accomplished using the reaction control system maneuver program. All pre-maneuver checks were completed nominally and the maneuver was performed satisfactorily.

9.6.2 Lunar Module Activation, Undocking and Separation

On the day scheduled for landing, entry into the lunar module was about 40 minutes early. Final closure of the suit zippers was accomplished in the lunar module. One procedural change was made in order to purge the suit umbilical hoses: Both suit isolation valves were placed in the FLOW position for 15 seconds, then in the DISCONNECT position, after which the suit gas diverter valve was placed in the CABIN position. Checklist functions were generally performed 10 minutes ahead of schedule.

As noted in earlier flights, stars were difficult to see through the alignment optical telescope while docked with the command module. However, the results of a two-star sighting using the cursor-spiral technique indicated platform realignment could be achieved with the optics.

The suit loop integrity check was unsuccessful on the first attempt. The checklist procedure was followed, but there was obviously a leak because the pressure drop was approximately 1 psi in 30 seconds. The valve detents were checked, the regulator was rechecked, and then another integrity check was made. This time, the pressure drop was acceptable at 0.1 psi in 1 minute. The time a1lowed to accomplish the required functions for powered descent is more than sufficient. This became apparent when a number of unanticipated events occurred. Condensate had formed on the lunar module windows and the heaters had to be activated in order to clear them. Undocking was delayed for approximately 40 minutes because the command module/lunar module power transfer umbilical connections were not electrically engaged. A descent engine throttle check had to be redone because the descent engine control assembly circuit breaker was in the open position during the first check. The timeline was regained by the time of the scheduled guidance and navigation system platform realignment and the pace was very leisurely as the time for powered descent initiation approached; the crew even had time to eat lunch. The rendezvous radar self-test was normal but, after separation, the range indicated by the rendezvous radar was approximately twice that indicated by VHF ranging (see sec. 7.4).

9.7 POWERED DESCENT AND LANDING

The angle of the final descent trajectory after high gate was increased from 14 degrees to 25 degrees for Apollo 15. This afforded improved dispersion conditions during the braking phase over the Apennine Mountains, better visibility after pitchover, and more precise control of manual landing site redesignations.

After receiving final uplinks from the Manned Space Flight Network, the powered descent program was called up in the lunar module guidance computer 10 minutes prior to ignition. The landing radar circuit breaker was closed 5 minutes prior to ignition, as planned, and all events were nominal through the first minute of powered flight. Automatic ullage and ignition were clearly evident by physiological cues. A correction was manually entered into the computer to move the targeted landing site about 853 meters (2800 feet) west (downrange) just prior to ignition plus 2 minutes. The indicated quantity of onboard fuel was 2 percent low at this time, but this was considered acceptable by ground control. Three minutes after ignition, the spacecraft was yawed to the planned inplane face-up attitude. Immediately thereafter, at approximately 43 000 feet altitude, landing radar data became acceptable and computer updates were initiated. Landing radar data were solid throughout the remainder of powered flight.

Throttle recovery occurred on time, and manual attitude hold was evaluated with the following expected results: positive response, considerable reaction control system activity, and rapid return to smooth automatic guidance at the Completion of the check. Predicted pitchover time (high gate) was checked in the computer, and conformed to the preflight nominal time of 9 minutes 22 seconds.

At an altitude of approximately 9000 feet, the upper fourth of Hadley Delta Mountain (11,000 feet high) was visible out of the left window. The feeling of slow, forward, floating motion was experienced and, because of the relative position and motion with respect to the mountain, an impression of a downrange overshoot was experienced. At about 8000 feet altitude, ground control informed the crew that the expected landing site was to be approximately 915 meters (3000 feet) south of the targeted site.

Pitchover occurred on time and the only positive recognizable lunar surface feature was Hadley Rille. Topographic relief was much less than had been anticipated from the enhanced 20-meter (65-foot) resolution photography and the associated preflight lunar terrain models. Sharp landmark recognition features within the Plain of Hadley were almost nonexistent; however the South Cluster was soon identified. Based upon the apparent position relative to this feature, plus the 915-meter miss distance to the south given by ground control, several landing point redesignations were made to the right (north).

At an altitude of approximately 5000 feet, a pair of subdued craters, which appeared to be Salyut and its northerly adjacent neighbor, were identified. Uprange landing point redesignations were made so that the landing could be made in the correct area northwest of Salyut Crater. The touchdown point was selected from an altitude of 2000 feet and the lunar module was maneuvered to land on what appeared to be a smooth level surface. The low-gate phase (manual control) of the trajectory was manually selected and confirmed at an altitude of 400 feet. Descent rate reduction was initiated at a height of about 200 feet, and visual reference was maintained by watching several fragments on the lunar surface which were located 30 to 40 meters (100 to 130 feet) west of the selected site. A trace of blowing surface dust was observed at a height of 130 feet with only a slight increase down to 60 feet. Beginning at this altitude, out-of-the window visibility was completely obscured by dust until after touchdown.

Tapemeter altitude and altitude rate data readings, provided orally by the Lunar Module Pilot, appeared to be consistent with the visual observations throughout the terminal phase of the landing. Surface features and texture became well defined at an altitude of approximately 1000 feet and, based on preflight experience with visual simulator displays, descent rates appeared completely nominal and comfortable. Sensations after manual takeover at 400 feet were almost identical with those experienced in lunar landing training vehicle operations. The combination of visual simulations and lunar landing training vehicle flying provided excellent training for the manual portion of the lunar landing. Comfort and confidence existed throughout this phase.

Additional manual maneuvering south and west could easily have been made below 400 feet; however, because of increased surface mobility afforded by the lunar roving vehicle, a landing anywhere within the 3-sigma dispersion ellipse was considered a precise landing, and additional maneuvering within this ellipse, other than for terrain obstacle avoidance, was considered unnecessary.

The engine stop button was activated shortly after the contact lights were illuminated to preclude excessive pressure buildup within the nozzle of the descent engine (which had been extended 10 inches since Apollo 14). Touchdown was firm but only slightly more so than nominal lunar landing training vehicle landings. Roll and pitch rates were evident at touchdown as the rear and left foot pads came to rest in a shallow subdued crater which was not visible during the final phase of the landing. The posttouchdown events were nominal; no spurious reaction control system firings occurred, and permission for the lunar stay was voiced by Houston in a timely manner.

9.8 LUNAR SURFACE OPERATIONS

9.8.1 Lunar Module Cabin Activity

Standup extravehicular activity This operation went very smoothly. No problem was encountered in removing and stowing the drogue. There was no direct sunlight on the lunar module panels as observations were made and pictures taken from the high vantage point. The base of the Apennine Front at Hadley Delta, as well as the North Complex, was visible from this point, and because of the lack of obstacles, acceptable lunar roving vehicle trafficability over all traverse routes was verified.

The secondary water separator was selected during this period because of a caution light during primary separator operation. After the standup extravehicular activity, the primary separator was reselected.

A picture taken during the standup extravehicular activity which reveals the stratigraphy of Silver Spur is shown in **Figure 9-2**. The sun angle during subsequent extravehicular activities did not allow this observation.

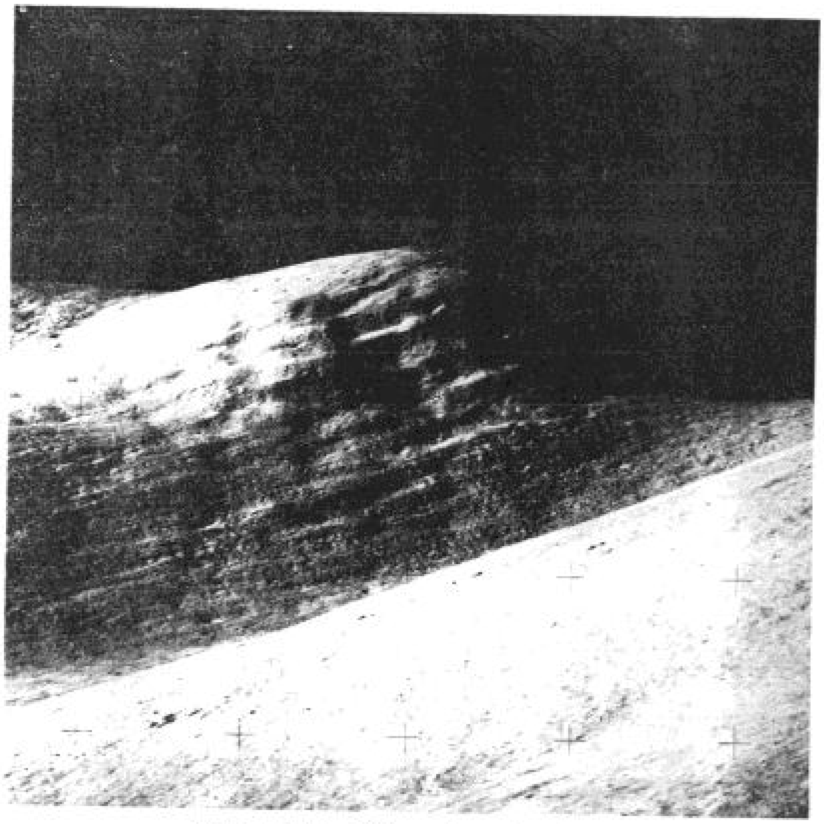


Figure 9-2.- Silver Spur landmark.

Sleep.- The crew was able to sleep fairly well. Noise was minimized by configuring the environmental control system in accordance with the checklist and by using earplugs. The temperature was ideal for sleeping in the constant-wear garment and sleeping bag, or in the constant-wear garment and coveralls. A wider hammock would improve the conditions for sleeping. Aslight light leak through the stitching on the window shades interfered with getting to sleep.

Extravehicular activity preparation and post -extravehicular activity. The times for preparation were consistently shorter than the times allowed on the checklist. The only difficulty encountered was movement in the cabin when in the pressurized suits. Several areas presented obstacles: the forward corner on the data file, the portable life support system stowage handle, and the stowed water hose. The portable life support system recharge was accomplished during the eat period in order to save time and the Lunar Module Pilot had difficulty in turning the portable life support system water valve off. The suit was easy to don and doff in 1/6 earth gravity. The crew found that it was possible to lift themselves up, using the overhead bar, and place both feet in the suit simultaneously.

Housekeeping.- When doffing the pressure garment assembly after lunar surface extravehicular operations, the Commander stood on the midsection step and the Lunar

Module Pilot stood on his oxygen purge system to avoid the dirty floor. A jettison bag was placed over the legs of the suit to contain the dirt.

9.8.2 Lunar Geology

The geological setting of the Hadley-Apennine landing site is such that a great variety of features and samples were expected. Lack of high resolution Photography of the site insured that variations in preflight estimates of topographic relief, and surface debris and cratering could also be expected. In all cases, actual conditions exceeded expectations.

In general, the mare surface at Hadley is characterized by a hummocky lunar terrain produced by a high density of rounded, subdued, low-rimmed craters of all sizes. The craters range in size up to several hundred meters in diameter and are poorly sorted. There is a notable absenc of large areas of fragmental debris or boulder fields. Unique, fresh, 1- to 2- meter-diameter, debris-filled craters, with glass-covered fragments in their central 10 percent, occurred on less than 1 percent of the mare surface.

The large blocks comprising the Apennine Mountains have extremely rounded profiles with less than 0.1 percent exposed surface outcroppings or fresh young craters. However, massive units of well-organized uniformly parallel lineations appear within all blocks, each block having a different orientation within the Hadley area. Mount Hadley is the most dramatic of these blocks, where at least 200 lineations (**Fig. 9-3**), dipping approximately 30 degrees to the west-northwest, are exposed on its southwest slope. Discontinuous, linear, patterned ground is visible superimposed over these lineations. A more definitive exposure of these units was observed at Silver Spur (**Fig. 9-2**) where an upper unit of seven 60-meter (200-foot) thick layers is in contact with a lower section of somewhat thinner parallel layering having evidence of crossbedding and subhorizontal fractures. Also, three continuous, subhorizontal, non-uniform lineations are visible within, and unique to, the lower 10 percent of the Mount Hadley vertical profile.

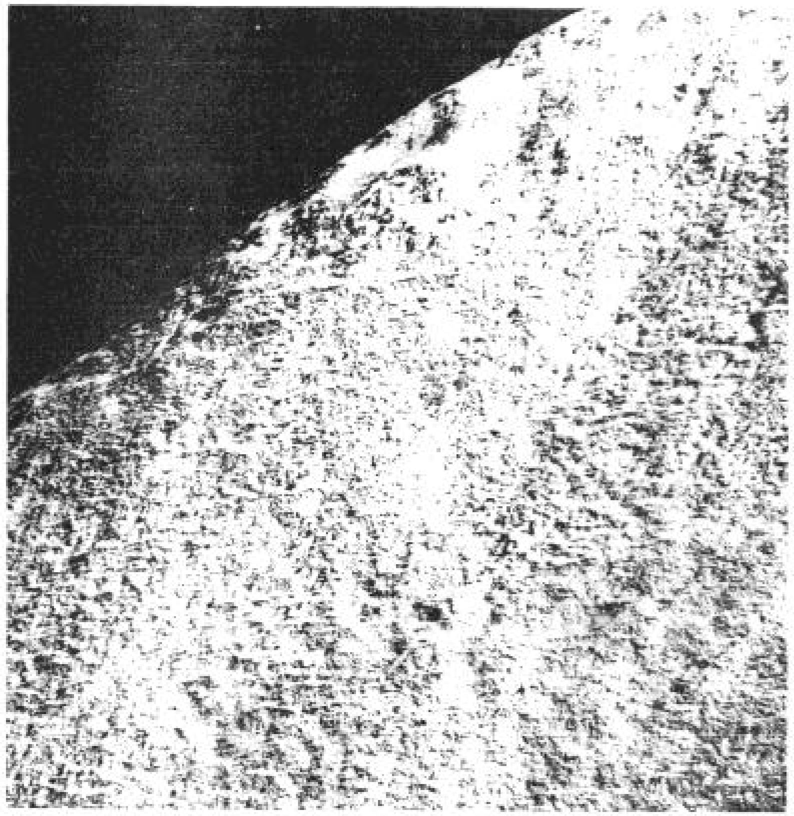


Figure 9-3.- Lineations visible on southwest slope of Mount Handley.

The most distinctive feature of Hadley Rille is the exposed layering within the bedrock on the upper 15 percent of the rille walls (Fig. 9-4). Two major units can be identified in this region; the upper 10 percent appears as poorly organized massive blocks with an apparent fracture orientation dipping approximately 45 degrees to the north. The lower 5 percent is a distinct horizontal unit exposed as discontinuous outcrops partially covered with talus and fines. Each exposure is characterized by approximately 10 different multilayered parallel horizontal bedding planes. The remainder of the slope is covered with talus, 20 to 30 percent of which is fragmental debris, with a suggestion of another massive unit with a heavy cover of fines at a level 40 percent downward from the top. The exposures at this level appear lighter in color and more rounded than the general talus debris. No significant collection of talus is apparent at any one level. The upper 10 percent of the eastern side of the rille is characterized by massive subangular blocks of fine-grained vesicular porphyritic basalt containing up to 15 percent phenocrysts. This unit, as viewed toward the south, has the same character as the upper unit on the western wall. The bottom of the rille is gently sloping and smooth with no evidence of flow in any direction. No accumulation of talus was evident on the bottom except for occasional boulders up to 2 meters (6.6 feet) in size.

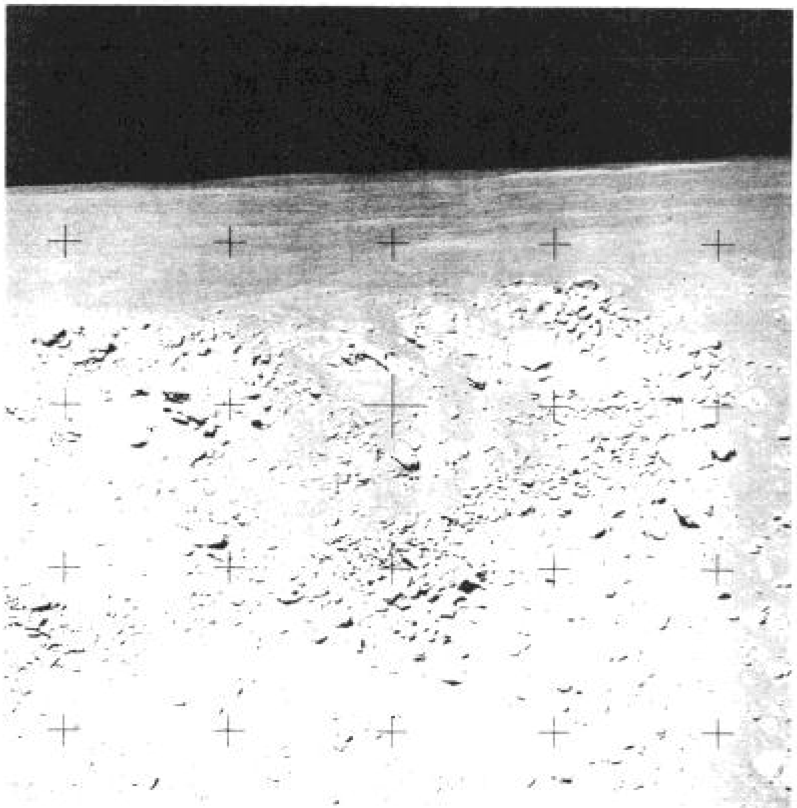


Figure 9-4.- Exposed layering within the bedrock in Hadley Rille.

The major concentration of craters, depicted on preflight maps, is the South Cluster on the Hadley Plain. Because of the general lack of morphological features on the slopes of Mount Hadley and Hadley Delta, a linear concentration of craters up the slope of Hadley Delta, directly south of the Cluster, indicates that a sweep of secondary fragments from the north may have been the origin of the South Cluster. A buildup of debris on the southern rim of these craters was not evident, although the approximately 10-percent coverage of the surface by fragmental debris in the region of the South Cluster is unique within the Hadley region.

Sampling was accomplished in the general vicinity of all preplanned locations with the exception of the North Complex, which was unfortunately excluded because of higher priorities of activities associated with lunar surface experiments. A great variety of samples were collected; some are obviously associated with their location, while others will require further study to determine a relationship. The capability to identify rock types at the time of collection was comparable to a terresterial exercise and was unhampered by the unique environment of the moon. Identifiable sample features include: anorthosite; basalts with vesicules of various sizes, distribution, and orientation; basalts with phenocrysts of various quantities, sizes, shapes, and orientation; olivine- and pyroxene-rich basalts; third-order breccias with a variety of well-defined clasts; rounded glass fragments; glass-filled fractures and glass-covered fragments; and other surface features such as slickensides.

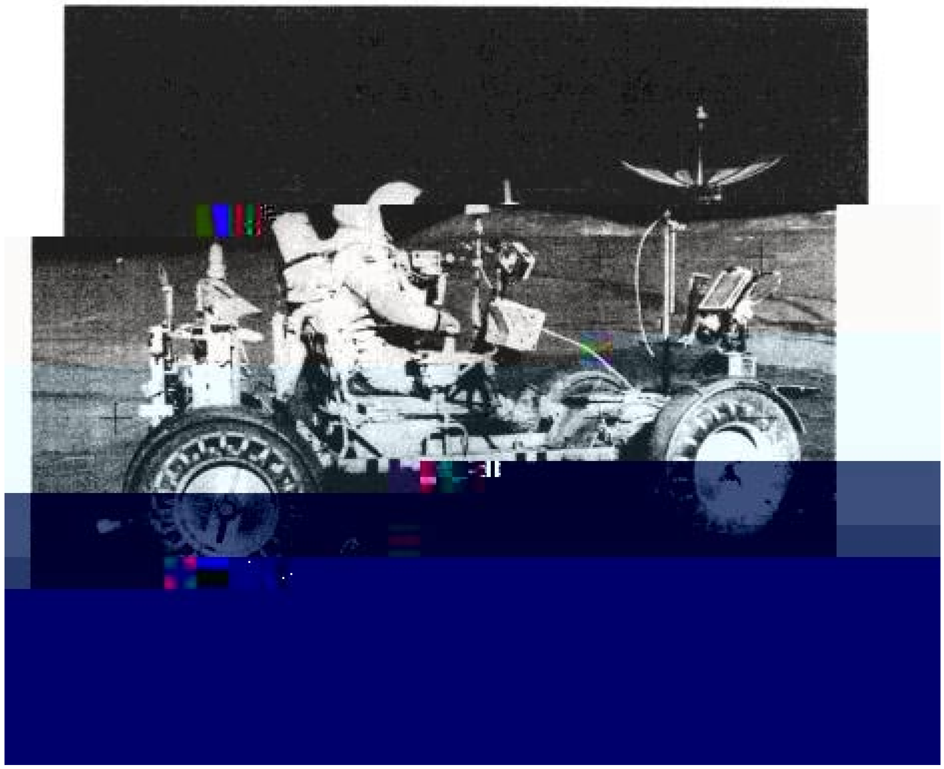
9.8.3 Lunar Surface Mobility Systems Performance

Extravehicular mobility unit.- The mobility of the modified suit allowed the lunar roving vehicle to be mounted easily. It was also possible to bend down on one knee to retrieve objects from the surface.

The cooling performance of the portable life support system was excellent. The Commander used maximum cooling for tasks such as the drilling operations. The Lunar Module Pilot never used more than intermediate cooling. For the driving portion of the lunar surface exploration, minimum cooling was quite comfortable. During the first extravehicular activity, the Lunar Module Pilot experienced several warning tones. The suspected cause was a bubble in the portable life support system water supply. When switchover to auxiliary water was required, ground control recommended minimum cooling, which was new information to the crew. The temperature in the suits gradually increased over the three extravehicular activities.

The portable life support system straps were adjusted during the preflight crew compartment fit and function procedure. The Commander's straps worked fine. However, the Lunar Module Pilot's seemed short since the controls were located too high and too far to the left for him to reach. The Commander's portable life support system seemed loose at the end of the third extravehicular activity.

Lunar roving vehicle.- The major hardware innovation for the lunar exploration phase of the Apollo 15 mission was the lunar roving vehicle (**Fig. 9-5**) Because of geological requirements during surface traverses, time was limited for evaluating the characteristics of the vehicle. However, during the traverses, a number of qualitative evaluations were made. The following text discusses the performance, and the stability and control of "Rover 1", as well as other operational considerations pertaining to the vehicle.



The manual deployment technique worked very well. Simulations had demonstrated the effectiveness of this technique and, with several minor exceptions, it worked exactly as in preflight demonstrations. The first unexpected condition was noticed immediately after removing the thermal blanket when both walking hinges were found open. They were reset and the vehicle was deployed in a nominal manner. The support saddle, however, was difficult to remove after the vehicle was on the surface. No apparent cause was evident. Additionally, both left front hinge pins were out of their normal detent positions; both were reset with the appropriate tool. After removal of the support saddle, the rover was manually positioned such that "forward" would be the initial driving mode.

Front steering was inoperative during the first extravehicular activity. All switches and circuit breakers were cycled a number of times during the early portion of the first extravehicular activity with no effect on the steering. Subsequently, at the beginning of the second extravehicular activity, cycling of the front steering switch apparently enabled the front steering capability which was then utilized throughout the remaining traverses.

Mounting and dismounting the rover was comparable to preflight experience in 1/6-gravity simulations in the KC-135 aircraft. Little difficulty was encountered. The normal mounting technique included grasping the staff near the console and, with a small hop, positioning the body in the seat. Final adjustment was made by sliding, while using the footrest and the back of the seat for leverage. It was determined early in the traverses that some method of restraining the crew members to their seats was absolutely essential. In the case of Rover 1, the seatbelts worked adequately; however, excessive time and effort were required to attach the belts. The pressure suit interface with the rover was adequate in all respects. None of the preflight problems of visibility and suit pressure points were encountered.

The performance of the vehicle was excellent. The lunar terrain conditions in general were very hummocky, having a smooth texture and only small areas of fragmental debris. A wide variety of craters was encountered. Approximately 90 percent had smooth, subdued rims which were, in general, level with the surrounding surface. Slopes up to approximately 15 percent were encountered. The vehicle could be maneuvered through any region very effectively. The surface material varied from a thin powdered dust [which the boots would penetrate to a depth of 5 to 8 centimeters (2 to 3 inches) on the slope of the Apennine Front to a firm rille soil which was penetrated about 1 centimeter (one-quarter to one-half inch) by the boot. In all cases, the rover's performance was changed very little.

The velocity of the rover on the level surface reached a maximum of 13 kilometers (7 miles) per hour. Driving directly upslope on the soft surface material at the Apennine Front, maximum velocities of 10 kilometers (5.4 miles) per hour were maintained. Comparable velocities could be maintained obliquely on the slopes unless crater avoidance became necessary. Under these conditions, the downhill wheel tended to dig in and the speed was reduced for safety.

Acceleration was normally smooth with very little wheel slippage, although some soil could be observed impacting on the rear part of the fenders as the vehicle was accelerated with maximum throttle. During a "Lunar Grand Prix", a roostertail was noted above, behind, and over the front of the rover during the acceleration phase. This was approximately 3 meters (10 feet) high and went some 3 meters forward of the rover. No debris was noted forward or above the vehicle during constant velocity motion. Traction of the wire wheels was excellent uphill, downhill, and during acceleration. A speed of 10 kilometers per hour could be attained in approximately three vehicle lengths with very little wheel slip. Braking was positive except at the high speeds. At any speed under 5 kilometers (2.7 miles) per hour, braking appeared to occur in approximately the same distance as when using the 1-g trainer. From straight-line travel at velocities of approximately 10 kilometers per hour on a level surface, the vehicle could be stopped in a distance of approximately twice that experienced in the 1-g trainer. Braking was less effective if the vehicle was in a turn, especially at higher velocities.

Dust accumulation on the vehicle was considered minimal and only very small particulate matter accumulated over a long period of time. Larger particles appeared to be controlled very well by the fenders. The majority of the dust accumulation occurred on the lower horizontal surfaces such as floorboards, seatpans, and the rear wheel area. Soil accumulation within the wheels was not observed. Those particles which did pass through the wire seemed to come out cleanly. Dust posed no problem to visibility.

Obstacle avoidance was commensurate with speed. Lateral skidding occurred during any hardover or maximum-rate turn above 5 kilometers per hour. Associated with the lateral skidding was a loss of braking effectiveness. The suspension bottomed out approximately three times during the entire surface activity with no apparent ill effect. An angular 30- centimeter (1-foot) high fragment was traversed by the left front wheel with no loss of controllability or steering, although the suspension did bottom out. A relatively straight-line traverse was easily maintained by selection of a point on the horizon for directional control, in spite of the necessity to maneuver around the smaller subdued craters. Fragmental debris was clearly visible and easy to avoid on the surface. The small, hummocky craters were the major problem in negotiating the traverse, and the avoidance of these craters seemed necessary to prevent controllability loss and bottoming of the suspension system.

Vehicle tracks were prominent on the surface and very little variation of depth occurred when the bearing on all four wheels was equal. On steep slopes, where increased loads were carried by the downhill wheels, deeper tracks were encountered - perhaps up to 3 or 4 centimeters (an inch or two) in depth. There was no noticeable effect of driving on previously deposited tracks, although these effects were not specifically investigated. The chevron tread pattern left distinct and sharp imprints. In the soft, loose soil at the Apollo lunar surface experiment package site, one occurrence of wheel spin was corrected by manually moving the rover to a new surface.

The general stability and control of the lunar roving vehicle was excellent. The vehicle was statically stable on any slopes encountered and the only problem associated with steep slopes was the tendency of the vehicle to slide downslope when both crewmen were off the vehicle. The rover is dynamically stable in roll and pitch. There was no tendency for the vehicle to roll even when traveling upslope or downslope, across contour lines or parallel to contour lines. However, qualitative evaluation indicates that roll instability would be approached on the 15-degree slopes if the vehicle were traveling a contour line with one crewmember on the downhill side. Both long- and short-period pitch motions were experienced in response to vehicle motion over the cratered, hummocky terrain, and the motion introduced by individual wheel obstacles. The long-period motion was very similar to that encountered in the 1-g trainer, although more lightly damped. The "floating" of the crewmembers in the 1/6-g field was quite noticeable in comparison to 1- g simulations. Contributions of shortperiod motion of each wheel were unnoticed and it was difficult to tell how many wheels were off the ground at any one time. At one point during the "Lunar Grand Prix", all four wheels were off the ground, although this was undetectable from the driver's seat.

Maneuvering was quite responsive at speeds below approximately 5 kilometers per hour. At speeds on the order of 10 kilometers per hour, response to turning was very poor until speed was reduced. The optimum technique for obstacle avoidance was to slow below 5 kilometers per hour and then apply turning correction. Hardover turns using any steering mode at 10 kilometers per hour would result in a breakout of the rear wheels and lateral skidding of the front wheels. This effect was magnified when only the rear wheels were used for steering. There was no tendency toward overturn instability due to steering or turning alone. There was one instance of breakout and lateral skidding of the rear wheels into a crater approximately 1/2 meter (1-112 feet) deep and 1-1/4 meters (4 feet) wide. This resulted in a rear wheel contacting the far wall of the crater and subsequent lateral bounce. There was no subsequent roll instability or tendency to turn over, even though visual motion cues indicated a roll instability might develop.

The response and the handling qualities using the control stick are considered adequate. The hand controller was effective throughout the speed range, and directional control was considered excellent. Minor difficulty was experienced with feedback through the suited crewmember to the hand controller during driving. However, this feedback could be improved by a more positive method of restraint in the seat. Maximum velocity on a level surface can be maintained by leaving the control stick in any throttle position and steering with small inputs left or right. A firm grip on the handle at all times is unnecessary. Directional control response is excellent although, because of the many dynamic links between the steering mechanism and the hand on the throttle, considerable feedback through the pressure suit to the control stick exists. A light touch on the hand grip reduces the effect of this feedback. An increase in the lateral and breakout forces in the directional hand controller should minimize feedback into the steering.

Two steering modes were investigated. On the first extravehicular activity, where rear-wheel-only steering was available, the vehicle had a tendency to dig in with the front wheels and break out with the rear wheels with large, but less than hardover, directional corrections. On the second extravehicular activity, front-wheel-only steering was attempted, but was abandoned because of the lack of rear wheel centering. Four-wheel steering was utilized for the remainder of the mission. It is felt that for the higher speeds, optimum steering would be obtained utilizing front steering provided the rear wheels are center-locked. For lower speeds and maximum obstacle avoidance, four-wheel steering would be optimal. Any hardover failure of the steering mechanism would be recognized immediately and could be controlled safely by maximum braking.

Forward visibility was excellent throughout the range of conditions encountered with the exception of driving toward the zero-phase direction. Washout, under these conditions, made obstacle avoidance difficult. Up-sun was comparable to cross-sun if the opaque visor on the lunar extravehicular visor assembly was lowered to a point which blocks the direct rays of the sun. In this condition, crater shadows and debris were easily seen. General lunar terrain features were detectable within 10 degrees of the zero phase region. Detection of features under high-sun conditions was somewhat more difficult because of the lack of shadows, but with constant attention, 10 to 11 kilometers (5-1/2 to 6 miles) per hour could be maintained. The problem encountered was recognizing the subtle, subdued craters directly in the vehicle path. In general, 1-meter (3 1/4-foot) craters were not detectable until the front wheels had approached to within 2 to 3 meters (6-1/2 to 10 feet).

The reverse feature of the vehicle was utilized several times, and preflight-developed techniques worked well. Only short distances were covered, and then only with a dismounted crewmember confirming the general condition of the surface to be covered.

The 1-g trainer provides adequate training for lunar roving vehicle operation on the lunar surface. Adaptation to lunar characteristics is rapid. Handling characteristics are quite natural after several minutes of driving. The major difference encountered with respect to preflight training was the necessity to pay constant attention to the lunar terrain in order to have adequate warning for obstacle avoidance if maximum average speeds were to be maintained. Handling characteristics of the actual lunar roving vehicle were similar to those of the 1-g trainer with two exceptions: braking requires approximately twice the distance, and steering is not responsive in the 8- to 10-kilometer (4- to 5 1/2-mile) per hour range with hardover control inputs. Suspension characteristics appeared to be approximately the same between the two vehicles and the 1/6-g suspension simulation is considered to be an accurate representation with the exception of the crewmembers' weight.

The navigation system is accurate and a high degree of confidence was attained in a very short time. Displays are also adequate for the lunar roving vehicle systems.

Lunar communications relay unit.- The lunar communications relay unit and associated equipment operated well throughout the lunar surface activities. The deployment techniques and procedures are good, and the operational constraints and activation overhead are minimum. Alignment of the high-gain antenna was the only difficulty encountered, and this was due to the very dim image of the earth presented through the optical sighting device. The use of signal strength as indicated on the automatic gain control meter was an acceptable back-up alignment technique.

9.8.4 Lunar Surface Science Equipment Performance

Apollo lunar surface experiment package.- The packages were manually removed from the scientific equipment bay. During unstowing of equipment, the universal handling tools were difficult to remove from the stowed position and the scientific equipment bay doors required cycling to the fully closed position. In deploying the central station, the strings which pull the rear pins on the sun shield cover were broken, requiring the Lunar Module Pilot to pull the pins with his fingers. Connection of the suprathermal ion detector experiment to the central station was very difficult. The task required the Lunar Module Pilot to use both hands and all the weight that he could bring to bear on the locking collar. Another difficulty was in the deployment of the suprathermal ion detector experiment. The universal handling tool was not locked, which caused the suprathermal ion detector experiment to fall off the tool when positioning the experiment.

Emplacement of the heat flow experiment and collection of the deep core sample were difficult and required far more time and effort than anticipated. Operation of the hardware components was acceptable with the exception of the vise on the geology pallet. The vise was installed incorrectly and was useless for separating the assembled stems.

The primary cause of the working difficulties encountered with the lunar drill was the lack of knowledge of the regolith encountered at the Hadley site. Because of the hardness of the material 1 meter (3 1/4 feet) below the surface, the bore stems for drilling the holes for the heat flow experiment did not penetrate at the expected rates and did not excavate deep material to the surface. Because of the resulting high torque levels on the chuck-stem interface, the chuck bound to the stems and, in one case, required destruction of the stem to remove the chuck and drill. The deep core sample could not be extracted from the hard soil by normal methods and required both crewmen lifting on the drill handles to remove it. The exterior flutes contributed to this condition since the core stems were pulled into the lunar surface when the drill was activated. See section 14.4.1 for further discussion.

Soil mechanics.- The classic trench was easily dug in the vicinity of the Apollo lunar surface experiment deployment site. Penetrometer measurements were made at the trench and in the lunar roving vehicle tracks. The floor of the trench was a very hard resistant layer. In making the penetrometer measurements, the trench side was collapsed by pushing on the flat plate positioned about 10 centimeters (4 inches) from the trench wall. A problem with the penetrometer was that the ground plane would not stay in the extended position because of excessive spring force (see section 4.13).

Geology tools.- The retractable tethers (yo-yo's) failed during the first extravehicular activity. These devices were used by the Commander to secure tongs and by the Lunar Module Pilot to secure the extension handle during the geology work. They would have been used to hold the universal handling tools during deployment of the Apollo lunar surface experiment package. Unfortunately, both yo-yos failed before the experiment package was deployed. Cord was used for the flight equipment instead of wire, as on the training equipment. The tongs, scoop, hammer, and rake worked well, and the rake also functioned well as a scoop. The newly designed core tube worked well in that the sample was completely retained. Penetration of the surface with the core tube was usually accomplished with a hard push; however, the hammer was required to obtain a double core. The locking and unlocking of the buddy secondary life support system bag attached to the rear of the geology pallet was very difficult because the locking tab was hidden behind the bag. Sample return container 2 was not sealed because a portion of the collection bag was caught in the rear hinge.

Cameras.- The film in the 16-mm data acquisition camera would not pull through the camera. Only one magazine worked on the lunar surface. Also, the Lunar Module Pilot's 70-mm Hasselblad electric data camera malfunctioned at the end of the second extravehicular activity. An inspection in the lunar module cabin revealed excessive lunar material on the film drive. The camera failed again on the third extravehicular activity and was returned to earth. These anomalies are discussed in sections 14.5.3 and 14-5.4.

9.9 LUNAR ORBITAL SOLO OPERATIONS

9.9.1 Maneuvers

Solo maneuvers in lunar orbit included circularization and a plane change. Both of these maneuvers were accomplished using service propulsion system bank B only because of the aforementioned circuit problem with bank A. The maneuvers were nominal and were accomplished with residual velocities of an order that required no further maneuvering.

9.9.2 Science and Photography

Scientific instrument module experiments.- The scientific instrument module was operated during the three days of lunar surface activity according to carefully detailed preflight planning. Because of the complexity of the scientific instrument module, all operations during this period were to be accomplished without deviation from the flight plan. In the event that difficulties were encountered, items were to be dropped from the flight plan. Some flight difficulties were experienced with the scientific instrument module operations. These difficulties were associated with the retraction of the mass spectrometer boom and with the extension and retraction of the mapping camera. The mass spectrometer boom extended normally but did not always indicate full retraction. It was suspected that the boom was retracting into the carriage, but not far enough to cause an indication of full retraction. The monitoring, as well as the timing of the boom extensions and retractions, required an expenditure of time which had not been anticipated preflight. The mapping camera extended and retracted more slowly than had been anticipated and it eventually failed in the extended position. This also required additional monitoring time on the part of the Command Module Pilot. The mass spectrometer boom retraction problem is discussed in more detail in section 14.1.6 and additional discussion on the mapping camera problem is given in section 14.3.3.

The scientific instrument module bay activity was essentially a monitoring operation. Functions were performed at a prescribed time and required very careful attention to the details in the flight plan. One procedure that was used to assist in this monitoring activity was the use of computer time on the display keyboard in the lower equipment bay. The procedure required the initiation of an external delta-velocity program at a prescribed time. The clock in the computer would then count down to, and up from, that time. However, because of the calculations required by the computer during operation of this program, the spacecraft actually deviated out of the attitude control dead bands. Therefore, after the first day in lunar orbit, the computer program was used for very short intervals of time only. Consequently, the monitoring of the scientific instrument module bay became much more difficult because the timing of these events had to be accomplished using ground elapsed time, and not time relative to an event. Also complicating the monitoring was the fact that the lights in the lower equipment bay could no longer illuminate the mission timer because of the previously described short in the a-c electrical system.

All of the solo operations in lunar orbit were accomplished well within the capability of the Command Module Pilot with respect to the amount of work that had to be done in the time available. There were times when visual observation of the surface and hand-held photography were accomplished in conjunction with the operation of the scientific instrument module bay. This posed no problem and was accomplished as prescribed.

Command and service module photography.- The onboard photography was accomplished generally as prescribed in the flight plan except that the operation was more detailed than had been anticipated prior to flight. Acquisition of all photographic targets was based on flight plan time. However, with additional training just prior to flight, the Command Module Pilot attained a sufficient degree of proficiency in target recognition and in the geology of the lunar surface so that detailed flight plan times were not required.

The photography was accomplished using the settings prescribed in the flight plan and additional photographs were taken utilizing the settings based on sun angles that were listed in both the orbit monitor charts and by an orbit monitor wheel which was developed for that purpose. The photography from window 5 posed some problems because of a Lexan filter installed inside of the spacecraft (since no ultraviolet filter existed within the window). The Lexan filter, at this time, was scratched and it did not appear that good photography could be taken through that window, so the filter was removed for the photography and then replaced.

Visual observations.- In conjunction with the photography, visual observations of selected surface features were made. These observations were designed to allow a better understanding of large-scale geologic processes. Three areas of special interest were centered around the crater Tsiolkovsky, the Littrow area, and the Aristarchus Plateau.

Tsiolkovsky is a large impact crater centered at 128 degrees east latitude, and uniquely placed in the region between the large mare basins and the upland areas on the back side. It is a deep crater with a prominent central peak and steep rim walls; the crater walls are cut by several faults. The smooth, dark crater floor resembles the mare surfaces visible on the moon's near side. There is much evidence of volcanic processes on the eastern side of the crater as shown by numerous lava flows originating along fault zones and filling minor craters around Tsiolkovsky. On the western side, there is a large rock avalanche that extends from the rim northwest into the subdued crater Fermi.

The Littrow area was viewed because of distinct color banding extending out into Mare Serenitatis. This banding appears to have been produced by volcanism in the form of flows or volcanic ash deposits. Within the darkest band, there were numerous small positive features believed to be cinder cones. These are the first well-documented cinder cones observed on the moon.

The Aristarchus Plateau appears to be the most active volcanic area on the moon. There are many lava flows and rille-like features in the central plateau area.

One of the mysteries about the rilles has been the rille termini. If these features were formed by lava flows, there would be delta-shaped flow tongues formed at the outlets. Inflight observation resulted in the conclusion that if these delta-shaped flow tongues were present, they were covered by lava flows that inundated the rilles.

9.10 ASCENT, RENDEZVOUS AND DOCKING

9.10.1 Ascent

Ascent ignition was automatic, the programmed pitchover was smooth and positive, and the trajectory appeared nominal throughout the maneuver. Five minutes after lift-off, radar lock-on was attempted with negative results; 5 seconds of high slew in each direction also resulted in no signal strength. Approaching insertion, Houston advised of a radial error in the primary guidance and navigation system and recommended an in-plane trim of the abort guidance system velocity residuals. At automatic primary guidance and navigation system shutdown, the abort guidance system indicated a residual velocity of minus 3.5 ft/sec. This was trimmed to minus 2 ft/sec along the longitudinal axis. No vernier adjustment was required, and the ground advised that the terminal phase initiate maneuver would be off-nominal and that final approach would be from near horizontal; these factors were due to the command and service module orbit.

9.10.2 Rendezvous

Lunar module.- The abort guidance system warning light came on shortly after insertion. The light was reset normally and the abort guidance system self-test was satisfactory. After insertion, there was early confirmation of rendezvous radar, primay guidance and navigation system, and abort guidance system guidance data. Automatic updating was enabled in both the primary guidance system and the abort guidance system. At final computation for terminal phase initiation, there were 26 marks in the primary guidance and navigation system, and 13 range marks and 13 range-rate marks in the abort guidance system. Another accelerometer bias update was made on the primary guidance system before terminal phase initiation. The primay guidance and navigation system solution was used.

Nominal procedures were used for primary guidance and navigation system midcourse corrections. For the abort guidance system, several rangerate inputs were manually inserted to insure that there were sufficient marks to obtain good solutions. The technique used was to watch the mark counter until the range changed to a plus value, then the range rate was manually entered. The command and service module tracking light was not visible until 40 minutes after sunset at a range of approximately 18 miles.

When approaching the last braking gate (1500 feet separation distance), the Commander was surprised to see that no line-of-sight rates were indicated by the rendezvous radar crosspointers. (Refer to sec. 14.2.7 for a discussion of this anomaly.) Line of site rates were verified by the Command Module Pilot. Thrusting left and up approximately 4 ft/sec was required to null the line-of-site rates. The resulting out-of-plane angle at station keeping was approximately 20 degrees.

Command and service module.- The command and service module was prepared for the rendezvous by deactivating all of the scientific instrument module bay experiments, retracting all of the booms, and closing the camera and experiment covers. All but four reaction control jets were activated 3 hours before lunar module ascent initiation to allow proper ground tracking and orbit determination. On the rendezvous revolution itself, VHF contact was made just prior to ascent and the Manned Space Flight Network relay was deactivated. All communications with the lunar module were accomplished using the VHF. Just prior to insertion, VHF ranging was activated. Several resets were required before the ranging was locked, and subsequently, lock was broken only once.

After insertion, a lunar module state vector was uplinked from the ground and an automatic maneuver was made to the rendezvous tracking attitude. The rendezvous was completed using a minimum-key-stroke (automatic sequencing) computer program. This program was new for this flight, and was designed to relieve the Command Module Pilot's workload. The computer automatically sequenced through the rendezvous maneuvers and tracking periods. It was initiated at the pre-terminal phase initiation program and was terminated with the final rendezvous computer program, which maneuvered the command and service module to the desired tracking attitude just prior to docking. The program functioned as anticipated and allowed the Command Module Pilot much greater time for optical tracking and systems monitoring.

There was same difficulty at first in actually seeing the lunar module tracking light because the lunar module was not centered in the scanning telescope. After going into darkness, the light was observed at about 15 degrees from the center of the telescope. After two marks were taken, the optics tracked the lunar module in the center of the sextant. A total of 18 optical and 19 VHF marks were taken before the final solution was initiated. The maneuver to the terminal phase initiate attitude was a small maneuver of approximately 20 to 30 degrees in pitch. After the lunar module performed the terminal phase initiation maneuver, the actual velocity changes were inserted into the computer. The command and service module then was maneuvered automatically to the tracking attitude. Ten optics and nine VHF marks were taken prior to the first midcourse correction and 18 optics and 11 VHF marks were taken prior to the second midcourse correction. All solutions were compared with the lunar module solutions and were within the prescribed limits. The lunar module subsequently accomplished the maneuvers based on its own solutions.

9.10.3 Docking and Crew Transfer

Beginning at terminal phase finalization, the spacecraft was maneuvered to the crew-optical-alignment-sight tracking attitude to monitor the lunar module and to verify line-of-sight rates. The lunar module assumed a station keeping position with the command and service module and a maneuver was initiated to allow photographs to be taken of the scientific instrument module bay. After this was accomplished, the spacecraft were maneuvered to the docking attitude. The docking was initiated and completed by the command and service module. Again, the closing rates were approximately 0.1 ft/sec, and the docking was completed by thrusting along the longitudinal axis on contact until capture latch engagement was indicated. After the capture latches were engaged and the attitudes were stabilized, the probe was retracted and a hard dock was accomplished.

Several operations were initiated almost simultaneously after the docking. The scientific instrument module bay experiments were activated and operated throughout the time of transfer of equipment from the lunar module to the command and service module. The experiments operations hindered the transfer to some extent because the Command Module Pilot was required to monitor and observe the scientific instrument panel in the command and service module. However, the transfer was successfully completed and all transfer bags were stowed in the proper locations. The lunar module crew transferred back into the command and service module and preparations were made for undocking.

9.11 POST-DOCKING LUNAR ORBITAL OPERATIONS

9.11.1 Lunar Module Jettison

After all equipment was stowed, the crew donned their helmets and gloves and prepared the tunnel for lunar module Jettison. Some difficulty was experienced with venting the pressure in the tunnel. The differential pressure across the tunnel hatch would not increase as expected. The hatch was removed and the seals on both the lunar module hatch and the command module hatch were checked. Both hatches were replaced and the differential pressure check was completed satisfactorily. A pressure suit integrity check was then accomplished; again, with some difficulty. The crew considered that the liquid cooled garment connector was responsible for the failure of one of the suits to pressurize properly, so a plug was inserted into the Commander's suit. After the plug was installed and the suits were rezipped, the suit circuit pressure integrity check was accomplished normally. Because of the difficulty with the tunnel and with the suit circuit integrity check, the lunar module jettison was delayed approximately one revolution, after which it was accomplished normally. However, because of the difference in orbital position from the planned position at the time of the lunar module jettision, the separation maneuver was recomputed to assure a positive separation distance. This was accomplished about 20 minutes after jettision and all subsequent events were nominal.

9.11.2 Flight Plan Updating

After rendezvous and with all three crewmen aboard the command and service module, the flight plan was updated to utilize the full capability of the scientific instrument module bay. The flight plan changes were considerable, but with one crewman free to copy the updates, the other two crewmen were available to monitor and perform the scientific instrument module activities. This meant that all three crewmen were utilized a good percentage of the time. The operation was performed satisfactorily and the real-time changing of the flight plan was accomplished without difficulty. The philosophy that there would be no changes in the flight plan during the solo operations and that the flight plan would be subject to real-time change when all three crewmen were aboard was satisfactory.

9.11.3 Maneuvers

Prior to the transearth injection maneuver, an orbital shaping maneuver was performed to launch the subsatellite into an orbit guaranteeing a long lifetime. This was a relatively short thrusting maneuver and was accomplished using service propulsion system bank B. The subsatellite was jettisoned as scheduled and it was observed approximately 15 to 20 feet away from the spacecraft. All arms were extended and it was rotating with a coning angle of approximately 10 degrees.

The next maneuver was the transearth injection maneuver which was accomplished without difficulty. The service propulsion system was again activated by the special procedure. Gimbal position indications were very smooth and there was very little attitude excursion. The maneuver was completed nominally.

9.11.4 Command and Service Module Housekeeping

Particular emphasis was placed on housekeeping throughout the flight in order to maintain organization within the command module crew compartment with the additional stowage requirements for the Apollo 15 mission. Normal cabin living activities required more time than anticipated preflight because of additional equipment, onboard stowage conditions, new pressure suits, a strict adherence to nutrition schedules, and limitations on overboard dump periods. The most efficient manner of completing these activities was to perform all cleaning, dumping, canister change, and chlorination operations just prior to a rest period, exclusive of any scientific instrument module activities. Similarly, an exclusive waking and eat period just after the rest period and prior to any other activities (such as scientific instrument module activation and flight plan updates) conforms to normal daily activities on earth and results in far more efficient utilization of time during flight.

9.12 TRANSEARTH FLIGHT OPERATIONS

9.12.1 Transearth Coast Extravehicular Activity

Approximately 16 hours after the transearth injection maneuver, the crew had completed preparations for an extravehicular activity which was specifically planned to retrieve the panoramic and mapping camera cassettes from the scientific instrument module. The preparation for the extravehicular activity was accomplished in a nominal fashion and required approximately 5 112 hours. Preparation of the command module was partially accomplished during the night preceding the extravehicular activity and was completed approximately 2 hours before the flight plan time for the event. This allowed an unhurried, careful preparation of all equipment and resulted in an extravehicular activity that was accomplished on time and without difficulty. The final preparation associated with the extravehicular activity involved the relocation of some rock bags and containers, removal of the center couch, donning of pressure suits, suit integrity checks, and the donning of the special extravehicular activity umbilical and pressure suit equipment by the Command Module Pilot. This was accomplished satisfactorily per the check- list. The spacecraft was maneuvered to the extravehicular activity sun-angle attitude which allowed illumination of the scientific instrument module bay, while insuring that the sun did not shine directly into the command module hatch. In this attitude the sun angle was low with respect to the scientific instrument module, but reflections in and around the module illuminated all of the equipment. After side hatch opening, the television and 16-mm cameras were installed on the hatch to record the extravehicular activity. The 16-mm camera operated for only 3 or 4 frames and produced only one recoverable picture (**Fig. 9-6**). The camera had apparently been turned on and then inadvertently turned off after a three-second interval while set at a frame rate of one frame per second. The television camera operated properly. The Command Module Pilot proceeded to the scientific instrument module bay in a fashion similar to that used during training. The operation required about 16 minutes and was completed in an efficient manner even though an off-nominal condition existed in that the mapping camera was extended and could not be retracted. The panoramic camera cassette was returned to the hatch and was tethered inside the command module. The mapping camera cassette was returned on the second trip. Because of the difficulty with the mass spectrometer boom, and the mapping camera extension and retraction mechanism, a third trip was made to the scientific instrument module to investigate these pieces of equipment. The spectrometer was observed to have retracted to the point of capture by the guide pins in the carriage but had not retracted fully. No external jamming of the mapping camera carriage was seen. One additional problem, associated with the panoramic camera, was investigated during the third trip. The panoramic camera velocity/altitude sensor malfunctioned during lunar orbit operations. The sensor was examined and nothing was in the line of sight of the velocity/altitude sensor to account for the failure. Following the extravehicular activity, the Command Module Pilot ingressed, the hatch was closed, and the command module was pressurized using the three 1-pound oxygen bottles from the rapid repressurization system, the Command Module Pilot's extravehicular umbilical flow, and the oxygen purge system.

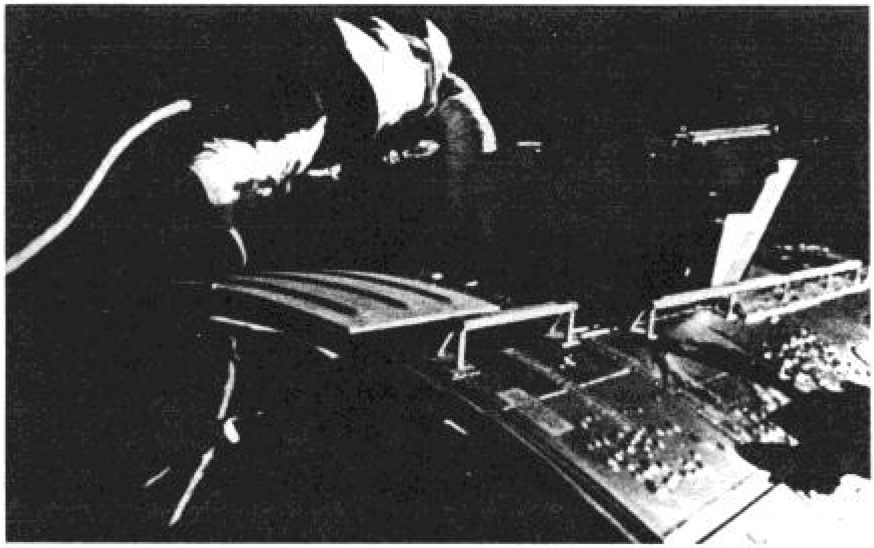


Figure 9-6.- Command Module Pilot moving toward scientific instrument module during transearth extravehicular activity

9.12.2 Science and Photography

The instruments in the scientific instrument module were operated during the transearth coast to obtain background data needed for interpretation of data obtained in lunar orbit and to acquire information on celestial sources. These operations, at times, required specific attitude pointing, and at other times, were accomplished during passive thermal control periods. The operations, although accomplished in large part based upon real-time planning, posed no difficulty in adhering to the preflight-planned timeline. During transearth flight, ultraviolet photographs were taken of both the earth and the moon, star patterns were photographed through the sextant, and photographs were taken in an attempt to record the particulate matter around the spacecraft following a waste water dumping operation.

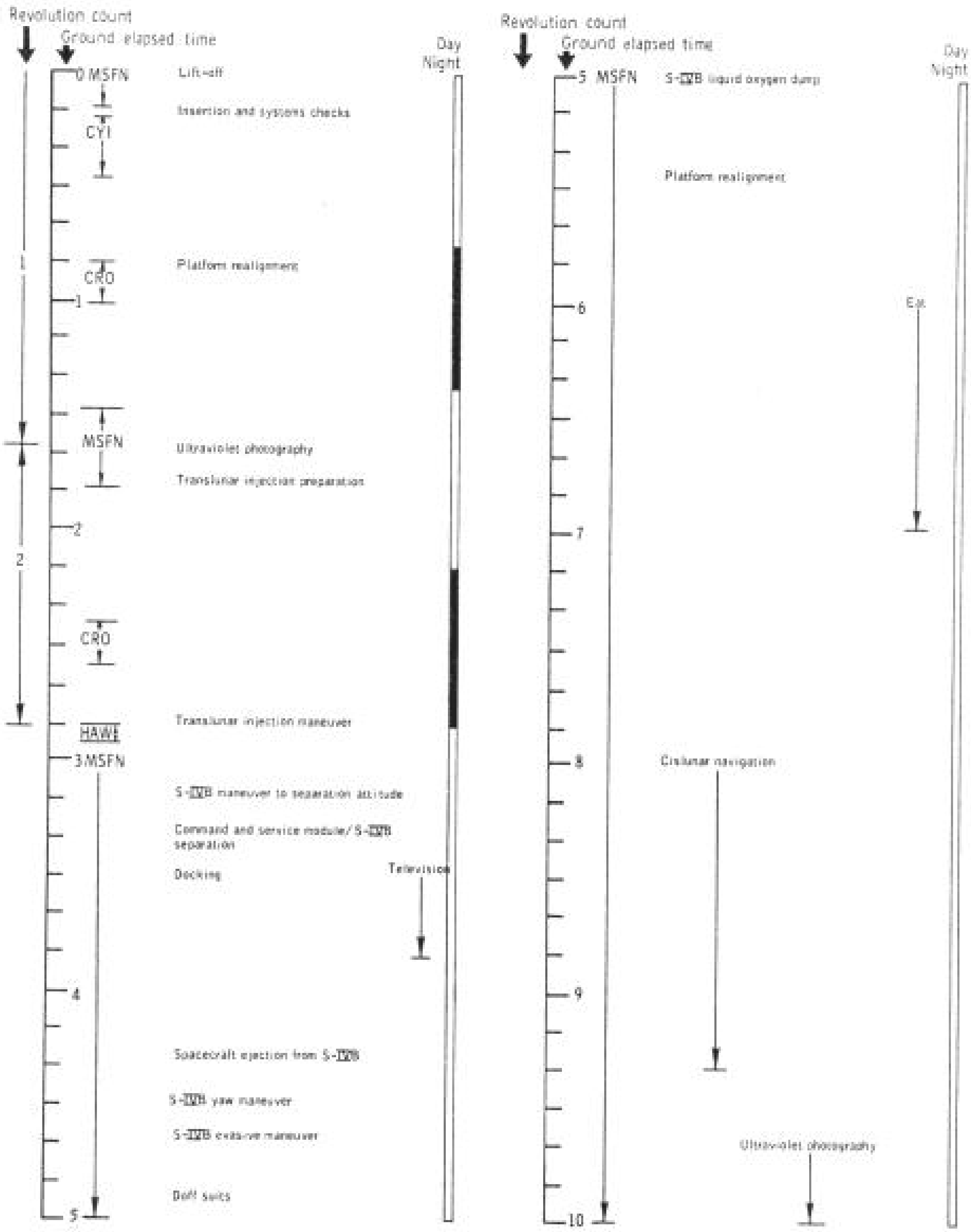
9.12.3 Navigation

During transearth flight, a large portion of time was devoted to cislunar midcourse navigation. This was done to demonstrate the capability to perform onboard navigation to achieve safe entry conditions in the event Manned Space Flight Network communications are lost. Calibrations having been accomplished on translunar coast, the midcourse exercises were performed, as closely as possible, according to the schedule in the contingency checklist. This navigational exercise was accomplished by maintaining a separate state vector stored in the command module computer registers normally used for lunar module state vectors. It was discovered that the navigation could, in fact, be performed onboard to at least validate the state vector during a nominal transearth coast. The techniques for accomplishing the cislunar sightings were essentially the same as had been used during translunar coast. The earth at this time appeared as a very thin crescent because of the earth-sun relationship, but the horizon was easily discernible. The sightings were taken with the spacecraft in minimum-impulse control, and all but the last set of sightings were accomplished using uncoupled thrusters for attitude control. Low attitude rates were maintained and the sightings were easier than had been experienced preflight. The onboard state vector was maintained until just prior to entry and it would have been satisfactory in the event that a loss of communications had been experienced.

9.13 ENTRY AND LANDING

The preparation for entry was accomplished normally and the third midcourse correction was performed to insure that the target point was acceptable. In preparation for service module separation, all systems were checked, chill-down of the spacecraft was accomplished as prescribed, and the spacecraft was maneuvered to the service module jettison attitude. The jettison was accomplished as planned. Entry was nominal, with the entry interface occurring at the proper time. The entry monitor system indicated 0.05g at the expected time and the entry monitor system, the guidance and navigation system, and the accelerometers were all in agreement during entry. The lack of entry monitor system background lighting did not affect observation of the scroll. The entry was normal, but during descent on the main parachutes, one of the parachutes partially deflated. The main parachutes deployed normally at 10 000 feet, and checklist items were performed. However, following the reaction control system depletion firing, the partially-deflated parachute was observed. The condition resulted in a higher rate of descent than with three fully-inflated parachutes. Calls were received from the recovery team indicating that the situation was being observed by ground personnel. All checks subsequent to this were made according to the checklist and, because of the higher rate of descent, touchdown was accomplished about 32 seconds earlier than it would have with all parachutes fully inflated. The landing loads were higher than normal; however, it did not appear that the couch struts had stroked. The only internal indication of a hard landing was that the crew optical alignment sight was detached from its stowage bracket and fell to the aft bulkhead.

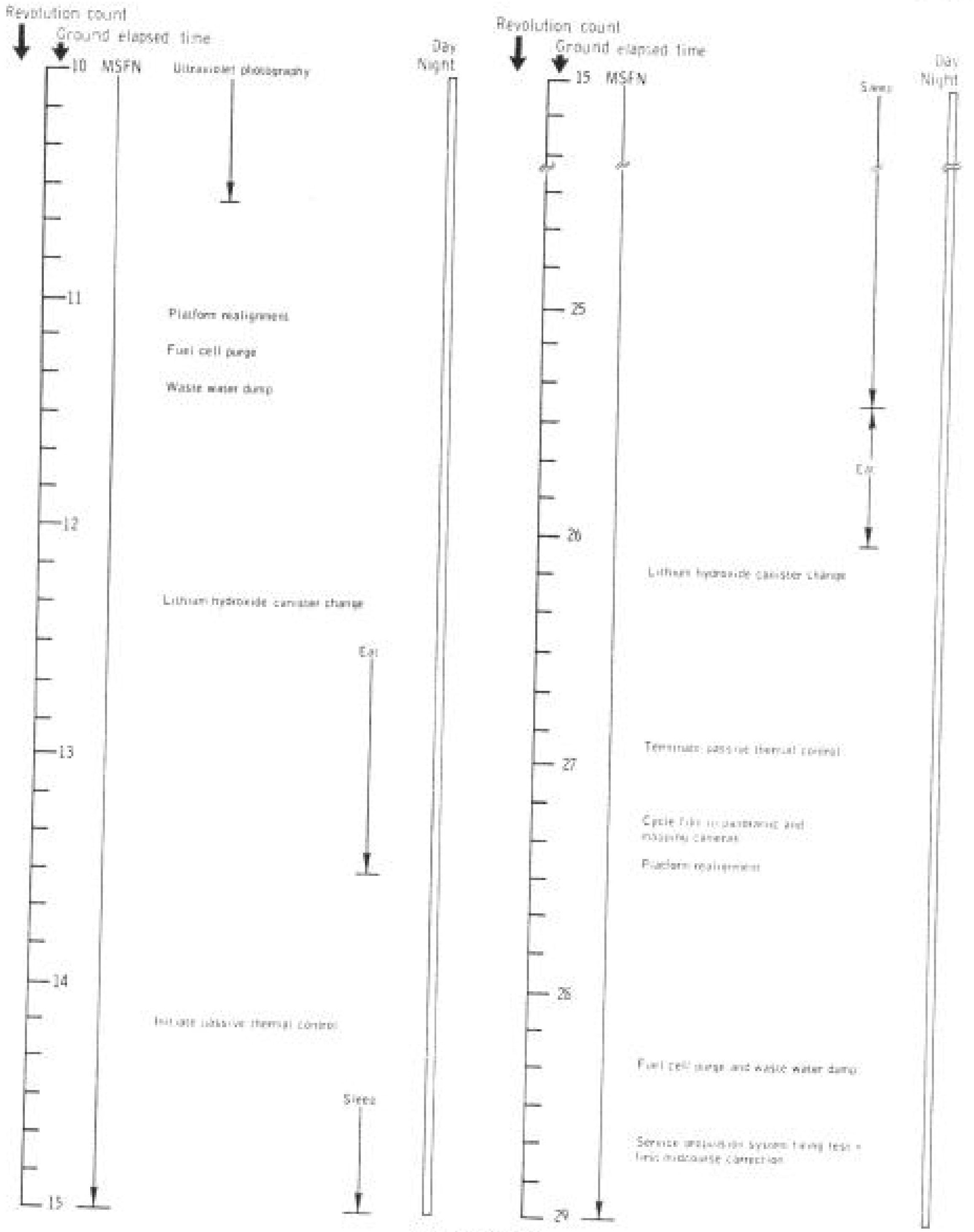
All events after landing were normal. The parachutes were released and, because of the low wind condition, settled around the command module. The recovery ship and forces were near the spacecraft at landing and recovery operations were normal.



(a) 0 to 10 hours.

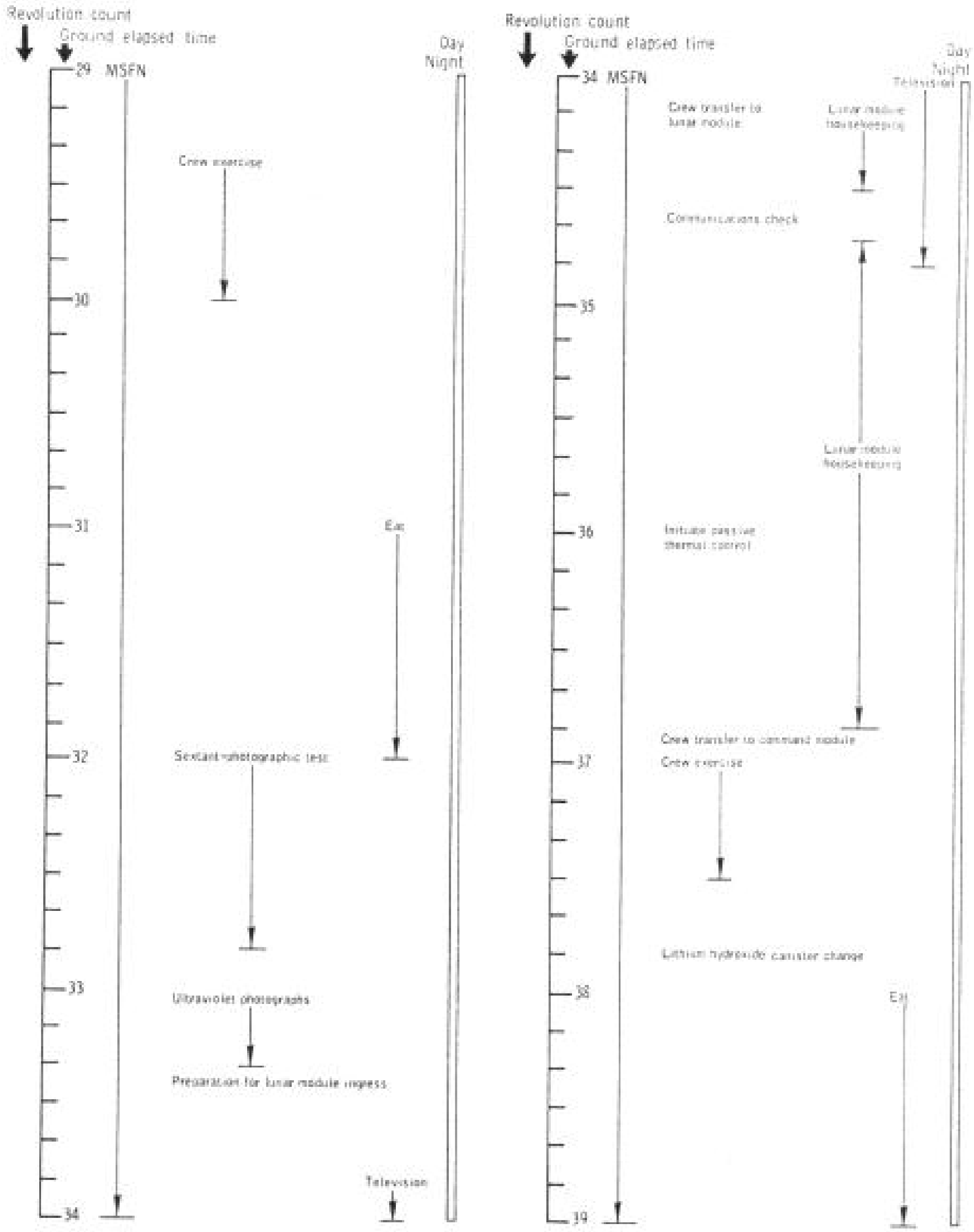
Figure 9-1. - Flight plan activities.

Abbreviated Timeline 1



(b) 10 to 29 hours.

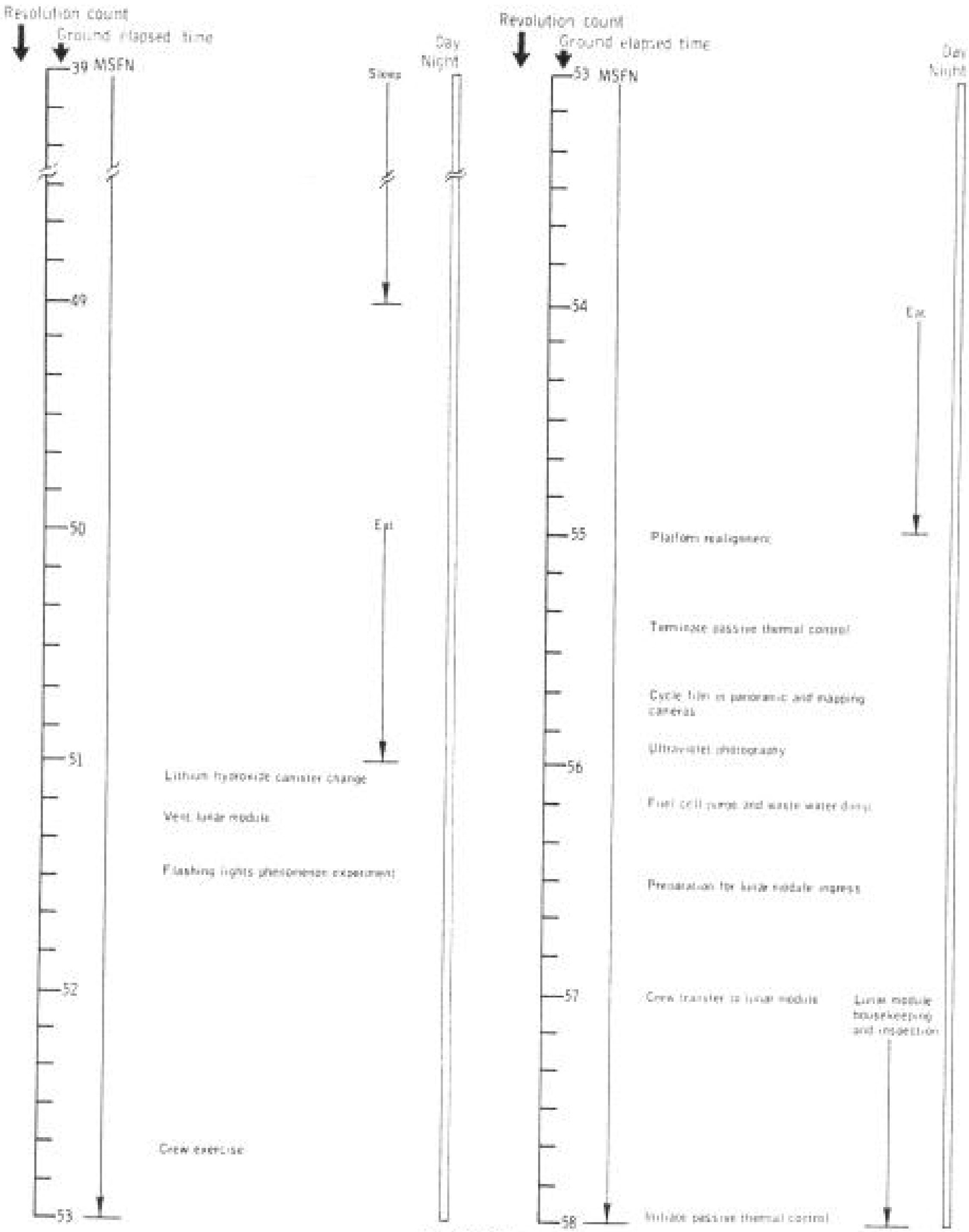
Abbreviated Timeline 2



(c) 29 to 39 hours.

Figure 9-1. - Continued.

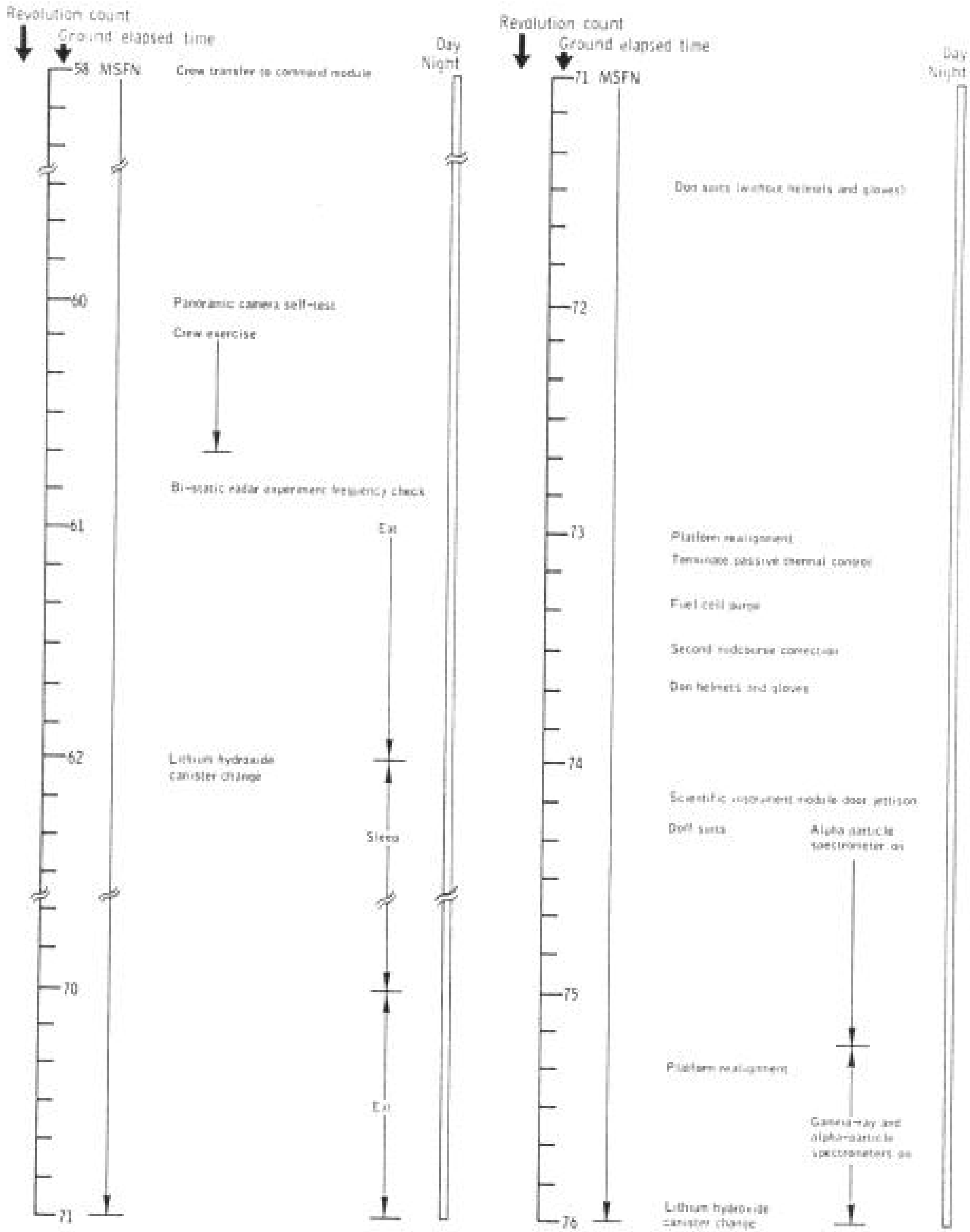
Abbreviated Timeline 3



(d) 39 to 58 hours.

Figure 9-1. - Continued.

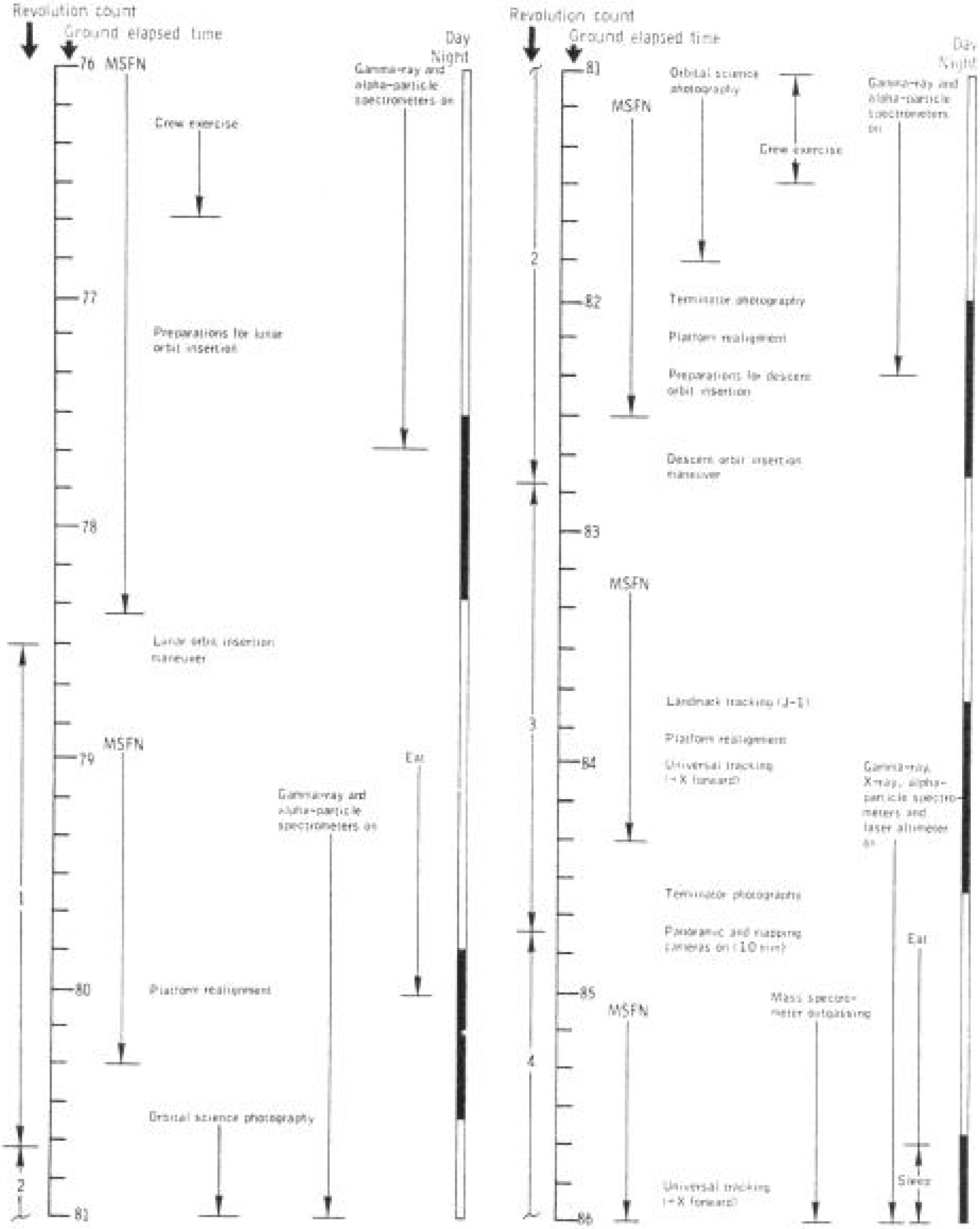
Abbreviated Timeline 4



(e) 58 to 76 hours.

Figure 9-1.- Continued.

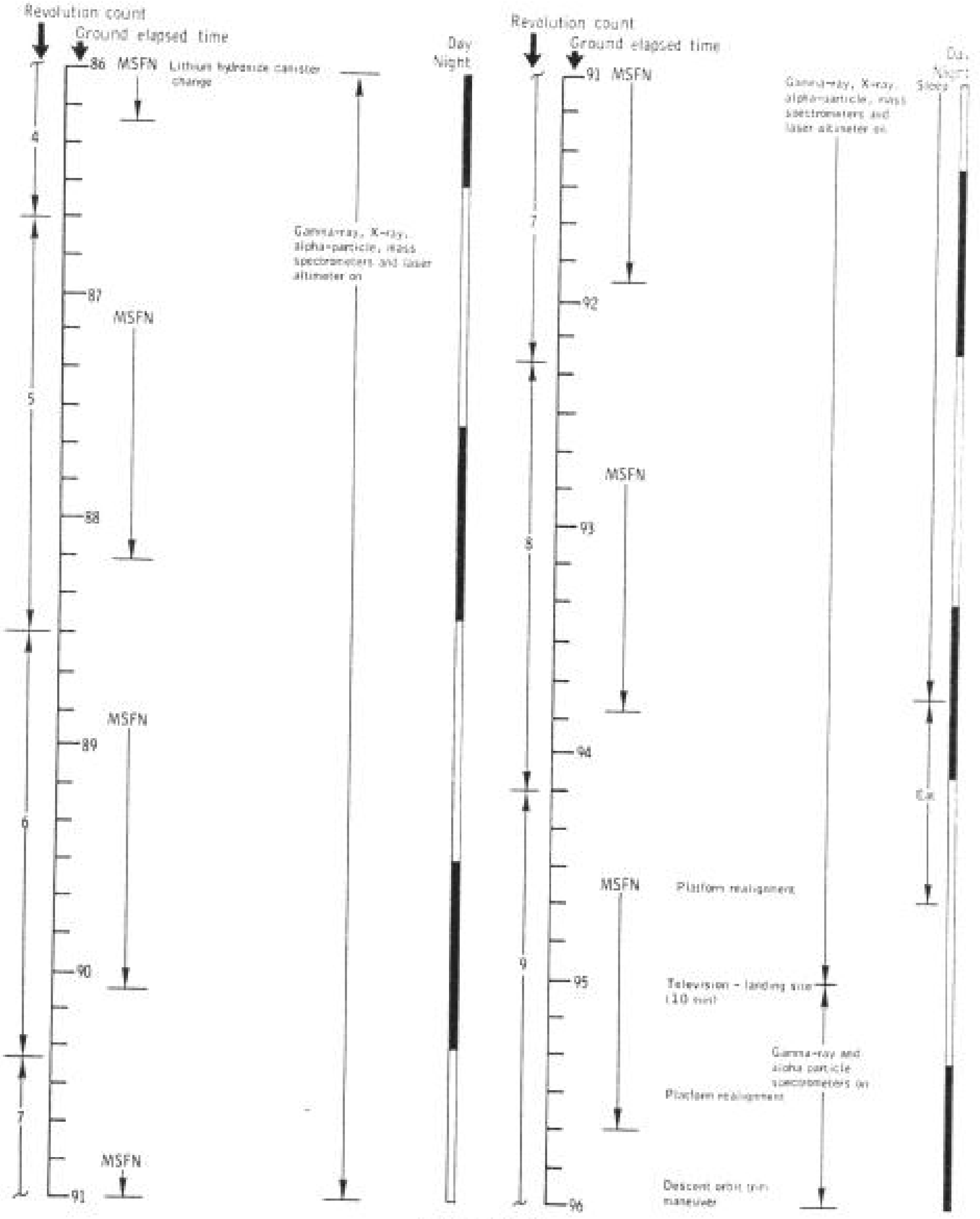
Abbreviated Timeline 5



(f) 76 to 86 hours.

Figure 9-1. - Continued.

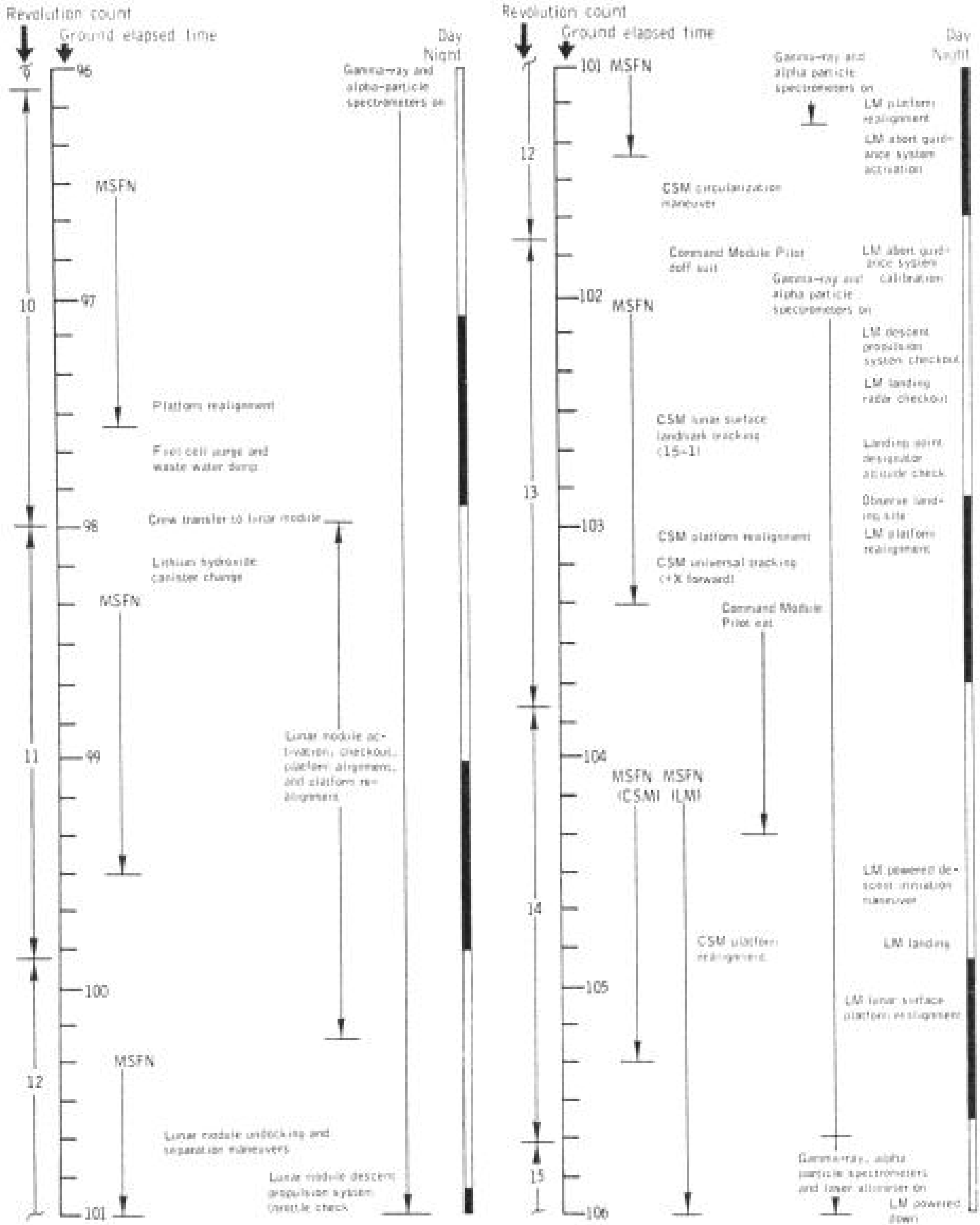
Abbreviated Timeline 6



(g) 86 to 96 hours.

Figure 9-1. - Continued.

Abbreviated Timeline 7



(m) 96 to 106 hours.

Figure 9-1. - Continued.