Apollo-11 lunar orbit rendezvous, crew report and mission report

Rendezvous

At orbital insertion, the primary guidance system showed an orbit of 47.3 by 9.5 miles, as compared to the abort guidance system solution of 46.6 by 9.5 miles. Since radar range-rate data were not available, the Manned Space Flight Network quickly confirmed that the orbital insertion was satisfactory.

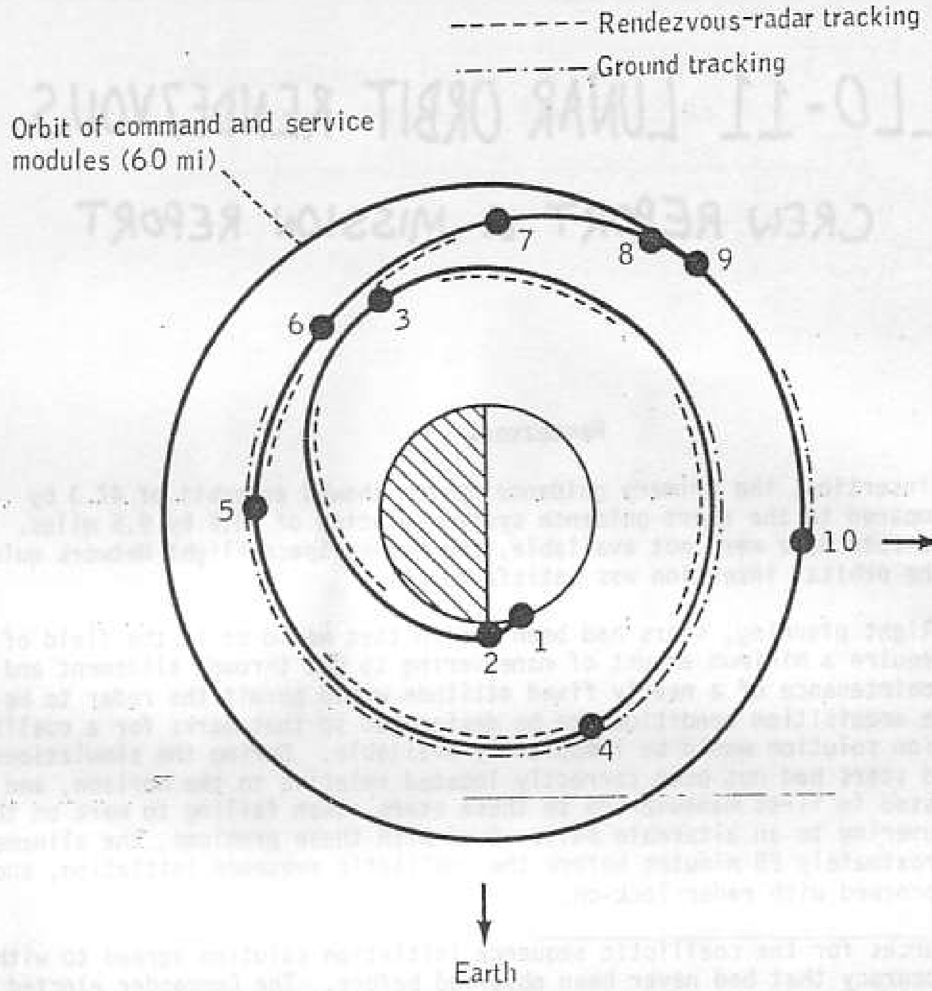
In the preflight planning, stars had been chosen that would be in the field of view and that would require a minimum amount of maneuvering to get through alinement and back in plane. This maintenance of a nearly fixed attitude would permit the radar to be turned on and the acquisition conditions to be designated so that marks for a coelliptic sequence initiation solution would be immediately available. During the simulations, these preselected stars had not been correctly located relative to the horizon, and time and fuel were wasted in first maneuvering to these stars, then failing to mark on them, and finally maneuvering to an alternate pair. Even with these problems, the alinement was finished approximately 28 minutes before the coelliptic sequence initiation, and it was possible to proceed with radar lock-on.

All four sources for the coelliptic sequence initiation solution agreed to within 0.2 ft/sec, an accuracy that had never been observed before. The Commander elected to use the primary guidance solution without any out-of-plane thrusting.

The coelliptic sequence initiation maneuver was accomplished by using the plus Z thrusters, and the radar lock-on was maintained throughout the firing. Continued navigation tracking by both spacecraft indicated a plane-change maneuver of approximately 2.5 ft/sec, but the crew elected to defer this small correction until terminal phase initiation. The small out-of-plane velocities that existed between the spacecraft orbits indicated a highly accurate lunar surface alinement. As a result of the higher-than-expected ellipticity of the command module orbit, backup chart solutions were not possible for the first two rendezvous maneuvers, and the constant-differential height maneuver had a higher-than-expected vertical component. The computers in both spacecraft agreed closely on the maneuver values, and the lunar module primary guidance computer solution was executed by using the minus X thrusters.

During the coelliptic phase, radar tracking data were inserted into the abort guidance system to obtain an independent intercept guidance solution. The primary guidance solution was 6-1/2 minutes later than planned. However, the intercept trajectory was nominal, with only two small midcourse corrections of 1.0 and 1.5 ft/sec. The line-of-sight rates were low, and the planned braking schedule was used to reach a station-keeping position.

In the process of maneuvering the lunar module to the docking attitude, while at the same time avoiding direct sunlight in the forward windows, the platform inadvertently reached gimbal lock. The docking was completed by using the abort guidance system for attitude control.



	Event	Time
1	Lift-off	124:22:00.8
2	Lunar module insertion	124:29:15.7
3	Coelliptic sequence initiation	125:19:35.0
4	Constant differential height phase	126:17:49.6
5	Terminal phase initiation	127:03:51.8
6	First midcourse correction	127:18:30.8
7	Second midcourse correction	127:33:30.8
8	Beginning of braking	127:36:57.3
9	Beginning of station keeping	127:52:05.3
10	Docking	128:03:00.0

Figure 5-19.- Ascent and rendezvous trajectory.

Rendezvous

Immediately after ascent insertion, the Commander began a platform alinement by using the lunar module telescope. During this time, the ground relayed the lunar module state vector to the command module computer to permit execution of navigation updates by using the sextant and the vhf ranging system. The lunar module platform alinement took longer than expected; consequently, the coelliptic sequence initiation program was entered into the computer approximately 7 minutes later than planned. This delay allowed less than the nominal 18 radar navigation updates between insertion and the first rendezvous maneuver. Also, the first range-rate measurement for the backup solution was missed; however, this loss was not significant because both the lunar module and the command module guidance systems performed normally. Figure 5-19 shows the ascent and rendezvous trajectories and their relationship in lunar orbit.

Prior to the coelliptic sequence initiation, the lunar module out-of-plane velocity was computed by the command module to be -1.0 ft/sec, a value small enough to be deferred until terminal phase initiation. The final lunar module solution for coelliptic sequence initiation was a 51.5-ft/sec maneuver to be performed with the Z-axis reaction control thrusters, with a planned ignition time of 125:19:34.7.

Following the coelliptic sequence initiation maneuver, the constant differential height program was called up in both spacecraft. Operation of the guidance systems continued to be normal, and successful navigation updates were obtained by using the sextant, the vhf ranging system, and the rendezvous radar. The Lunar Module Pilot reported that the backup range-rate measurement at 36 minutes prior to the constant differential height maneuver was outside the limits of the backup chart. Postflight trajectory analysis has shown that the off-nominal command module orbit (62 by 56 miles) caused the range-rate measurement to be approximately 60 ft/sec below nominal at the 36-minute data point. The command module was near pericynthion and the lunar module was near apocynthion at the measurement point. These conditions, which decreased the lunar module closure rate to below the nominal value, are apparent in figure 5-20, a relative motion plot of the two spacecraft between insertion and the constant differential height maneuver. Figure 5-20 was obtained by forward and backward integration of the last available lunar module state vector prior to loss of signal following insertion and the final constant differential height maneuver vector integrated backward to the coelliptic sequence initiation point. The dynamic range of the backup charts has been increased for future landing missions. The constant differential height maneuver was accomplished at the lunar module primary guidance computer time of 126:17:49.6.

The constant differential height maneuver was performed with a total velocity change of 19.9 ft/sec. In a nominal coelliptic flight plan with a circular target orbit for the command module, the velocity change for this maneuver would be zero. However, the ellipticity of the command module orbit required a real-time change in the rendezvous plan prior to lift-off to include approximately 5 ft/sec (applied retrograde) to compensate for the change in differential height upon arriving at this maneuver point and approximately 11 ft/sec (applied vertically) to rotate the line of apsides to the correct angle. Actual execution errors in ascent insertion and coelliptic sequence initiation resulted in an additional velocity change requirement of approximately 8 ft/sec, which yielded the actual total of 19.9 ft/sec.

Following the constant differential height maneuver, the computers in both spacecraft were configured for terminal phase initiation. Navigation updates were made, and several computer recycles were performed to obtain an early indication of the maneuver time. The final computation was initiated 12 minutes prior to the maneuver, as planned. Ignition had been computed to occur at 127:03:39, or 6 minutes 39 seconds later than planned.

Soon after the terminal phase initiation maneuver, both spacecraft passed behind the moon. At the next acquisition, the spacecraft were flying in formation in preparation for docking. The crew reported that the rendezvous was nominal, with the velocity change for the first midcourse maneuver less than 1 ft/sec and for the second approximately 1.5 ft/sec. The midcourse maneuvers were performed by thrusting the body-axis components to zero, while the lunar module plus Z axis remained pointed at the command module. The line-of-sight rates were reported to be small, and the planned braking was used for the approach to station keeping. The lunar module and command module maneuver solutions are summarized in tables 5-VI and 5-VII, respectively.

During the docking maneuver, two unexpected events occurred. In the alinement procedure for docking, the lunar module was maneuvered through the platform gimbal-lock attitude, and the docking had to be completed by using the abort guidance system for attitude control. The off-nominal attitude resulted from an added rotation to avoid sunlight interference in the forward windows. The sun elevation was approximately 20° higher than planned because the angle for initiation of the terminal phase was reached approximately 6 minutes late.

The second unexpected event occurred after docking and consisted of relative vehicle alinement excursions of as much as 15° following initiation of the retract sequence. The proper docking sequence consists of (1) initial contact, (2) lunar module plus X thrusting from initial contact to capture latch, (3) switching of the command module control from the automatic to the manual mode, (4) relative motions to be damped to within ±3°, and (5) initiation of retract to achieve hard docking. The Commander detected the relatively low velocity at initial contact and applied plus X thrusting; however, the thrusting was continued until after the misalinement excursion had developed because the Commander had received no indication of the capture event. The dynamics were complicated further when the Command Module Pilot also noticed the excursions and reversed the command module control mode from manual to automatic. At this time, both the lunar module and the command module were in the minimum-deadband attitude-hold mode, thereby causing considerable thruster firing until the lunar module was placed in maximum deadband. The spacecraft were stabilized by using manual control just prior to achieving a successful hard dock. The initial observed misalinement excursion is considered to have been caused by the continued lunar module thrusting following capture because the thrust vector does not pass through the center of gravity of the command and service modules.

The rendezvous was successful and was similar to that for Apollo 10, with all guidance and control systems operating satisfactorily. The Command Module Pilot reported that the vhf ranging broke lock approximately 25 times following ascent insertion; however, lock-on was reestablished each time, and navigation updates were successful. The lunar module reaction control propellant usage was nearly nominal.

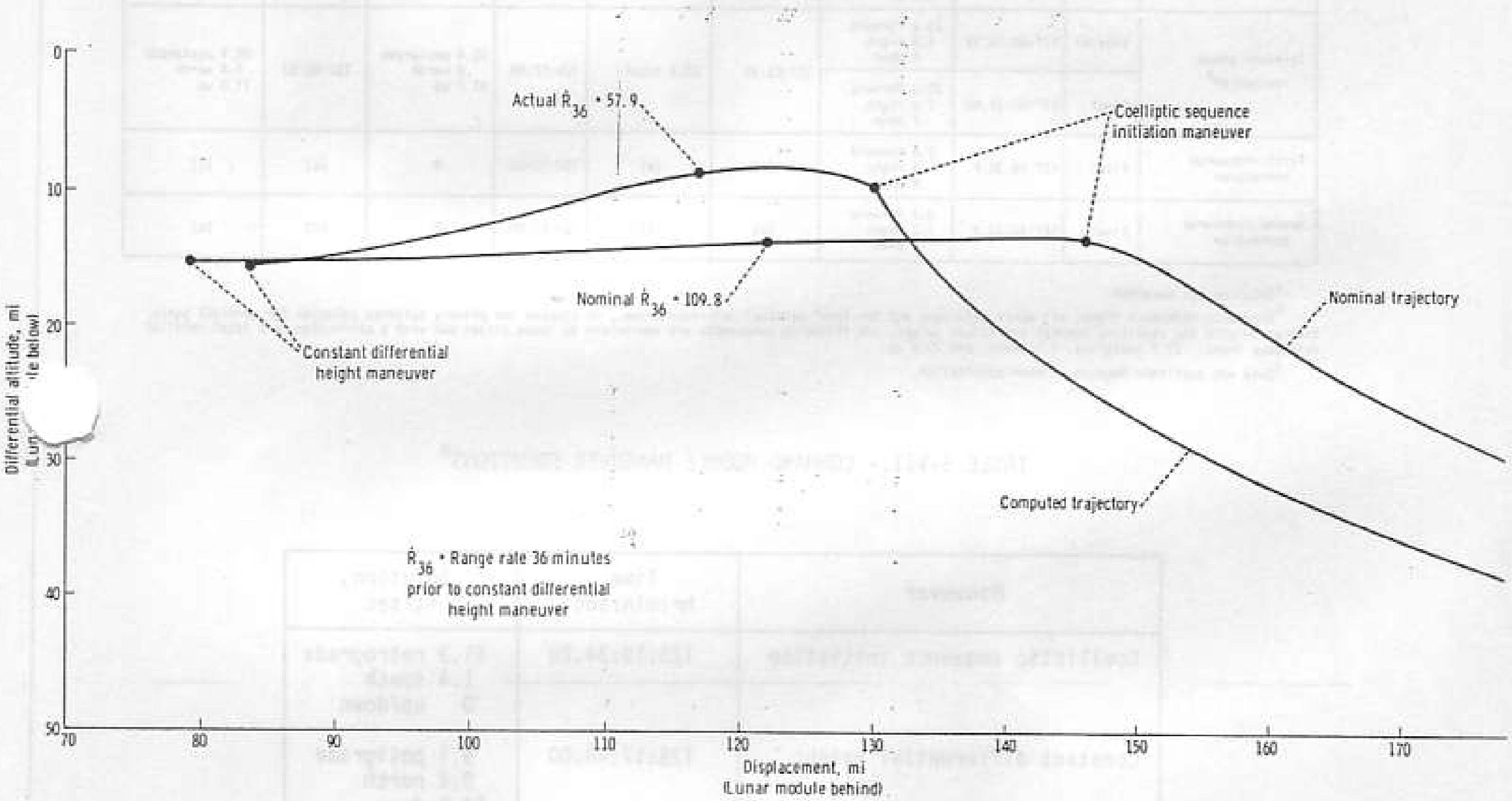


Figure 5-20.- Relative spacecraft motion during rendezvous.

TABLE 5-VI.- LUNAR MODULE MANEUVER SOLUTIONS

Maneuver	Primary guidance			Abort guidance		Real-time nominal		Actual	
	Solution	Time, hr:min:sec	Velocity, ft/sec	Time, hr:min:sec	Velocity, ft/sec	Time, hr:min:sec	Velocity, ft/sec	Time, hr:min:sec	Velocity, ft/sec
Coelliptic sequence initiation	Initial	125:19:35.48	49.4 posigrade	125:19:34.70	51.3 posigrade	125:19:35	52.9 posigrade	125:19:35	51.6 posigrade .7 south .1 down
	Final	125:19:35.48	51.5 posigrade						
Constant differential height	Initial	126:17:46.36	8.1 retrograde 1.8 south 17.7 up	(a)	(a)	126:17:42	5.1 retrograde 11.0 up	126:17:50	8.0 retrograde 1.7 south 18.1 up
	Final	126:17:46.36	8.1 retrograde 18.2 up						
Terminal phase initiation[b]	Initial	127:03:16.12	25.2 forward 1.9 right .4 down	127:03:39	23.4 total	126:57:00	22.4 posigrade .2 north 11.7 up	127:03:52	22.9 posigrade 1.4 north 11.0 up
	Final	127:03:31.60	25.0 forward 2.0 right .7 down						
First midcourse correction	Final	127:18:30.8	0.0 forward .4 right .9 down	(a)	(a)	127:12:00	0	(c)	(c)
Second midcourse correction	Final	127:33:30.8	0.1 forward 1.2 right .5 down	(a)	(a)	127:27:00	0	(c)	(c)

[a] Solution not obtained.

[b] Body-axis reference frame; all other solutions are for local-vertical reference frame. To compare the primary guidance solution for terminal phase initiation with the real-time nominal and actual values, the following components are equivalent to those listed but with a correction to a local-vertical reference frame: 22.7 posigrade, 1.5 north, and 10.6 up.

[c] Data not available because of moon occultation.

TABLE 5-VII.- COMMAND MODULE MANEUVER SOLUTIONS[a]

Maneuver	Time, hr:min:sec	Solution, ft/sec
Coelliptic sequence initiation	125:19:34.70	51.3 retrograde 1.4 south 0 up/down
Constant differential height	126:17:46.00	9.1 posigrade 2.4 north 14.6 down
Terminal phase initiation	[b] 127:02:34.50 [c] 127:03:30.8	 22.9 retrograde 1.7 south 11.9 down
First midcourse correction	127:18:30.8	1.3 retrograde .6 south
Second midcourse correction	127:33:30.8	.1 retrograde 1.0 south .6 down

[a] All solutions are in the local-horizontal coordinate frame.

[b] Initial computed time of ignition using nominal elevation angle of 208.3° for terminal phase initiation.

[c] Final solution using lunar module time of ignition.