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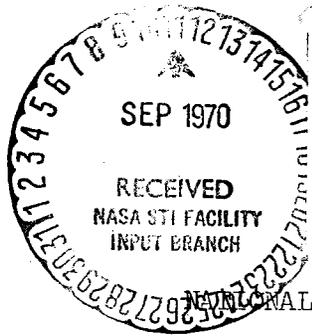
A BRIEF INVESTIGATION OF CSM RESCUE OF LEM

Prepared by: Charles R. Price
Charles R. Price

Floyd V. Bennett
Floyd V. Bennett

Approved: Jack Funk
Jack Funk
Chief, Theoretical Mechanics
Branch

Approved: David C. Cheatham for
Chief, Guidance and Control



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SUMMARY

A brief investigation of the CSM rescue of the LEM based on impulsive maneuvers is presented. The results indicate that the fuel and time design allowances will not yield rescue for all possible relative states of the spacecrafts; however, it is also shown that the LEM can readily avoid these regions of no rescue.

INTRODUCTION

The CSM characteristic velocity budget has an allowance for rescue of the LEM crew in the event that the LEM engines become inoperative (no fuel, no electric power, damaged engine, etc.) after reaching a clear pericyynthion orbit. Also, LEM systems design includes a contingency time allowance after LEM launch to orbit for the LEM crew to reach the CSM. Therefore, a brief investigation on the compatibility of these two design allowances was undertaken by the Theoretical Mechanics Branch and is reported herein.

RESCUE MANEUVERS

It is assumed that the LEM may be launched at any time, that is, regardless of CSM position or phasing, to a clear pericyynthion orbit (altitude less than or greater than CSM). For purposes of this study, no further LEM maneuvers are considered. The CSM must, therefore, perform the intercept and rendezvous maneuvers to rescue the LEM crew, and then inject into the earth return trajectory from the LEM orbit. In order to perform these maneuvers for all possible phasings between the spacecrafts and to prevent the fuel and time requirements from becoming prohibitively large, it is necessary to consider several types of transfers. A brief description of the types of transfers considered herein are given in the following sections.

Direct transfer.- The direct or immediate transfer as shown in figure 1 is a two-impulse transfer which is initiated as soon as the LEM establishes its orbit. The pericynthion of this transfer is limited to a clear-pericynthion altitude (safe altitude above lunar terrain) which may be less than that of the LEM orbit. These transfers will be short time transfers (less than two hours) and will be limited by the characteristic velocity (or fuel) allowance.

Delayed transfer.- Since the orbital angular velocity of a spacecraft is inversely proportional to its altitude the phase angle between the CSM and the LEM will change with time without any thrusting (except when LEM and CSM are displaced in the same orbit; see next type of transfer). Thus, if the phase angle between the spacecrafts is such that the velocity requirements for an immediate transfer are prohibitive, then the CSM need only wait in its orbit until the proper phasing for transfer is obtained, see figure 2. This type of transfer is called a delayed transfer and will be limited by the contingency time allowance.

Modified delayed transfer.- If the phase angle between the spacecrafts is such that the delayed transfer exceeds the time allowance, then the CSM can ascend or descend, as required, to a new altitude and coast until the proper phasing for transfer is obtained (see figure 3). This type of maneuver is referred to as a modified delayed transfer and will be limited by both velocity and time allowances.

SCOPE OF CALCULATIONS

For purposes of this investigation it is assumed that the CSM is initially in an 80-nautical-mile circular orbit and that the LEM is in a circular orbit between the altitudes of 50,000 ft and 160 nautical miles. Furthermore, the out-of-plane angle between the orbits of the spacecrafts is assumed to be less than or equal to $\frac{1}{2}$ degree. The rescue maneuvers are based on impulsive conic calculations and are limited to a characteristic velocity allowance of 455 fps and a contingency time allowance of 9 hours. This time allowance starts at the time LEM establishes circular orbit and ends at rendezvous. These numbers are consistent with the design requirements for both spacecrafts. No allowance is included for midcourse guidance corrections in this investigation.

Also, only a typical variation of the characteristic velocity requirement for insertion into the earth return trajectory with orbit altitude is assumed as shown in figure 4. Thus, for any particular Apollo flight the rescue maneuvers are expected to vary slightly from the results of this investigation.

RESULTS AND DISCUSSION

The variation of the rescue time with phase angle between LEM and CSM for several LEM orbital altitudes is illustrated in figure 5 for coplanar rescue. The velocity requirements for these rescue maneuvers are shown in table 1. For the LEM in a 50,000-ft orbit, (figure 5a) it is seen that the 9-hour contingency time allowance is exceeded for some lead angles equivalent to a 35-minute increment of surface phase time (time since CSM last passed overhead) each CSM orbital period (121.8 minutes). However, the time of exceeding the 9-hour limit is shown in the subsequent parts of figure 5 to decrease with LEM altitude. For example, for a 60-nautical-mile LEM altitude the 9-hour limit is exceeded for only 16 minutes during each CSM period. The effects of LEM altitude and phase angle are better illustrated in the composite picture of figure 6 for coplanar rescue. In this figure the altitude-phase angle regions are shaded differently for each type of rescue maneuver, thus, clearly outlining the regions of no reserve capability within the design limitations. Similar results are shown in figure 7 for the LEM orbit $\frac{1}{2}^{\circ}$ out-of-plane with the CSM orbit. On both figures 6 and 7 the boundary for maximum LEM orbit capability is based on using the entire ascent fuel budget (without design reserve) establishing circular orbit only.

Based on the results of figures 6 and 7 it is evident that the present CSM rescue budget is insufficient to provide reserve capability for the anytime launch situation for the LEM at any altitude between 50,000 ft and 144 nautical miles. However, by a judicious choice of LEM orbit altitude

depending on the phase angle which can be adequately determined from surface phase time, then the rescue budget is quite satisfactory. For example, consider the coplanar rescue results (figure 6). For phase angles from 8° to 263° the LEM need only be launched into the clear pericyntion orbit of 50,000 ft in order to insure rescue. However, for any other phase angles the LEM must be launched into orbits as high as 60 nautical miles ($\gamma = 263^{\circ}$ plus) to insure rescue. The requirements illustrated by this example are not considered to be unreasonable on either the LEM crew or LEM systems. (The 60-nautical-mile orbit requires only 143 fps more velocity than the 50,000-ft orbit, and a velocity increment of 360 fps plus a 334 fps design reserve are available for the job).

As stated earlier, this study is primarily based on the anytime launch situation to circular orbit. However, the results of figure 6 can also be interpreted for aborts during landing. Should the abort after injection into the Hohmann descent transfer and prior to initiation of powered descent at 50,000 ft, then the LEM could continue to coast back to 80 nautical miles and circularize at that altitude (to presume that the LEM could not do this would be to presume simultaneous failures of the LEM descent, ascent, and RCS engines). At this time the phase angle would be -18.8° or 341.2° and from figure 6 it is evident that rescue could be performed by either of two types of maneuvers. For aborts after initiation of powered descent the phase angle ranges from -9.4° (350.6°) to about $+10^{\circ}$ or $+12^{\circ}$ (depending on thrust-to-initial weight ratio). Thus, from figure 6, again, the LEM must abort back to circular orbit altitudes as high as 16 nautical miles. This altitude requirement occurs for aborts early in the descent when an over abundance of fuel is available; hence, LEM rescue descent aborts are quite adequately covered by the present design allowances.

CONCLUDING REMARKS

A brief investigation of the compatibility of the design fuel allowance for CSM rescue of the LEM with the associated contingency time allowance on LEM systems design has been presented. This study is based on conic trajectory and does not include any midcourse guidance corrections. The results of the study indicate that for some combinations of LEM orbit altitude and phase angle, rescue cannot be performed with the present design allowances. However, the results also show that the regions of no rescue can readily be avoided by the LEM for aborts during descent and for the anytime surface abort situation as well.

Table I. Velocity Requirements for Coplanar Rescue Maneuvers * (ft/sec)

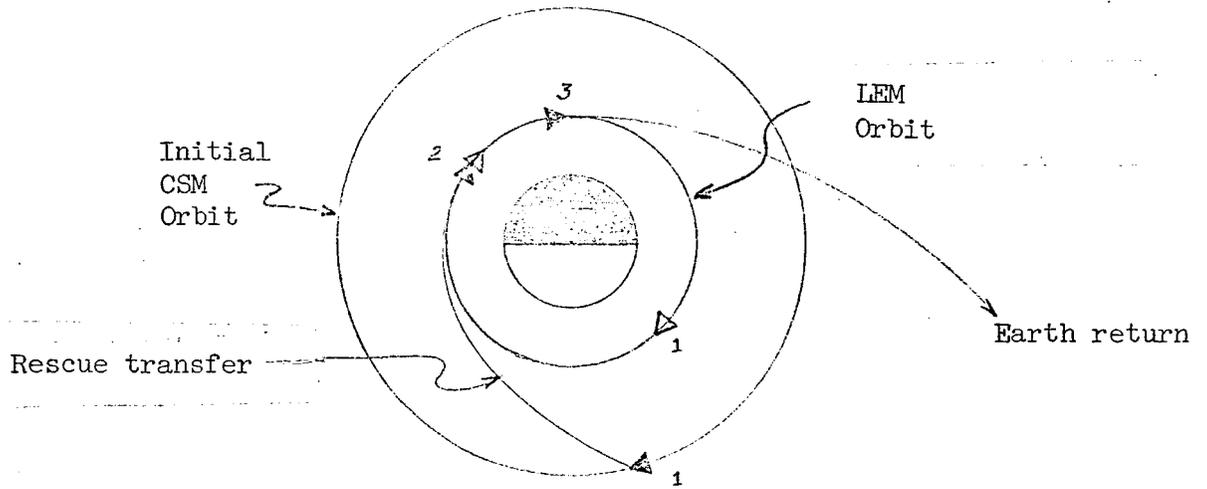
LEM ALTITUDE	IMMEDIATE TRANSFER	DELAYED TRANSFER**	MODIFIED DELAYED TRANSFER	
			(ASCENDING)	(DESCENDING)***
50,000'	233 to 455	233	455	233
20 n.mi.	192 to 455	192	455	261
40 n.mi.	126 to 455	126	455	307
60 n.mi.	63 to 455	63	455	351
80 n.mi.	0 to 455	Not Applicable	455	394
100 n.mi.	41 to 455	41	455	445
120 n.mi.	82 to 455	82	455	455
140 n.mi.	118 to 455	118	455	455
160 n.mi.	156 to 455	156	455	455

* No allowance for midcourse guidance corrections

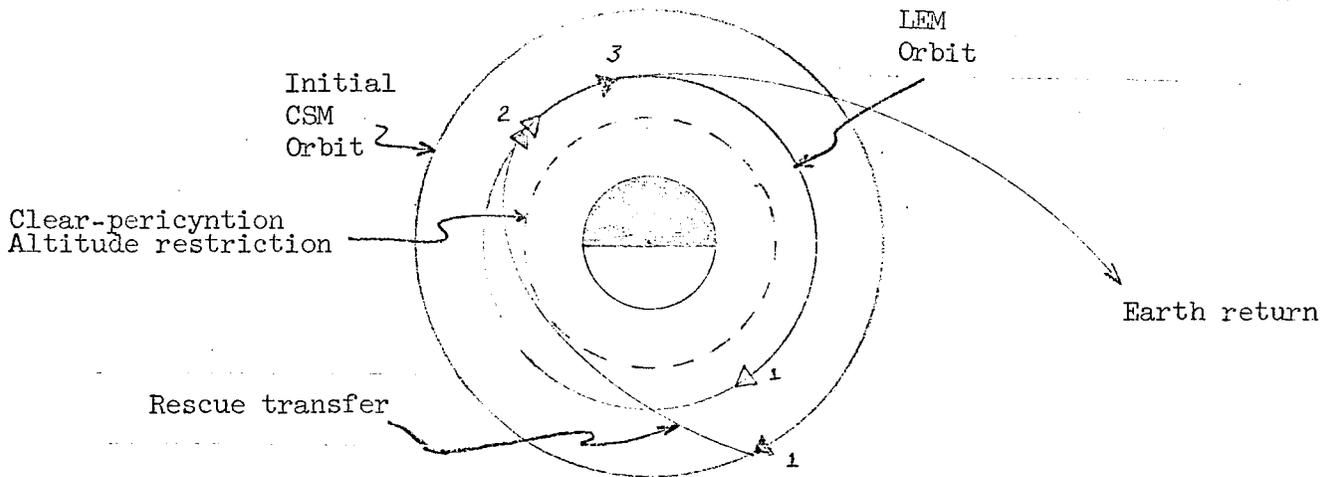
** Hohmann transfers

*** Descent altitude limited by 50,000' clear-pericynthion restriction.

1. Initial positions and initiation of rescue transfer
2. Rendezvous (rescue)
3. Injection to earth return

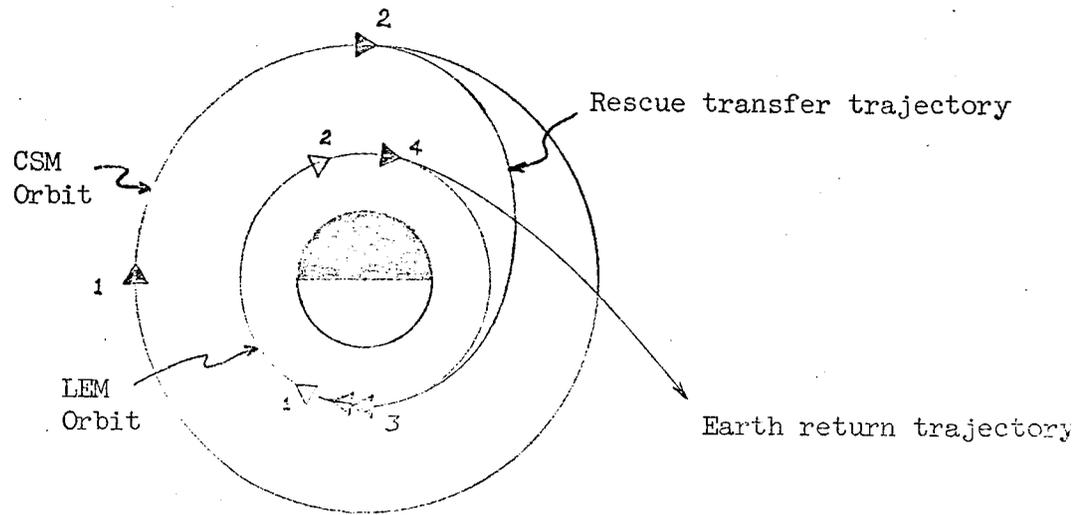


a) Pericynthion restricted to LEM altitude



b) Pericynthion restricted to safe altitude

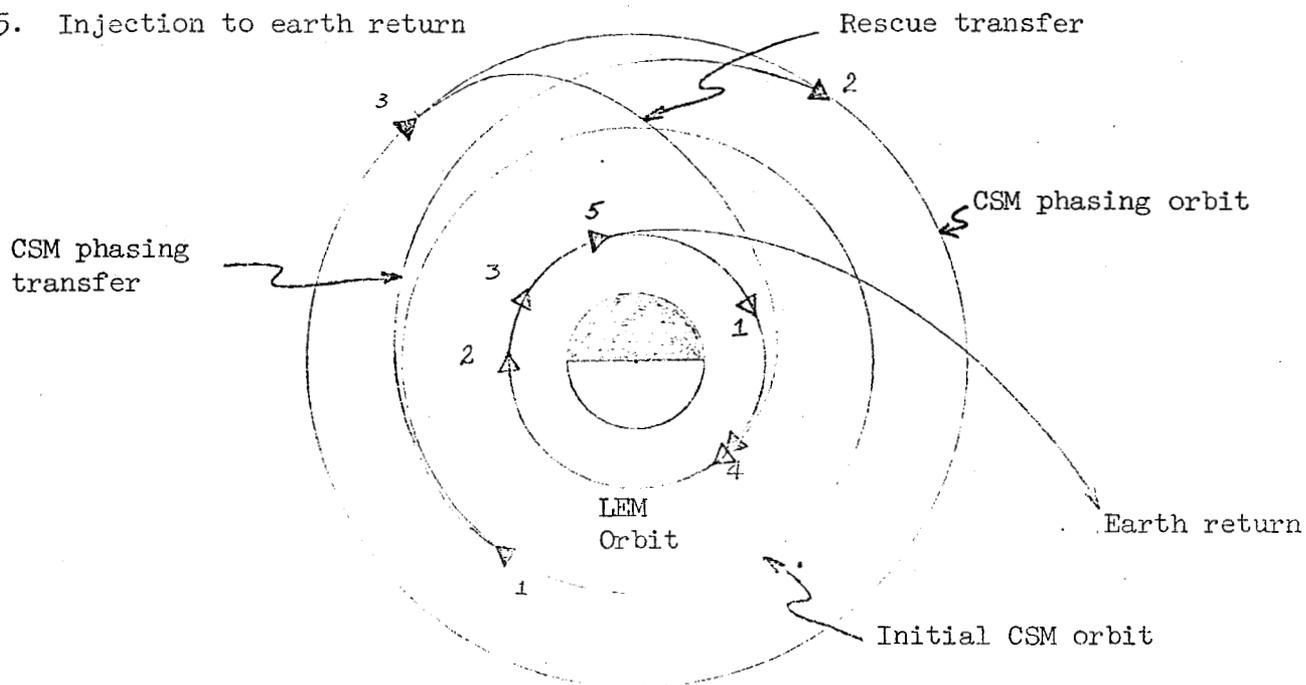
Figure 1.- Direct or immediate transfer



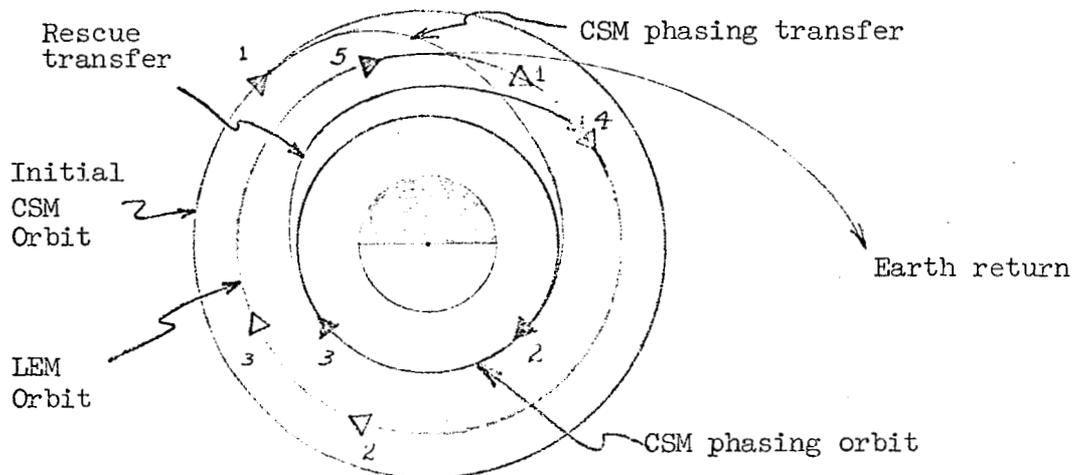
1. Initial positions
2. Position at end of phasing coast and initiation of rescue transfer (Hohmann)
3. Rendezvous (rescue)
4. Injection to earth return

Figure 2.- Delayed transfer

1. Initial positions and initiation of phasing transfer
2. Positions at initiation of phasing coast
3. Positions after phasing coast and initiation of rescue transfer
4. Rendezvous (rescue)
5. Injection to earth return



a) Ascend for phasing



b) Descend for phasing

Figure 3.- Modified delayed transfer

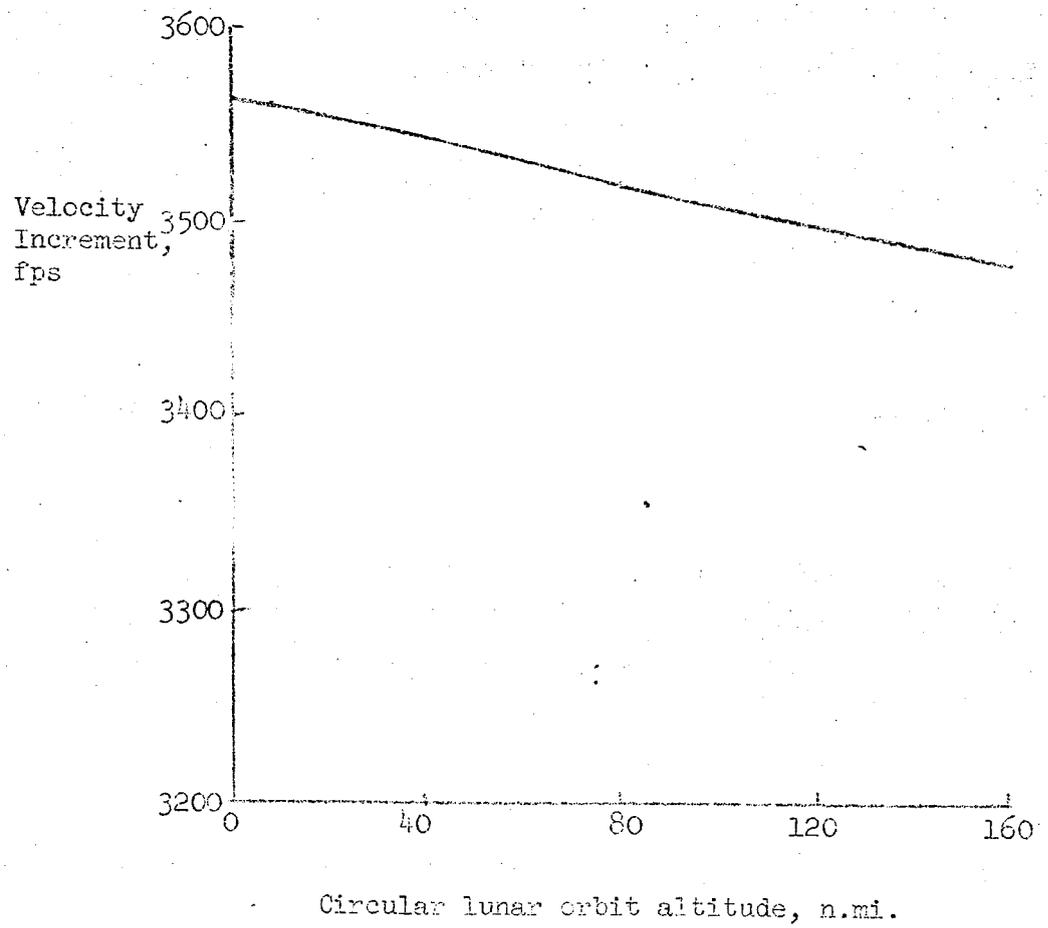


Figure 4.- Typical variation of incremental velocity required to inject into earth return trajectory.

a.) LEM orbit altitude 50,000 ft

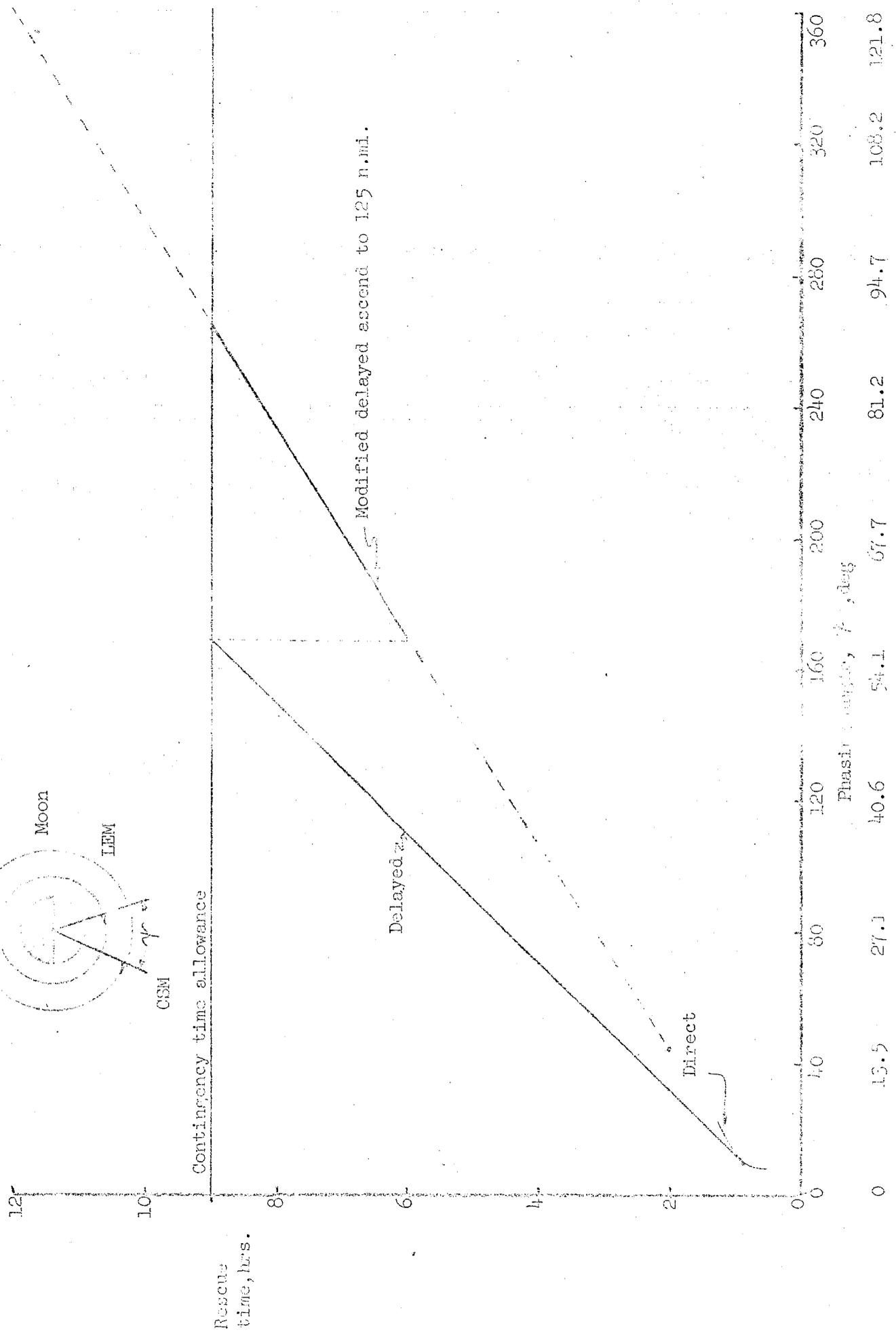
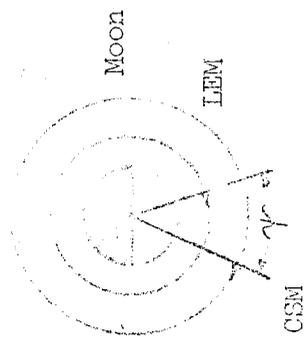


Figure 5.- Variation of rescue time with phase angle. (LEM @ 50 v.mi.)

b) LEM orbit altitude 20 n.mi.

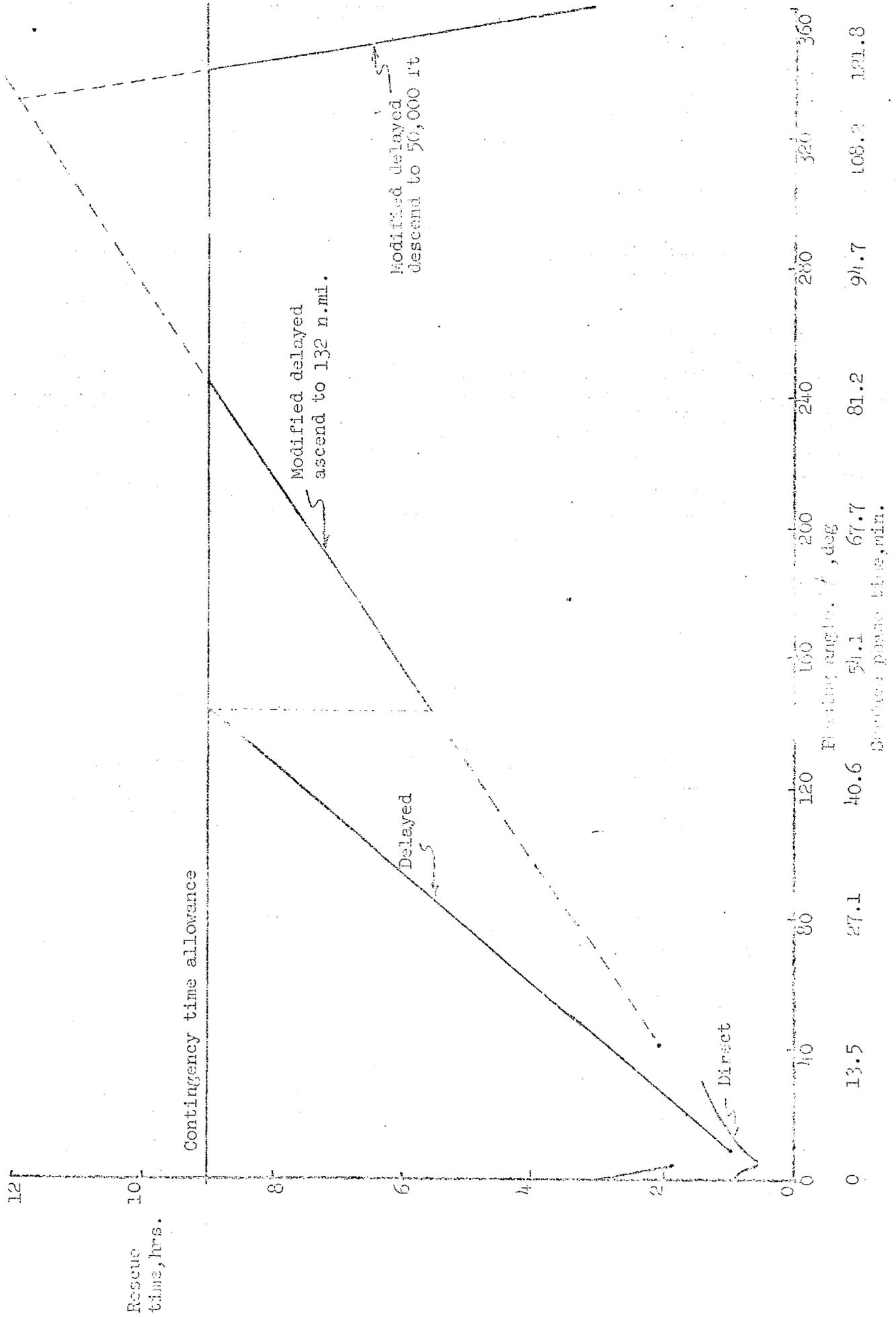


Figure 5... Continued

c) LEM orbit altitude 40 n.mi.

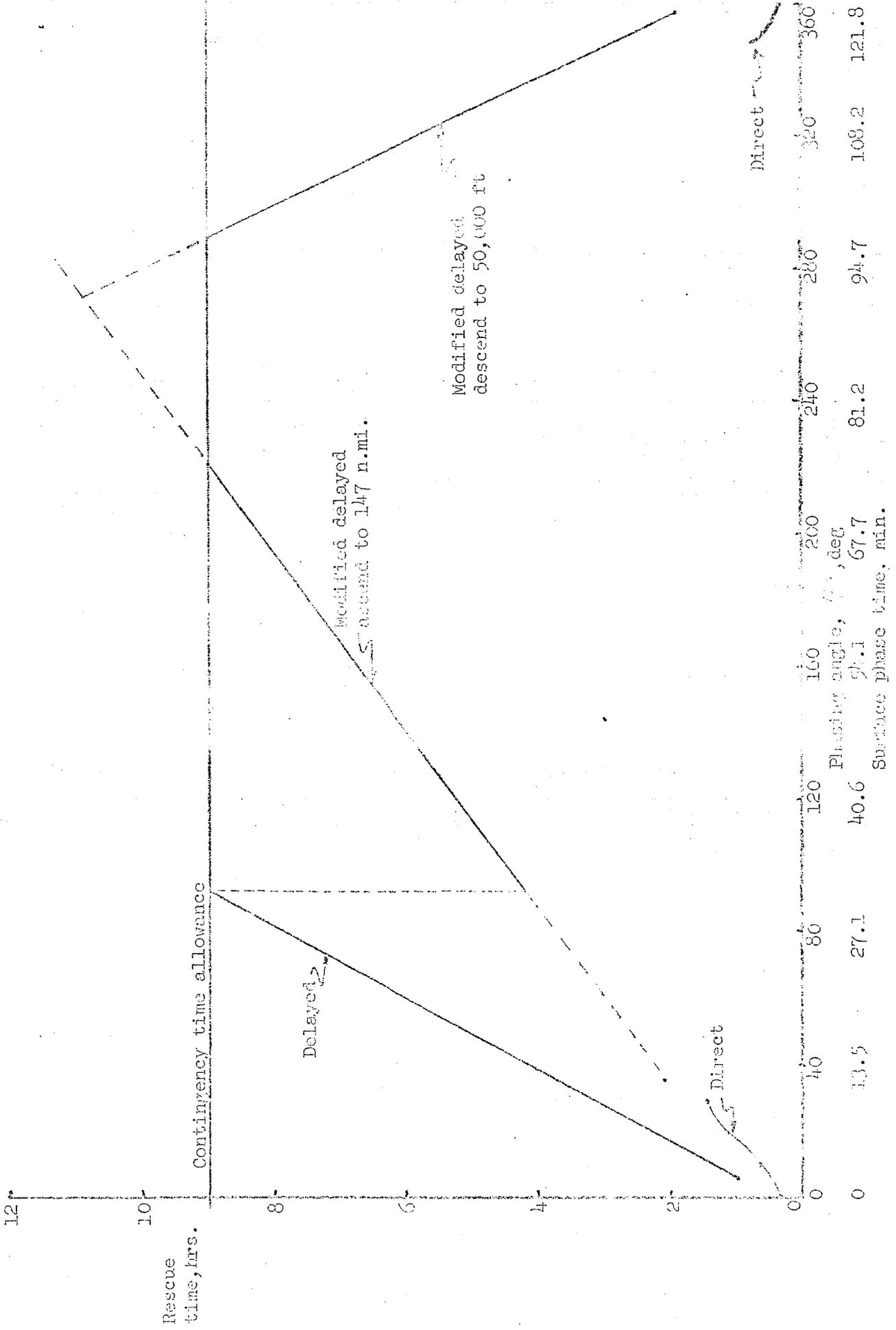


Figure 5.- Continued

a) LEM orbit altitude 60 n.mi.

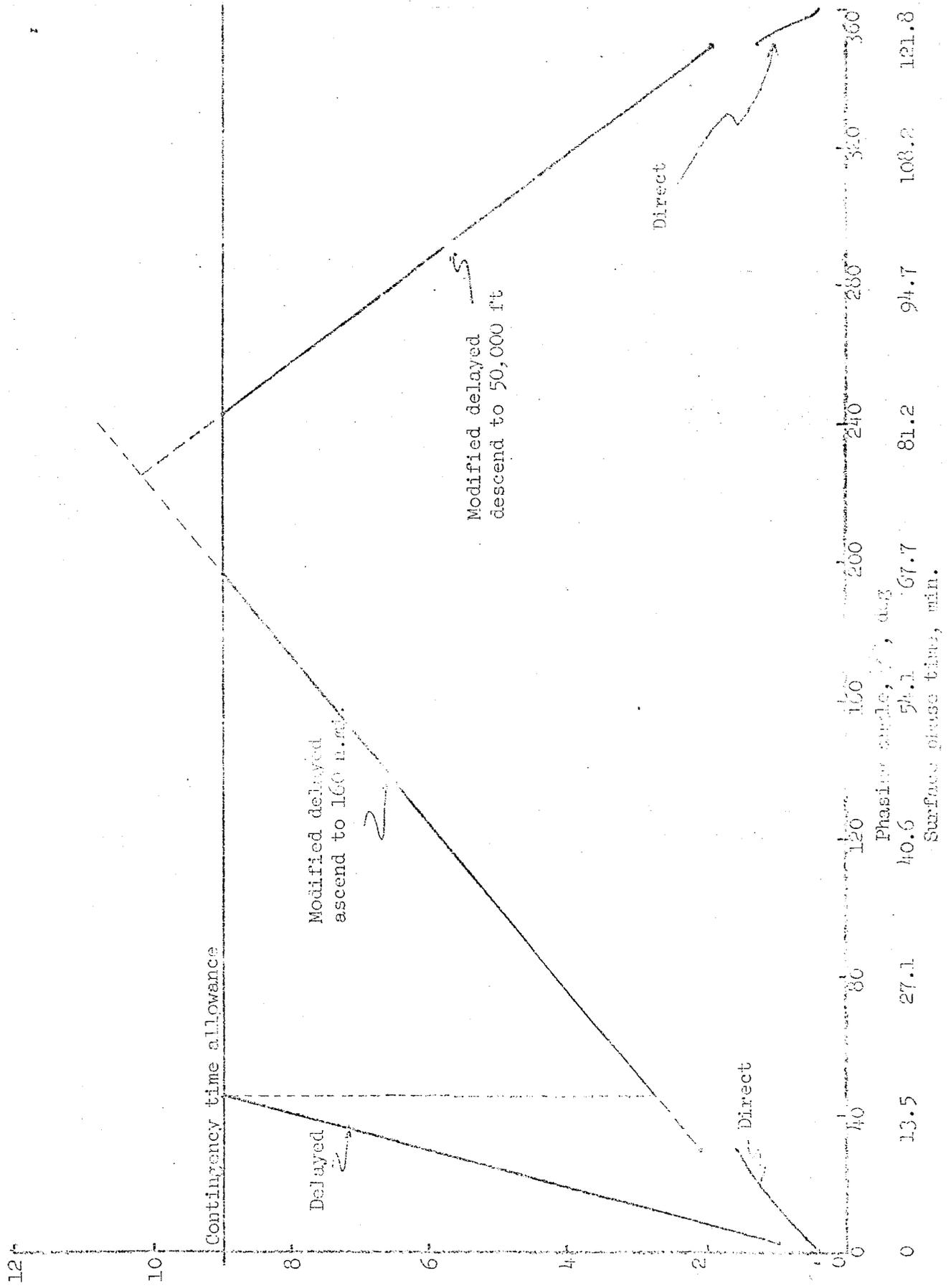
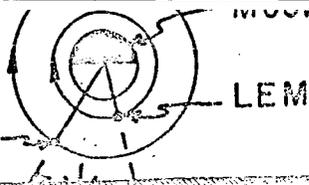
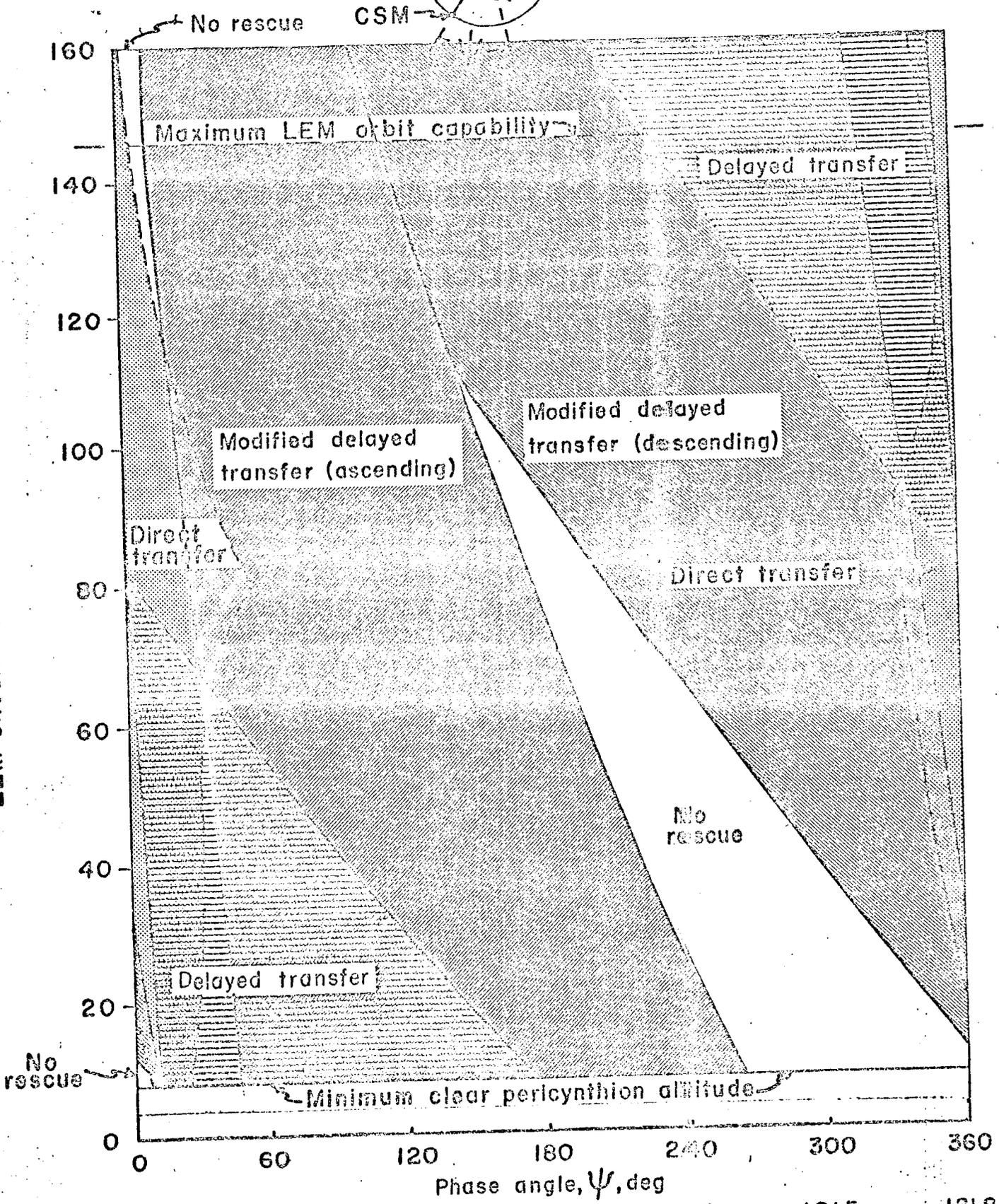


Figure 5.- Continued



LEM circular orbit altitude n. mi.



0	60	120	180	240	300	360
0	20.3	40.6	60.9	81.2	101.5	121.8
	Surface phase time, min.					

Fig. 6 Composite of CSM maneuvers for LEM rescue (in plane).

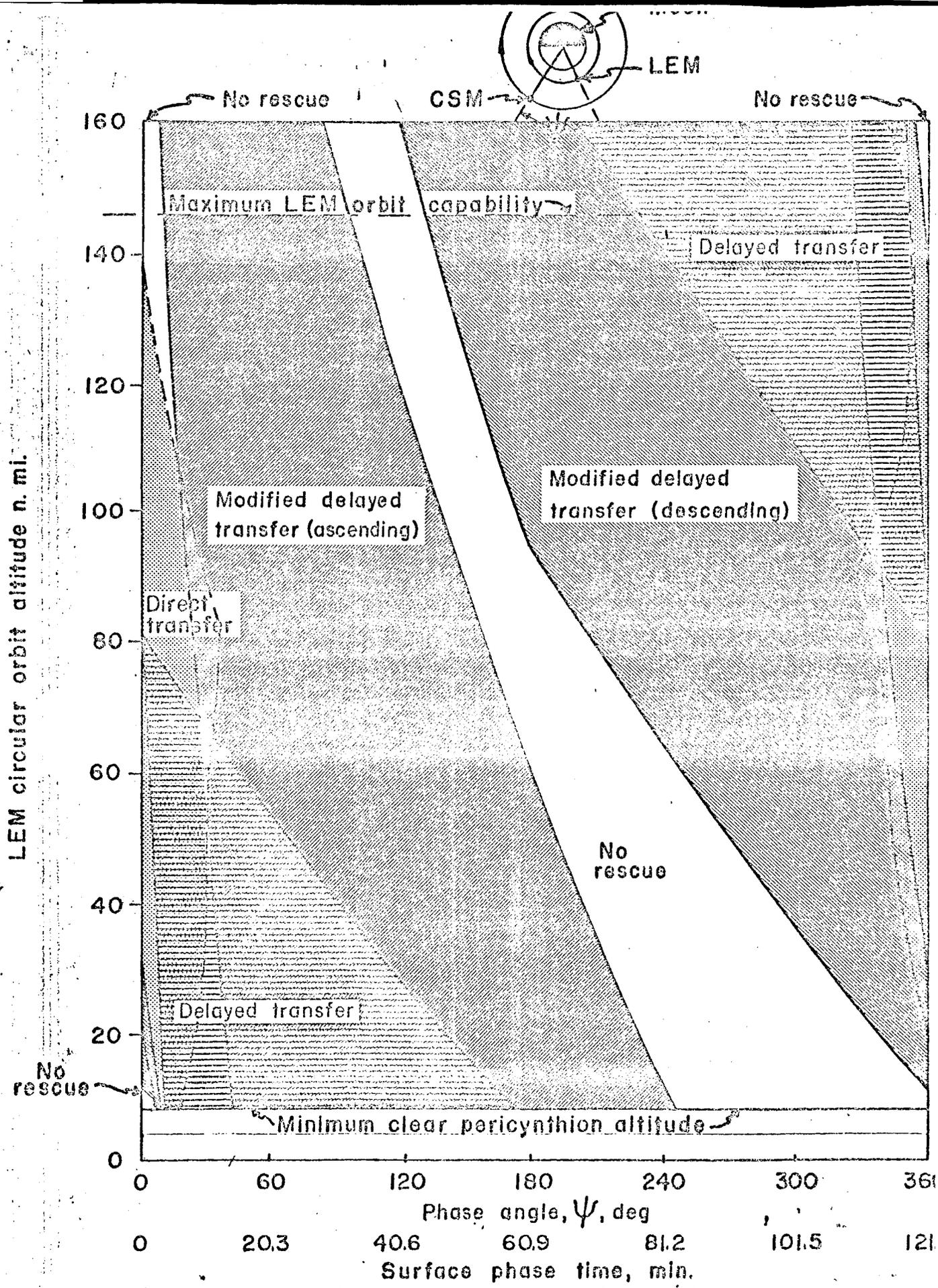


Fig. 7 Composite of CSM maneuvers for LEM rescue ($1/2^\circ$ out-of-plane)