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MSC INTERNAL NOTE NO. 69-FM-175

June 27, 1969

OPERATIONAL LM ABORT AND RESCUE PLAN FOR APOLLO 11 (MISSION G)

VOLUME II

RENDEZVOUS AND RESCUE

Orbital Mission Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FROM : FM13/Chief, Mission Planning Support Office

SUBJECT: Apollo 11 Operational LM Abort and Rescue Plan, Volume II--Rendezvous and Rescue

The attached document presents the LM rendezvous and CSM rescue plans following a LM abort during descent. The Preliminary Plans as contained in MSC I.N. 68-FM-268 are updated and replaced by the attached document. The most significant change has been the onboard variable insertion (velocity) targeting which permits the initiation of the normal co-elliptic sequence approximately 50 minutes after insertion. Other developments that have changed the plan are described in the document.

Volume I--Aborts from Powered Descent and Ascent--is expected to be available by July 3, 1969.

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APPROVED BY:

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PROJECT APOLLO

OPERATIONAL LM ABORT AND RESCUE PLAN FOR APOLLO 11 (MISSION G) VOLUME II - RENDEZVOUS AND RESCUE

By Lunar Contingency Rendezvous Working Group
Orbital Mission Analysis Branch

June 27, 1969

MISSION PLANNING AND ANALYSIS DIVISION
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OPERATIONAL LM ABORT AND RESCUE PLAN

FOR APOLLO 11 (MISSION G)

By Lunar Contingency Rendezvous Working Group

1.0 SUMMARY

The purpose of this report is to present the operational lunar module (LM) abort and rescue plan for Apollo 11 (Mission G). Explanations and data are presented for both the first and second landing opportunities after descent orbit insertion (DOI), the second opportunity being one revolution after the nominal first opportunity. Included are non-time-critical abort and rescue plans for failures that occur anytime from command/service module (CSM) separation to approximately 9.5 minutes after touchdown for the first landing opportunity and to approximately 7 minutes after touchdown for the second landing opportunity. In addition, rendezvous for lift-off at correct phasing (for the nominal ascent plan) approximately one CSM revolution after touchdown are presented. Information is not included for time-critical rendezvous or anytime lift-off cases because operational analyses were not considered necessary for these situations. Neither a single failure which would require a time-critical rendezvous nor a realistic anytime lift-off case has been identified.

Several developments have changed the plan significantly from that presented in the preliminary report (ref. 1). The most prominent development has been the onboard variable insertion (velocity) targeting; for aborts after powered descent initiation (PDI), this targeting places the LM in the required orbit to permit initiation of the normal coelliptic sequence approximately 50 minutes after insertion. This capability exists during the first 10 minutes of powered descent for the first landing opportunity and all of powered descent and approximately 2.5 minutes after touchdown for the second landing opportunity. For the first landing opportunity, a constant insertion region is designed to permit continuous abort plans until approximately 3 minutes after landing. For each of the landing opportunities, a later single-point lift-off time is designed for aborts which use the ascent program after the descent program has been exited. Abort points are also designed at 12 minutes after PDI time for each landing opportunity in situations for which the decision is

made not to initiate powered descent or for which the descent propulsion system (DPS) fails at PDI. Another major decision has been always to apply the direct return abort whenever DOI results in an orbit from which a landing could not be made.

However, the general complexity of the overall abort and rescue plan has been increased because of the added capability for a second landing opportunity. Although basically the abort and rescue techniques are the same as those used for part of the first landing opportunity, the boundaries of the regions are different and the relative parameters are different from those for the same abort point (relative to PDI) for the first landing opportunity. Furthermore, a fairly large part of the abort and rescue situation for a second landing opportunity is considerably complicated because of relative ranges outside the rendezvous radar capability and because of extended total rescue time requirements. However, this backup landing opportunity could save the landing if timeline problems or a procedure error should void the first landing opportunity.

As long as either the DPS or the ascent propulsion system (APS) is available, no ΔV problem should exist for the LM. However, LM reaction control system (RCS) only capability could become marginal in certain cases for which large radial components are required at CDH. The service propulsion system (SPS) would be marginal only in the contingency orbit insertion situation in which the CSM could not obtain within the LM lifetime the required phase angle change by transferring to an orbit below the LM. In this case, the CSM would be required to establish an extremely high orbit to allow the LM to catch up after approximately a full 360° phase angle. The same scarcity of SM RCS propellant exists for all potential rescues in lunar orbit; that is, if the resultant coelliptic Δh should increase to above 17 or 18 n. mi., a marginal situation would exist. There are cases for which the relative range is too large to permit onboard navigational updates prior to CSI. Probably the most critical of these cases is the no-PDI abort for the second landing opportunity.

2.0 INTRODUCTION

Since the publication of the preliminary plan, major efforts have been made to simplify and standardize the LM abort and rescue plan for Apollo 11 (Mission G). A major step toward general simplification was the elimination of official operational planning and documentation (and, therefore, potential crew training) for both time-critical abort rendezvous and anytime lift-off rendezvous. Operational planning and documentation was not performed because the probability was extremely low that they would occur in real time. However, general procedures and planning tools will be made available to cover these situations in real time.

A major development toward simplification and standardization of the non-time-critical procedures was the incorporation of the onboard variable insertion targeting for aborts after PDI. This capability permits rendezvous to occur approximately according to the nominal time-line and with the nominal relative situation beginning at CDH for a large portion of the designed abort points (section 1.0). In fact, for all of the abort and rescue plans (except the direct-return abort), the LM is always below the CSM during the coelliptic and terminal phases, and the time line becomes essentially equivalent to that of the nominal ascent from the final CSI maneuver to terminal phase finalization (TPF). For cases in which preceding maneuvers are required to set up this final CSI to TPF sequence, the setup maneuvers are obtainable either from the onboard computers (such as preceding CSI's) or through use of onboard charts (such as special phasing maneuvers). The external ΔV maneuvers which are prime from the ground are sent either prior to the failure (e.g., pre-DOI) or soon after the abort to provide ample time for crew evaluation and application.

The rescue plan has been simplified so that the rescue sequence is essentially either a mirror image of the abort (LM-active) plan or a rescue 2 sequence. (The rescue 2 sequence was part of the Apollo 10 plan.) For simplification, the six-impulse rescue sequence presented in the preliminary report has been eliminated from the operational plan.

Also for standardization, the initial maneuver for most of the abort and rescue sequences is scheduled either at a fixed time (g.e.t.) or at a fixed Δt from a previous event instead of exactly on the predicted LM line of apsides. The ground support procedures are considerably simpler because the line of apsides does not have to be determined after the abort maneuver. This fixed-time or fixed-Δt technique also assures an acceptable Δt between CDH and TPI from an onboard tracking and targeting standpoint.

Both summary and specific case data are presented, although detailed data such as state vectors, detailed maneuver tables, and MSFN coverage are not included. Such data for a number of cases is available upon request (section 6.12). In this report, the emphasis is on the Δt between events and not on g.e.t. because these techniques and sequences are applicable for all acceptable launch dates and lunar landing sites.

Previously, the term abort has indicated a totally LM-active rendezvous. However, because terminology such as rescue after an abort from powered descent is required in this report, the totally LM-active rendezvous are identified by the term LM-active rendezvous.

3.0 SYMBOLS AND DEFINITIONS

3.1 Symbols

AGS	abort guidance system
A.I.	abort initiation
AOS	acquisition of signal
apo	apolune
APS	ascent propulsion system
ASAP	as soon as possible
CDH	constant differential height (coelliptic) maneuver
CM	command module
CSI	coelliptic sequence initiation
CSM	command and service modules
DKI	docking initiation processor (in RTCC)
DOI	descent orbit insertion
DPS	descent propulsion system
F.T.	full throttle
G.m.t.	Greenwich mean time
g.e.t.	ground elapsed time (from earth launch)
init	initiation
insert	insertion
LM	lunar module
LOS	loss of signal
MSFN	Manned Space Flight Network

nom	nominal
no-PDI	powered descent is not initiated
PC	plane change
PDI	powered descent initiation
PDI-1	first landing opportunity PDI
PDI-2	second (backup) landing opportunity PDI
PGNCS	primary guidance and navigation control system
pha	phase adjustment
RCS	reaction control system
RTACF	Real-Time Auxiliary Computer Facility
RTCC	Real-Time Computer Complex
rev	revolution
SC	spacecraft
SM	service module
SPS	service propulsion system
TPI	terminal phase initiation
TPF	terminal phase finalization
Δh	differential altitude
ΔV	velocity increment
ΔV_X	horizontal ΔV
ΔV_Z	radial ΔV
Δt	elapsed time

3.2 Definitions

abort	a LM-active change from the nominal plan
abort initiation	first abort maneuver in a LM-active sequence
anytime lift-off	LM lift-off for any given phase angle with CSM
coelliptic Δh	Δh during the coelliptic phase for which the differential altitude remains nearly constant
constant insertion	section 6.6
direct return	section 5.1
elevation angle	angle measured upward from a vehicle's local horizontal in the direction of motion to the line of sight to the other vehicle
external maneuver	a maneuver for which the solution (targets) comes from a source other than the onboard computer
four-impulse (CSI/CDH) sequence	section 5.2
height adjustment maneuver	external maneuver which sets up the establishment of the desired coelliptic Δh 180° later
high dwell sequence	section 5.6
LM-active rendezvous	rendezvous for which the LM is the totally active vehicle
maneuver-line logic	logic for which rendezvous sequence maneuvers (prior to terminal phase) occur on an inertial maneuver line so that they are approximately 180° or multiples of 180° apart

non-time-critical situation	situation for which at least the normal lifetime of the LM ascent stage is available for completion of rendezvous and crew transfer
phase adjustment maneuver	external maneuver which establishes the desired phase (central) angle at the subsequent maneuver
phasing/CSI-for-CDH sequence	section 5.4
preferred lift-off	section 6.7
pressurized RCS	regular LM RCS system which uses the propellant in the RCS tanks
RCS interconnect	system which burns APS propellant through the +X-axis RCS thrusters
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
rescue 2	first rescue maneuver in the rescue 2 sequence
rescue 2 sequence	section 5.5
theoretical ΔV	Keplerian impulsive ΔV; for example, the TPF ΔV for the impulsive intercept velocity match
two-impulse to CDH-offset sequence	section 5.3
variable insertion	section 6.5

4.0 GUIDELINES AND ASSUMPTIONS

A summary of the nominal LM-active profile, the ground rules, and the assumptions on which the abort and rescue procedures are based are presented in this section. The assumptions include study characteristics, design guidelines, standard parameters, and performance characteristics.

4.1 Nominal Mission Design

The nominal LM-active profile assumed for this report is discussed in detail in reference 2; however, a brief summary of the profile is as follows.

1. Earth lift-off occurred on July 16, 1969, at $13^h31^m45.3^s$ G.m.t.

2. The LM-active profile begins with DOI at $99^h42^m26^s$ g.e.t. The retrograde maneuver (71.4 fps) is performed with the DPS and places the LM into a 60-n. mi. by 50 000-foot orbit.

3. At $100^h38^m56.8^s$ g.e.t., powered descent is initiated with a trim phase for 26 seconds (DPS 10 percent) followed by a throttle up to full thrust. The total descent time is approximately 713 seconds from the beginning of the 10 percent phase to touchdown.

4. At $105^h09^m71.1^s$ g.e.t., the CSM performs a plane change to place the CSM orbit over the landing site at the time of LM lift-off. This maneuver is performed with the SPS, and the ΔV is approximately 17 fps.

5. After remaining on the lunar surface for approximately 21.5 hours, the LM lifts off at $122^h28^m10.8^s$ g.e.t. and performs insertion at an altitude of 60 000 feet above the landing site with a horizontal velocity of 5535.6 fps and a radial velocity of 32 fps. Insertion occurs at $122^h35^m25.462^s$ g.e.t. The insertion orbit apolune is approximately 15 n. mi. below the CSM orbit.

6. Approximately 51 minutes after insertion, the LM performs the CSI maneuver at the apolune. The ΔV is 50.1 fps horizontal (posigrade) and is performed with the +Z RCS thrusters. CSI occurs at $123^h26^m27.2^s$ g.e.t.

7. The LM performs CDH at $124^h24^m24.6^s$ g.e.t., one-half revolution after CSI. This mainly radial burn is performed with the RCS (four-jet -X thrusters), and the ΔV is 6.0 fps. The nominal coelliptic Δh of 15 n. mi. is then established.

8. Approximately 37 minutes after CDH ($125^h02^m45.4^s$ g.e.t.), TPI is performed. This maneuver (25.7 fps) occurs at the midpoint of darkness and is directed along the line of sight by use of LM RCS +Z thrusters.

9. After two nominally zero midcourse maneuvers and four braking maneuvers, docking occurs at approximately $126^h00^m00^s$ g.e.t.

A nominally-zero separate PC maneuver is scheduled approximately halfway between CSI and CDH (approximately 90° from each) for the nominal profile. The plane-change technique is explained in reference 3. Although it is not indicated, a PC maneuver actually would be scheduled between the last CSI and CDH maneuvers (which are 180° apart) for the abort and rescue procedures. Note that if a large PC maneuver were required, the CSM might be required to perform the maneuver even for an otherwise LM-active situation, depending upon the magnitude of the maneuver.

4.2 Ground Rules

1. The procedures must be applicable for all potential trajectories for Apollo 11 (Mission G); that is, for all acceptable earth launch times and lunar landing sites.

2. The procedures must be consistent with known SC, crew, and operational capabilities.

3. The minimum acceptable perilune is 35 000 feet with respect to the landing site.

4. For targeting purposes, the minimum time between maneuvers is assumed to be approximately 34 minutes.

5. The SPS is used for all CSM maneuvers for which the SPS burn duration is longer than 0.5 second (including TPI); the only exception to the rule is that for CSM braking, the SM RCS (four-jet X-axis) must be used.

6. All ground-targeted external maneuvers for rescue or abort (with the exception of the tweak after insertion) are initiated at fixed ground elapsed times; the times are based on whether PDI is to occur on the first or second opportunity or on whether PDI was performed or not.

7. The CSM will target with the LM t_{IG} to back up LM maneuvers when the CSM is in contact with the LM at the maneuver.

8. After performance of an initial ground targeted (or chart derived) external ΔV maneuver for either abort or rescue, it should be possible to obtain solutions for the subsequent maneuvers from the onboard computers.

9. The LM is prime to perform all the rendezvous maneuvers when possible.

10. Because of the large ΔV requirements involved, the APS or DPS will be used when possible for some of the LM-active rendezvous maneuvers after early aborts from powered descent.

11. If the LM performs a nonnominal DOI maneuver for which landing is not possible, it returns immediately to the CSM. The direct return is initiated if the PGNCS fails during DOI.

12. For propulsion failures of the nominal engine (DPS or APS) during the no-PDI-1 or -2 plus 12 minute abort, the LM should attempt to complete the burn with the APS or RCS or try to achieve 100 fps with the RCS.

13. A landing will not be performed if the PGNCS fails.

14. The LM must have the capability to recover from an overburn at DOI which would result in an impact trajectory. There is no immediate rescue for this situation.

15. The LM should make every effort to achieve its exact targeted insertion conditions with the RCS if the APS fails during powered ascent after lift-off from the lunar surface or an abort from powered descent.

16. The one-half period (multiples) option for CDH in the onboard pre-CSI program will be used.

17. When the LM carries the descent stage back into orbit, the CSM will perform the tweak after LM abort from powered descent at insertion plus 12 minutes; if the LM staged the DPS prior to orbital insertion, the LM will perform the tweak within insertion plus 2 minutes.

18. TPI lighting (23 minutes prior to sunrise) is required for a LM-active rendezvous; although this exact lighting is not a requirement for rescue, it can be used for rescue whenever it does not decrease the Δt between CDH and TPI to less than approximately 34 minutes.

19. The designed anytime lift-off capability should exist for approximately 2.5 to 3 minutes after landing; subsequent lift-offs should occur at either the preferred lift-off time or at the correct phasing time on subsequent CSM passes.

20. The LM will never intentionally remain in the insertion orbit for more than one-half revolution. It will boost the perilune at least 5 to 7 n. mi.

21. The general criterion for LM RCS Z-axis (two-jet) or X-axis (four-jet) is that Z-axis is used if the burn duration does not exceed approximately 45 seconds, with the following exceptions.

a. Z-axis is always used for terminal braking.

b. X-axis is used for small maneuvers when the LM is not staged and when the DPS should not be used.

c. X-axis is used for small, primarily radial burns (such as CDH) if Z usage would cause a break in rendezvous radar lock.

d. X-axis is used when RCS interconnect capability safely exists, although the APS would be used if the ΔV were as large as 25 to 30 fps if sufficient APS propellant is available.

22. The DPS will be used as much as possible without a sacrifice in LM-active capability.

23. The tweak maneuver after insertion will be performed only when the first in-orbit maneuver is to be the CSI.

24. Only horizontal residuals will be trimmed.

25. If the main engine (DPS or APS) fails during an in-orbit burn, AGS control will be used for the backup engine.

4.3 Assumptions and Input Data

4.3.1 Study characteristics.-

1. For this study, the operational trajectory (ref. 2) was used to obtain the initial conditions at each abort point along the nominal trajectory where applicable.

2. The RTACF program was used to generate the data.

a. For the summary information presented in this report, all maneuvers (except powered descent and ascent) are assumed to be impulsive.

b. For the specific detailed cases shown in the tables, references 2 and 4 were used to obtain the latest weights and performance characteristics. All maneuvers were simulated with finite burns.

3. No error sources or dispersions were considered; however, premature engine shutdown was considered for the no-PDI abort initiations.

4. Data for out-of-plane situations are not included.

5. CSM failures are not considered.

6. Time-critical situations are not considered.

7. Anytime lift-off is not considered with the exception of lift-offs that occur up to approximately 3 minutes after landing.

8. The only types of failures assumed were propulsion failures or known failures which would require a special rendezvous technique. No attempt was made to identify the exact cause of any failure.

4.3.2 Design guidelines.-

1. Onboard independence is stressed; that is, use of the CSI/CDH coelliptic sequence is involved except for the immediate return that follows the DOI maneuver.

2. When ground assistance is required, current ground capabilities should suffice.

3. An effort is made to minimize additional crew training.

4. An effort is made to simplify the ground procedures.

5. Emphasis is placed on achievement of the nominal terminal phase, the nominal maneuver sequence, and even the nominal time line as far as possible.

6. The earliest rendezvous is incorporated which is relatively safe and which maintains nominal coelliptic sequence characteristics (especially beginning at CDH).

4.3.3 Standard trajectory parameters.-

1. TPI position: 23 minutes prior to sunrise for LM-active rendezvous

2. Coelliptic Δh: between 10 n. mi. and 15 n. mi. (LM below)

3. TPI elevation angle: 26.6° when active vehicle is below, 208.3° (-28.3°) when active vehicle is above

4. Terminal phase target vehicle travel angle: 130°

5. Operational trajectory (ref. 2) launch date and landing site (site 2)

4.3.4 Performance characteristics.-

1. The weights from the operational trajectory (ref. 2) are assumed.

2. The engine characteristics from the data book (ref. 4) used for the operational trajectory are assumed.

3. The assumed ascent stage lifetime for a continuously fully-powered LM is approximately 7.5 to 8 hours; for this lifetime, TPI must occur within approximately 6 to 6.5 hours after staging. By powering down certain equipment, the LM lifetime can be extended to approximately 12 hours.

4. The following constraints on burn durations were considered.

a. Minimum SPS burn: 0.5 second

b. Maximum continuous burn of the LM RCS thrusters relative to impingement problems

(1) -X: 30 seconds

(2) +X (unstaged): 25 seconds (including ullage)
+X (staged): 85 seconds (including ullage)

5. Assumed ΔV budgets for contingency rendezvous; these values are approximate and not official

a. SM RCS: 120 fps

b. SPS: 800 fps

c. LM RCS (staged): 425 ± 25 fps, based on when the abort occurs in powered descent

5.0 RENDEZVOUS TECHNIQUES

The abort and rescue rendezvous (trajectory) techniques involved in the operational plan are described in this section. With the exception of the LM-active direct return immediately after DOI, the basic technique for both the LM and CSM-active rendezvous is the four-impulse CSI/CDH sequence. However, because this sequence alone does not permit control of terminal phase (lighting and/or coelliptic Δh) for situations in which the proper phasing does not exist initially, sequences with a maneuver that precedes the four-impulse CSI/CDH sequence are required. This preceding external maneuver is either a phase adjustment or a height adjustment maneuver which makes possible the use of some form of the onboard logic for the CSI/CDH sequence to perform rendezvous.

5.1 Direct Return

The direct return technique is a manual rendezvous and is used for only one specific situation: an immediate LM return that follows the DOI maneuver. The maneuver is initiated by pointing the LM approximately in the direction of the CSM and then thrusting until a satisfactory closing rate is established. When the closing rate has been obtained, the line-of-sight rate and range rate are controlled according to the predetermined braking schedule until rendezvous is achieved. The braking schedule will be designed to reduce the closing velocity and to insure that the vehicles maintain an intercept trajectory. This technique is totally onboard and manual.

5.2 Four-Impulse CSI/CDH Sequence

The four-impulse CSI/CDH sequence is initiated by CSI, which is always a horizontal maneuver. For all of the currently recommended procedures, the option is incorporated which results in the occurrence of CDH n times one-half period after CSI (where n = 1, 2, etc.). Therefore, CDH probably will involve a radial component if CSI is not on an apsis, if the target orbit is noncircular, or if certain dispersions exist. The TPI and TPF maneuvers are the last two impulses of the sequence for the four-impulse definition. Actually, several terminal phase midcourse and braking maneuvers are performed during terminal phase. Also, a separate PC maneuver between CSI and CDH is involved which is defined in reference 3 and which is explained briefly in section 4.1. The technique is always targeted to result in a nominal terminal phase with a coelliptic Δh of 15 n. mi. (or 10 n. mi. for certain rescue cases) and with TPI approximately 23 minutes before sunrise (or for certain rescue cases, at the time that would correspond to 23 minutes before sunrise if the CSM had not been maneuvered).

The sequence can be used alone (i.e., without any initial external maneuver) only when the needed phasing has already been established. Otherwise, it must be preceded by an initial setup maneuver. It is possible to obtain solutions for this four-impulse CSI/CDH sequence onboard both the LM and the CSM when either vehicle is assumed to be active.

5.3 Two-Impulse to CDH-Offset Sequence

Basically, this technique involves a two-impulse (Lambert) transfer at a selected time to a central phase angle and differential height offset from the target vehicle at a later time. When the offset is reached, a coelliptic maneuver (CDH) is applied to begin the coelliptic phase. After the initial maneuver is applied, however, a CSI is inserted into the maneuver sequence at one-half period prior to CDH. If both the information for and execution of the initial maneuver are accurate, the CSI should have zero ΔV.

Specifically, this technique is used for the no-PDI plus 12 minute aborts. The initial maneuver (referred to as abort initiation) is calculated by use of the RTCC two-impulse processor and is sent from ground control prior to DOI. After abort initiation, the remaining maneuver solutions can be obtained onboard. A schematic of this technique is shown in figure 1(a).

5.4 Phasing/CSI-for-CDH Sequence

The phasing/CSI-for-CDH technique is used for aborts from powered descent or after touchdown when the LM must insert into an orbit which does not allow for the natural catchup that permits direct application of the CSI/CDH sequence. The initial maneuver for this sequence is a phase adjustment maneuver referred to as phasing. It is always a horizontal posigrade maneuver for the LM and is scheduled either at a fixed g.e.t. (i.e., at a fixed Δt after PDI or at a fixed Δt after insertion, depending on the exact situation). The ground (through the DKI processor) is prime to supply the solution for this phasing, although a crew chart which involves use of the onboard CSI/CDH equations will be available. Onboard solution capability exists after phasing. An original CSI (CSI-1) is scheduled one-half revolution after phasing. (For the last preferred lift-off case for the first landing opportunity, one and one-half revolutions are required between phasing and CSI-1. The original

CDH maneuver is targeted to occur one-half period after CSI-1, which leaves approximately 95 minutes between CDH and TPI. However, after CSI-1 is performed, the original CDH is replaced by a second CSI (CSI-2). The CDH is again targeted one-half period after CSI-2 and the Δt between CDH and TPI is approximately 35 minutes. The CSI-2 maneuver is approximately of the same magnitude as the original CDH because the phasing maneuver is designed to set up the desired coelliptic Δh at the original CDH. However, if radial components are present in the original CDH, they cannot be accounted for with the CSI-2 maneuver. If such radial components exist, the resultant coelliptic Δh (at the actual CDH) will differ slightly from the Δh at CSI-2. A schematic of this technique is shown in figure 1(b).

This same sequence is also used for rescue when the corresponding LM phasing maneuver would not have exceeded 48 fps. The rescue phasing maneuver is the mirror image of the LM phasing maneuver. The CSI-1 time, however, is at the LM CSI-1 time instead of exactly one-half revoltuion after phasing (as in the LM-active case).

5.5 Rescue 2 Sequence

The initial external maneuver for the rescue 2 sequence, referred to as the rescue 2 maneuver, is a horizontal maneuver that establishes a desired Δh one-half revolution from the point at which the external maneuver is performed. This Δh will be the coelliptic Δh after CDH. The original CSI is performed one-half revolution after rescue 2, and the original CDH occurs either one, two, or three full revolutions after CSI, depending on the exact situation. The rescue 2 maneuver is a height adjustment maneuver, and the original CSI serves as a phase adjustment maneuver. For the rescue 2 sequence, additional CSI maneuvers would be scheduled at the full revolution increments between the original CSI and CDH, and a final CSI would be scheduled essentially one-half period prior to CDH. All of these additional CSI maneuvers would have zero ΔV if the information for and execution of CSI-1 were accurate.

The prime solution for the rescue 2 maneuver is provided by the ground control (DKI processor). It is predicted that this maneuver can be updated after one of the particular failures for which the sequence is used. However, if a ground update is not achieved in certain cases, either an onboard chart or canned maneuver will be available.

The rescue sequence used when the LM phasing ΔV is greater than 48 fps (section 5.4) is equivalent to the rescue 2 sequence except that the initial maneuver has a fixed ΔV of 48 fps and the original CSI is at the LM CSI time and is, therefore, not necessarily one-half revolution after the rescue 2 maneuver. A schematic of this technique is shown in figure 1(c).

It is emphasized that when the actual DKI-setup rescue 2 sequence is used, such as for partial no-PDI abort initiations and after partial DOI maneuvers, TPI is placed at the optimum lighting (LM at 23 minutes until daylight). For the rescue 2 case discussed in section 6.6.2.1, however, the optimum lighting is not set up initially.

When the original six-impulse rescue sequence was part of the rescue plan, there were two external maneuvers prior to CSI: rescue 1 and rescue 2. When the six-impulse sequence was eliminated from the plan, the rescue 1 maneuver was also eliminated, and rescue 2 remained as the name of the single external maneuver for the five-impulse rescue sequence.

5.6 High Dwell Sequence

The high dwell sequence would be required only for the very low probability case of a contingency orbit LM insertion for which the required phasing (catchup) could not be accomplished within the LM lifetime by a low CSM orbit. Therefore, the CSM would be required to transfer into an orbit high enough to allow the LM to catch up roughly 360° in the opposite phasing direction. That is, the LM would traverse approximately one revolution more than the CSM during the rescue. The dwell initiation maneuver would be a phase adjustment maneuver, and CSI, which would occur three full revolutions later, would be a height adjustment maneuver. The DKI processor in the RTCC would be used to supply data for the dwell initiation maneuver. A schematic of this technique is shown in figure 1(d).

6.0 DISCUSSION

The LM-active and rescue maneuver procedures, sequences, and time lines which would apply for the various failure situations are presented in this section. The discussion is divided into the various phases, continuous abort regions, and single-point abort times. The failure situations are discussed only to the extent that they determine the procedures. A summary of the plan is presented in table I. Explanations of and references to the accompanying data are also included in this section. Most of the general data are presented in summary plots for which the various ΔV's, orbital apsis altitudes, and elapsed times between maneuvers are shown as a function either of partial burn ΔV (for DOI and no-PDI aborts) or of time of abort after PDI. In addition, maneuver summary tables and relative motion plots are presented for various specific-point cases. Included as subplots for some of the summary figures and specific-point case figures are relative range time histories. When the relative range time history for a rescue region (or case) is approximately the same as the one for the corresponding abort region (or case), the relative range data for the rescue case are not shown. For situations in which the coelliptic Δh varies from the targeted value because of the technique involved, separate coelliptic Δh subplots for the summary data are shown. It is emphasized that the LM is always below during the coelliptic and terminal phases regardless of the case. An attempt was made to select specific-point cases which would represent each of the various types of sequences and time lines for the various phases, continuous abort regions, and single-point abort times. Specific data such as exact lighting, MSFN coverage, and various vectors have been generated for these specific-point cases and can be made available upon request (section 6.12).

All TPF data are based on a theoretical TPF because the programs used to generate the data are not configured to simulate the manual braking. Operationally, the nominal braking and the terminal phase midcourse maneuvers require propellant equivalent to 1.5 to 2.0 times the propellant that would be required for the theoretical TPF. Summary curves are not shown for most of the terminal phase ΔV's because these ΔV's are essentially constant for the applicable coelliptic Δh. As coelliptic Δh varies from 10 to 15 n. mi., TPI ΔV varies from 16 to 25 fps, and theoretical TPF ΔV varies from approximately 20 to 31 fps. The duration of terminal phase (TPI to TPF) is essentially a function of the apolune altitude for rescue cases in which the LM perilune altitude is approximately 8 to 15 n. mi. and its location is the landing site longitude ±15° or 20°. In figure 46, the TPI-to-TPF Δt for this situation is presented as a function of apolune altitude. The curve should be accurate to within 20 or 30 seconds.

Two TPI times are sent from the ground prior to DOI. They are two CSM arrival times at the midpoint of darkness (actually 23 minutes prior to the end of darkness) for the second and third darkness periods after DOI; is is assumed that the CSM remains in the nominal parking orbit. Other maneuver times and maneuver ΔV's are supplied from the ground as they are needed. Most of the abort maneuver times and ΔV's are contained in onboard charts or can be determined by use of onboard charts of fixed parameter information.

The probability of a rescue, especially a total rescue, being required is very small. Double or triple failures must occur for a total rescue to be required. However, for consistency and simplicity of presentation, all rescue data presented assume a total CSM-active rendezvous.

The darkness periods shown on the relative motion curves represent the darkness periods for the target vehicle. A CSI in parenthesis, (CSI), on the relative motion plots and relative range time history plots indicates a potential recycle CSI. For an accurate original CSI, the recycle CSI has a ΔV of zero fps. For the summary data figures, a positive (+) radial ΔV component is down (toward the center of the moon). All of the altitudes are referenced to the landing site radius.

6.1 CSM Separation to DOI

A manual rendezvous technique would be applied if a NO-GO for DOI occurs. Because during this phase the vehicles are on near-intercept trajectories with a maximum relative range of approximately 1.75 n. mi., it should be possible to execute either a LM-active or a CSM-active manual rendezvous (braking) without major difficulty. The rendezvous involves establishing a closing rate and then manual braking. If the DPS fails to ignite at the nominal DOI time, the ΔV from the ullage maneuver will be backed out so that the vehicles remain on near-intercept trajectories. In such cases, a real-time decision might be made to attempt to ignite the DPS and to perform DOI one revolution after nominal DOI time.

6.2 DOI to DOI plus ~10 minutes

6.2.1 LM-active rendezvous.- A direct return will be initiated within DOI plus 10 minutes for any DOI burn after which the powered descent could not be performed. That is, there is no plan to perform a rendezvous simply for the sake of performing a rendezvous when it is realized immediately after DOI that there is no chance of landing.

The direct return is a manual technique which is initiated as soon after DOI as the need can be determined. The initial maneuver is performed along the line of sight to the CSM (or according to recent simulations, at a small fixed angle off this line of sight). The currently defined magnitude of the maneuver is approximately equivalent to the magnitude of the applied DOI maneuver plus eight times the relative range. The initial maneuver establishes a near-intercept of the vehicles with a closing rate that will make it possible for the velocity match to be achieved by a reasonable braking sequence, although the approach is not nominal. The DPS will probably be used to perform most of the initial manual maneuver. Near the end of the initial maneuver, the LM probably will be staged, and the maneuver will be completed with the RCS. This procedure would not only conserve RCS but would also allow a safe separation from the descent stage. Range, range rate, and the magnitude of the initial maneuver at various times after DOI are shown in figure 2 as functions of the magnitude of the DOI maneuver. Although these particular data were generated for Apollo 10, they apply accurately to Apollo 11 (Mission G).

6.2.2 Rescue.- A rescue sequence referred to in Apollo 10 as the rescue 2 sequence is used when the LM is nonpropulsive after DOI, that is, when the LM cannot perform the direct return abort. The rescue 2 maneuver is performed approximately one revolution after DOI when the CSM returns to the maneuver line defined at DOI cutoff. The Δt from DOI to rescue 2 is approximately 119 minutes. The maneuver sequence is described in section 5.5. The first CSI maneuver (CSI-1) is always performed one-half revolution after rescue 2, but the central angle from CSI-1 to CDH depends on the DOI ΔV. If the DOI ΔV is greater than approximately 27 fps, two revolutions are required between CSI-1 and CDH to avoid unsafe perilune. A second and a third CSI, such as those explained in section 6.2.2.2, would be scheduled for this situation. If the DOI ΔV is less than 27 fps, only one revolution is required between CSI-1 and CDH. A second CSI (section 6.3.2.2) would be scheduled for this situation. For the partial DOI region, the targeted coelliptic Δh for the rescue sequence is 10 n. mi. Generally, a coelliptic Δh of 10 n. mi. would be applied only when it would permit rendezvous to occur a revolution earlier than it would have with a Δh of 15 n. mi. However, for the post-DOI rescue situation, the region is very small for which a coelliptic Δh of 15 n. mi. would not involve an additional revolution because of unsafe perilune; this region includes only partial DOI's of less than approximately 10 fps. Therefore, the coelliptic Δh of 10 n. mi. is targeted for all of the partial DOI region. If the DOI ΔV is less than 27 fps, TPI will occur approximately two and three-fourths revolutions after DOI; if the DOI ΔV is greater than 27 fps, TPI will occur approximately three and three-fourths revolutions after DOI. The TPI maneuver is performed at 23 minutes until sunrise for the

LM and approximately 35 minutes after CDH for either case. Summary data for these cases are presented in figure 3. Although these particular data were generated for Apollo 10, they are sufficiently accurate from a summary standpoint for Apollo 11 (Mission G). Two representative specific point cases are included. A summary of a rescue after a partial DOI of 20 fps is presented in table II, and the relative motion for the same rescue is presented in figure 4. The same type of information is presented in table III and figure 5 for a rescue after a partial DOI of 60 fps. The relative range time histories for these cases are included in the summary data figure.

6.3 No-PDI-1 plus 12 minutes

6.3.1 LM-active rendezvous.- The no-PDI-1 plus 12 minute abort is applicable when the decision to abort is made prior to PDI-1 (but after DOI plus 10 min) or immediately after the DPS fails at PDI-1, that is, the decision is made not to attempt a second opportunity landing. The abort initiation is scheduled at 12 minutes after PDI time to allow time to make the abort or second opportunity decision and then to set up the abort maneuver if the decision is made to abort for the case in which the DPS fails at PDI. For this case, the APS would be used for the abort initiation. For the case in which the decision to abort is made prior to PDI and the DPS is thought to be good, the DPS would be used for the abort initiation.

The abort technique is a two-impulse transfer to a CDH offset which permits a nominal terminal phase (coelliptic Δh = 15 n. mi. with LM below and TPI at the midpoint of darkness) and a Δt between CDH and TPI of approximately 40 minutes (section 5.3). A CSI is then scheduled one-half LM period prior to CDH. The CSI ΔV should be nearly zero if the abort initiation is accurate. The CSI would be executed with the RCS if the burn duration were smaller than the minimum burn for the applicable major engine (DPS or APS). The CDH probably would be executed with the same major engine as was used for the abort initiation. The abort initiation maneuver and t_{IG} and CSI and TPI times are sent from the ground control prior to DOI. A nominal DOI is assumed because the direct return is used for a nonnominal DOI.

The abort initiation was originally scheduled at 10 minutes after PDI. However, the resultant perilune altitudes are significantly higher for the 12-minute Δt. Detailed data concerning this situation are presented in reference 5. If the abort initiation time were scheduled later, however, the time line between abort initiation and CSI would become extremely rushed if the CDH-to-TPI Δt of approximately 40 minutes were maintained. The abort initiation to CSI Δt is approximately 46 minutes for the no-PDI-1 plus 12 minute case.

A summary of the no-PDI-1 plus 12 minute abort is presented in table IV. The relative motion and relative range time history for this case are shown in figure 6.

If the DPS is being used and fails during the abort initiation, an attempt to complete the burn with the APS under AGS control is made. If the APS fails during the abort initiation, the RCS should be used (under AGS control) to complete the burn is possible within the +X-axis thruster impingement limit. This limit of approximately 85 seconds permits a ΔV of approximately 100 fps for this situation. If the burn cannot be completed, the RCS should be used only to obtain the ΔV which will decrease the rescue time to a minimum (i.e., to one revolution between the original CSI and CDH). For the no-PDI-1 plus 12 minute case (section 6.3.2.2), this ΔV is 60 fps. For the no-PDI-2 plus 12 minute case (section 6.4.2.2), this ΔV is 90 fps. The RCS should not be used to increase the ΔV significantly beyond these values unless the burn can be completed because large partial burns would increase the rescue ΔV requirement. A standard ΔV for both of the no-PDI cases to which the RCS should thrust if both the DPS and APS fail would probably be 100 fps. However, the RCS should not be used to return to 100 fps if the DPS and APS ΔV exceeds 100 fps because an unsafe perilune might result. The switch to AGS control when the nominal main engine fails permits immediate continuation of the burn with the APS or RCS. Reentry into the thrust program would be necessary if PGNCS control were to be maintained.

6.3.2 Rescue.- There are two types of rescue situations for the no-PDI-1 plus 12 minute case: (1) If the abort initiation is completed accurately by the LM and then the CSM must rescue, and (2) if a partial abort initiation occurs.

6.3.2.1 Rescue after an accurate LM abort initiation: For this case, the CSM applies a CSI/CDH sequence based on the LM CSI and TPI times, with n = 1 for CDH half periods. If the LM TPI time is used, the CSM TPI will not have exactly the desired lighting, but the slightly nonnominal lighting is accepted to avoid a separate CSM TPI time for this case and also to avoid a decrease in the CDH to TPI Δt. Although the maneuvers differ slightly from those applicable for the LM, the CSM sequence is essentially a mirror image of the LM sequence. A summary of this rescue is presented in table V and the relative motion is shown in figure 7. The relative range time history shown in figure 6 suffices for this case.

6.3.2.2 Rescue after a partial LM abort initiation: The technique required for this situation is referred to as the rescue 2 sequence. This technique is generally defined in section 5.5. The total rescue time (i.e., the number of revolutions required for phasing between the original CSI and CDH) depends on the magnitude of the partial LM abort initiation. If the partial ΔV is greater than approximately 60 fps, only one revolution is required between the original CSI (CSI-1) and CDH, and TPI occurs approximately two and one-fourth revolutions after the abort initiation. If the partial ΔV is less than approximately 60 fps, two revolutions are required between CSI-1 and CDH, and TPI occurs approximately three and one-fourth revolutions after the abort initiation. For either situation, the rescue 2 maneuver is performed one CSM revolution after DOI cutoff (where the rescue maneuver line is defined). The Δt between the partial abort initiation and the rescue 2 maneuver is approximately 51 minutes. Also, for either situation, CSI-1 occurs one-half revolution after rescue initiation. A second CSI (CSI-2) is scheduled halfway between CSI-1 and CDH for either situation; for the $\Delta V \geq 60$ fps region, CSI-1, CSI-2, and CDH are at one-half revolution increments; for the $\Delta V < 60$ fps region, CSI-1, CSI-2, and CDH are at full revolution increments. However, for the $\Delta V < 60$ fps region, a third CSI (CSI-3) is scheduled halfway between CSI-2 and CDH. If accurate information and execution exist at CSI-1, the subsequent CSI maneuvers will have zero ΔV. The nominal-magnitude coelliptic Δh of 15 n. mi. is applied for the $\Delta V \geq 60$ fps region, but a coelliptic Δh of 10 n. mi. is applied for the $\Delta V < 60$ fps region. For part of this latter region, an additional revolution would be required (to avoid an unsafe perilune) if a coelliptic Δh of 15 n. mi. were applied; therefore, to simplify the procedures, the 10 n. mi. value is used throughout the region. Summary data for the partial no-PDI-1 plus 12 minute cases are presented in figure 8. A representative case for both the $\Delta V < 60$ fps region and the $\Delta V \geq 60$ fps region are presented. The maneuver summary for $\Delta V = 0$ is presented in table VI, and the relative motion for the maneuver is presented in figure 9. The maneuver summary for $\Delta V = 60$ fps is presented in table VII, and the relative motion is presented in figure 10. The relative range time histories for these cases are included in the summary data figure.

6.4 No-PDI-2 plus 12 minutes

6.4.1 LM-active rendezvous.- The no-PDI-2 plus 12 minute abort is used when the decision to abort is made prior to PDI-2 (but after a temporary GO for second opportunity landing was made at no-PDI-1) or when the DPS fails at PDI-2. Except that there would be no consideration given to a possible third landing opportunity, the explanation in section 6.3.1 concerning the technique and engine usage applies here. The two-impulse ΔV's and burn attitudes and relative conditions differ from those for the no-PDI-1 plus 12 minute abort, but the technique is the same and the time line varies only slightly. The maneuver summary for the no-PDI-2 plus 12 minute abort is presented in table VIII, and the relative motion and relative range time history are presented in figure 11.

6.4.2 Rescue.- The same two types of rescue apply here as for the no-PDI-1 plus 12 minute case (section 6.3.2).

6.4.2.1 Rescue after an accurate LM abort initiation: The explanation in section 6.3.2.1 applies here. The summary for this case is presented in table IX, and the relative motion is presented in figure 12. The relative range time history in figure 11 suffices for this case.

6.4.2.2 Rescue after a partial LM abort initiation: As for the corresponding situation for no-PDI-1 plus 12 minutes, the rescue technique is the rescue 2 sequence, and the total rescue time depends on the magnitude of the partial abort initiation. For the partial no-PDI-2 plus 12 minute situation, however, there are three regions, and the regional boundaries differ from those for the partial no-PDI-1 plus 12 minute situation. If the partial ΔV is less than 40 fps, three revolutions are required between CSI-1 and CDH. For this case, CSI-2 probably would be two revolutions after CSI-1, although a real-time decision might place CSI-2 one revolution after CSI-1; if so, four CSI maneuvers could be scheduled for this case. A coelliptic Δh of 10 n. mi. would be applied throughout this ΔV < 40 fps region for the same reasons given for the ΔV < 60 fps region (section 6.3.2.2).

If the partial ΔV is greater than 40 fps but less than 90 fps, two revolutions are required between CSI-1 and CDH. When the partial ΔV is greater than approximately 90 fps, only one revolution is required between CSI-1 and CDH. For both of these last two regions, a coelliptic Δh of 15 n. mi. can be applied. Additional CSI maneuvers would be scheduled as for the corresponding time lines for the partial no-PDI-1 plus 12 minute regions.

The summary data for the partial no-PDI-2 plus 12 minute rescues are presented in figure 12. Maneuver summaries and relative motion plots are presented for representative specific-point cases in each region: for zero ΔV in table X and figure 14, for 65 fps ΔV in table XI and figure 15, and for 90 fps ΔV in table XII and figure 16. The relative range time histories for these cases are included in the summary data figure.

6.5 PDI-1 to PDI-1 plus ~10 minutes

For aborts from this region of the first opportunity powered descent, the onboard equations are designed to yield a variable (horizontal) insertion velocity. Therefore, this region is referred to as the first opportunity variable insertion region. A constant radially-upward component of 19.5 fps is targeted for insertion independent of the abort time. The reason for this radial component is given in section 6.5.1. In effect, as a function of abort time, the LM inserts into the required orbit which permits initiation of the nominal-type coelliptic sequence at 50 minutes after insertion. That is, CDH is one-half period after CSI; TPI is at the midpoint of the first darkness per period following CDH; and the coelliptic Δh is 15 n. mi. (LM below). At PDI-1, the LM leads the CSM by approximately 7°. During the powered descent, however, the CSM rapidly gains in phase angle. Therefore, the later the abort from powered descent occurs, the lower the apolune of the LM insertion orbit required to set up the proper phasing. The required apolune for an abort at PDI-1 is approximately 128 n. mi. The required apolune is decreased to 30 n. mi. for an abort at approximately 10 minutes after PDI-1. At this time, the variable insertion region ends because for targeting purposes 30 n. mi. is the minimum acceptable apolune altitude. After this time, the insertion velocity which yields a 30-n. mi. apolune is used, unless the LM remains on the surface until the next CSM pass.

The insertion orbit differs based on whether the DPS is used after the abort. Therefore, the data presented for this region involve two curves for each abort time: one for full use of the DPS and one for use of the APS only after the abort. Furthermore, the time (relative to PDI-1) at which the region actually ends depends on whether the DPS is used to start the abort. The region actually ends when the minimum acceptable insertion velocity occurs. If the DPS is used, the region actually ends 15 to 20 seconds earlier than if the DPS is not used. For the APS-only abort, the end of the region is almost exactly at PDI-1 plus 10 minutes. Presented in figure 17 are summary data concerning the powered flight and insertion conditions. The variable insertion region could be extended by approximately 0.5 minute if the coelliptic Δh is allowed to increase to 20 n. mi.

The variable insertion equations are based on curve fits and, therefore, in many cases do not yield the exact insertion orbit which will result in the nominal coelliptic Δh of 15 n. mi. Furthermore, dispersions in the powered flight add to the inaccuracy of the insertion orbit. Therefore, a tweak maneuver applied soon after insertion is usually required to obtain the nominal coelliptic Δh. This maneuver is computed by the ground control based on telemetry at insertion. It is currently predicted that this maneuver can be computed and sent to the LM or CSM within 1.5 minutes after insertion. The LM will perform the tweak maneuver as soon as possible but at least by 2 minutes after insertion if the DPS has been staged. If the LM is unstaged at insertion or if the staged LM is unable to perform the tweak maneuver, the CSM performs the tweak maneuver at 12 minutes after insertion. When unstaged, the LM is greatly restricted because of impingement problems. Because the correct coefficients for the variable insertion equations were not available when the presented data were generated, actual tweak maneuver information is not included. The perfect insertion orbits were obtained by impulsively tweaking instantly at insertion. However, the presented data are essentially the same as would result for the actual tweak maneuvers, based on the same initial conditions. The coefficients for the variable insertion equations (polynomials) will be updated in real time prior to DOI as a function of the resultant lunar orbit.

6.5.1 LM-active rendezvous.- The basic explanation of the abort technique is contained in the preceding explanation of the variable insertion region. However, a few technicalities should be explained further. The CSI is scheduled at 50 minutes after insertion (instead of at the resultant apolune) to assure adequate time between CDH and TPI for the entire region. For early aborts, however, the Δt between CDH and TPI is more than adequate because the insertion longitude is considerably further east than for the later aborts. For the insertion orbit with the 30-n. mi. apolune, the 19.5 fps radially-upward component at insertion places apolune at 50 minutes after insertion. Therefore, for the earlier aborts, the insertion orbit apolune is later than 50 minutes after insertion. The earlier the abort is the further CSI occurs from apolune, and, therefore, the larger the radial component is at CDH. However, for the early aborts, a major engine (DPS or APS) should be available for CDH. The fuel-critical situations are the low apolune cases because for these cases the RCS probably will have to be used for all the rendezvous maneuvers. Because CSI is near apolune for these cases, the radial component at CDH should be relatively small. The summary data for aborts in this region are contained in figure 18. Two representative specific-point cases are included. One case is for an abort at PDI-1 plus 5 minutes (for which the DPS is not staged until after insertion). The maneuver summary for this case is presented in table XIII and the relative motion plot is presented in figure 19. The other case is for an APS-only abort at PDI-1 plus 10 minutes, approximately at the end of the variable insertion region. The maneuver summary is shown in table XIV, and the relative motion plot is presented in figure 20. The relative range time histories for these cases are included in the summary data figure.

6.5.2 Rescue.-

6.5.2.1 Accurate insertion orbits: If the LM obtains the required orbit at insertion, the rescue technique is simply the direct application of the normal CSI/CDH coelliptic sequence because the required phasing is established (section 6.3.2.1). The LM CSI and TPI times are used. The summary data for these rescues are shown in figure 21. The specific-point rescue cases correspond to the specific-point LM-active cases for the variable insertion region. The maneuver summary and relative motion for the PDI-1 plus 5 minute case are presented in table XV and figure 22;

the same type of data for the PDI-1 plus 10 minute case are presented in table XVI and figure 23. The relative range data presented in figure 18 suffice for these cases.

6.5.2.2 Contingency insertion orbits: A contingency insertion orbit is one which is dispersed so much that the normally planned rendezvous sequence cannot be used. For example, if the targeted insertion orbit apolune were 120 n. mi. and if the resultant apolune (after an attempt to trim residual) were 20 n. mi., a special contingency rendezvous sequence would be required. An analysis is presently being initiated to describe contingency insertion rescue cases, especially for this variable insertion region in which such cases would be most critical. For early abort times in this region, if the LM were able to obtain only a minimum orbit, the rescue would involve a high dwell orbit. The normal rescue 2 sequence could not be used because the CSM could not achieve an orbit low enough below the LM orbit to gain the required phase angle in the allowable time (LM ascent stage lifetime). Therefore, the CSM would have to dwell high enough for the LM to catch up almost a complete 360° in the opposite phasing direction. One main objective of the contingency orbit analysis is to define the situation (as a function of abort time) for which the CSM would be required to dwell in a high orbit instead of applying the rescue 2 sequence. The data in figure 47 summarize the contingency insertion orbit situation for the variable insertion regions from a required technique standpoint for the first opportunity and the second opportunity. The top curve represents the targeted insertion velocity as a function of the abort time. The lower curves indicate the switchover points relative to the number of required revolutions between the original CSI and CDH for the rescue 2 sequence. If an insertion velocity less than that shown on the bottom curve should result, the high dwell technique would be required.

A typical high dwell case is presented in this report to indicate the type of technique required. The maneuver summary is presented in table XVII, and the relative motion plot and relative range time history are presented in figure 24. For this case, an abort at PDI-1 plus 6 minutes into a 10-n. mi. circular orbit is assumed. At 67 minutes after PDI-1, a phasing (dwell) maneuver is performed. Three revolutions later, a height maneuver (or CSI) is performed to set up a coelliptic Δh of 10 n. mi. In DKI terminology, the phasing maneuver is an NC1 maneuver at 0.5, and the height maneuver is a NH maneuver at 3.5. The NSR (CDH) is at 4.0, one-half revolution after the height maneuver, and TPI is at the midpoint of the first darkness period after CDH.

6.5.2.3 CSI bias: To achieve the desired terminal phase lighting when one vehicle uses the other vehicle's CSI solution, a ΔV bias must be included. The CSI biases for the variable insertion region for both first and second landing opportunities are presented as a function of abort time (referenced to PDI) in figure 45.

6.6 PDI-1 plus ~10 minutes to PDI-1 plus ~15 minutes

This first opportunity region includes approximately the last 2 minutes of powered descent and approximately the first 3 minutes on the surface. Nominal landing (no hover included) is predicted to occur at PDI plus 11 minutes 53 seconds. For all abort times in this region, the LM is targeted for the minimum acceptable insertion orbit (30-n. mi. apolune). The constant 19.5-fps radially-upward component is targeted throughout the region at insertion. Therefore, the region is referred to as the first opportunity constant insertion region. For aborts from this region, the CSM is too far ahead at insertion to permit direct application of the nominal rendezvous sequence (i.e., when the first maneuver after insertion is CSI). The LM equations are not configured to initiate a second variable insertion region beginning at approximately PDI-1 plus 10 minutes; there is a proposal for this added capability for future lunar landing missions, although there is a high probability that the APS would be depleted prior to insertion early in this type of second variable insertion region.

For Apollo 11 (Mission G), however, the first opportunity constant insertion region definitely exists. It is agreed that 2.33 to 3 minutes of continuous lift-off capability immediately after landing is sufficient. This immediate lift-off period is made available for aborts caused by sinking, tilting, or by certain serious problems that result from the landing impact. Note that prior to landing separate DPS-to-full-use and APS-only cases exist. However, because of difficulty in generation of the DPS data, only data for APS-only cases are presented.

6.6.1 LM-active rendezvous.- Because the required phasing is not set up at insertion, a special phasing maneuver must be included in the rendezvous sequence, and the rendezvous completion is necessarily delayed one revolution, compared to the nominal time line from insertion. Because the phasing maneuver is used to adjust the phasing, a tweak maneuver is not applied immediately after insertion for this constant insertion region. The phasing maneuver for an abort at any time in this region is performed at 67 minutes after PDI instead of at 50 minutes after insertion. Therefore, the Δt between insertion and phasing varies from approximately 50 to 45 minutes as the abort time varies from PDI plus 10 minutes to PDI plus 15 minutes. The use of the fixed g.e.t. for phasings maintains an adequate Δt between CDH and TPI if a CSM takeover is required at phasing time. A fixed Δt of 50 minutes between insertion and phasing would not maintain an adequate CDH to TPI Δt for rescues after aborts in the latter part of this region.

The phasing maneuver is a horizontal posigrade maneuver whose magnitude is a function of abort time. Throughout the constant insertion region, the mean motion of the LM must be decreased compared with the mean motion if it remains in the insertion orbit. The earlier the abort, the more the LM must slow down; that is, the more the phasing maneuver must boost its orbit. The largest phasing maneuver is approximately 88 fps, and the smallest planned phasing maneuver is 10 fps. In fact, the 10 fps phasing maneuver is the criterion for the end of the constant insertion region; it is desirable always to raise the LM perilune with the phasing maneuver. The prime source of the phasing maneuver solution is the ground control; however, onboard charts for this solution will be available.

The phasing maneuver sets up the phasing such that a first CSI can be performed one-half revolution later (in front of the moon) and the resulting coelliptic Δh will be 15 n. mi. (LM below). For this θS1-1, n = 1 is used for the original CDH, and TPI is at the midpoint of the first darkness period after CDH. Therefore, the Δt between the orginal CDH and TPI is approximately 95 minutes because the original CDH is performed behind the moon and one-half revolution earlier than normal (relative to TPI). After CSI-1 is performed, however, a CSI-2 replaces the original CDH, based on the original CDH time and n = 1 for the actual CDH. Therefore, the CSI-2 ΔV is approximately equal to the original CDH ΔV, and the actual CDH ΔV is nearly zero (unless navigation or execution errors are involved). Because of the radial component in the original CDH which cannot be compensated for by CSI-2, the resultant coelliptic Δh will vary noticeably from the nominally-targeted 15 n. mi. For situations in which the CSI-2 and original CDH solutions are nearly equal, the original CDH might actually be performed. However, operationally, the CSI-2 would usually be required to maintain optimum terminal phase lighting. The time line after CSI-1 is essentially equivalent to the nominal time line from LM insertion after lift-off from the surface. The RCS would probably be used for all of these maneuvers because only a small quantity of APS propellant would remain.

The summary data for aborts during the first opportunity constant insertion region are presented in figure 25. Two representative specific-point cases are presented, one for an abort at PDI-1 plus 12 minutes and one for an abort at PDI-1 plus 14 minutes 12 seconds. The summary and relative motion for the PDI-1 plus 12 minute case are presented in table XVIII and figure 26. Corresponding data are presented for the PDI-1 plus 14 minute 12 second case in table XIX and figure 27. The relative range data are included in the summary data figure.

6.6.2 Rescues.- The first paragraph of section 6.6.1 applies to rescues in the constant insertion region. However, two different types of rendezvous sequences are required for rescue depending on the magnitude of the required phasing maneuver (which is horizontal retrograde for rescues). The rescue phasing maneuver is simply the mirror image of the LM phasing maneuver when the ΔV is less than 48 fps. If the LM phasing maneuver had exceeded 48 fps, the CSM phasing maneuver would have remained at 48 fps. The 48-fps case occurs for an abort at approximately PDI-1 plus 12.5 minutes. For later aborts, the phasing ΔV is less than 48 fps.

6.6.2.1 Rescue when LM phasing ΔV would have exceeded 48 fps (PDI-1 plus ~10 min to PDI-1 plus ~12.5 min): In this region, the constant 48-fps rescue phasing maneuver is applied. The 48-fps maneuver serves as a height maneuver which establishes a Δh of approximately 15 n. mi. one-half revolution after phasing. The mirror image phasing could not have been performed for aborts during the early part of the constant insertion region because an impact trajectory would have resulted. Instead of enlarging the mirror image region by increasing the phasing ΔV to be as large as possible, the switch point is set at the ΔV when either sequence (mirror image or constant phasing) can be applied. In other words, if a rescue phasing ΔV greater than 48 fps were applied, a coelliptic Δh of 15 n. mi. could not be maintained if the technique presented in this subsection were applied.

The constant rescue phasing technique is essentially equivalent to the rescue 2 sequence explained in section 6.3.2.2. The LM times are used for phasing, CSI-1, and TPI; although after CSI-1 the TPI time might be shifted closer to the LM midpoint of darkness if the coelliptic Δh were not increased too much or if the Δt between CDH and TPI were not decreased too much. For the data presented in this report, it is assumed that TPI is not optimized for lighting after CSI-1. The summary data for rescues in the constant phasing part of the constant insertion region are presented in figure 28. The summary and relative motion for the representative specific-point case of abort at PDI-1 plus 12 minutes are presented in table XX and figure 29. The relative range data are included in the summary data figure.

6.6.2.2 Rescue when LM phasing ΔV would have been less than 48 fps (PDI-1 plus ~12.5 min to PDI-1 plus ~15 min): In this region, the mirror image of the LM phasing maneuver is applied for the rescue phasing. Then the same type of sequence explained in section 6.6.1 for the LM-active rendezvous in the constant insertion region is performed. The LM times are used for phasing, CSI-1, and TPI, although TPI time might be optimized for lighting after CSI-1 (section 6.6.2.1). The summary data for rescues in the mirror-image phasing part of the constant insertion region are presented in figure 30. The representative specific-point case of abort at PDI plus 14 minutes 12 seconds is summarized in table XXI, and the relative motion plot is shown in figure 31. The relative range time history is contained in the summary data figure.

6.7 PDI-1 plus 21 minutes 24 seconds

The single-point abort time of PDI-1 plus 21 minutes 24 seconds is referred to as the preferred lift-off time (T2) for the first opportunity landing. That is, if the LM does not abort at this time, it should wait at least until the next CSM pass to lift off. If the LM has not aborted at PDI-1 plus ~15 minutes, it has committed to stay on the surface at least approximately 6.5 minutes more. The descent program is then exited, and the ascent program is initiated. An appraisal of the APS is made, and if a leak or some other problem is discovered which prevents a stay for one CSM revolution, the LM lifts off at the preferred time (PDI-1 plus 21 min 24 sec). The insertion orbit is the 30-n. mi. apolune orbit with the 19.5-fps radially-upward component.

6.7.1 LM-active rendezvous.- The LM-active rendezvous technique is equivalent to that explained for the PDI-1 plus ~15 minute abort except that an additional revolution is required between phasing and CSI-1. That is, the fixed phasing ΔV is 10 fps as for the PDI-1 plus ~15 minute case, but one and one-half revolutions (instead of one-half revolution) are required between phasing and CSI-1 for the preferred lift-off case. The data presented for this case are based on the phasing maneuver being at 50 minutes after insertion. Recently, it has been proposed that the insertion to phasing Δt be decreased to 45 minutes to increase the Δt between CDH and TPI. Whether this change will be incorporated is not definite at present. TPI for the preferred lift-off case is approximately four and one-half revolutions after insertion. Beginning at CSI-1, the sequence is equivalent to that explained for the constant insertion region (section 6.6.1), except that CSI-1 will probably not be a totally onboard CSI. Instead, it will be a ground or chart-derived phase adjustment maneuver based on the occurrence of a subsequent CSI one-half revolution later. This case is summarized in table XXII, and the relative motion plot and relative range time history are shown in figure 32.

6.7.2 Rescue.- At LM phasing, the central phase angle is so large that the vehicle-to-vehicle line of sight intersects the moon and, therefore, there is no vehicle-to-vehicle communication. Furthermore, because the maneuver is performed behind the moon, the CSM does not know if the LM has performed the phasing maneuver until MSFN AOS of the LM. If the LM has not performed the phasing and a rescue is required, the rescue phasing is performed approximately at the CSM's return to the longitude at which the LM phasing was to be performed. This rescue phasing time will be a fixed g.e.t. in real time. Beginning at phasing, the rescue sequence is equivalent to the sequence for the mirror-image phasing part of the constant insertion region (section 6.6.2.2), except that everything is delayed approximately one revolution. The phasing ΔV is obtained through a ground DKI solution or by the addition of a bias to the LM phasing maneuver. The TPI lighting in this case probably will be optimized initially. This rescue case is summarized in table XXIII, and the relative motion plot and relative range time history are presented in figure 33.

6.8 PDI-1 Plus Approximately One Revolution (2 hr 6 min 51 sec)

If the LM remains on the surface for approximately one revolution before an abort, it lifts off at the correct phasing time to perform essentially the nominal ascent rendezvous. That is, the insertion orbit has a 45-n. mi. apolune, and the radially-upward component is 32 fps. The CSI is performed approximately 50 minutes after insertion; CDH, one-half period after CSI; and TPI, at the first midpoint of darkness after CDH. The slight difference from the nominal is that the total Δt from insertion to TPI is approximately 3 minutes shorter because the moon would not have rotated as far as for the 21-hour-stay nominal. Because the Δt's between insertion and CSI and between CSI and CDH are constant, the Δt between CDH and TPI is decreased approximately 3 minutes. Potentially, a correct phasing lift-off is available for every CSM pass. The closer such an abort might be to the nominal stay lift-off time, the less different it would be from the nominal. The rescue for this case would be essentially the mirror-image type, for which the CSM generates its own solutions by use of the LM CSI and TPI times. The summary data for the one-revolution stay LM-active rendezvous are presented in table XXIV, and the relative motion plot and relative range time history are presented in figure 34. The summary data for the one-revolution stay rescue are presented in table XXV, and the relative motion plot is presented in figure 35. The relative range data presented in figure 34 suffice for this case.

6.9 PDI-2 to PDI-2 plus 14 minutes 24 seconds

The variable insertion region for the second opportunity landing extends from PDI-2 to PDI-2 plus 14 minutes 24 seconds or approximately to 2.5 minutes after nominal landing (11 min 53 sec). The CSM is approximately 21° behind the LM at PDI-2 as compared to approximately 7° at PDI-1. Therefore, the insertion orbit apolune required for a given abort time in this region is considerably higher than the apolune required for the corresponding abort in the first opportunity variable insertion region. Consequently, the variable insertion region lasts longer for the second opportunity. The summary data for the powered ascent and insertion conditions are presented in figure 36.

Except for reference times, the discussions of both the LM-active and rescue techniques for the first opportunity variable insertion region including the tweak maneuver discussion apply for the second opportunity variable insertion region [sections 6.5 (general), 6.5.1 (LM-active), and 6.5.2 (rescue)]. The coefficients for the variable insertion equations (polynomials) for the second landing opportunity would be updated soon after the decision was made to land at the second opportunity.

Because the variable insertion region extends to approximately 2.5 minutes after landing, it has been agreed that no constant insertion region is required for the second opportunity landing. However, last preferred lift-off time, is provided (section 6.10).

The summary data for LM-active rendezvous for the second opportunity variable insertion region are presented in figure 37. A representative case with abort at PDI plus 14 minutes 24 seconds is summarized in table XXVI, and the relative motion plot is presented in figure 38. The relative range data are included in the summary data figure. For this same abort time, the rescue case is summarized in table XXVII, and the relative motion plot is presented in figure 40. The summary data for the rescue situation for this second opportunity variable insertion region are presented in figure 39. These rescue data assume that the LM inserts into the targeted insertion orbit. As for the corresponding first opportunity region, an analysis of contingency orbit insertions is being performed and will be documented separately from this document (section 6.5.2).

6.10 PDI-2 plus 19 minutes 22 seconds

The time PDI-2 plus 19 minutes 22 seconds is the preferred lift-off time (T2) for the second opportunity landing. The purpose of this abort point is the same as that explained for the first opportunity landing. However, the rendezvous sequences and time lines for both LM-active rendezvous and rescue are equivalent to those for the constant insertion region for the first opportunity landing (specifically, the PDI-1 plus ~15 min abort) instead of being equivalent to the preferred lift-off abort for the first opportunity landing. That is, (1) the time of the 10-fps phasing is fixed relative to PDI (approximately PDI-2 plus 72 min) because the CSM can back up this maneuver directly; and (2) CSI-1 is only one-half revolution after phasing. Therefore, relative to the respective PDI maneuvers, the preferred lift-off abort for the second opportunity landing requires one less revolution for rendezvous than does the preferred lift-off abort for the first opportunity landing (LM-active or rescue). For the second opportunity landing, the Δt between the end of the variable insertion region and the preferred lift-off time is only approximately 4.5 minutes, but it is assumed that this amount of time is adequate for analyzing the APS and switching to the ascent program. If not, a later preferred lift-off time could be designed, but an additional revolution for rendezvous would be required. In other words, this type of later preferred lift-off would require a time line similar to the time line for the first opportunity landing preferred lift-off abort.

The summary data for the LM-active rendezvous for the PDI-2 plus 19 minute 22 second abort are presented in table XXVIII, and the relative motion plot is presented in figure 41. The summary data for the corresponding rescue are presented in table XXIX, and the relative motion plot is presented in figure 42. The relative range data presented in figure 25 apply for these cases.

6.11 PDI-2 Plus Approximately One Revolution (2 hr 11 min 23 sec)

The discussion presented in section 6.8 applies for this case. The summary data for the LM-active rendezvous are presented in table XXX, and the relative motion plot is presented in figure 43. The corresponding rescue summary data are presented in table XXXI, and the relative motion plot is presented in figure 44. The relative range data are presented in figure 34.

A summary of pertinent abort lift-off times for both the first and second landing opportunities is presented in table XXXII. These lift-off times include the latest lift-off time based on the descent program, the preferred lift-off time based on the ascent program, and the lift-off time approximately one CSM revolution later.

6.12 Specific Cases Available Upon Request

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

1. Rescue after partial DOI of 20 fps
2. Rescue after partial DOI of 60 fps
3. LM-active no-PDI-1 plus 12 minute abort

4. Rescue after accurate abort initiation for number 3

5. Rescue after zero abort initiation for number 3

6. Rescue after partial abort initiation of 60 fps for number 3

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

8. Rescue after accurate abort initiation for number 7

9. Rescue after zero abort initiation for number 7

10. Rescue after partial abort initiation of 65 fps for number 7

11. Rescue after partial abort initiation of 90 fps for number 7

12. LM-active PDI-1 plus 5 minute abort (DPS through insertion)

13. Rescue for number 12, assuming accurate insertion

14. LM-active PDI-1 plus 10 minute abort (APS only after abort)

15. Rescue for number 14, assuming accurate insertion

16. Rescue (high dwell) after contingency insertion for PDI-1 plus 6 minute abort

17. LM-active PDI-1 plus 12 minute abort

18. Rescue for number 17, assuming accurate insertion

19. LM-active PDI-1 plus 14 minute 12 second abort

20. Rescue for number 19, assuming accurate insertion

21. LM-active PDI-1 plus 21 minute 24 second abort (preferred)

22. Rescue for number 21, assuming accurate insertion

23. LM-active PDI-1 plus approximately one CSM revolution (correct phasing)

24. Rescue for number 23, assuming accurate insertion

25. LM-active PDI-2 plus 14 minute 24 second abort

26. Rescue for number 25, assuming accurate insertion

27. LM-active PDI-2 plus 19 minute abort (preferred)

28. Rescue for number 27, assuming accurate insertion

29. LM-active PDI-2 plus approximately one CSM revolution (correct phasing)

30. Rescue for number 29, assuming accurate insertion

6.13 General Comments

It is assumed that the LM will always make every possible effort to trim to the targeted insertion velocity, even when overburns occur at insertion. Therefore, if a contingency insertion orbit should remain after efforts to trim, a rescue probably would be required. As emphasized in section 6.5.2.2, the most critical regions for contingency insertion orbits are the variable insertion regions (first and second landing opportunities). If contingency insertion orbits should result for the later designed lift-off times (including nominal lift-off), rendezvous could probably be accomplished within at least one or two extra revolutions; in some situations, rendezvous could be accomplished in the same time as for the accurate insertion case. The applicable resuce sequence would be either a rescue 2 sequence or a sequence similar to the phasing sequence discussed in section 6.6.2.2. In most cases, the DKI processor would be used to set up the sequence and to supply the initial maneuver. Overburn insertion data will be included in the forthcoming contingency insertion orbit memorandum.

It is emphasized that the CSM is prepared to immediately back up all LM burns after insertion (when vehicle-to-vehicle contact exists) and after abort initiation for the no-PDI cases. The LM t_{IG} time is used to target the backup burn; for CSI, the LM-active TPI time is used. The abort initiation for the no-PDI cases is not backed up immediately, but the rescue 2 sequence is initiated approximately 50 minutes later. For the first landing opportunity preferred lift-off, the LM phasing is not backed up until approximately one revolution later because vehicle-to-vehicle contact does not exist, and the vehicles are behind the moon at the time of LM phasing.

If a partial LM RCS burn should occur, the LM should pitch 90° and complete the burn ΔV with the other axis thrusters. If this method is not feasible, the ΔV-to-go should be voiced to the CSM, and the CSM should apply this ΔV in the opposite direction. If neither of these methods can be used, a two-impulse or DKI sequence from the ground would be required.

Although no plane-change data are presented in this report, the LM in-orbit plane-change technique is discussed briefly in section 4.1. Further explanation is contained in reference 3. A half-degree plane-change capability is allotted for powered ascent, and the CSM rescue plane-change capability is between 100 and 200 fps (in addition to the 800 fps inplane budget), depending on the exact situation.

For expected conditions, the ground control will be able to supply accurate solutions for all external maneuvers. However, it is emphasized that either canned or chart solutions will be available for all of the external maneuvers for which there is any reasonable chance that accurate ground support capability might not exist.

Although the presented data indicate a total rescue when a rescue has been initiated, there are situations in which the LM might resume the active role after one or more rescue maneuvers had been performed. The rescue 2 sequence could involve such a situation. If the LM were to become active during a rescue sequence, the relative motion and relative range time history would be essentially the same as those shown for the total rescue case; and the LM-active ΔV's and Δt's would vary only slightly from those shown for the total rescue case.

The criteria for a switch to AGS control during powered descent or ascent are not included in this report.

7.0 CONCLUSION

The abort and rescue plans discussed in this document present acceptable rendezvous procedures for the various contingency situations that could occur during the LM-active phases of Apollo 11 (Mission G). The procedures have been agreed to by the crew and by Flight Control; therefore, they are thought to be feasible from the points of view of crew training, ground support, and other operational considerations. From a procedures and techniques point of view, the overall plan has been considerably simplified and standardized since publication of the preliminary report. Although the backup landing opportunity increases the magnitude of the plan, it could save the landing planned for Apollo 11 (Mission G) and, therefore, is definitely worthwhile. A summary of the total plan is presented in table I.

The LM RCS, SM RCS, and SPS ΔV capabilities could become marginal for certain cases in which multiple failures or excessive dispersions occur. However, for most of the normal abort and rescue situations, these ΔV requirements are safely within the assumed budgets. For most rescue situations, rendezvous can be accomplished within the normal LM ascent stage lifetime. However, there are certain low-probability rescue cases for which the LM must power down to extend its lifetime to approximately 12 hours.

The information and data included in this report should provide a detailed understanding of the operational abort and rescue plan. The supplementary specific data, which are available upon request, should accurately serve as the basis for the various consumables, time line, software, and propulsion analyses, even if the exact nominal CSM lunar parking orbit or the launch date should be changed from those on which the data were generated.

TABLE 1 - SUMMARY OF OPERATIONAL LM ABORT AND RESCUE PLAN FOR APOLLO 11 (MISSION G)

Abort phase, region, or single-point	Time reference of abort phase, region, or single-point	Active vehicle	Specific comment	Discussion section	Rendezvous technique (sequence)	Initial maneuver point[a]	Original CSI-to-CDH revs	Approx revs insert[b]-to-TPF (target vehicle)
Minifootball	CSM SEP to DOI	Either	NO-GO for DOI	6.1	Manual braking			
Post-DOI/ direct return	DOI to DOI plus 10 min	LM	NO-GO for landing	6.2.1	Direct return	DOI plus one CSM rev		
		CSM	DOI ΔV < 27 fps	6.2.2	Rescue 2	DOI plus 1 CSM rev	1	[illegible]
			DOI ΔV > 27 fps	6.2.2	Rescue 2	DOI plus 1 CSM rev	2	[illegible]
First opportunity no-PDI	No-PDI-1 plus 12 min	LM[c]	Failure prior to or at PDI-1	6.3.1	Two-impulse to CDH offset	A.I. plus 46 min	½	[illegible]
		CSM	Accurate A.I.	6.3.2.1	CSM CSI/CDH	A.I. plus 46 min	[illegible]	[illegible]
			A.I. ΔV < 60 fps	6.3.2.2	Rescue 2	DOI plus one CSM rev	[illegible]	[illegible]
			A.I. ΔV ≥ 60 fps	6.3.2.2	Rescue 2	DOI + 1 CSM rev	1	[illegible]
Second opportunity no-PDI	No-PDI-2 plus 12 min	LM[c]	Failure prior to or at PDI-2	6.4.1	Two-impulse to CDH offset	A.I. plus 49 min	½	[illegible]
		CSM	Accurate A.I.	6.4.2.1	CSM CSI/CDH	A.I. plus 49 min	[illegible]	[illegible]
			A.I. ΔV < 40 fps	6.4.2.2	Rescue 2	DOI plus two CSM revs	[illegible]	[illegible]
			A.I. ΔV = 40-90 fps	6.4.2.2	Rescue 2	DOI plus two CSM revs	2	[illegible]
			A.I. ΔV ≥ 90 fps	6.4.2.2	Rescue 2	DOI plus two CSM revs	1	[illegible]
First opportunity variable insertion	PDI-1 to PDI-1 plus 10 min	LM	Variable insert apo	6.5.1	CSI/CDH	Insert plus 50 min	½	[illegible]
		CSM	Accurate insert	6.5.2.1	CSM CSI/CDH	Insert plus 50 min	½	[illegible]
			Contingency insert[d]	6.5.2.2	High dwell	PDI plus 67 min	[illegible]	[illegible]
First opportunity constant insertion	PDI-1 plus 10 min to PDI-1 plus 15 min (landing at 11:53)	LM	30-n. mi. insert apo	6.6.1	Pha/CSI-for-CDH	PDI plus 67 min	½	[illegible]
		CSM	LM pha ΔV ≥ 48 fps	6.6.2.1	Similar to rescue 2	PDI plus 67 min	1	[illegible]
			LM pha ΔV < 48 fps	6.6.2.2	Mirror-image pha/CSI-for-CDH	PDI plus 67 min	½	[illegible]
First opportunity (last) preferred	PDI-1 plus 21 min 24 sec	LM	30-n. mi. insert apo	6.7.1	Pha/CSI for CDH[e]	Insert plus 50 min	[illegible]	[illegible]
		CSM	Accurate insert	6.7.2	CSM pha/CSI-for-CDH	Insert plus 2 hr 34 min	[illegible]	[illegible]
First opportunity CSM rev after landing	PDI-1 plus 2 hr 6 min 51 sec	LM	Correct phasing/ 45-n. mi. insert apo	6.8	Nom CSI/CDH	Insert plus 51 min	½	[illegible]
		CSM	Accurate insert	6.8	CSM CSI/CDH	Insert plus 51 min	½	[illegible]
Second opportunity variable insertion	PDI-2 to PDI-2 plus 14 min 24 sec	LM	Variable insert apo	6.9	CSI/CDH	Insert plus 50 min	½	[illegible]
		CSM	Accurate insert	6.9	CSM CSI/CDH	Insert plus 50 min	½	[illegible]
			Contingency insert[d]	6.9	High dwell	PDI plus 67 min	[illegible]	[illegible]
Second opportunity (last) preferred	PDI-2 plus 19 min 22 sec	LM	30-n. mi. insert apo	6.10	Pha/CSI-for-CDH	PDI plus 67 min	½	[illegible]
		CSM	Accurate insert	6.10	Mirror-image pha/CSI-for-CDH[f]	PDI plus 67 min	½	[illegible]
Second opportunity CSM rev after landing	PDI-2 plus 2 hr 11 min 23 sec	LM	Correct phasing/ 45-n. mi. insert apo	6.11	Nom CSI/CDH	Insert plus 51 min	½	[illegible]
		CSM	Accurate insert	6.11	CSM CSI/CDH	Insert plus 51 min	½	[illegible]

[a]After DOI for partial DOI rescues, after abort initiation for no-PDI cases, and after insertion for cases where powered descent is initiated

[b]Or from where insertion would have occurred if powered descent had been initiated

[c]If main engine failure occurs during burn, LM attempts to complete burn with backup engine (APS or RCS) or increases ΔV to 100 fps with RCS (section 6.3.1)

[d]Contingency orbit for which CSM cannot obtain required phase angle change in low phasing orbit

[e]Approximately 1.5 revolutions between phasing maneuver and CSI-1

[f]Equivalent to PDI-1 plus 15 min situation

Abbreviations

A.I. - abort initiation

apo - apolune

approx - approximate

ASAP - as soon as possible

insert - insertion

nom - nominal

pha - phasing maneuver

rev - revolution

TABLE II.- RESCUE AFTER A PARTIAL DOI OF 20 FPS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Partial DOI	99:42:18.8	[e]0:59:04.4	DPS	[f]17.0	20.0	-20.0	0.0	60.0/44.9
Rescue 2	101:41:25.0	1:59:6.3	SM/RCS	17.5	6.4	- 6.4	0.0	60.2/54.7
CSI[g]	102:40:43.3	0:59:18.3	SPS	2.8	55.6	-55.6	0.0	54.9/19.6
CDH	104:35:21.6	1:54:38.3	SPS	3.5	69.1	69.0	- 4.3	70.0/54.9
TPI	105:12:14.4	0:36:52.9	SPS	0.8	16.4	-14.5	7.5	66.8/47.2
TPF	105:55:06.2	0:42:51.7	SM/RCS	56.7	21.0	-12.0	-17.2	60.0/44.9

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From CSM separation.
[f] 15 seconds at 10%, then to 40%.
[g] A second (zero) CSI would be scheduled halfway between the original CSI and CDH.

TABLE III.- RESCUE AFTER A PARTIAL DOI OF 60 FPS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
DOI	99:42:18.8	[e]0:59:04.4	DPS	[f]28.4	60.0	-60.0	0.4	60.0/16.2
Phasing	101:41:32.3	1:59:13.5	SPS	2.3	45.8	-45.8	0.0	60.0/26.2
CSI[g]	102:39:26.6	0:57:54.3	SPS	2.8	55.4	-55.4	0.0	26.3/19.9
CDH	106:23:45.1	3:44:18.5	SPS	3.5	69.1	68.8	- 6.4	70.0/26.2
TPI	106:59:23.5	0:35:38.4	SPS	0.8	16.2	-15.0	6.0	66.1/19.1
TPF	107:42:18.9	0:42:55.4	SM/RCS	57.8	21.5	-12.0	-17.9	60.0/16.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From CSM separation.
[f] 15 seconds at 10%, then to 40%.
[g] A second (zero) CSI would be scheduled halfway between the original CSI and CDH, and a third (zero) CSI would be scheduled halfway between the second CSI and CDH.

TABLE IV.- LM-ACTIVE RENDEZVOUS FOR NO-PDI-1 PLUS 12 MINUTE ABORT

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Abort init.	100:50:22.0	[e]1:08:03.2	DPS	[f]47.0	200.3	116.6	162.9	147.9/11.8
CSI	101:36:42.7	0:46:20.7	RCS(X)	0.6	0.1	0.1	0.0	147.9/11.9
CDH	102:37:7.9	1:0:25.3	DPS	[f]58.6	320.0	-82.3	-309.3	45.9/43.8
TPI[g]	103:17:51.1	0:40:43.2	RCS(Z)	42.0	24.7	22.0	- 11.1	62.3/43.6
TPF	104:0:40.6	0:42:49.5	RCS(Z)	52.1	30.7	18.2	24.7	61.0/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.
[g] Staging 10 minutes prior to TPI.

TABLE V.- RESCUE AFTER AN ACCURATE NO-PDI-1 PLUS 12 MINUTE ABORT INITIATION

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Abort init.	100:50:22.0	[e]1:08:03.2	DPS	[f]47.0	200.3	116.6	162.9	147.9/11.8
CSI	101:36:35.2	0:46:13.2	SM/RCS	15.9	5.8	- 5.8	0.0	60.0/55.4
CDH	102:37:41.1	1:1:5.9	SPS	16.0	301.1	88.6	287.8	163.3/27.3
TPI	103:17:47.7	0:40:6.6	SPS	0.9	21.9	-21.5	4.0	150.9/22.4
TPF	104:5:11.0	0:47:23.3	SM/RCS	87.6	33.1	-17.4	-28.1	147.7/12.0

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.

TABLE [illegible] - [illegible] AFTER A [illegible] NO-PDI-1 PLUS 1[illegible] MINUTE ABORT INITIATION

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Zero abort initiation	100:50:22	[e]1:08:03.2	DPS	0.0	0.0	0.0	0.0	60.0/8.2
Rescue 2	101:41:31.9	0:51:09.9	SPS	2.9	57.0	-57.0	0.0	60.0/18.2
CSI[f]	102:39:05.4	0:57:33.4	SPS	3.1	61.4	-61.4	0.0	18.5/15.5
CDH	106:21:16.5	3:42:11.1	SPS	3.8	75.3	74.9	-7.6	70.0/18.2
TPI	106:56:36.4	0:35:19.9	SPS	0.8	16.1	-15.2	5.5	66.1/11.1
TPF	107:39:32.2	0:42:55.8	SM/RCS	58.2	21.7	-12.1	-18.0	60.0/8.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] A second (zero) CSI would be scheduled halfway between the original CSI and CDH, and a third (zero) CSI would be scheduled halfway between the second CSI and CDH.

TABLE VII.- RESCUE AFTER A PARTIAL NO-PDI-1 PLUS 12 MINUTE ABORT INITIATION OF 60 FPS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune n. mi.
60 fps abort initiation	100:50:22.0	[e]1:08:03.2	DPS	[f]32.4	60.0	34.1	49.4	81.4/12.4
Rescue 2	101:41:32.4	0:51:10.4	SPS	2.0	40.1	-40.1	0.0	60.0/30.2
CSI[g]	102:39:37.2	0:58:4.8	SPS	3.6	70.1	-70.1	0.0	30.3/9.7
CDH	104:31:12.2	1:51:35.0	SPS	7.0	134.0	113.9	70.6	96.4/27.4
TPI	105:6:9.3	0:34:57.1	SPS	1.0	23.3	-22.3	6.8	86.9/20.2
TPF	105:50:11.3	0:44:2.0	SM/RCS	87.2	32.7	-18.1	-27.3	81.2/12.5

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.
[g] A second (zero) CSI would be scheduled halfway between the original CSI and CDH.

TABLE VIII.- LM-ACTIVE RENDEZVOUS FOR NO-PDI-2 PLUS 12 MINUTE ABORT

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune n. mi.
Abort init.	102:44:25.5	[e]3:02:06.7	DPS	[f]47.7	207.4	174.6	112.0	194.7/13.0
CSI	103:33:5.5	0:48:40.0	RCS(X)	0.0	0.0	0.0	0.0	194.7/13.1
CDH	104:35:37.5	1:2:32.0	DPS	[f]65.4	388.1	-139.4	-362.2	45.8/43.8
TPI[g]	105:16:0.1	0:40:22.5	RCS(Z)	42.2	24.8	22.2	-11.2	62.3/43.5
TPF	105:58:48.8	0:42:48.7	RCS(Z)	53.0	31.2	18.5	25.2	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.
[g] Staging 10 minutes prior to TPI.

TABLE IX.- RESCUE AFTER AN ACCURATE NO-PDI-2 PLUS 12 MINUTE ABORT INITIATION

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Abort init.	102:44:25.5	[e]3:02:06.7	DPS	[f]47.7	207.4	174.6	112.0	194.7/13.0
CSI	103:32:56.4	0:48:30.9	SM/RCS	18.7	6.8	- 6.8	0.0	59.8/54.8
CDH	104:36:12.7	1:03:16.2	SPS	19.3	362.1	144.6	331.9	210.3/28.6
TPI	105:16:7.5	0:39:54.9	SPS	0.9	21.4	-21.4	0.1	199.1/22.1
TPF	106:6:52.8	0:50:45.3	SM/RCS	85.4	32.4	-16.3	-28.0	194.6/13.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.

[illegible] -PDI-2 [illegible] ABORT INITIATION

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Zero abort initiation	102:44:25.5	[e]3:02:06.7	DPS	0.0	0.0	0.0	0.0	60.0/8.2
Rescue 2	103:40:10.7	0:55:45.2	SPS	2.9	57.0	-57.0	0.0	60.0/18.2
CSI[f]	104:37:43.9	0:57:33.2	SPS	3.6	70.1	-70.1	0.0	18.3/9.8
CDH	110:09:26.5	5:31:42.6	SPS	4.3	84.0	83.6	-8.1	70.0/18.2
TPI	110:44:47.5	0:35:21.0	SPS	0.8	16.2	-15.2	5.6	66.1/11.1
TPF	111:27:43.5	0:42:56.0	SM/RCS	57.9	21.6	-12.2	-17.9	60.0/8.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] A second and a third (zero) CSI would be scheduled at equal LM period increments after the original CSI, and then a final fourth (zero) CSI would be scheduled halfway between the third CSI and CDH.

TABLE XI.- RESCUE AFTER A PARTIAL NO-PDI-2 PLUS 12 MINUTE ABORT INITIATION OF 65 FPS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
65 fps abort initiation	102:44:25.5	[e]3:02:06.7	DPS	[f]32.9	65.0	54.1	36.0	96.9/12.0
Rescue 2	103:40:11.2	0:55:45.7	SPS	2.0	40.3	-40.3	0.0	60.0/30.1
CSI[g]	104:38:16.6	0:58:5.4	SPS	1.7	35.4	-35.4	0.0	34.4/29.9
CDH	108:25:43.4	3:47:26.8	SPS	6.7	128.0	98.8	81.4	112.0/27.1
TPI	109:0:11.4	0:34:28.1	SPS	1.0	22.8	-22.1	5.6	102.4/19.9
TPF	109:45:12.1	0:45:0.7	SM/RCS	87.2	32.6	-17.7	-27.4	96.8/12.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.
[g] A second (zero) CSI would be scheduled halfway between the original CSI and CDH, and a third (zero) CSI would be scheduled halfway between the second CSI and CDH.

TABLE XII.- RESCUE AFTER A PARTIAL NO-PDI-2 PLUS 12 MINUTE ABORT INITIATION OF 90 FPS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
90 fps abort initiation	102:44:25.5	[e]3:02:06.7	LM/DPS	[f]35.5	90.0	75.1	49.7	112.8/12.0
Rescue 2	103:40:11.3	0:55:45.8	CSM/SPS	1.8	36.6	-36.6	0.0	60.0/32.8
CSI[g]	104:38:23.1	0:58:11.9	CSM/SPS	2.9	57.3	-57.3	0.0	32.9/18.6
CDH	106:30:56.7	1:52:33.6	CSM/SPS	9.5	179.7	137.3	116.0	127.9/27.6
TPI	107:5:15.9	0:34:19.2	CSM/SPS	1.0	22.3	-21.7	5.0	117.4/21.3
TPF	107:51:6.0	0:45:50.2	CSM/RCS	85.9	32.3	-17.0	-27.5	112.6/12.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From DOI.
[f] 26 sec at 10%, then to F.T.P.
[g] A second (zero) CSI would be scheduled halfway between the original CSI and CDH.

TABLE XIII.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT PDI-1 PLUS 5 MINUTES

[DPS through insertion]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
CSI[e]	101:37:37.3	[f]0:49:57.8	APS	4.1	42.2	42.2	0.0	109.0/38.6
CDH	102:38:6.6	1:00:29.3	APS	12.5	128.5	-75.0	-104.3	46.1/43.9
TPI	103:17:49.1	0:39:42.6	RCS(Z)	40.8	24.5	21.7	- 10.8	62.3/43.7
TPF	104:0:38.8	0:42:49.7	RCS(Z)	51.0	30.6	18.5	25.3	61.0/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] Staging 10 minutes prior to CSI.
[f] From insertion.

TABLE XIV.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT PDI-1 PLUS 10 MINUTES

[APS-only after abort]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune n. mi.
CSI	101:45:55.3	[e]0:49:52.5	APS	2.7	50.1	50.1	0.0	44.9/29.7
CDH	102:43:14.5	0:57:19.1	APS	1.2	22.5	21.6	6.2	46.1/44.0
TPI	103:17:48.5	0:34:34.0	RCS(Z)	22.2	24.3	21.7	-10.9	62.3/43.8
TPF	104:00:38.2	0:42:49.7	RCS(Z)	28.2	30.7	18.4	25.1	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XV.- RESCUE AFTER ABORT AT PDI-1 PLUS 5 MINUTES

[DPS through insertion]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
CSI	101:37:38.2	[e]0:49:58.7	SPS	2.1	43.1	43.1	0.0	59.8/28.3
CDH	102:35:30.2	0:57:52.0	SPS	6.8	128.8	73.3	105.9	121.3/23.9
TPI	103:17:46.5	0:42:16.2	SPS	0.9	21.3	-21.0	3.7	115.2/14.3
TPF	104:3:51.3	0:46:4.8	SM/RCS	80.9	30.1	-15.5	-25.8	107.1/9.9

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

Maneuver	Time of ignition, hr:min:sec, g.e.t.	Δt from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune n. mi.
CSI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-50.9	[illegible]	[illegible]
CDH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-24.4	[illegible]	[illegible]
TPI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-19.9	[illegible]	[illegible]/11.3
TPF	[illegible]	[illegible]	[illegible]/RCS	76.9	[illegible]8.4	-15.7	[illegible]	29.6/9.4

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon ([illegible]) is plus (+).
[e] From insertion.

TABLE XVII.- RESCUE AFTER CONTINGENCY INSERTION ABORT AT PDI-1 PLUS 6 MINUTES

[By CSM high dwell orbit]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Dwell init.[e]	101:45:48.1	[f]0:55:42.0	SPS	16.9	316.7	316.7	2.4	336.4/60.2
CSI	108:58:21.9	7:12:33.9	SPS	19.1	371.1	-371.1	-3.4	60.3/19.9
CDH	109:56:10.6	0:57:48.6	SPS	2.6	56.1	- 55.5	-8.1	20.2/19.9
TPI	110:28:25.3	0:32:14.8	SPS	0.8	17.8	- 15.4	8.8	20.3/9.0
TPF	111:08:04.6	0:39:39.2	SM/RCS	56.9	22.4	- 12.8	-18.4	10.2/9.8

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] Corrections to the dwell orbit might be performed at CSM period increments after dwell initiation.
[f] From insertion.

TABLE XVIII.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT PDI-1 PLUS 12 MINUTES

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Phasing	101:45:43.9	[e]0:47:29.0	RCS(X)	25.8	56.0	56.0	0.0	49.3/29.9
CSI_1	102:43:24.7	00:57:40.8	RCS(Z)	19.0	20.7	20.7	0.0	49.6/44.6
CSI_2[f]	103:41:41.9	00:58:17.2	RCS(Z)	5.8	6.3	-6.3	0.0	46.1/43.6
CDH	104:39:42.0	00:58:00.7	RCS(Z)	1.2	1.3	-0.2	-1.3	45.7/43.6
TPI	105:16:22.4	00:36:39.8	RCS(Z)	22.8	25.0	22.2	-11.1	62.3/43.4
TPF	105:59:11.9	00:42:49.5	RCS(Z)	28.7	31.5	18.9	25.7	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XIX.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT PDI-1 PLUS 14 MINUTES 12 SECONDS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Phasing	101:45:47.4	[e]00:45:20.5	RCS(Z)	18.9	20.5	20.5	0.0	30.7/23.1
CSI_1	102:42:22.6	00:56:35.2	RCS(Z)	19.3	20.9	20.9	0.0	45.1/23.6
CSI_2[f]	103:39:22.3	00:56:59.7	RCS(Z)	25.7	28.0	28.0	0.0	46.9/42.0
CDH	104:37:28.1	00:58:05.8	RCS(Z)	7.0	7.7	-1.0	-7.6	45.1/43.0
TPI	105:16:22.2	00:38:54.1	RCS(Z)	23.8	25.9	23.1	-11.7	62.4/42.8
TPF	105:59:11.8	00:42:49.6	RCS(Z)	29.8	32.7	19.7	26.6	60.9/58.9

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XX.- RESCUE AFTER ABORT AT PDI-1 PLUS 12 MINUTES

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Phasing	101:45:55.4	[e]0:47:40.5	SPS	2.4	47.8	-47.8	0.0	60.3/24.5
CSI[f]	102:43:33.1	00:57:37.8	SPS	1.7	34.8	-34.8	0.0	35.0/24.5
CDH	104:36:50.8	01:53:17.6	SPS	0.9	21.4	14.0	-16.2	45.1/24.4
TPI	105:16:23.0	00:39:32.2	SPS	1.2	25.7	-23.4	10.7	43.0/10.0
TPF	105:57:11.3	00:40:48.3	SM/RCS	90.3	33.4	-11.6	-31.4	30.0/9.1

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] A second (zero) CSI would be scheduled halfway between the original CSI and CDH.

TABLE XXI.- RESCUE AFTER ABORT AT PDI-1 PLUS 14 MINUTES 12 SECONDS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Phasing	101:45:56.2	[e]00:45:29.3	SPS	0.9	20.3	-20.3	0.0	60.3/44.3
CSI_1	102:42:31.7	00:56:35.5	SPS	0.9	21.1	-21.2	0.0	46.4/42.7
CSI_2[f]	103:40:28.1	00:57:56.4	SPS	1.4	30.6	-30.7	0.0	44.7/22.3
CDH	104:37:07.5	00:56:39.4	CSM-RCS	40.1	14.7	- 1.8	-14.6	43.2/22.5
TPI	105:16:20.7	00:39:13.2	SPS	1.0	22.3	-20.3	9.4	40.6/10.7
TPF	105:57:17.5	00:40:56.7	CSM-RCS	81.2	30.0	-16.7	-24.8	29.8/9.5

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XXII.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT LAST PREFERRED LIFT-OFF TIME FOR FIRST OPPORTUNITY

[PDI-1 plus 21 minutes 24 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Phasing	101:57:33.8	[e]0:49:55.4	RCS(Z)	9.2	10.0	10.0	0.0	30.0/16.3
CSI_1	104:45:42.8	2:48:8.9	RCS(Z)	19.3	20.9	20.9	0.0	45.1/16.3
CSI_2[f]	105:42:17.3	0:56:36.6	RCS(Z)	37.1	40.4	40.4	0.0	45.3/45.0
CDH	10[illegible]:40:33.3	0:58:16.0	RCS(Z)	5.8	6.3	0.9	6.3	46.5/44.4
TPI	107:14:55.7	0:34:22.4	RCS(Z)	21.6	23.6	21.0	-10.5	62.3/44.2
TPF	107:57:45.4	0:42:49.7	RCS(Z)	27.3	30.0	17.9	24.5	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XXIII.- RESCUE AFTER ABORT AT LAST PREFERRED LIFT-OFF TIME FOR FIRST OPPORTUNITY

[PDI-1 plus 21 minutes 24 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Phasing	103:41:15.5	[e]2:33:37.1	SPS	0.8	18.5	-18.5	0.0	60.1/45.8
CSI_1	104:40:02.8	0:58:47.3	SPS	0.9	20.4	-20.4	0.0	46.5/44.3
CSI_2[f]	105:38:04.4	0:58:01.6	SPS	1.5	30.8	-30.8	0.0	45.1/23.7
CDH	106:34:50.9	0:56:46.5	SM/RCS	35.4	6.5	- 0.8	- 6.4	44.4/23.7
TPI	107:10:29.2	0:35:38.3	SPS	1.1	24.4	-22.2	10.1	40.3/12.0
TPF	107:51:17.6	0:40:48.	SM/RCS	87.0	32.1	-16.3	-27.7	30.0/9.4

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXIV.- LM-ACTIVE RENDEZVOUS AFTER CORRECT PHASING LIFT-OFF ON NEXT CSM PASS AFTER FIRST OPPORTUNITY LANDING

[PDI-1 plus 2 hours 6 minutes 51 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
CSI	103:44:3.1	[e]0:51:00.6	RCS(X)	22.4	49.6	49.6	0.0	45.1/44.2
CDH	104:42:0.1	0:57:57.0	RCS(Z)	5.4	6.0	0.3	6.0	45.7/43.6
TPI	105:16:22.0	0:34:22.0	RCS(Z)	22.6	25.0	22.2	11.2	62.3/43.4
TPF	105:59:11.8	0:42:49.7	RCS(Z)	28.5	31.5	18.9	25.8	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXV.- RESCUE AFTER CORRECT PHASING LIFT-OFF ON NEXT CSM PASS AFTER FIRST OPPORTUNITY LANDING

[PDI-1 plus 2 hours 6 minutes 51 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune n. mi.
CSI	103:44:3.0	[e]0:51:00.5	SPS	2.5	50.6	-50.6	0.0	60.2/22.6
CDH	104:41:44.1	0:57:41.1	SPS	0.9	20.3	- 2.6	-20.2	58.5/22.4
TPI	105:16:22.4	0:34:38.3	SPS	1.0	22.1	-20.5	8.3	54.4/11.8
TPF	105:58:19.7	0:41:57.2	SM/RCS	79.2	29.2	-15.9	24.5	45.1/9.1

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXVI.- LM-ACTIVE RENDEZVOUS AFTER ABORT AT PDI-2 PLUS 14 MINUTES 24 SECONDS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
CSI	103:44:9.9	[e]0:49:48.6	RCS(X)	22.9	49.6	49.6	0.0	44.6/30.0
CDH	104:41:34.9	0:57:25.1	RCS(Z)	19.8	21.6	20.7	6.2	45.8/43.7
TPI	105:16:22.2	0:34:47.3	RCS(Z)	22.6	24.8	22.1	-11.1	62.3/43.5
TPF	105:59:11.9	0:42:49.7	RCS(Z)	28.6	31.3	18.8	25.6	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXVII.- RESCUE AFTER ABORT AT PDI-2 PLUS 14 MINUTES 24 SECONDS

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
CSI	103:44:19.8	[e]0:49:58.5	SPS	2.5	50.5	-50.5	0.0	60.2/22.6
CDH	104:42:0.8	0:57:41.0	SPS	1.3	28.7	-23.5	-16.5	43.2/22.5
TPI	105:16:22.0	0:34:21.3	SPS	1.0	22.4	-20.3	9.5	39.9/11.3
TPF	105:57:13.6	0:40:51.5	SM/RCS	78.5	29.0	-15.1	-24.7	30.0/9.3

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXVIII.-LM-ACTIVE RENDEZVOUS AFTER ABORT AT LAST PREFERRED LIFT-OFF TIME FOR SECOND OPPORTUNITY

[PDI-2 plus 19 minutes 22 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/ perilune, n. mi.
Phasing	103:44:16.7	[e]0:44:57.5	RCS(Z)	9.2	10.0	10.0	0.0	30.2/16.1
CSI_1	104:20:28.7	00:56:12.1	RCS(Z)	19.3	21.0	21.0	0.0	45.0/16.4
CSI_2[f]	105:37:04.4	00:56:35.7	RCS(Z)	35.2	38.3	38.3	0.0	47.1/41.7
CDH	106:35:14.1	00:58:09.7	RCS(Z)	8.1	8.9	-1.1	- 8.8	45.0/42.9
TPI	107:14:55.8	00:39:41.7	RCS(Z)	24.0	26.2	23.2	-11.8	62.4/42.6
TPF	107:57:45.4	00:42:49.6	RCS(Z)	30.0	32.9	19.8	26.8	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XXIX.- RESCUE AFTER ABORT AT LAST PREFERRED LIFT-OFF TIME FOR SECOND OPPORTUNITY

[PDI-1 plus 19 minutes 22 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
Phasing	103:44:07.7	[e]0:44:48.5	SM/RCS	27.4	10.0	-10.0	0.0	60.3/51.9
CSI_1	104:40:37.8	0:56:30.1	SPS	0.9	21.1	-21.1	0.0	52.5/44.1
CSI_2[f]	105:38:54.2	0:58:16.3	SPS	2.0	40.9	-40.9	0.0	44.6/22.6
CDH	106:35:38.2	0:56:44.1	SM/RCS	31.9	11.7	- 1.5	-11.6	43.4/22.7
TPI	107:14:54.1	0:39:15.9	SPS	1.0	22.7	-20.6	9.5	40.7/10.8
TPF	107:55:45.1	0:40:51.0	SM/RCS	79.6	29.4	-14.6	-25.5	30.0/9.2

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.
[f] Replaces original CDH.

TABLE XXX.- LM-ACTIVE RENDEZVOUS AFTER CORRECT PHASING LIFT-OFF ON NEXT PASS

AFTER SECOND OPPORTUNITY LANDING

[PDI-2 plus 2 hours 11 minutes 23 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
CSI	105:42:17.3	[e]0:51:01.2	RCS(X)	22.5	49.7	49.7	0.0	45.1/44.5
CDH	106:40:14.5	0:57:57.2	RCS(Z)	5.5	6.0	-0.3	6.0	45.8/43.6
TPI	107:14:54.7	0:34:40.2	RCS(Z)	22.6	25.0	22.2	-11.1	62.3/43.4
TPF	107:57:44.4	0:42:49.7	RCS(Z)	28.4	31.5	18.8	25.7	60.9/58.7

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXXI.- RESCUE AFTER CORRECT PHASING LIFT-OFF ON NEXT CSM PASS

AFTER SECOND OPPORTUNITY LANDING

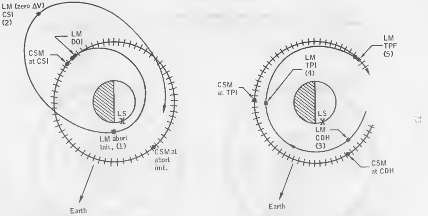
[PDI-2 plus 2 hours 11 minutes 23 seconds]

Maneuver	Time of ignition, hr:min:sec, g.e.t.	ΔT from previous maneuver,[a] hr:min:sec	Main engine	Burn duration,[b] sec	ΔV vector, fps	Horizontal ΔV,[c] fps	Radial ΔV,[d] fps	Resultant orbit apolune/perilune, n. mi.
CSI	105:42:17.2	[e]0:51:01.1	SPS	2.5	50.7	-50.7	0.0	60.2/22.5
CDH	106:39:58.1	00:57:41.0	SPS	0.9	20.4	- 2.6	-20.3	58.4/22.4
TPI	107:14:56.0	00:34:57.9	SPS	1.0	22.1	-20.4	8.3	54.5/11.7
TPF	107:56:53.2	00:41:57.2	SM/RCS	78.9	29.1	-15.8	-24.4	45.1/9.1

[a] t_{IG} to t_{IG}.
[b] Main engine, not including ullage or tailoff.
[c] Posigrade is plus (+).
[d] Toward center of moon (down) is plus (+).
[e] From insertion.

TABLE XXXII.- PERTINENT ABORT LIFT-OFF TIMES

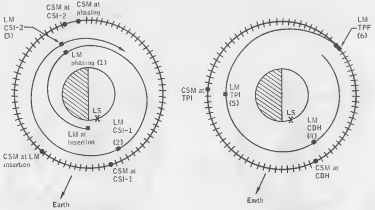
Time	First PDI opportunity	Second PDI opportunity
Latest lift-off time based on the descent program		
g.e.t., hr:min:sec	100:53:47	102:47:03
Δt from PDI, hr:min:sec	0:14:50	0:14:24
Time of maneuver, hr:min:sec	101:45:56.8 (phasing)	103:44:21.3 (CSI)
Preferred lift-off time after switch to ascent program		
g.e.t., hr:min:sec	101:00:20.2	102:52:01
Δt from PDI, hr:min:sec	0:21:24	0:19:22
Time of 10 fps phasing maneuver, hr:min:sec	101:57:38	103:44:21.3
Lift-off time approximately one CSM revolution after touchdown		
g.e.t, hr:min:sec	102:45:48.2	104:44:01.8
Δt from PDI, hr:min:sec	2:06:51	2:11:23
Time of CSI, hr:min:sec	103:44:02.7	105:42:16.5



(a) LM-active two-impulse to CDH-offset sequence (used for no-PDI plus 12 minute aborts).

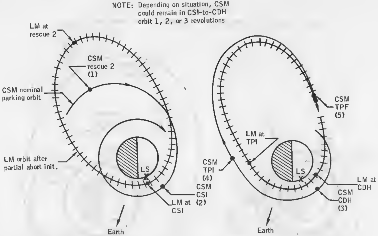
Figure 1.- Schematics of rendezvous technique sequences.

NOTE: CSI-2 replaces the original CDH



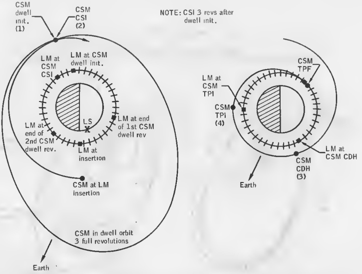
(b) Phasing/CSI for CDH sequence - LM-active; CSM-active (rescue) is mirror-image (used for rendezvous after aborts in constant insertion region).

Figure 1.- Continued.



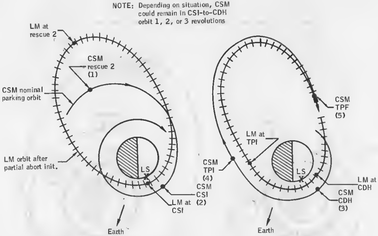
(c) CSM-active rescue 2 sequence (used for rescues after certain partial LM in-orbit maneuvers and certain contingency orbit insertion cases).

Figure 1.- Continued.



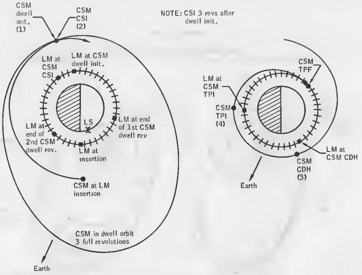
(d) High dwell rescue sequence (used for certain contingency orbit insertion cases).

Figure 1.- Concluded.



(c) CSM-active rescue 2 sequence (used for rescues after certain partial LM in-orbit maneuvers and certain contingency orbit insertion cases).

Figure 1.- Continued.



(d) High dwell rescue sequence (used for certain contingency orbit insertion cases).

Figure 1.- Concluded.

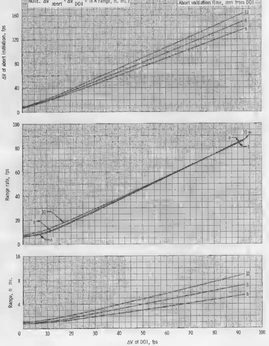
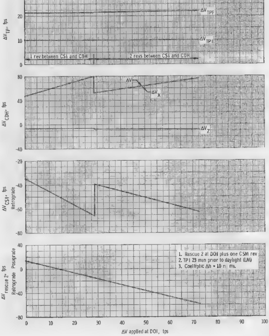
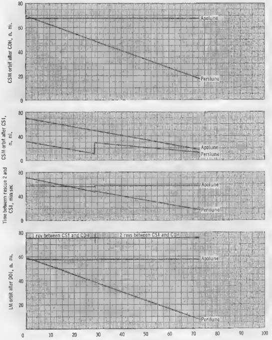


Figure 2 - Range, range rate, and ΔV of abort initiation for the direct return abort as a function of ΔV of DOI.



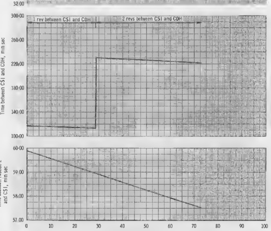
(a) ΔV requirements.

Figure 3 - Summary data for CSM rescue for a LM totally inactive after the DOI maneuver.



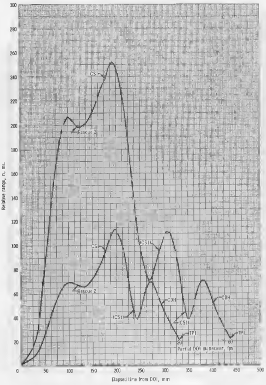
(b) Resulting orbits.

Figure 3 - Continued.



(c) Time between maneuvers.

Figure 3.- Continued.



(d) Time history of relative range

Figure 3. - Concluded.

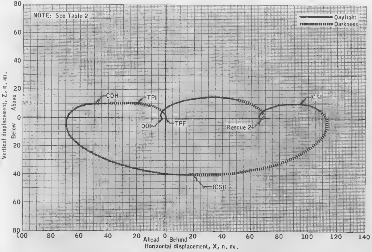


Figure 4.- Relative motion (curvilinear, LM-centered) for a rescue after a partial DOI of 20 feet per second.

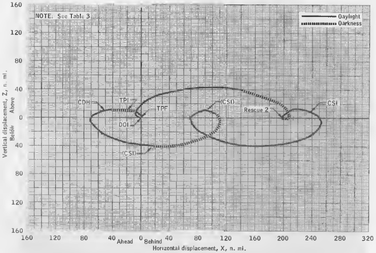
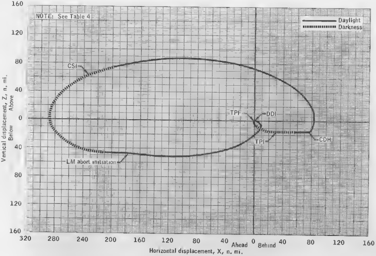
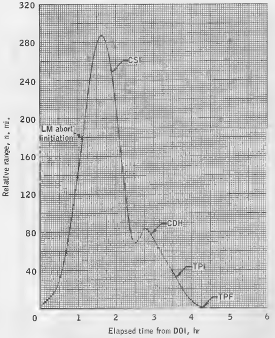


Figure 5. - Relative motion (curvilinear, LM-centered) for a rescue after a partial DOI of 60 feet per second.



(a) Relative motion (curvilinear, CSM-centered).

Figure 6.- LM-active rendezvous for no PDI-1 plus 12 minute abort.



(b) Time history of relative range.

Figure 6.- Concluded.

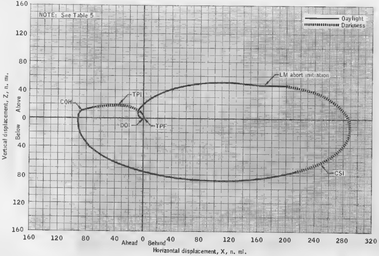
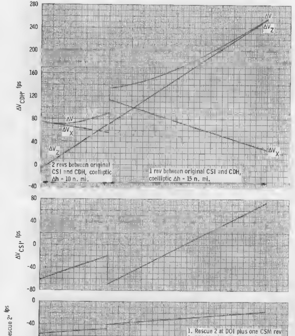
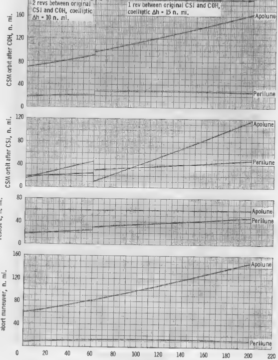


Figure 7.- Relative motion (curvilinear, LM-centered) for a rescue after an accurate no-PDI-1 plus 12 minute abort.



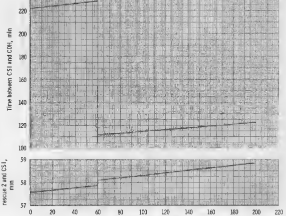
(a) ΔV requirements.

Figure 8.- Summary data for rescue after partial no-PDI-1 plus 12 minute abort.



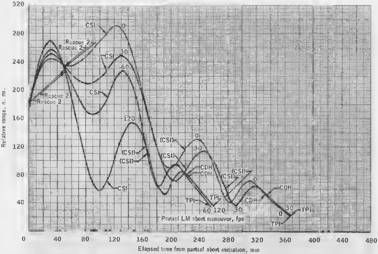
(b) Resulting orbits.

Figure 8.- Continued.



(c) Time between maneuvers.

Figure 8.- Continued.



(d) Relative range time history.

Figure 8.- Concluded.

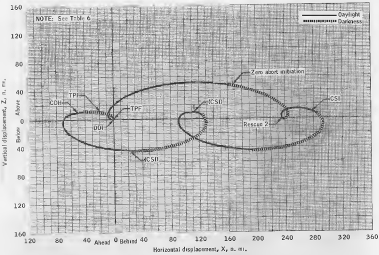


Figure 9.- Relative motion (curvilinear, LM-centered) for a rescue after a zero no-PDI-1 plus 12 minute abort.

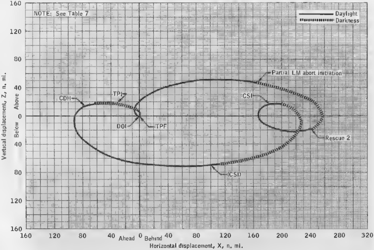
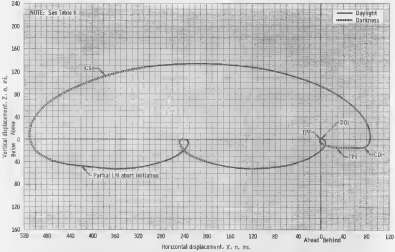
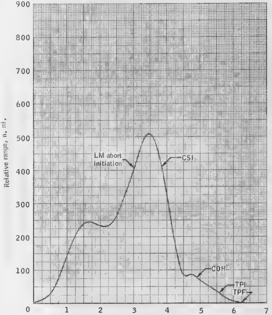


Figure 10.- Relative motion (curvilinear, LM-centered) for a rescue after a partial no-PDI-1 plus 12 minute abort of 60 feet per second.



(a) Relative motion (curvilinear, CSM-centered).

Figure 11. - LM-active rendezvous for no-PDI-2 plus 12 minute abort.



(b) Time history of relative range.

Figure 11.- Concluded.

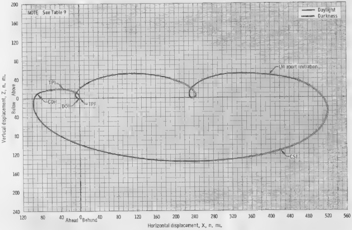
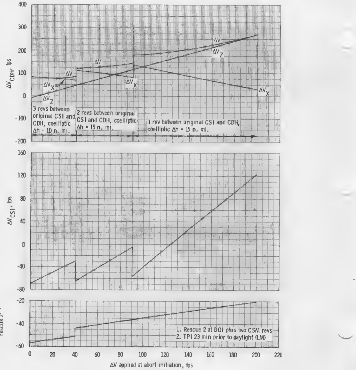
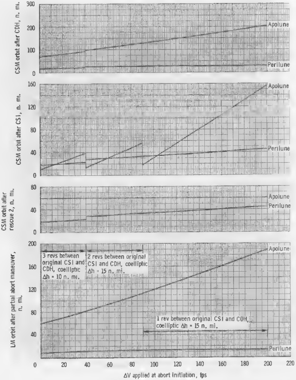


Figure 12. - Relative motion (curvilinear, LM-centered) for a rescue after an accurate no-PDI-2 plus 12 minute abort.



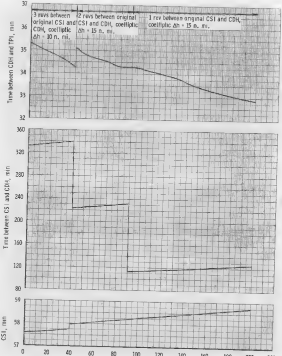
(a) ΔV requirements.

Figure 13. - Summary data for rescue after partial no-PDI-2 plus 12 minute abort.



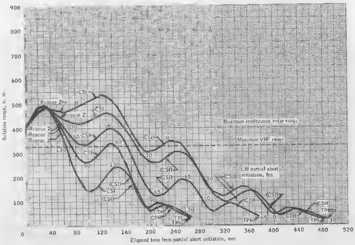
(b) Resulting orbits.

Figure 13. - Continued.



(c) Time between maneuvers.

Figure 13. - Continued.



(d) Relative range time history.

Figure 13.- Concluded

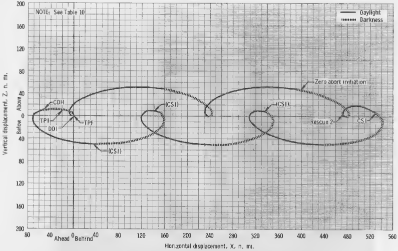


Figure 14. - Relative motion (curvilinear, LM-centered) for a rescue after a zero no-P01-2 plus 12 minute abort.

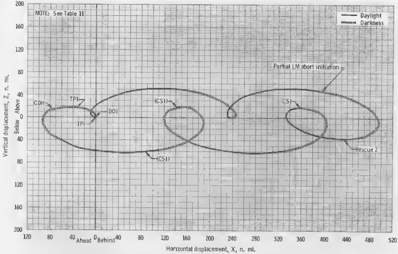


Figure 15. - Relative motion (curvilinear, LM-centered) for a rescue after a partial no-PDI-2 plus 12 minute abort of 65 feet per second.

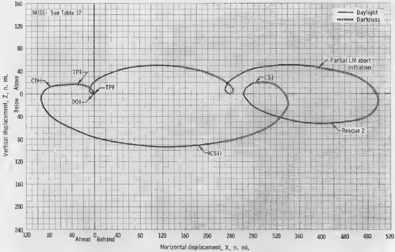


Figure 16. - Relative motion (curvilinear, LM-centered) for a rescue after partial no-PDI-2 plus 12 minute abort of 90 feet per second.

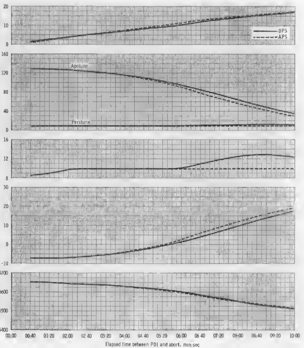
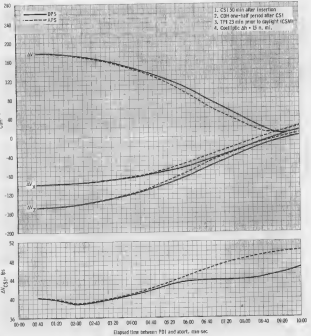
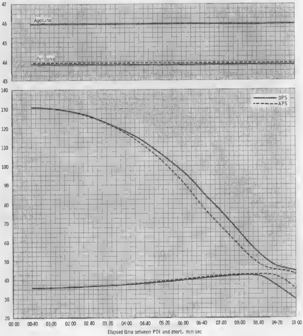


Figure 17.- Summary of insertion data for first opportunity variable insertion region (PDI-1 to PDI-1 plus ~ 10 minutes)



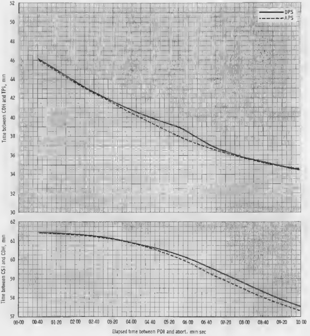
(a) ΔV requirements.

Figure 18.- Summary data for LM-active rendezvous for first opportunity variable insertion region (PDI-1 to PDI-1 plus ~ 10 minutes)



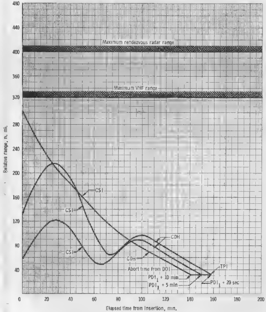
(b) Resulting orbits.

Figure 18. - Continued.



(c) Time between maneuvers

Figure 18. - Continued.



(d) Relative range time history.

Figure 18. - Concluded.

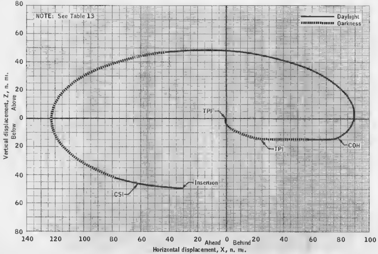


Figure 19.- Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after abort at PDI-1 plus 5 minutes (DPS through insertion).

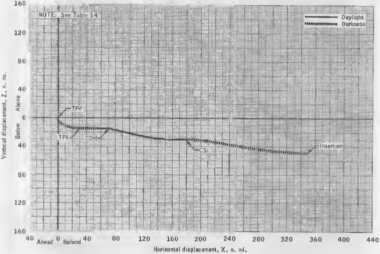
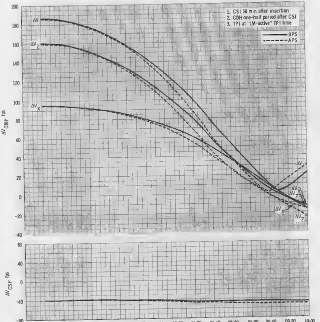
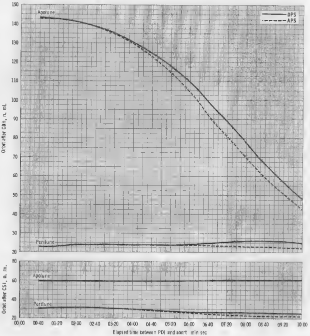


Figure 20.- Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after abort at PDI-1 plus 10 minutes (APS only after abort).



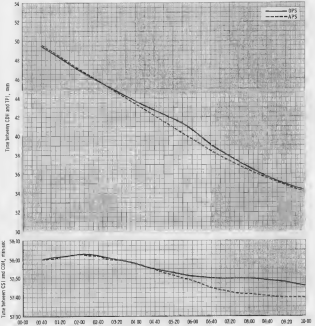
(a) ΔV requirements.

Figure 21. - Summary data for rescue for first opportunity variable insertion region (PDI-1 to PDI-1 plus ~10 minutes).



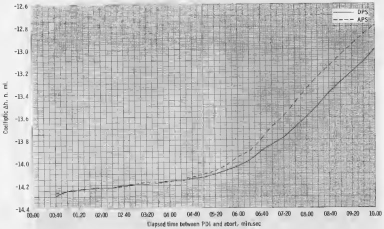
(b) Resulting orbits.

Figure 21. - Continued.



(c) Time between maneuvers.

Figure 21. - Continued.



(d) Coelliptic Δh.

Figure 21.- Continued.

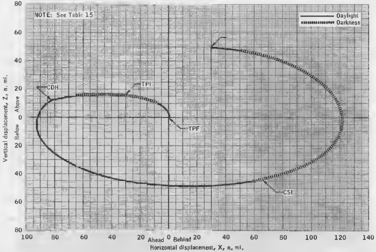


Figure 22.- Relative motion (curvilinear, LM-centered) for a rescue after abort at POI-1 plus 5 minutes (OPS through insertion).

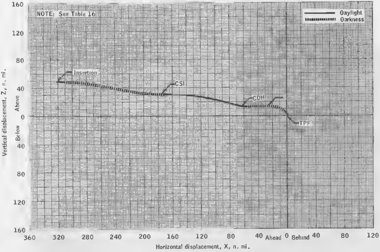
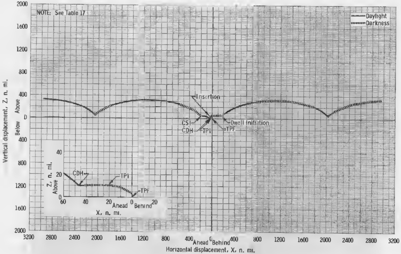
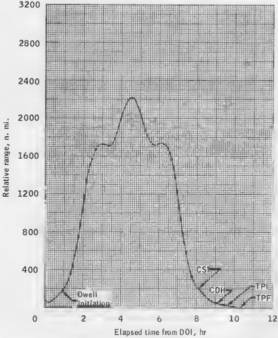


Figure 23.- Relative motion (curvilinear, LM-centered) for a rescue after abort at POI-1 plus 10 minutes (APS only to insertion).



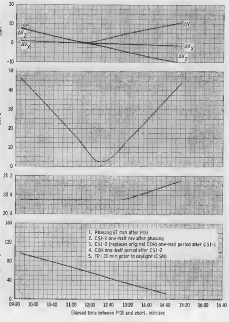
(a) Relative motion (curvilinear, LM-centered).

Figure 24. - Rescue after contingency insertion after abort at PDI-1 plus 6 minutes (via CSM high dwell orbit).



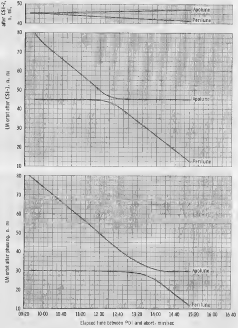
(b) Time history of relative range.

Figure 24.- Concluded.



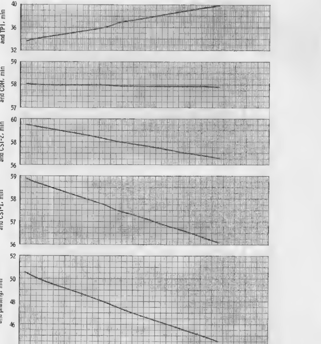
(a) ΔV requirements

Figure 25.- Summary data for LM-active rendezvous for first opportunity constant insertion region (PDI-1 plus ~10 minutes to PDI-1 plus 15 minutes).



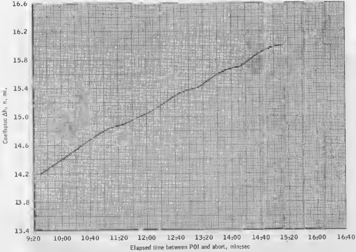
(b) Resulting orbits.

Figure 25 - Continued



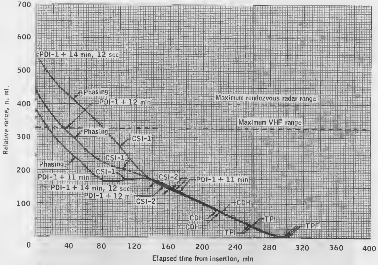
(c) Time between maneuvers.

Figure 25. - Continued.



(d) Coelliptic Δh.

Figure 25.- Continued.



(e) Relative range time history.

Figure 25.- Concluded.

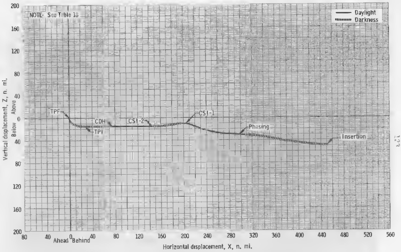


Figure 26. - Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after abort at PDI-1 plus 12 minutes.

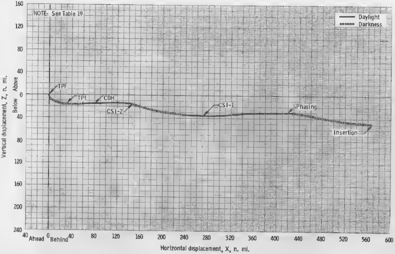
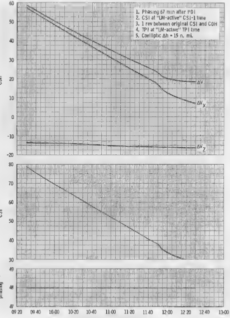
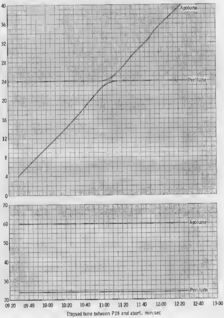


Figure 27. - Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous for no-PDI plus 14 minutes 12 seconds abort.



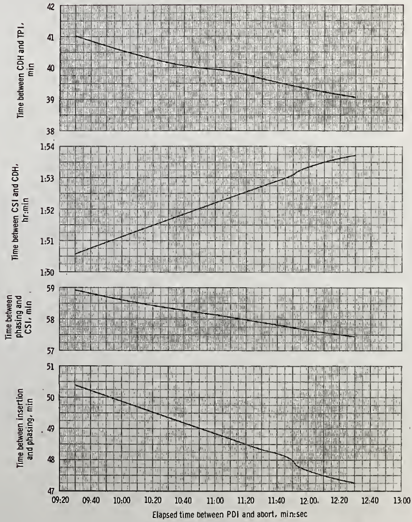
(a) ΔV requirements.

Figure 28. - Summary for rescue for constant phasing part of first opportunity constant insertion region (PDI-1 + ~10 minutes to PDI-1 + ~12.5 minutes.



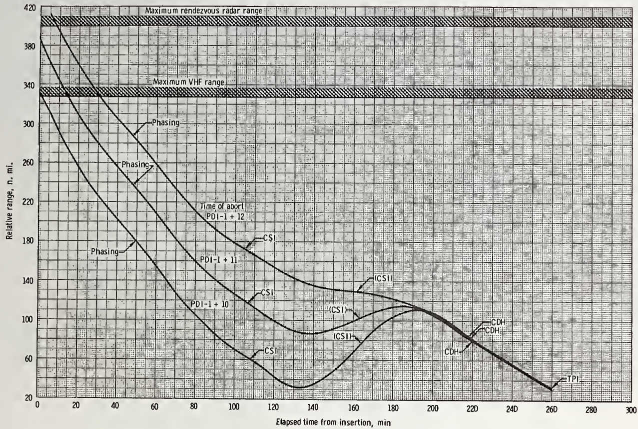
(b) Resulting orbits.

Figure 28. - Continued.



(c) Time between manuvers.

Figure 28. - Continued.



(d) Time history of relative range.

Figure 28.- Concluded.

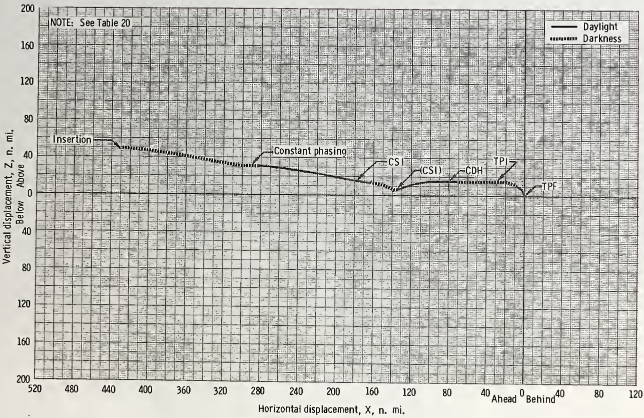
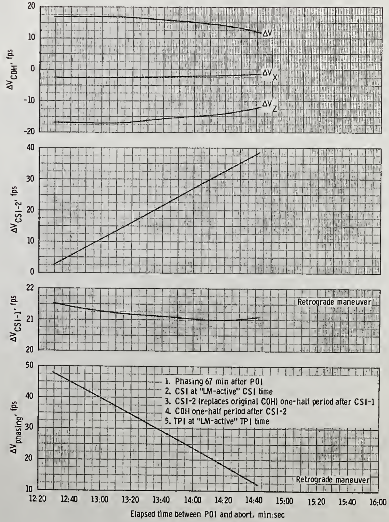
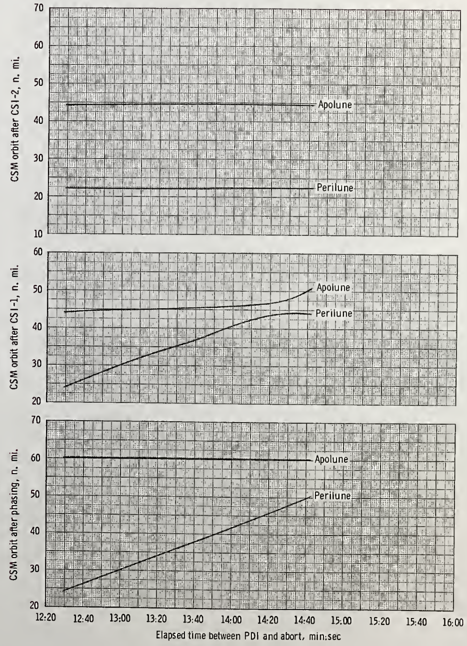


Figure 29. - Relative motion (curvilinear, LM-centered) for a rescue after abort at PDI-1 plus 12 minutes.



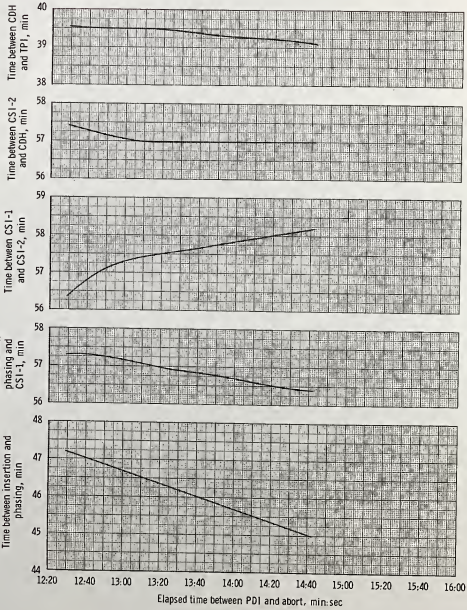
(a) ΔV requirements.

Figure 30. - Summary data for rescue for mirror-image phasing part of first opportunity constant insertion region (P01-1 plus ~ 12.5 minutes to P01-1 plus ~ 15 minutes).



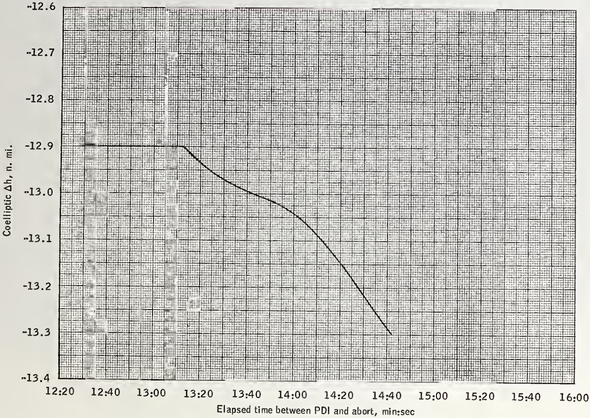
(b) Resulting orbits.

Figure 30. - Continued.



(c) Time between maneuvers.

Figure 30. - Continued.



(d) Coelliptic Δh.

Figure 30.- Concluded.

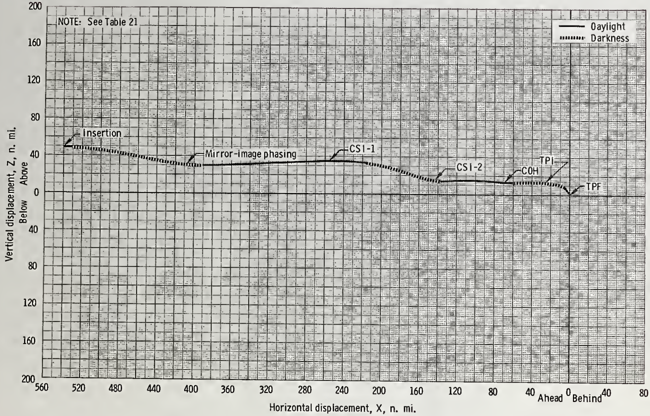
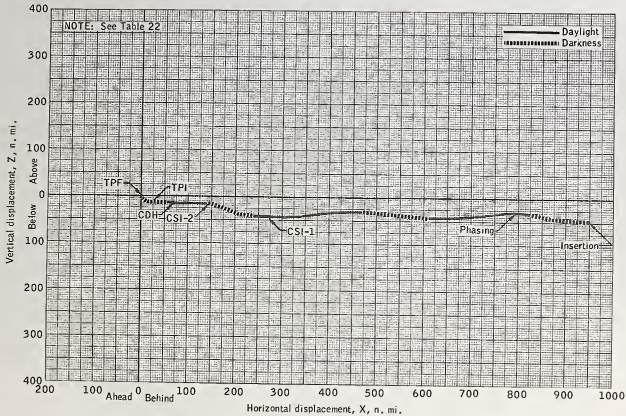
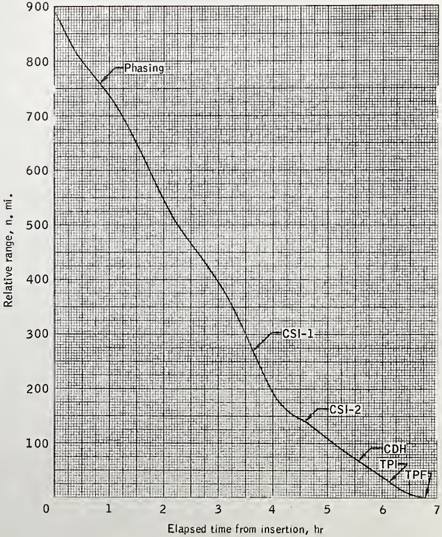


Figure 31. - Relative motion (curvilinear, LM-centered) for a rescue after abort at PDI-1 plus 14 minutes 12 seconds.



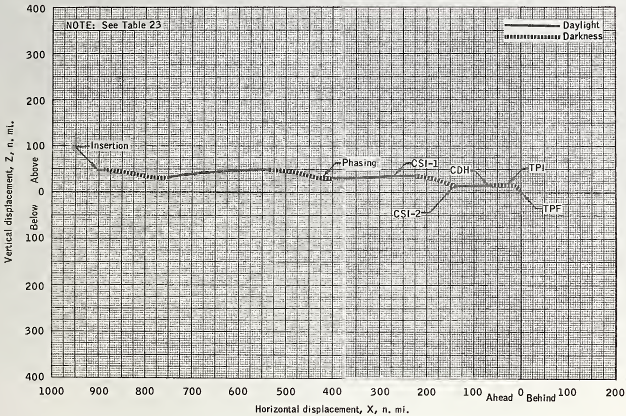
(a) Relative motion (curvilinear, CSM-centered).

Figure 32.- LM-active rendezvous after abort at last-preferred lift-off time for first opportunity (PDI-1 plus 21 minutes 24 seconds).



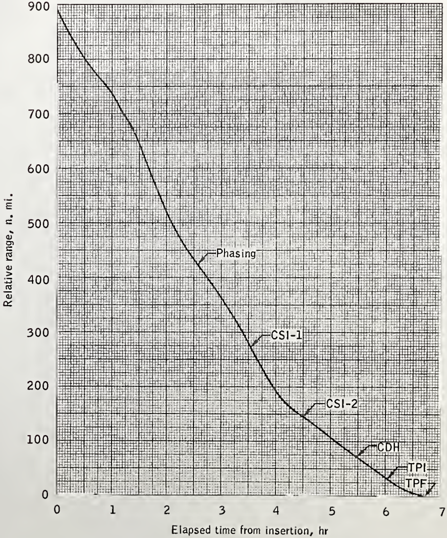
(b) Time history of relative range.

Figure 32.- Concluded.



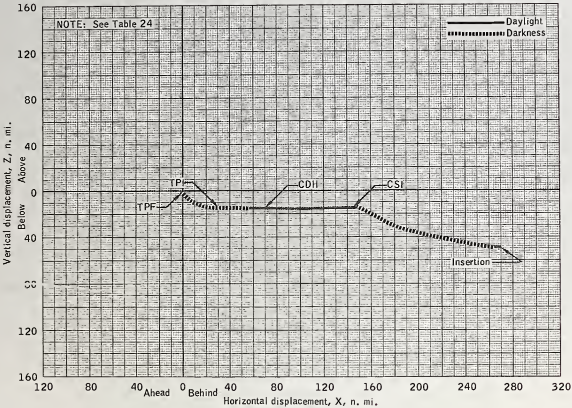
(a) Relative motion (curvilinear, LM–centered).

Figure 33.- Rescue after abort at last preferred lift-off time for first opportunity (PDI-1 plus 21 minutes 24 seconds).



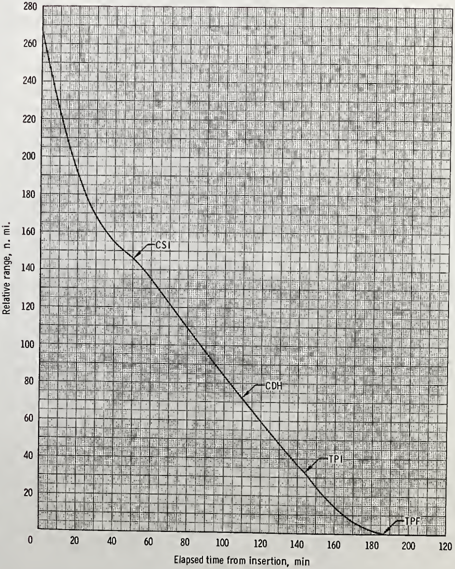
(b) Time history of relative range.

Figure 33.- Concluded.



(a) Relative motion (curvilinear, CSM-centered).

Figure 34.- LM-active rendezvous after correct-phasing lift-off on next CSM pass after first opportunity landing (PDI-1 plus 2 hours 6 minutes 51 seconds).



(b) Time history of relative range.

Figure 34. - Concluded.

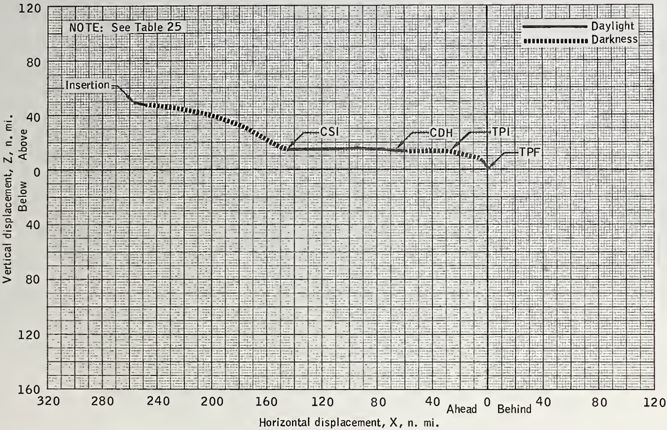


Figure 35.- Relative motion (curvilinear, LM-centered) for a rescue after correct-phasing lift-off on next CSM pass after first opportunity landing (PDI-1 plus 2 hours 6 minutes 51 seconds).

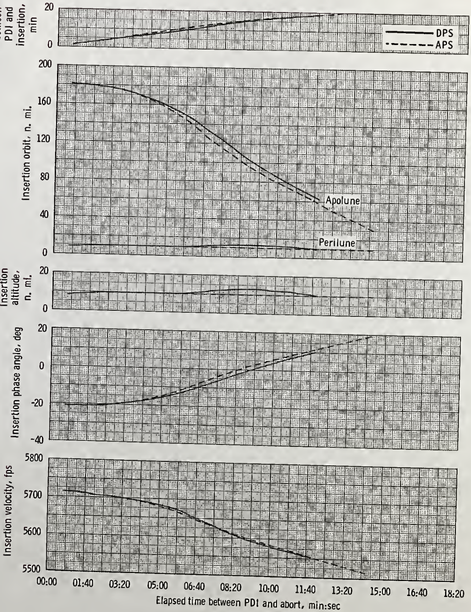
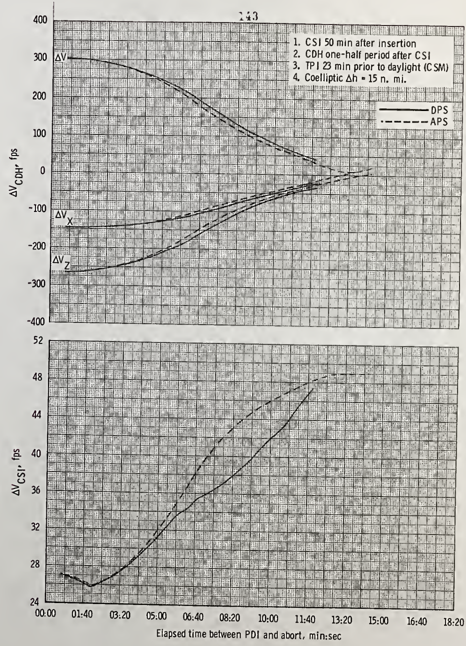
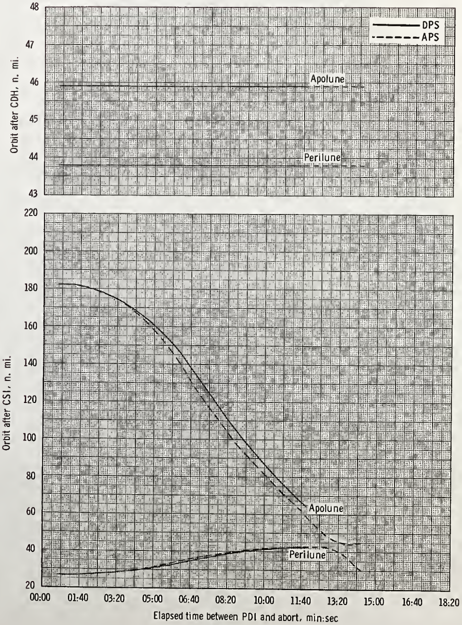


Figure 36. - Summary of insertion data for second opportunity variable insertion region (PDI-2 to PDI-2 plus 14 minutes 24 seconds).



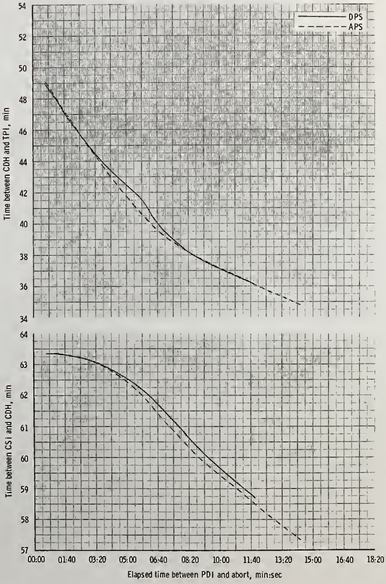
(a) ΔV requirements.

Figure 37. - Summary data for LM-active rendezvous for second opportunity variable insertion region (PDI-2 to PDI-2 plus 14 minutes 24 seconds).



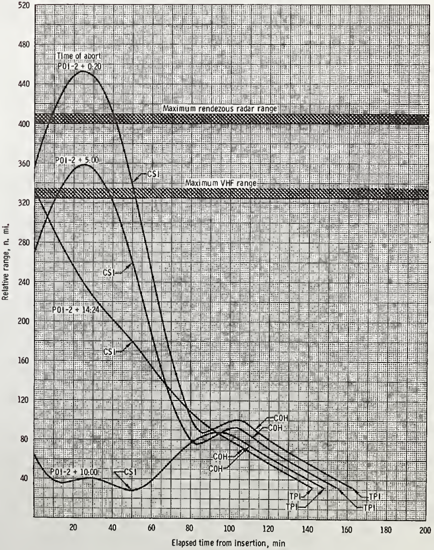
(b) Resulting orbits.

Figure 37. - Continued.



(c) Time between maneuvers.

Figure 37. - Continued.



(d) Time history of relative range.

Figure 37. - Concluded.

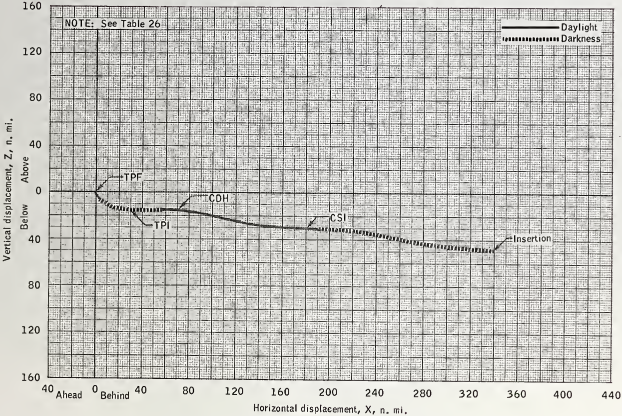
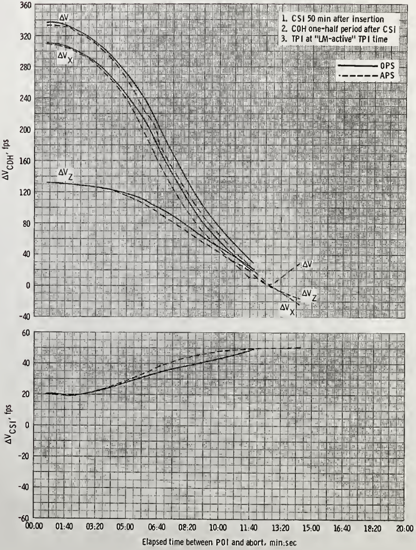
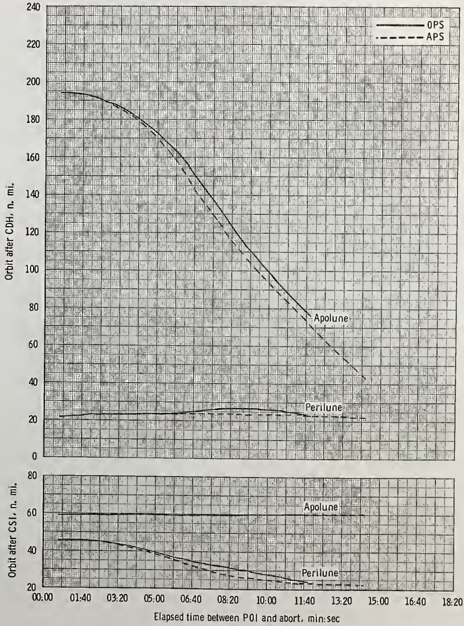


Figure 3B.- Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after abort at PDI-2 plus 14 minutes 24 seconds.



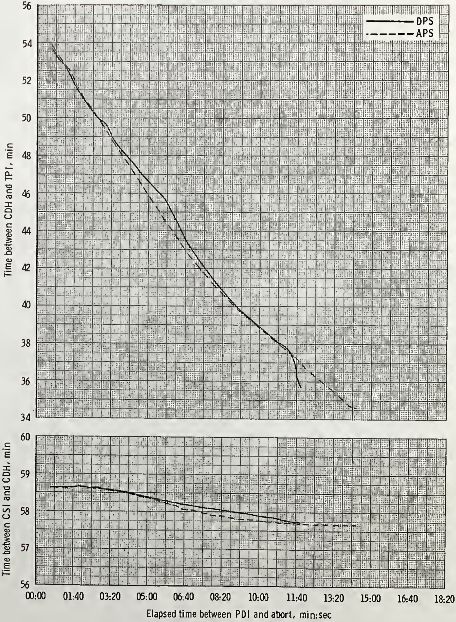
(a) ΔV requirements.

Figure 39. - Summary data for rescue for second opportunity variable insertion region (P01-2 to P01-2 plus 14 minutes 24 seconds).



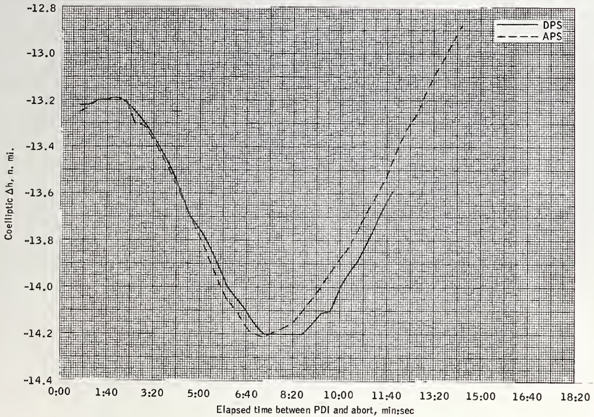
(b) Resulting orbits.

Figure 39. - Continued.



(c) Time between maneuvers.

Figure 39. - Continued.



(d) Coelliptic Δh.

Figure 39.- Continued.

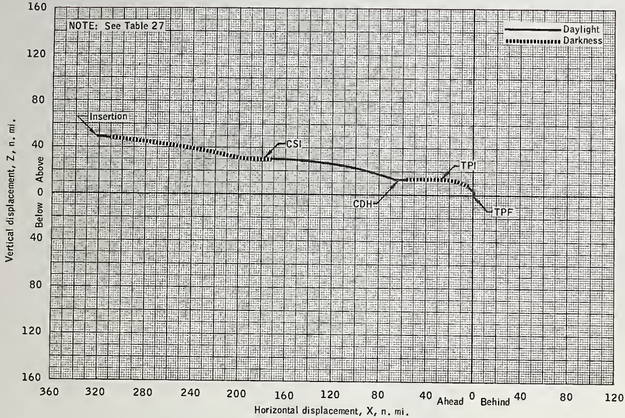


Figure 40.- Relative motion (curvilinear, LM-centered) for a rescue after abort at PDI-2 plus 14 minutes 24 seconds.

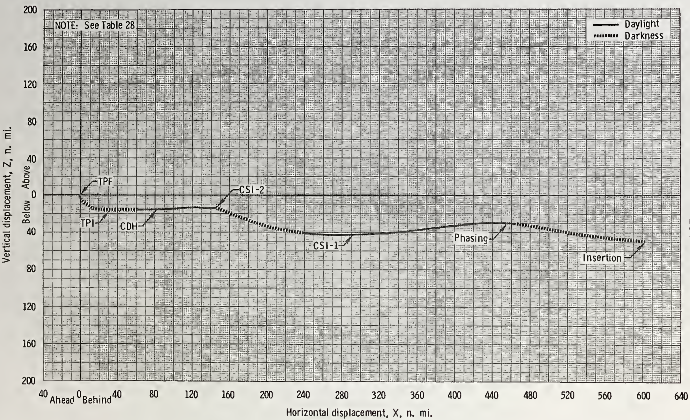


Figure 41. - Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after abort at last preferred lift-off time for a second opportunity (PDI-2 plus 19 minutes 22 seconds).

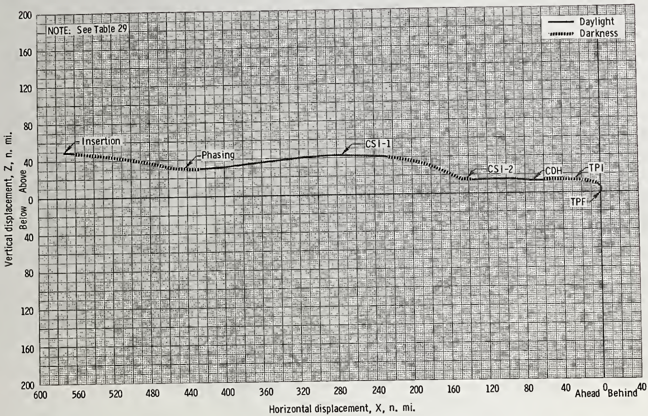


Figure 42. - Relative motion (curvilinear, LM-centered) for a rescue after abort at last preferred lift-off time for second opportunity (PDI-2 plus 19 minutes 22 seconds).

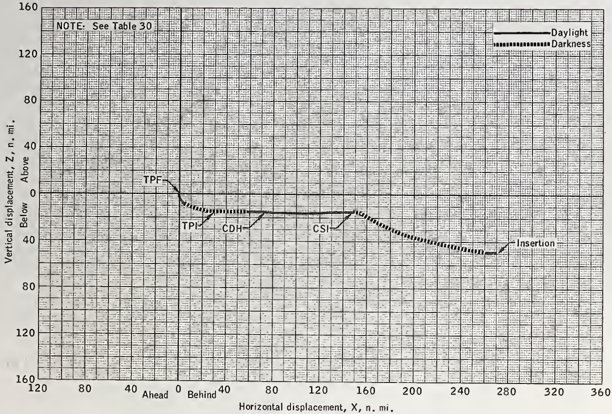


Figure 43.- Relative motion (curvilinear, CSM-centered) for a LM-active rendezvous after correct-phasing lift-off on next CSM pass after second opportunity landing (PDI-2 plus 2 hours 11 minutes 23 seconds).

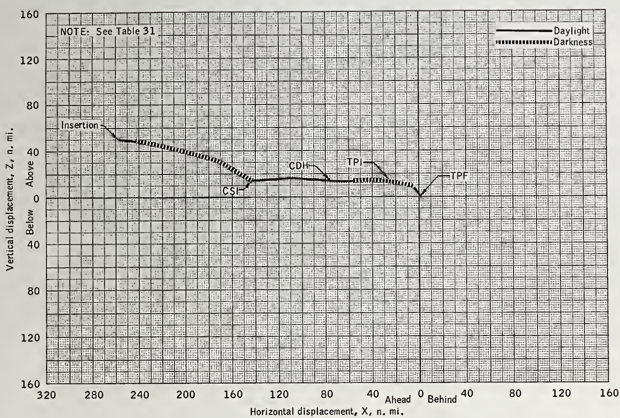


Figure 44.- Relative motion (curvilinear, LM-centered) for a rescue after correct-phasing lift-off on next CSM pass after second opportunity landing (PDI-2 plus 2 hours 11 minutes 23 seconds).

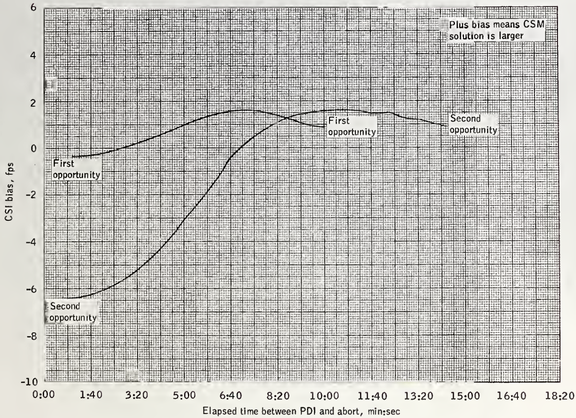


Figure 45.- Rescue CSI bias for variable insertion regions - first and second opportunities.

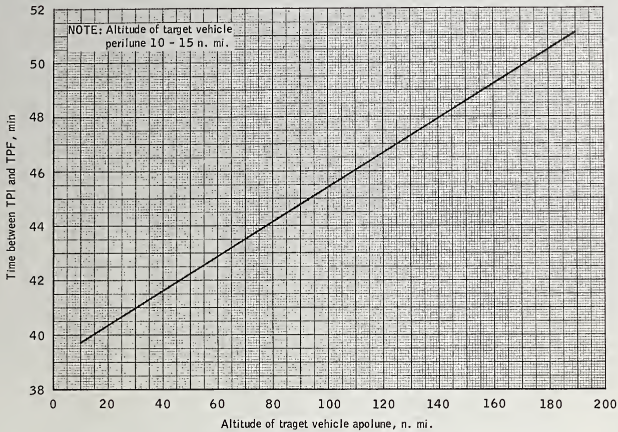
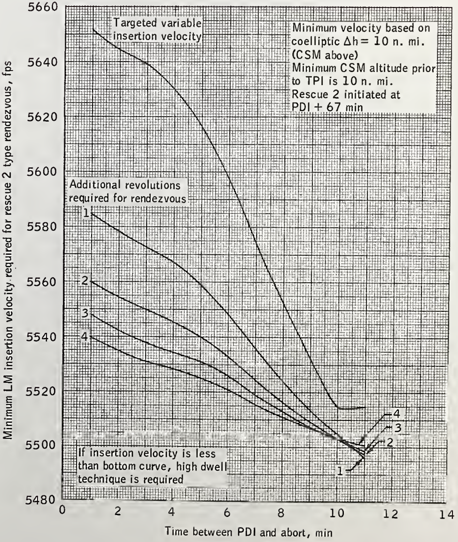
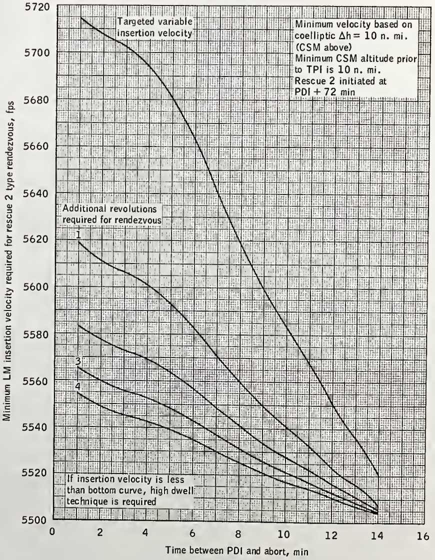


Figure 46.- Terminal phase duration for low perilune rescue situations.



(a) PDI at the first opportunity.

Figure 47.- Minimum LM insertion velocity as a function of abort time for various duration CSM rescue 2 rendezvous.



(b) PDI at the second opportunity.

Figure 47.- Concluded.

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3. Alexander, J. D.; and Moore, R. H.: Currently Proposed Rendezvous Profile for G Mission (LLM). MSC memorandum 69-FM64-325, October 28, 1968.

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5. Woronow, Alexander: Two-Impulse Solutions for G Mission Aborts Following a Failure to Initiate the Powered Descent Burn. MSC memorandum 69-FM64-108, May 28, 1969.