0.615	0.93	0.615
Redline limit	0.37		0.37	
[b]Feedwater, lb				
Loaded	12.50	12.5	12.50	12.5
Consumed	7.64	8.3	6.39	8.3
Remaining	4.86	4.2	6.11	4.2
Redline limit	0.91		0.91	

Note: Refer to the following page for notes indicated by a, b, and c.

TABLE 8-I.- Concluded

Condition	Commander		Lunar Module Pilot	
	Actual	[a]Predicted	Actual	[a]Predicted
Battery, amp-hr				
Loaded	25.7	25.7	25.7	25.7
Consumed	14.2	16.7	13.9	16.7
Remaining	11.5	9.0	11.8	9.0
Redline limit	2.6		2.6	

NOTES

[a]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	10
Second extravehicular activity	0.028	162
Third extravehicular activity	0.035	190

[b]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	0.029	8	.0155	8
Second extravehicular activity	0.031	142	.0210	142
Third extravehicular activity	0.031	176	.0210	176

[c]The assumption is made that 0.26 lb of feedwater was displaced by air.

8.2 LUNAR ROVING VEHICLE

The lunar roving vehicle (**Fig. 8-2**) performed well during the mission. During the three lunar surface extravehicular activities, the vehicle traveled 27.9 kilometers (15.1 miles) during 3 hours and 8 minutes of driving at an average speed of 9.2 kilometers (4.97 miles) per hour. A total of approximately 52 ampere-hours was consumed. Navigation errors were within expected tolerances with small distance errors and no apparent gyro drift. The combined wander and wheel slip factor was within predicted limits.

The front-wheel steering was inoperative during the first extravehicular activity, but operated normally for the second and third extravehicular activities. Simultaneous front- and rear-wheel steering was found to be more sensitive than desired, and difficulties were experienced with the seat belts; but overall, the crew was very pleased with the vehicle's performance, particularly, the speed and hill- climbing capability.

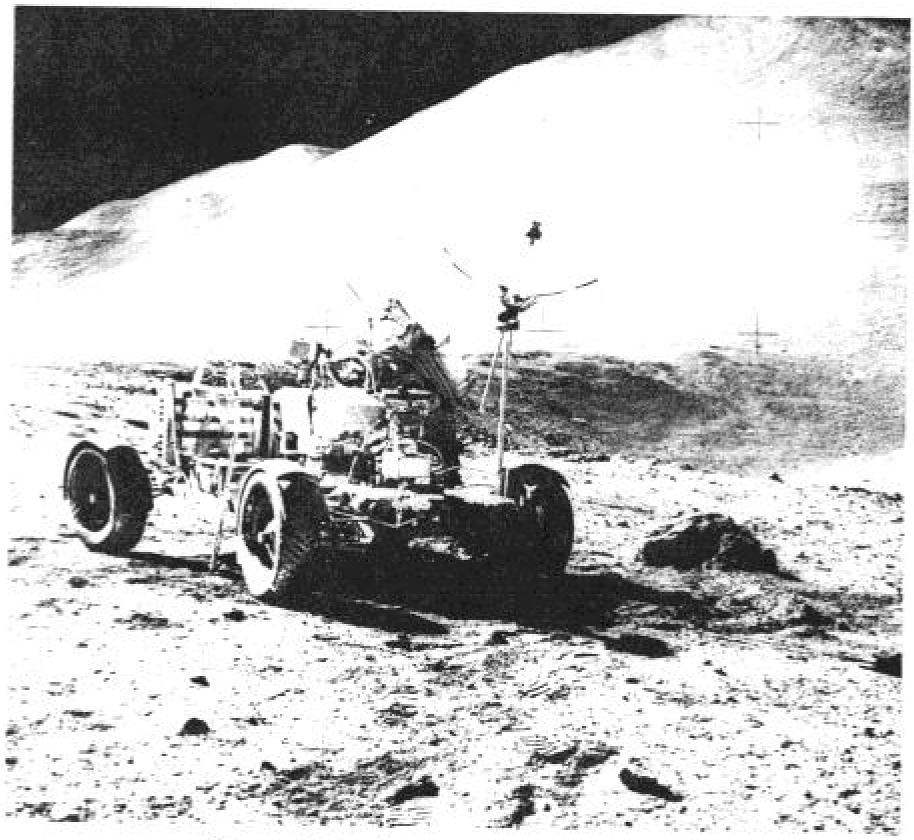


Figure 8-2.- Lunar roving vehicle.

8.2.1 Deployment

Both walking hinge latches were found unlatched during the predeployment inspection and were easily reset. Televised deployment operations showed that, when the deployment tapes were pulled, the vehicle bounced on the lunar surface in a manner similar to that seen during preflight 1/6-weight vehicle deployment tests. The orientation of the lunar module (6.9 degrees pitch up and 8.6 degrees roll to the left, resulting in a tilt of 11 degrees) required an additional hard pull on the deployment cable by the Lunar Module Pilot after all four wheels had contacted the surface. Two of the chassis hinge lock pins required additional pressure to seat them properly. (This possibility had been anticipated and corrective action was incorporated in the checklist.) The deployment saddle and the Velcro seat tie-down were difficult to release. The initial failure of the saddle to release was partially attributed to the vehicle's having been moved sideways on the surface before saddle release was attempted.

Section 14.6.1 discusses this problem further.

8.2.2 Steering

During preparations for the first traverse, the front wheels did not respond to steering commands. The Commander changed busses and observed the ammeter closely to find out if power was being applied to the front wheels in response to steering commands. No response was seen. He then tried, without success, to manually force the front wheels to turn. The front wheel steering remained inoperative, thus the rear wheels were used for steering during the first traverse (see sec. 14.6-3). Little difficulty was experienced in driving, except that attempts to avoid nearby objects resulted in the rear wheels sliding into small craters and objects that the driver was trying to avoid. In at least one slide, the vehicle rotated through 180 degrees.

During checkout of the vehicle for the second traverse, the crew cycled the forward steering power switch and circuit breaker, and found that the front wheel steering operated normally. In starting the second traverse, the Commander first tried dual steering. Then, after the dual steering was found to be very sensitive, he tried front-wheel-only steering. However, this mode was discontinued because the rear wheels tended to wander. (It had been decided not to lock the rear wheels mechanically because of the prior problem with the front wheels.) Therefore, the dual steering mode was used for the remainder of the second traverse and the entire third traverse.

8.2.3 Electrical Power

The lunar roving vehicle used less power than predicted. The predicted power consumption was based on worst-case surface roughness and soil composition, but the actual surface conditions were less severe. The cause of an initial ampere-hour reading of 105 ampere-hours instead of 121 amperehours is not known. Subsequent readings, correlated with ammeter readings, produce an estimated total power consumption of 52 ampere-hours of the 242 ampere- hours available. The consumed electrical power corresponds to a rate of 1.87 ampere-hours per kilometer. The preflight prediction of the usage rate was 3.67 ampere-hours per kilometer. Except for the ampere-hour indicator readings and the inoperative battery 2 volt/ammeter (sec. 14.6.2), the electrical power system operation was normal during the traverses.

After ascent, the video signal was lost from the lunar surface television camera. Postflight analysis and tests show that this loss (section 8-3) was probably caused by opening of the auxiliary power circuit breaker under combined electrical and thermal loads. This anomaly is discussed further in section 14-5.2.

8.2.4 Navigation

The vehicle navigation system operation was normal. The odometer showed a total distance traveled of 27.9 kilometers (15.1 miles). The navigation system provided sufficient information to locate the lunar module at any time during all traverses. Evaluation indicates that the gyro drift rate was essentially zero and the distance error at the maximum range of 5.0 kilometers (2-7 miles) was approximately 0.3 kilometer (0.16 mile). No traverse realignments were required. Closure errors for the three traverses were 0, 100, and 200 meters, well within predictions.

8.2.5 Thermal

The thermal control system, in general, performed satisfactorily. drive motors remained cool and battery temperatures were maintained within established limits.

At the beginning of the second extravehicular activity, the battery 1 cover had closed automatically, as expected. Battery 2 apparently had not cooled down enough and the cover was still open. It was closed manually powering up the vehicle. When the vehicle was activated, battery-1 temperature was 68 degrees F and battery-2 temperature was 78 degrees F. The difference was probably caused by the difference in dust accumulation on the thermal mirrors. These temperatures are consistent with predicted cool-down rates with the covers open and warm-up rates with the covers closed. During the second traverse, the battery-1 and battery-2 temperatures increased to 92 F and 98 F, respectively. The battery covers were opened at the conclusion of the second extravehicular activity period.

At the beginning of the third extravehicular activity, both covers were open. Little battery cool-down had occurred, probably because of further dust accumulation on both battery mirrors, although the battery covers had been closed for the traverses. The covers must not have been closed tight enough against the Velcro edges to keep dust off the mirror surfaces. Only a small amount of dust on the surface will preclude the desired cool-down. At the conclusion of the traverse, battery-1 and battery- 2 temperatures had increased to 108 F and 113 F, respectively, which is an acceptable level.

8.2.6 Crew Station

The crew station was satisfactory except that the seat belts were difficult to fasten (sec. 14.6.4). Prelaunch belt adjustment did not properly account for the reduced gravity in combination with the pressurized suits, and the belts were too short for lunar surface operations. Additionally, the Commander's seat belt hook caught repeatedly on the ground support equipment electrical connector on the console post.

8.2.7 EXTRAVEHICULAR COMMUNICATIONS EQUIPMENT

The lunar communications relay unit operated normally during all lunar surface extravehicular activities. The voice and data quality were good.

Communications from the lunar roving vehicle while it was in motion or temporarily stopped were satisfactory except that the lack of manual realignment of the low-gain antenna to earth resulted in noisy down-link voice at one time when the lunar roving vehicle was parked on a steep slope during the second extravehicular activity.

Fixed-site television operation on the lunar roving vehicle was satisfactory except for difficulty in using the antenna optical sight. With the lunar roving vehicle pointed in the down-sun direction, the sun was directly in the crewmen's eyes when using the optical sight. The design concept was to orient the rotatable sight to a position where sun glare would be avoided. When the lunar roving vehicle was parked north or south, the sun was 90 degrees to the side and no glare resulted. In those instances when glare prevented the use of the optical sight, the lunar communication relay unit automatic gain control meter was used.

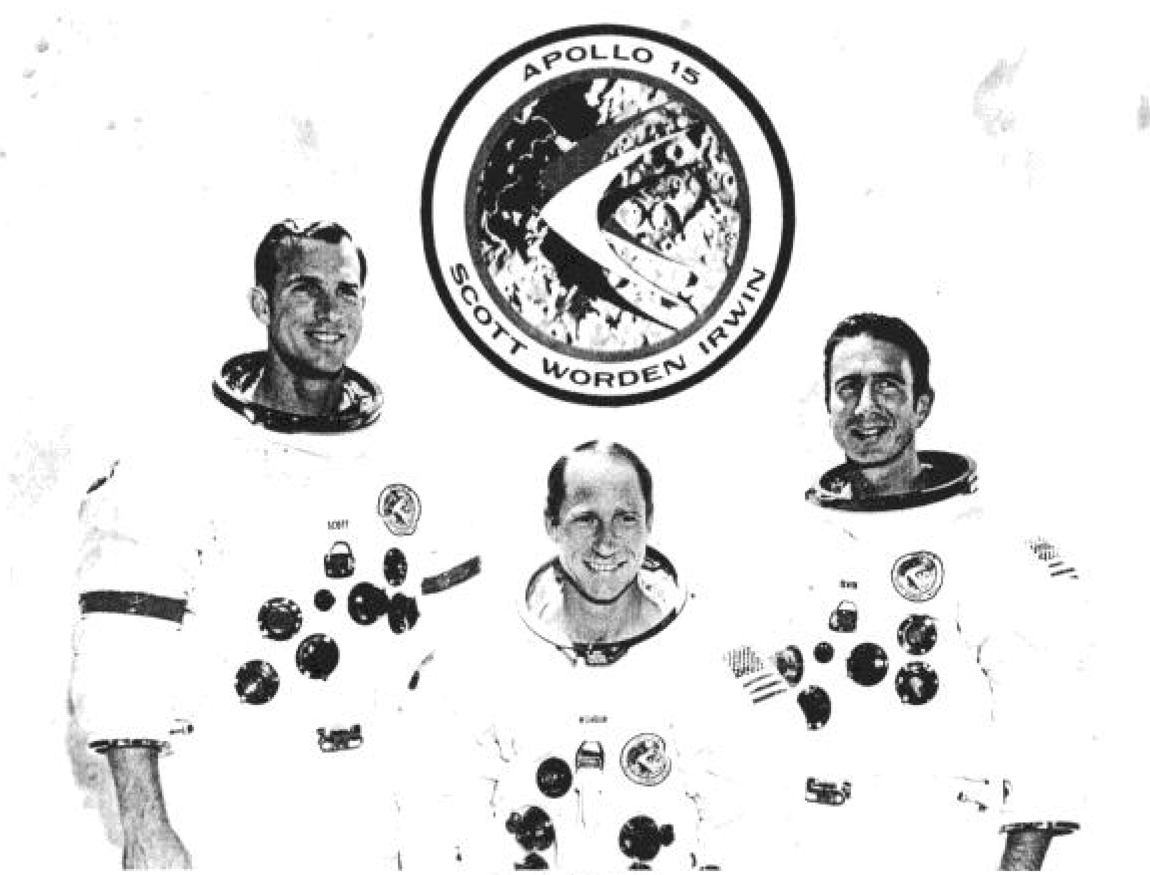
Lunar dust on the television camera lens caused a halo effect and sun reflected glints. Improvement in picture quality was restored periodically after the crew brushed the lens.

The ground-commanded television assembly operated successfully during the three extravehicular activity periods and provided coverage of the lunar lift- off. Good quality video signals were received while the camera was operating with the lunar module and the lunar communications relay unit. The elevation clutch began to slip during the second extravehicular period and the condition became worse during the third extravehicular period (section 14.5-1). The crew, on several occasions, manually assisted the elevation mechanism to regain an operative camera pitch angle.

The television camera was activated about 40 hours after the ascent from the lunar surface. After about 13 minutes of satisfactory operation, signals from the lunar communications relay unit were lost and all attempts to reactivate this system have failed. Refer to section 14.5.2 for a discussion of this anomaly.

9 PILOT'S REPORT

This section contains a description of the Apollo 15 mission from the standpoint of the pilots (Photo). The actual sequence of activities was very similar to the preflight plan. The flight plan, as executed, is summarized in figure 9-1, located at the end of this section.



Apollo 15 flight crew

Commander David R. Scott, Command Module Pilot Alfred J. Worden, and Lunar Module Pilot James B. Irwin

9.1 TRAINING

The crew of Apollo 15 was able to concentrate their training time primarily on learning new operational techniques and becoming qualified in scientific aspects of the mission because of the demonstrated reliability and performance of Apollo hardware and because they had the experience of one complete training cycle as backup crew for Apollo 12.

Approximately one-third of the crew's training time was applied to science. In addition, the crew participated in many phases of development and planning of the new operational and scientific techniques to be utilized in the accomplishment of the objectives of the Apollo 15 mission.

Standard training for Apollo 15 included emphasis on the following new items developed for this mission: Scientific instrument module and associated extravehicular activity; lunar roving vehicle and associated equipment; A7L-B pressure garment assembly; concepts and equipment for expanded lunar geology investigation; and major modifications to the computer program for the command module, lunar module, and abort guidance system. Because of the vast amount of new equipment programmed for lunar surface activity, considerable crew time and effort were devoted to development of procedures in order to optimize the time devoted to lunar surface exploration. Excellent support was received, both in training and procedures development, throughout the 20 months of preparation for the flight.

9.2 LAUNCH

Countdown and launch preparations were well coordinated and timely. Significant events were generally completed approximately 20 minutes ahead of schedule. The crew was comfortable and the crew station was in excellent condition.

Ignition and lift-off were positive with the same overall vehicle vibration frequency throughout S-IC flight that has been noted on previous flights. Noise levels were lower than those the Commander had experienced on Apollo 9, and communications were excellent throughout powered flight. S-IC staging was abrupt and was accompanied by a 3- to 4-degree vehicle yaw, which was corrected soon after S-II ignition. All other displayed and physiological cues were as reported on previous flights with the exception of a very low-amplitude 10- to 12-hertz vehicle vibration during both S-II and S-IVB powered flight, and the lack of a perceptible cue to the programmed shift in propellant utilization during S-II operation.

9.3 EARTH ORBITAL OPERATIONS

All systems checks during earth orbit were completed ahead of schedule and in a satisfactory manner. Those checks included an alignment of the inertial measurement unit, an entry monitor system test, and basic checks of the environmental control and reaction control systems. The alignment was within the drift tolerance voiced up from the ground, and the entry monitor system test indicated an accelerometer bias of 0.01 ft/

sec. The reaction control system was tested using minimum impulse to insure proper operation. During postinsertion checks, the secondary isolation valve for quad B was found closed, but the valve was reset satisfactorily. At about 1 hour, the quad D primary and secondary isolation valves were also found closed and these were also reset.

The systems preparations for translunar injection were completed approximately 20 minutes ahead of schedule, and updates were received in a timely manner. A new procedure was employed to align the flight director attitude indicator for translunar injection which would allow smooth manual takeover at any time. Also, a new computer program was utilized which allowed computer monitoring and shutdown of the translunar injection burn if takeover had been required.

9.4 TRANSLUNAR INJECTION

All events in the translunar injection sequence were as expected with two exceptions. First, in repressurization of the S-IVB hydrogen tank, the increase in pressure was much slower than that experienced in preflight training; however, the ground confirmed that the repressurization cycle was nominal and final pressure values were within the expected range. Second, an S-IVB propellant utilization shift was manifested as a marked surge in thrust 1 minute after ignition. A low-amplitude vibration of about 10 to 12 hertz was felt throughout the translunar injection maneuver. The S-IVB cutoff was 3 seconds early; however, the crew had been informed by Mission Control to expect this.

9.5 TRANSLUNAR FLIGHT OPERATIONS

9.5.1 Transposition, Docking, and Extraction

The transposition and docking were accomplished in a fashion that was slightly different from the checklist procedure. All of the procedures up to the point of separation were accomplished as prescribed. The separation was completed with the guidance and navigation system autopilot in control of the spacecraft attitude. After separation, however, attitude control was switched to the stabilization and control system. The manual attitude pitch switch was placed in ACCEL CMD and the spacecraft was pitched 180 degrees at a rate of 2 deg/sec. After completion of the 180-degree pitch maneuver, control of spacecraft attitude was returned to the guidance and navigation autopilot and an automatic maneuver was made to the docking attitude. While the automatic maneuver was being performed, forward thrusting was accomplished for approximately 4 seconds to insure positive closing of the command and service module and the S-IVB. The closing rate was approximately 0.1 ft/sec. On contact, there was no indication of probe capture latch engagement. Forward thrusting was applied for approximately 1 to 2 seconds and the capture latch indication was then received. The probe was activated to the retract position and the two spacecraft were hard-docked. At the completion of the docking maneuver, the forward hatch was removed and the latches were checked. One latch was not locked onto the docking ring. That latch was recocked and latched manually. The lunar module umbilicals were then attached, and the hatch was replaced. Extraction of the lunar module from the S-IVB was nominal and, at its completion, an automatic maneuver was made to an attitude which allowed a view of subsequent S-IVB maneuvers.

9.5.2 Translunar Coast

Spacecraft systems.- Shortly after the transposition and docking maneuver, the service propulsion system thrust light on the entry monitor system panel was illuminated, indicating a possible electrical short in the service propulsion ignition system. A fault isolation procedure was transmitted to the crew and the short was isolated to bank A of the service propulsion system electrical circuitry. The first midcourse correction was utilized for further troubleshooting. Ignition was initiated by closing the pilot valve main A circuit breaker. Since this started the engine, the nature and location of the short allowed bank A to be manually controlled for subsequent maneuvers. A special procedure was then developed for lunar orbit insertion and transearth injection whereby the service propulsion system maneuvers would be initiated normally with bank B after which the pilot valve main A circuit breaker would be closed manually, turning on bank A. Prior to the termination of the firing, the pilot valve main A circuit breaker would be opened and the firing would be terminated automatically on bank B. All other service propulsion system maneuvers were to be accomplished using bank B only.

Passive thermal control was employed to insure uniform surface heating as on previous flights. Because a new computer program was used to establish the spin rate, new procedures were developed for the initiation of passive thermal control. On the first two attempts, the pitch and yaw rates were not satisfactorily damped before starting the spin-up. However, passive thermal control was satisfactorily established on the third and all subsequent attempts.

An electrical short occurred in the a-c power system somewhere in the lower equipment bay -lighting circuitry, resulting in an opened circuit breaker on the electrical systems panel. No troubleshooting was performed to locate the short and the circuit breaker was left open. The affected lights in the lower equipment bay and on the entry monitor system scroll were out for the remainder of the mission. Rheostats for the operable lights in the lower equipment bay were taped in the positions in which they were found and they remained that way for the remainder of the flight.

During a chlorination cycle, a water leak was discovered on the water panel around the chlorine injector port. The leak appeared as a ball of water around the port. The water was absorbed by towels until information was received from Mission Control indicating that the insert in the open end of the chlorine injector port was possibly loose. Tools were obtained from the tool kit, the port was tightened, and the leak subsided.

The first entry into the lunar module was made on schedule and all planned equipment was transferred. The command and service module oxygen hose was not used. During the inspection, the tunnel misalignment was found to be less than 1 degree (plus or minus 10 degrees is allowed). Also, the range/range-rate tapemeter glass was found broken. The command module vacuum cleaner was used to clean up most of the glass fragments. An additional entry into the lunar module was made at about 57 hours at the request of Mission Control so that additional data on the batteries could be obtained. The vacuum cleaner and lunar module cabin fans were used to gather additional glass. No loose object was found that could account for glass breakage.

Simulated cislunar midcourse navigation sightings were accomplished during translunar coast for horizon calibration and on-the-job training. The midcourse navigation exercises were valuable from the standpoint that they allowed the Command Module Pilot to calibrate his eye to a horizon for subsequent use in all transearth coast sightings.

Science and photography.- All science operations during translunar coast were completed as scheduled. These operations included such things as sextant photography of star patterns and ultraviolet photography of the earth and moon. The ultraviolet photography was completed as prescribed, requiring specific spacecraft attitudes and special operations associated with command module window 5. A removable filter had been installed to protect the crew from ultraviolet radiation. This filter required removal to allow the ultraviolet photography. Because of the handling, the filter became increasingly scratched during the flight.

9.5.3 Scientific Instrument Module Door Jettisoning

The scientific instrument module door was jettisoned after the second midcourse correction and prior to lunar orbit insertion. To prepare for this, the crew donned their pressure garments, performed a pressure integrity check, and maneuvered the spacecraft to the proper attitude. Jettisoning of the door was felt as a very light "thud" in the command module. The only abnormal indication was the closing of the service module reaction control system B secondary propellant isolation valve, which was reset with no difficulty. The door was first observed from command module window 5 at a distance of about 50 feet and on a trajectory 90 degrees from the longitudinal axis of the spacecraft. Door jettison was accomplished without difficulty and with much less reaction than had been anticipated.

9.6 LUNAR ORBIT OPERATIONS PRIOR TO DESCENT

9.6.1 Lunar Orbit Insertion

All checks for lunar orbit insertion were completed as scheduled in the flight plan, and all systems were verified as acceptable for lunar orbit operations. The maneuver to the lunar orbit insertion attitude was verified by a sextant star check. Subsequently, the service propulsion system thrusting program was activated and the velocities and angles were verified by the ground. All commands from the ground were received in a timely manner. The firing was accomplished as described in section 9.5.2. The maneuver was initiated with very small transients, the attitude excursions were never greater than approximately 1 degree, and the gimbal position indications showed a very smooth and positive response to the shift in the center of gravity. The maneuver was terminated by the guidance and navigation system with zero residuals. The descent orbit initiation maneuver was accomplished using service propulsion system bank B alone. This maneuver, as in the lunar orbit insertion maneuver, was preceded by systems checks which were all nominal, and the maneuver was nominal. A subsequent descent orbit insertion trim maneuver that had been anticipated and scheduled prior to flight was, in fact, required before undocking because of perturbations in the orbit up to that point. It was a very small maneuver of approximately 3 ft/sec and was