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Orbital Mission Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

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By Allan L. DuPont and James D. Alexander
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OPERATIONAL LM ABORT AND RESCUE PLAN

FOR APOLLO 14 (MISSION H-3)

By Allan L. DuPont and James D. Alexander

1.0 SUMMARY

The purpose of this report is to present the changes and additions for the operational lunar module abort and rescue plan from Apollo 13 (ref. 1) to Apollo 14. The abort and rescue plan for Apollo 14 is essentially the same as for Apollo 13 except for the procedures associated with the new nominal direct rendezvous. Therefore, detailed explanations and data are presented only for failures that occur during the nominal ascent rendezvous.

As for Apollo 13, the Apollo 14 no-PDI-0 abort requires a 1-2/3 revolution rendezvous after an initial phasing maneuver. The no-PDI plus 12 minute aborts and early aborts for each PDI region require a 2-2/3 revolution rendezvous involving what is referred to as the HAM-CSI/CDH sequence. For aborts after approximately 6 minutes into the nominal powered descent opportunity and after approximately 9 minutes into the backup powered descent opportunity, the normal one-revolution CSI/CDH sequence is applied. The variable targeting regions extend to PDI plus approximately 15 minutes for both landing opportunities. The T2-1 and T2-2 rendezvous plans require 2-2/3 and 1-2/3 revolutions, respectively. Also, TPI again is scheduled at 16 minutes before the end of darkness to maintain an adequate Δt between CDH and TPI without causing large radial ΔV components at CDH.

The major change is the bailout abort or rescue procedure used when systems or execution errors prevent a completion of the nominal direct ascent technique. Either technique requires approximately 1-2/3 revolutions and consists of the following maneuvers: phasing maneuver (bailout maneuver) at insertion plus 5 minutes for the LM or at insertion plus 12 minutes for the CSM; CSI maneuver at insertion plus 55 minutes for either vehicle; CDH maneuver one-half period after CSI; TPI approximately 42 minutes after CDH at approximately 16 minutes before daylight; and TPF approximately 130° of target travel after TPI.

2.0 INTRODUCTION

The changes to the LM abort and rescue plan from Apollo 13 to Apollo 14 result primarily from the cnage to the nominal rendezvous profile. That is, the 1-2/3 revolution coelliptic rendezvous used for Apollo 13 is not the nominal profile for Apollo 14. A direct rendezvous is now used, with lift-off approximately 2.5 minutes earlier than for the coelliptic rendezvous, TPI 38 minutes after insertion, and TPF approximately 130° of target travel later.

The abort and rescue techniques for the descent phase of Apollo 14 are unchanged from Apollo 13. However, a new technique called the bailout rendezvous technique is now used for aborts and rescues for which the LM has lifted off the lunar surface at approximately the nominal time but is unable to continue the direct rendezvous because of contingency in the systems and/or the trajectory. The bailout rendezvous is a 1-2/3 revolution rendezvous beginning with a phasing maneuver near insertion followed by a standard coelliptic sequence.

One such condition for using the bailout technique is an uncorrectable overspeed or underspeed at insertion. For this situation, the LM is able to use the bailout technique for the region from approximately 50-fps underspeed to approximately 135-fps overspeed. However, the CSM can use only the bailout technique for rescues from approximately 18-fps underspeed to approximately 175-fps overspeed. For the region from 50- to 18-fps underspeed, the CSM must use the CSI-dwell sequence initiated at insertion plus 20 minutes. This high-dwell sequence is also used for anytime lift-off cases. For overspeeds greater than 170 fps, the CSM must use the manual-insertion type DKI in order to perform a rescue.

Data have been presented for the LM- and CSM-active bailouts and related techniques that are associated with the overspeed/underspeed conditions. Detailed data, such as state vectors, detailed maneuver tables, and MSFN coverage, are not included. For a number of cases, such detailed data are available upon request. In this report, the Δt between events, rather than the ground elapsed time, is emphasized because these techniques and sequences are applicable for all acceptable launch dates and lunar landing sites.

3.0 SYMBOLS AND DEFINITIONS

3.1 Symbols and Abbreviations

CDH	constant differential height (coelliptic) maneuver
CSI	coelliptic sequence initiation
CSM	command and service modules
DI	dwell initiation
DKI	docking initiation processor (in RTCC)
DT	dwell termination
HAM	height adjustment maneuver of HAM-CSI/CDH sequence (ref. 1)
LM	lunar module
MSFN	Manned Space Flight Network
NC1	DKI phase adjustment maneuver
NH	DKI height adjustment maneuver
NSR	DKI coelliptic maneuver
no-PDI	powered descent is not initiated
no-PDI-0	abort point one-half revolution after CSM circularization and one revolution prior to the nominal PDI
PDI	powered descent initiation
TPI	terminal phase initiation
TPF	terminal phase finalization
T2	single-point preferred lift-off after landing
Δh	differential altitude
Δt	elapsed time
ΔV	velocity increment

3.2 Definitions

bailout	section 4.1
coelliptic Δh	Δh during the coelliptic phase for which the differential altitude remains nearly constant
height adjustment maneuver of DKI	external maneuver which sets up the establishment of the desired coelliptic Δh 180° later
high-dwell sequence	section 4.2
LM-active rendezvous	rendezvous for which the LM is the totally active vehicle
manual insertion	section 4.3
phase adjustment maneuver of DKI	external maneuver which establishes the desired phase (central) angle at the subsequent maneuver
rescue	nonnominal rendezvous sequence for which the CSM performs one or more of the rendezvous maneuvers; for this report, it is assumed that the CSM is totally active during a rescue
theoretical ΔV	Keplerian impulsive ΔV; for example, the TPF ΔV for the impulsive intercept velocity match

4.0 RENDEZVOUS TECHNIQUES

The abort and rescue rendezvous techniques involved in the operational plan are described in this section. There is basically one new LM-active maneuver sequence, and it is used when the LM is unable to continue the direct rendezvous because of a contingency situation. This sequence, referred to as the bailout sequence, requires approximately 1-2/3 revolutions to rendezvous and uses the basic CSI-CDH coelliptic sequence.

Three rescue techniques are involved. If the LM is in a situation that requires a rescue, the CSM will utilize one of the following maneuver sequences: a CSM bailout sequence, a CSM high-dwell sequence, or a CSM DKI sequence similar to the manual-insertion DKI sequence.

4.1 Bailout Sequence

This five-impulse sequence is initiated by a phasing maneuver referred to as the bailout maneuver; it is directed along the local horizontal and is performed either at insertion plus 5 minutes for the LM-active sequence or at insertion plus 12 minutes for the CSM-active sequence.

The initial maneuver is followed by the CSI-CDH coelliptic sequence, with CSI at insertion plus 55 minutes for either vehicle. CDH is scheduled one-half period after CSI, with a separate plane change maneuver scheduled between CSI and CDH. The technique is targeted to obtain a Δh of approximately 15 n. mi. TPI occurs approximately 16 minutes before daylight. TPF is 130° of target travel after TPI. Figures 1 and 2 illustrate the bailout sequence.

4.2 High-Dwell Rescue Sequence

The high-dwell rescue sequence is essentially a six-maneuver CSM-active sequence initiated by a local horizontal phasing maneuver called dwell initiation (DI) at insertion plus 20 minutes. Dwell termination (DT) occurs at approximately the same longitude as the DI maneuver with approximately three revolutions between DI and DT. The dwell phase is followed by the CSI-CDH coelliptic sequence, with CSI 30 minutes after DT and CDH one-half period after CSI. The Δh is targeted for approximately 15 n. mi., with TPI lighting conditions the same as for the bailout technique. Figure 3 illustrates this rescue sequence.

4.3 Manual-Insertion-Type Rescue Sequence

This rescue technique is initiated by a ground-computed DKI plan at approximately insertion plus 110 minutes. The LM, if able, performs a 10-fps horizontal posigrade boost maneuver at approximately the first LM line-of-apsides after insertion. The initial rescue maneuver, a phase adjust maneuver (NC1), is performed approximately 110 minutes after insertion, approximately over the landing site. In real time, an attempt will be made to place this maneuver on the LM line-of-apsides to minimize the radial velocity component of the CDH maneuver. The second maneuver (NH), which is a height adjustment maneuver, is performed 1/2, 1-1/2, or 2-1/2 revolutions after NC1 depending on the LM apolune altitude. The onboard CSI logic would be used to compute the NH maneuver if pre-CSI tracking were obtainable. See figure 1(g) in reference 1 for an illustration of this rescue technique.

5.0 DISCUSSION

The LM-active and CSM active maneuver sequences that apply to the various LM failure situations are presented in this section. The discussion is divided into the different phases, and the failure situations are discussed only to the extent that they determine the procedures. A summary of the plan is presented in figure 4. Relative motion plots are presented for specific cases in each phase. Relative range time histories are also included for these cases. It is emphasized that the LM is always below during the coelliptic and terminal phases regardless of which vehicle is active. A coelliptic Δh of 15 n. mi. and TPI lighting of 16 minutes prior to daylight are the standard targeted values.

5.1 Discussion of the Bailout Sequence

5.1.1 LM-active rendezvous.- The bailout sequence is applicable when the decision to abort the direct rendezvous sequence is made after lift-off. Three possible reasons for an abort decision leading to the bailout technique are a velocity error at insertion that is not corrected by either a trim or a tweak maneuver, a tweak maneuver greater than 60-fps total ΔV or a post-tweak perilune altitude less than 5 n. mi.

The abort technique is the CSI/CDH sequence preceded by a phasing maneuver called the bailout maneuver. This phasing maneuver is ground-computed and is performed at insertion plus 5 minutes. CSI is performed 55 minutes after insertion. CDH is one-half period (n=1) after CSI and is targeted for a coelliptic Δh of 15 n. mi., with TPI 16 minutes prior to daylight and 130° of target travel later.

Figure 5 presents range and relative motion data for the bailout technique after nominal lift-off and insertion. Figure 6 provides similar information for an uncorrected insertion underspeed of 50 fps. This is approximately the minimum uncorrected underspeed acceptable at insertion because the LM would be on an impact trajectory with a larger underspeed. Figure 7 provides the same information for a LM uncorrected overspeed of 135 fps. At this point, the resulting bailout maneuver results in a perilune below the minimum allowable of 5 n. mi. Therefore, this is the maximum uncorrected overspeed allowed for which the LM bailout is applicable.

5.1.2 Rescue.- The rescue bailout technique is similar to the abort technique and is used whenever the LM is unable to perform the bailout maneuver. Again, the sequence is the CSI/CDH technique preceded by a ground-computed phasing maneuver. However, the CSM bailout maneuver is performed at insertion plus 12 minutes for the rescue case, with CSI 43 minutes after the bailout maneuver. CDH is one-half period after CSI and is targeted for a Δh of 15 n. mi. above the LM orbit. TPI is at the same g.e.t. as for the LM-active case, with TPF 130° of target travel later.

Figure 8 illustrates relative range and relative motion data for a CSM-active rendezvous after an on-time LM lift-off and an accurate LM insertion. Figure 9 contains the same information for a CSM bailout after a LM uncorrected insertion underspeed of 18 fps. After the CSI maneuver, this rendezvous reaches the low perilune limit of 5 n. mi. The CSM must pass through perilune to reach CDH in this underspeed area. Therefore, a LM insertion underspeed of 18 fps is the underspeed limit to the applicability of the CSM bailout technique. Figure 10 presents relative range and relative motion data for a LM uncorrected overspeed of 175 fps. This represents the LM insertion overspeed limit for use of the CSM bailout technique for the same reasons described previously. It should be noted that the CSM is able to take over the rescue during any of the rendezvous maneuvers.

5.2 Discussion of the High-Dwell Rescue Sequence

A LM insertion underspeed less than 18 fps allows the use of the CSM bailout technique. Also, if the LM is able to perform the bailout maneuver after any overspeed or underspeed, the CSM can perform essentially a "mirror image" CSI/CDH sequence.

However, if the LM is unable to maneuver after inserting with an underspeed greater than 18 fps, the CSM must use the high-dwell rendezvous sequence. This technique has been revised from that presented in reference 1 and now consists of ground-computed phasing maneuvers followed by the CSI/CDH sequence. The initial maneuver, dwell initiation, is performed 20 minutes after insertion, placing the CSM in an orbit with an apolune above 300 n. mi. Another phasing maneuver, dwell termination, is performed at approximately the same longitude as the DI maneuver, with at least three CSM revolutions between DI and DT. If required, an additional tweak phasing maneuver can be performed between DI and DT at each CSM crossing of the DI longitude.

The CSI/CDH sequence described previously completes the rendezvous, with CSI performed 30 minutes after the DT maneuver. The revised high-dwell sequence is being used because the range prior to CSI allows on-board tracking by either vehicle.

Figure 11 provides relative range a relative motion data for a 50-fps LM uncorrected underspeed at insertion.

5.3 Discussion of the Manual-Insertion-Type Rescue Sequence

The manual-insertion sequence (ref. 1) is used for situations in which a LM uncorrected overspeed at insertion is greater than approximately 175 fps. The maneuvers are ground-computed from the RTCC program and begin with a phasing maneuver (NC1) performed approximately 110 minutes after insertion. The second maneuver is a height maneuver (NH) that is performed an odd number of half revolutions after NC1 (i.e., one-half revolution later, 1-1/2 revolutions later, etc.). The factors that determine the necessary number of phasing revolutions are the total ΔV expended for the sequence and the total time necessary to rendezvous. The third maneuver, performed one-half revolution after NH, is the co-elliptic maneuver (NSR) and is targeted for a Δh of 15 n. mi. CSM TPI is 16 minutes prior to daylight, with TPF approximately 130° of target travel later.

Figure 12 illustrates relative range and relative motion data for a CSM rescue after a LM uncorrected overspeed of 180 fps.

5.4 Specific Cases Available Upon Request

The following specific cases have been generated and placed on tape and can be made available upon request to the authors. The detailed data for these cases include state vectors before and after each maneuver, detailed maneuver tables, exact lighting, and MSFN coverage.

a. LM-active no-PDI-0 abort

b. Rescue after accurate no-PDI-0 abort maneuver

c. Rescue after partial no-PDI-0 abort maneuver

   1. Partial ΔV = 0 fps, phasing orbits = 2 (n=4)

   2. Partial ΔV = 20 fps, phasing orbits = 2 (n=4)

   3. Partial ΔV = 20 fps, phasing orbits = 1 (n=2)

d. LM-active no-PDI-1 plus 12 minute abort

e. Rescue after accurate no-PDI-1 plus 12 minute abort

f. Rescue after partial no-PDI-1 plus 12 minute abort

1. Partial ΔV = 0 fps, phasing orbits = 3 (n=6)
2. Partial ΔV = 20 fps, phasing orbits = 3 (n=6)
3. Partial ΔV = 20 fps, phasing orbits = 2 (n=4)
4. Partial ΔV = 60 fps, phasing orbits = 2 (n=4)
5. Partial ΔV = 60 fps, phasing orbits = 1 (n-2)

g. LM-active no-PDI-2 plus 12 minute abort

h. Rescue after accurate no-PDI-2 plus 12 minute abort

i. Rescue after partial no-PDI-2 plus 12 minute abort

1. Partial ΔV = 0 fps, phasing orbits = 5 (n=10)
2. Partial ΔV = 5 fps, phasing orbits = 5 (n=10)
3. Partial ΔV = 5 fps, phasing orbits = 4 (n=8)
4. Partial ΔV = 20 fps, phasing orbits = 4 (n=8)
5. Partial ΔV = 20 fps, phasing orbits = 3 (n=6)
6. Partial ΔV = 50 fps, phasing orbits = 3 (n=6)
7. Partial ΔV = 50 fps, phasing orbits = 2 (n=4)
8. Partial ΔV = 95 fps, phasing orbits = 2 (n=4)
9. Partial ΔV = 95 fps, phasing orbits = 1 (n=2)

j. LM-active rendezvous following an abort each minute during PDI-1

k. LM-active rendezvous following abort at T2-1

l. LM-active rendezvous following abort each minute during PDI-2

m. LM-active rendezvous following abort at T2-2

n. LM-active direct rendezvous with LM bailout

o. LM-active direct rendezvous with CSM bailout

p. CSM rescue following manual LM insertion

   1. Low orbit

   2. Medium orbit

   3. High orbit

q. CSM rescue after LM contingency insertion into a 10- by 10-n. mi. orbit

6.0 CONCLUSIONS

The information and data discussed in this report present the operational abort and rescue plan for cases resulting from an attempt to execute the nominal direct ascent rendezvous profile. The supplementary specific data, which are available upon request, can provide a basis for the various consumables, time line, software, and propulsion analyses.

With two exceptions, reference 1 should provide accurate information for abort and rescue techniques for the remaining situations, including pre-PDI aborts, powered descent aborts, and aborts from the lunar surface. The exceptions are (1) the high-dwell sequence described in reference 1, which has been revised to the sequence described in this report, and (2) lift-off from the lunar surface for the manual insertion technique, which should be at 11.5 minutes instead of 9 minutes after the nominal time.

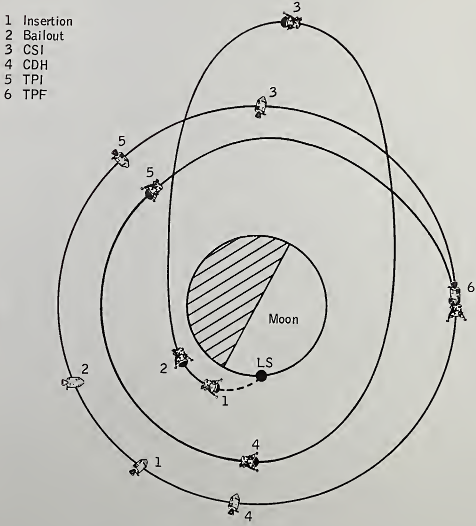


Figure 1.- LM-active rendezvous following a LM bailout maneuver.

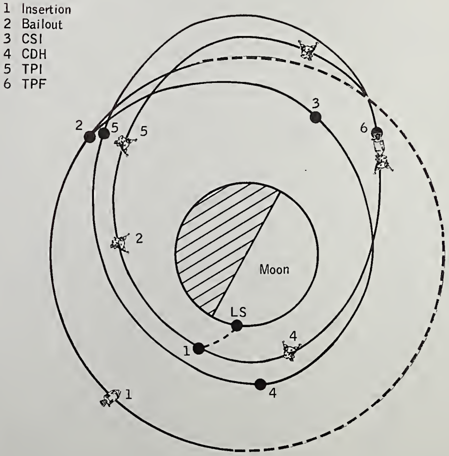
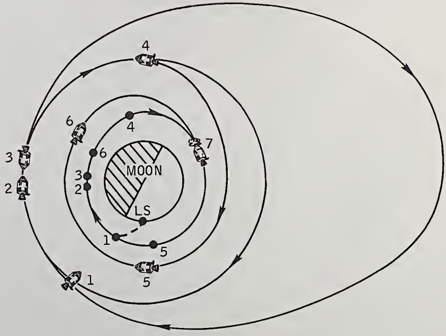


Figure 2.- CSM-active rendezvous following a CSM bailout maneuver.



Event

1 Insertion

2 Dwell initiation (DI)

3 Dwell termination (DT)

4 CSI

5 CDH

6 TPI

7 TPF

Figure 3.- CSM-active hi-dwell rescue sequence.

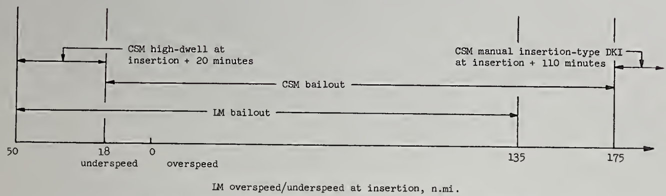
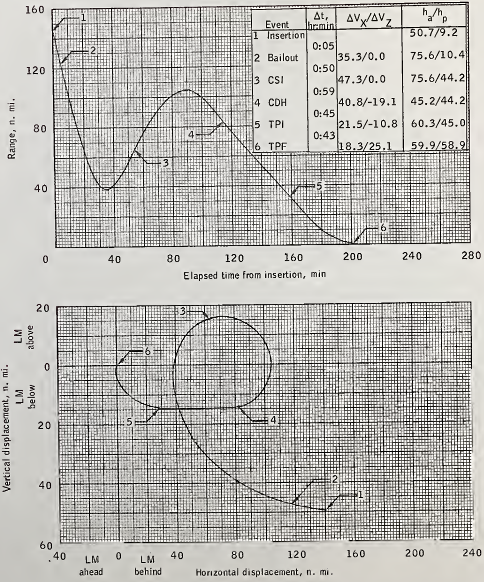


Figure 4.- Recommended rendezvous techniques for aborts and rescues after an on-time lift-off and a contingency orbit insertion.



Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			50.7/9.2
	0:05		
2 Bailout		35.3/0.0	75.6/10.4
	0:50		
3 CSI		47.3/0.0	75.6/44.2
	0:59		
4 CDH		40.8/-19.1	45.2/44.2
	0:45		
5 TPI		21.5/-10.8	60.3/45.0
	0:43		
6 TPF		18.3/25.1	59.9/58.9

Figure 5.- Range and relative motion (curvilinear, CSM-centered) data for a LM-active rendezvous following a LM bailout maneuver at insertion plus 5 minutes.

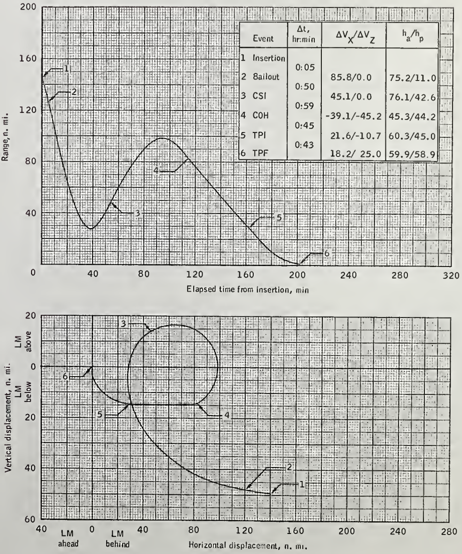
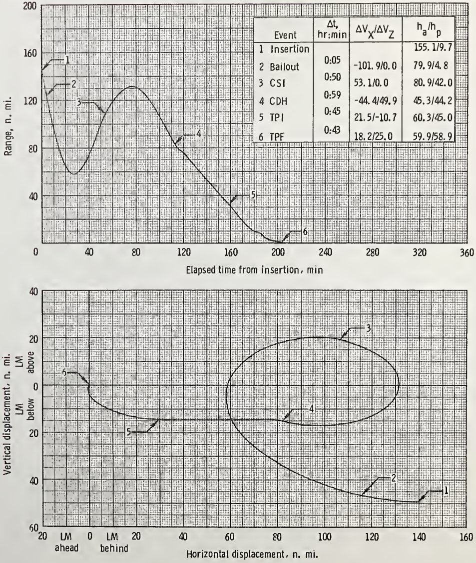
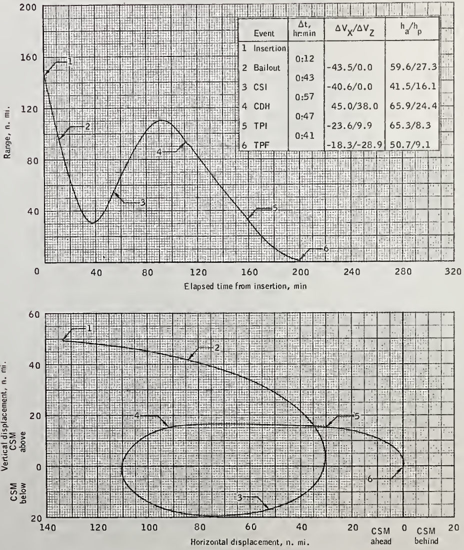


Figure 6.- Range and relative motion (curvilinear, CSM-centered) data for a LM-active rendezvous following a LM bailout maneuver for an insertion underspeed of 50 feet per second.



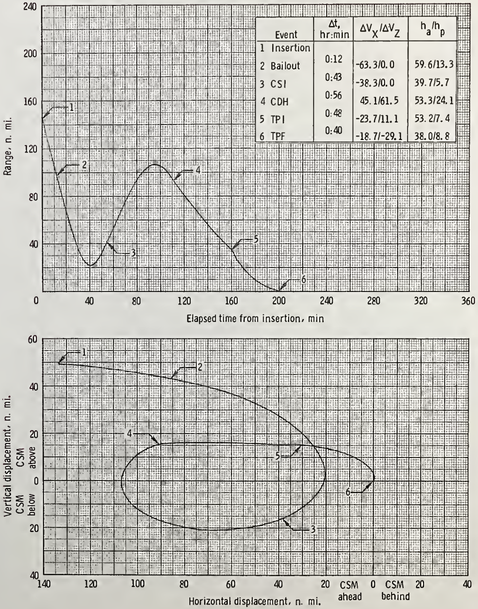
Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			155.1/9.7
2 Bailout	0:05	-101.9/0.0	79.9/4.8
3 CSI	0:50	53.1/0.0	80.9/42.0
4 CDH	0:59	-44.4/49.9	45.3/44.2
5 TPI	0:45	21.5/-10.7	60.3/45.0
6 TPF	0:43	18.2/25.0	59.9/58.9

Figure 7. - Range and relative motion (curvilinear, CSM-centered) data for a LM-active rendezvous following a LM bailout maneuver for an insertion overspeed of 135 feet per second.



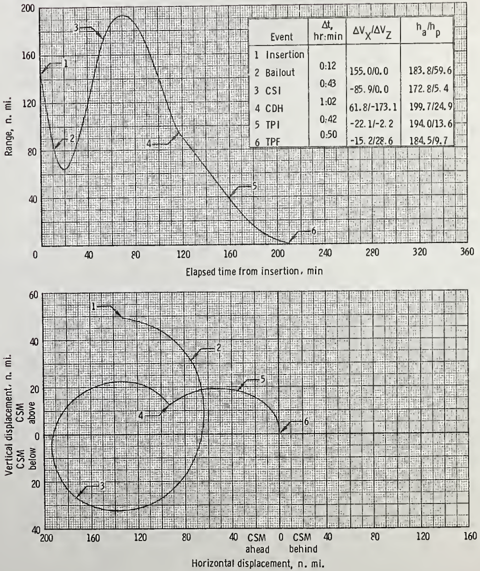
Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			
	0:12		
2 Bailout		-43.5/0.0	59.6/27.3
	0:43		
3 CSI		-40.6/0.0	41.5/16.1
	0:57		
4 CDH		45.0/38.0	65.9/24.4
	0:47		
5 TPI		-23.6/9.9	65.3/8.3
	0:41		
6 TPF		-18.3/-28.9	50.7/9.1

Figure 8.- Range and relative motion (curvilinear, LM-centered) data for a CSM-active rendezvous following a CSM bailout maneuver at insertion plus 12 minutes.



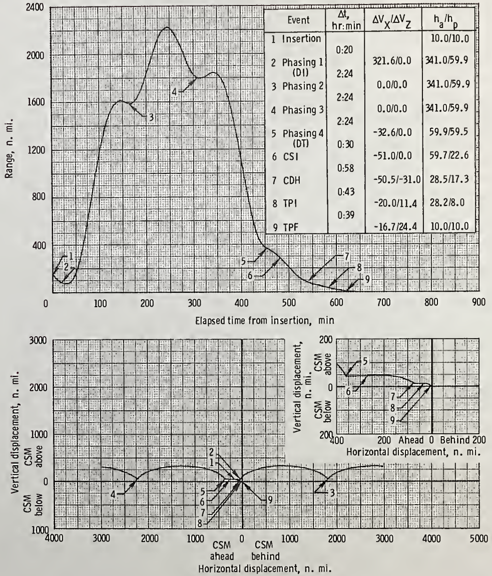
Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			
	0:12		
2 Bailout		-63.3/0.0	59.6/13.3
	0:43		
3 CSI		-38.3/0.0	39.7/5.7
	0:56		
4 CDH		45.1/61.5	53.3/24.1
	0:48		
5 TPI		-23.7/11.1	53.2/7.4
	0:40		
6 TPF		-18.7/-29.1	38.0/8.8

Figure 9.- Range and relative motion (curvilinear, LM-centered) data for a CSM-active rendezvous following a CSM bailout maneuver for an insertion underspeed of 18 feet per second.



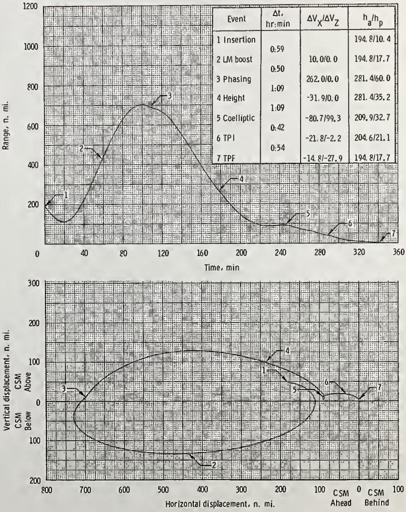
Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			
2 Bailout	0:12	155.0/0.0	183.8/59.6
3 CSI	0:43	-85.9/0.0	172.8/5.4
4 CDH	1:02	61.8/-173.1	199.7/24.9
5 TPI	0:42	-22.1/-2.2	194.0/13.6
6 TPF	0:50	-15.2/28.6	184.5/9.7

Figure 10. - Range and relative motion (curvilinear, LM-centered) data for CSM-active rendezvous following a CSM bailout maneuver for an insertion overspeed of 170 feet per second.



Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			10.0/10.0
	0:20		
2 Phasing 1 (DI)		321.6/0.0	341.0/59.9
	2:24		
3 Phasing 2		0.0/0.0	341.0/59.9
	2:24		
4 Phasing 3		0.0/0.0	341.0/59.9
	2:24		
5 Phasing 4 (DT)		-32.6/0.0	59.9/59.5
	0:30		
6 CSI		-51.0/0.0	59.7/22.6
	0:58		
7 CDH		-50.5/-31.0	28.5/17.3
	0:43		
8 TPI		-20.0/11.4	28.2/8.0
	0:39		
9 TPF		-16.7/24.4	10.0/10.0

Figure 11. - Range and relative motion (curvilinear, LM-centered) data for a CSM-active rendezvous following a LM insertion with an underspeed of 50 feet per second.



Event	Δt, hr:min	$\Delta V_X/\Delta V_Z$	h_a/h_p
1 Insertion			194.8/10.4
	0:59		
2 LM boost		10.0/0.0	194.8/17.7
	0:50		
3 Phasing		262.0/0.0	281.4/60.0
	1:09		
4 Height		-31.9/0.0	281.4/35.2
	1:09		
5 Coelliptic		-80.7/99.3	209.9/32.7
	0:42		
6 TPI		-21.8/-2.2	204.6/21.1
	0:54		
7 TPF		-14.8/-27.9	194.8/17.7

Figure 12. - Range and relative motion (curvilinear, LM-centered) data for a CSM-active rendezvous following a LM insertion with an overspeed of 180 feet per second.

REFERENCES

1. Lunar Contingency Rendezvous Working Group: Operational LM Abort and Rescue Plan for Apollo 13 (Mission H-2), Volume II - Rendezvous and Rescue. MSC IN 70-FM-9, Jan. 30, 1970.