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VELOCITY REQUIREMENTS AND PAYLOAD CAPABILITY FOR UNMANNED LEM LANDING

SUMMARY

Design velocity requirements and associated payload capability for an unmanned LEM lunar landing are presented. The design descent technique consists of a combined CM/LEM-Hohmann transfer from circular orbit at 80 nautical miles to 50,000-ft altitude; a fuel optimum LEM descent from this point to an altitude of 500 ft; and a vertical descent from 500 ft to the surface.

INTRODUCTION

The velocity budget for the manned LEM lunar landing includes some capability for maneuvers which are not necessary in an unmanned landing. For example, it was necessary to provide for crew safety in all mission phases and also to provide for some site selection capability. Hence, for an unmanned LEM landing, it is deemed necessary to design a new velocity budget in order to maximize payload capability for such a mission. The purpose of this paper is to discuss briefly some of the operational tradeoffs in an unmanned LEM mission in order to determine a realistic velocity and payload budget.

SYMBOLS

CM	Command Module
LEM	Lunar Excursion Module
GMT	Greenwhich Mean Time
g_o	Acceleration of gravity at earth sea level, ft/sec^2
h	Altitude, ft
h_p	Pericynthion altitude, ft
I_{sp}	Specific impulse, sec

SM	Service Module
T/W_o	Initial thrust-to-weight ratio
V	Velocity, fps
ΔV_a	Impulsive velocity increment required to initiate Hohmann transfer, fps
ΔV_c	Characteristic velocity, fps
ΔV_p	Impulsive velocity increment required to circularize at pericynthion of Hohmann transfer, fps
γ	Flight path angle defined as angle between local horizon and velocity vector, deg
θ	Pitch attitude, referenced to local horizon, deg
μ	Ratio of initial to final mass of spacecraft in powered flight

CHARACTERISTIC VELOCITY

In order to size fuel tanks for a spacecraft, fuel design requirements for performing each thrusting maneuver must be established. A measure of the fuel requirements can be obtained from the characteristic velocity, ΔV_c, necessary to perform the maneuvers. Characteristic velocity is defined as:

$$\Delta V_c = g_o I_{sp} \ln \mu$$

For orbital maneuvers which require only a short burst or impulse from the rocket engine then the characteristic velocity is approximated by the impulsive velocity increment dictated by Keplerian mechanics.

In the sections to follow the characteristic or impulsive velocity requirements for an unmanned LEM lunar landing mission are discussed briefly.

OPERATIONAL CONSIDERATIONS

Orbital Descent Transfer

For unmanned flight the primary operational consideration is fuel economy in order to maximize payload capability. This then suggests that the LEM descend on a minimum energy Hohmann transfer from the CM orbit to a low altitude from which powered descent can be made economically, see figure 1. The associated impulsive velocity requirements are given in table I for a pericynthion altitude of 50,000 ft. For unmanned flight, however, this transfer has two drawbacks. First, this transfer requires about one hour to reach the pericynthion altitude for initiation of powered descent, hence, IMU alinement becomes a problem. That is, the IMU must be alined one hour prior to powered descent; thus, considerable guidance error could build up due to IMU drift during this time. The second drawback, although a minor one, is the requirement of an automatic engine restart for mission success.

A compromise on fuel economy and the operational considerations of automatic guidance can be obtained by inserting both the CM and the LEM on a Hohmann transfer and separating the LEM near pericynthion so that the LEM performs only the powered descent from 50,000 ft (fig. 2). This transfer minimizes the IMU alinement problem and eliminates the engine restart; however, it does so by increasing the velocity requirements on the CM (table II). The first velocity impulse ΔV_a must now be performed by the CM to transfer the combined mass of the CM and LEM instead of the LEM alone and will, therefore, require more fuel weight onboard the CM than would have been needed in the LEM. In table II the CM velocity requirement is shown to be $2\Delta V_a$ since an additional amount of velocity impulse equal to ΔV_a will be required to circularize for injection of the CM into the earth return trajectory. It is felt, however, that these fuel penalties are not severe and therefore it is recommended that the combined CM/LEM orbital descent transfer be utilized for the unmanned LEM landing.

The combined CM/LEM descent transfer has an operational drawback in that it does not allow for an assessment from the CM of the LEM at LEM touchdown. This is due to the fact that the CM is at an altitude of only 50,000 ft, and consequently is over the horizon at LEM touchdown, thus, precluding any communications (telemetry) link between the spacecrafts at this time. However, this drawback is not considered to be a serious one since the assessment of the LEM condition at touchdown can readily be made by a communications link between the LEM and the earth. (This is, of course, presuming the landing site is on the earth side.) In fact, the earth link would perhaps be a better choice for

the assessment, since more ground equipment would be available to perform the necessary data reduction.

Powered Descent

As in the preceding phase, the primary operational factor during powered descent is also fuel economy. Hence, the powered descent trajectories are based on a calculus of variation, fuel optimization of the equations of motion as reported in reference 1. The equations of motion are based on two dimensional motion, a circular gravitational body, and a constant level of thrust. The characteristics of a fuel-optimum constant thrust descent for an initial thrust-to-weight ratio of 0.4 is shown in figure 3. The initial conditions for this descent are circular orbit at 50,000 ft and terminal conditions are 500 ft altitude with a vertical downward velocity of 10 fps. These terminal conditions were chosen in order to provide for altitude uncertainties at touchdown. In other words, should the altitude be in error by as much as 500 ft, then the LEM will still touchdown with a velocity of only 10 fps. The characteristic velocity required for this descent is 5,687 fps. An additional 260 fps is required to descend the final 500 ft to the surface while maintaining a vertical velocity of 10 fps. A fuel optimum descent with the same initial conditions which terminates at the surface instead of 500 ft altitude would require a characteristic velocity of 5,705 fps; hence, a velocity penalty of 242 fps is paid for the non-optimum, vertical descent from 500 ft altitude. Again this velocity penalty is not considered severe for what it yields--additional guidance insurance against a catastrophic impact.

DESIGN VELOCITY AND PAYLOAD BUDGET

The unmanned LEM landing design velocity budget is given in table III. This budget is based on the descent transfer of both the CM and LEM, (fig. 2) because of operational considerations discussed in the preceding section. The initial CM altitude is chosen as 80 nautical miles (same as manned LEM landing). This is not a minimum altitude and could be lowered if more fuel savings are desired. A velocity reserve of 5 percent is included in the design requirements for automatic guidance system errors. This reserve is less than the 10 percent used in manned flight since crew safety or recovery of the LEM is not a consideration in the event of system failure.

The amount of unmanned payload (dry weight) to be soft-landed on the lunar surface is a function of many variables and no thorough investigation of these variables is intended herein. Instead, the payload capability is determined for the design velocity budget of table III, for the CM/SM weights as of August 1, 1963, and for Saturn C-V

booster performance as of April 29, 1963. Furthermore, the landing site is assumed to be on the lunar equator and the translunar trajectories are restricted to be free earth return trajectories. The method of calculation is an unpublished matched conic digital computer program developed by Thomas F. Gibson and Jack Funk of the Guidance Analysis Branch, MSC. This program includes complete earth-moon geometry and utilizes two-body trajectories about the earth and moon which are matched at the boundary of the sphere of influence about the earth. The free earth return trajectories computed by this program have been found to agree within 1 percent of integrated trajectories. Typical results of maximum LEM total weight and payload weight are shown in figures 4 and 5, respectively, for launchings during the first 46 days of 1968. It is evident from these figures that a maximum LEM total weight of about 30,000 lbs and a maximum LEM payload weight of about 15,500 lbs can be launched nearly every day during this launch period and maintain a reentry range at earth of less than 5,000 nautical miles. About 1,000 lbs can be added to each of these weights provided a restricted launch window can be tolerated (3 day period every two weeks).

CONCLUDING REMARKS

The design velocity and payload budget has been presented for an unmanned LEM lunar landing based on operational considerations quite different from those for a manned landing. The primary considerations for an unmanned landing are fuel economy and automatic guidance considerations only. Based on trade-offs between these two considerations, the total design velocity requirements are shown to be 6,348 fps for the LEM and 204 fps for the CM (while in lunar orbit only). These requirements include a 5 percent reserve. Based on this velocity budget an unmanned LEM payload (dry weight) of about 15,500 lbs can be obtained.

REFERENCES

1. Miele, A.: "General Variational Theory of the Flight Paths of Rocket Aircraft, Missiles, and Satellite Carriers." AFOSR-TN-58-246(AD-154-148).

TABLE I.- LEM VELOCITY REQUIREMENTS FOR HOHMANN TRANSFER
(hp = 50,000 ft)

CM Altitude, n. mi.	ΔV_a, fps	ΔV_p, fps
50	58	59
60	71	72
70	85	86
80	97	99

TABLE II.- VELOCITY REQUIREMENTS FOR COMBINED CM/LEM TRANSFER

(hp = 50,000 ft)

Initial CM Altitude, N.Mi.	LEM Requirements (ΔV_p) fps	CM Requirements ($2\Delta V_a$) fps
50	59	116
60	72	142
70	86	170
80	99	194

TABLE III.- DESIGN VELOCITY BUDGET FOR UNMANNED LEM LANDING

(a) CM Budget*

Altitude	Comments	Characteristic Velocity, fps
80 n.mi.	Impulse for insertion into Hohmann descent transfer from 80-n.mi. circular orbit to 50,000 ft. altitude	97
80 n.mi.	Impulse for circularizing at 80 n.mi. from Hohmann transfer	97
	Total	194
5 percent reserve		10
	TOTAL DESIGN REQUIREMENT	204

*Requirements while in lunar orbit only.

TABLE III.- DESIGN VELOCITY BUDGET FOR UNMANNED LEM LANDING

(b) LEM Budget

Altitude	Comments	Characteristic Velocity, fps
50,000 ft.	Circularize from 80 n.mi.-50,000 ft Hohmann Transfer	99
50,000 ft.-500 ft.	Fuel optimum, constant-thrust descent, $T/W_o = 0.4$,	5687
500 ft. to surface	Constant vertical descent rate to surface with impact velocity of 10 fps	260
	Total	6046
	5 percent reserve	302
	TOTAL DESIGN REQUIREMENT	6348

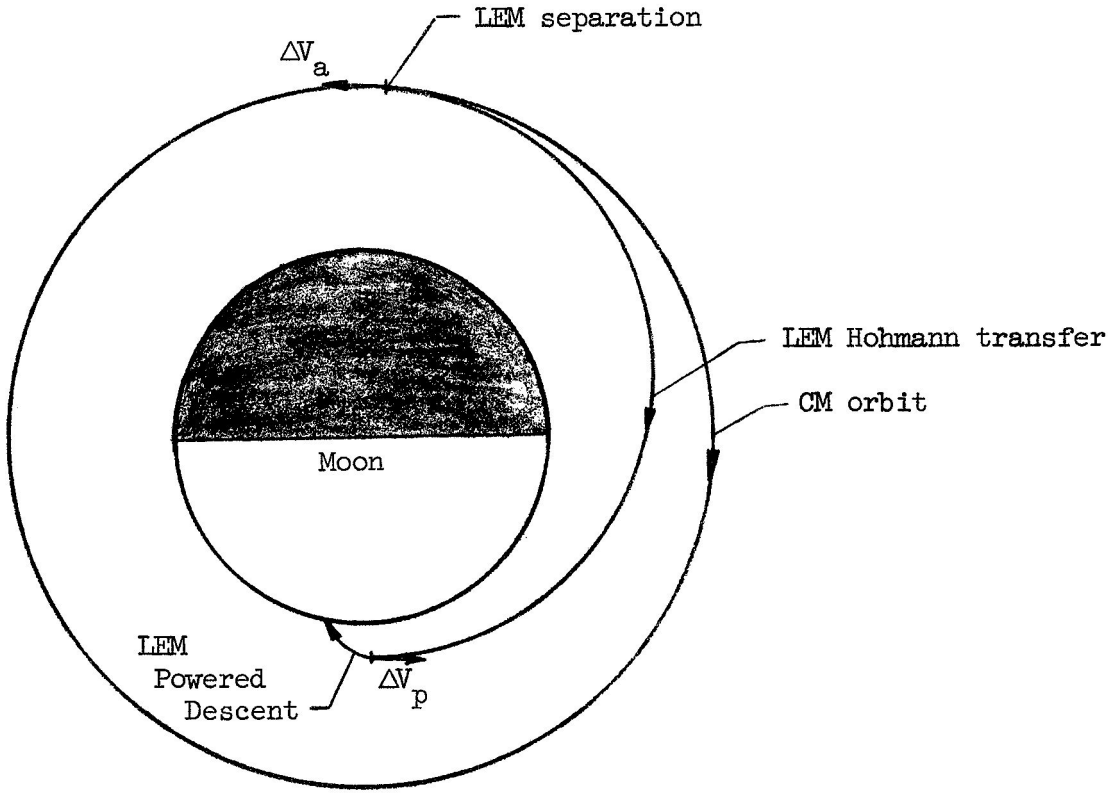

Figure 1.- LEM-alone descent transfer

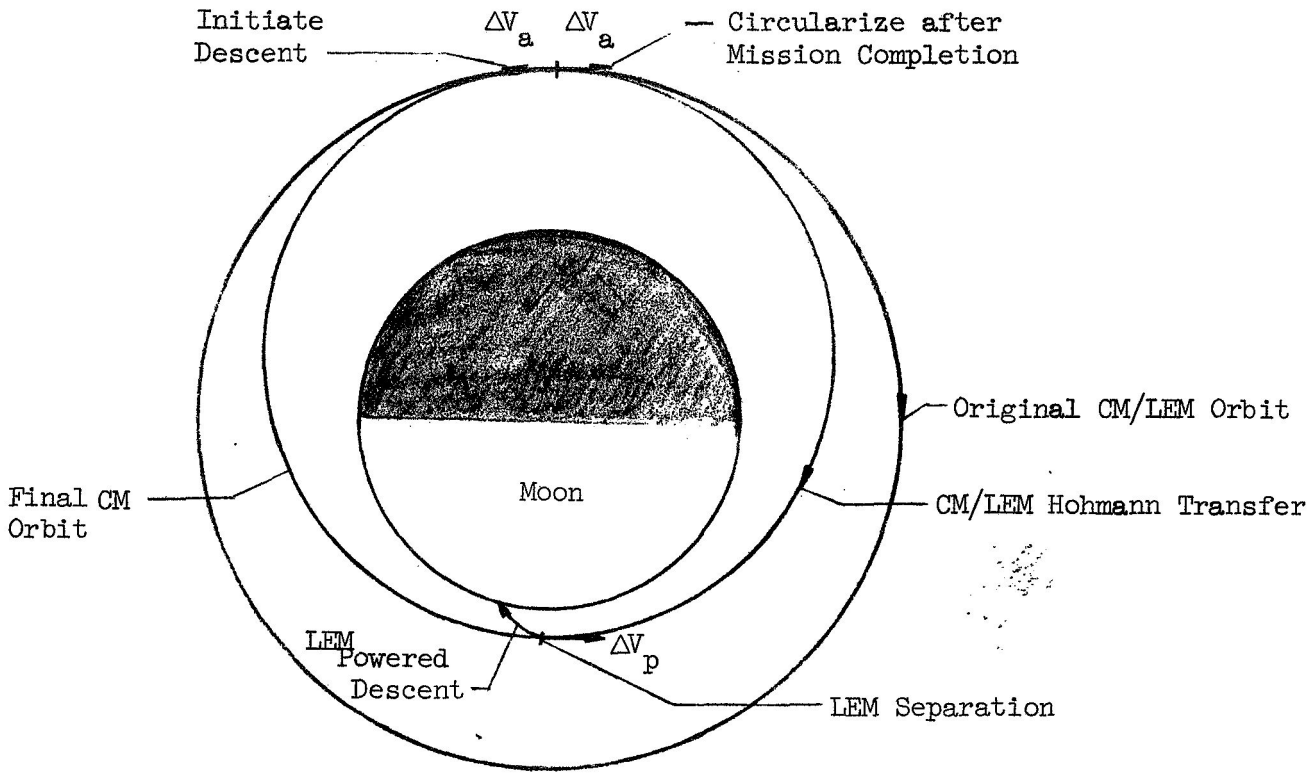

Figure 2.- Combined CM/LEM descent transfer

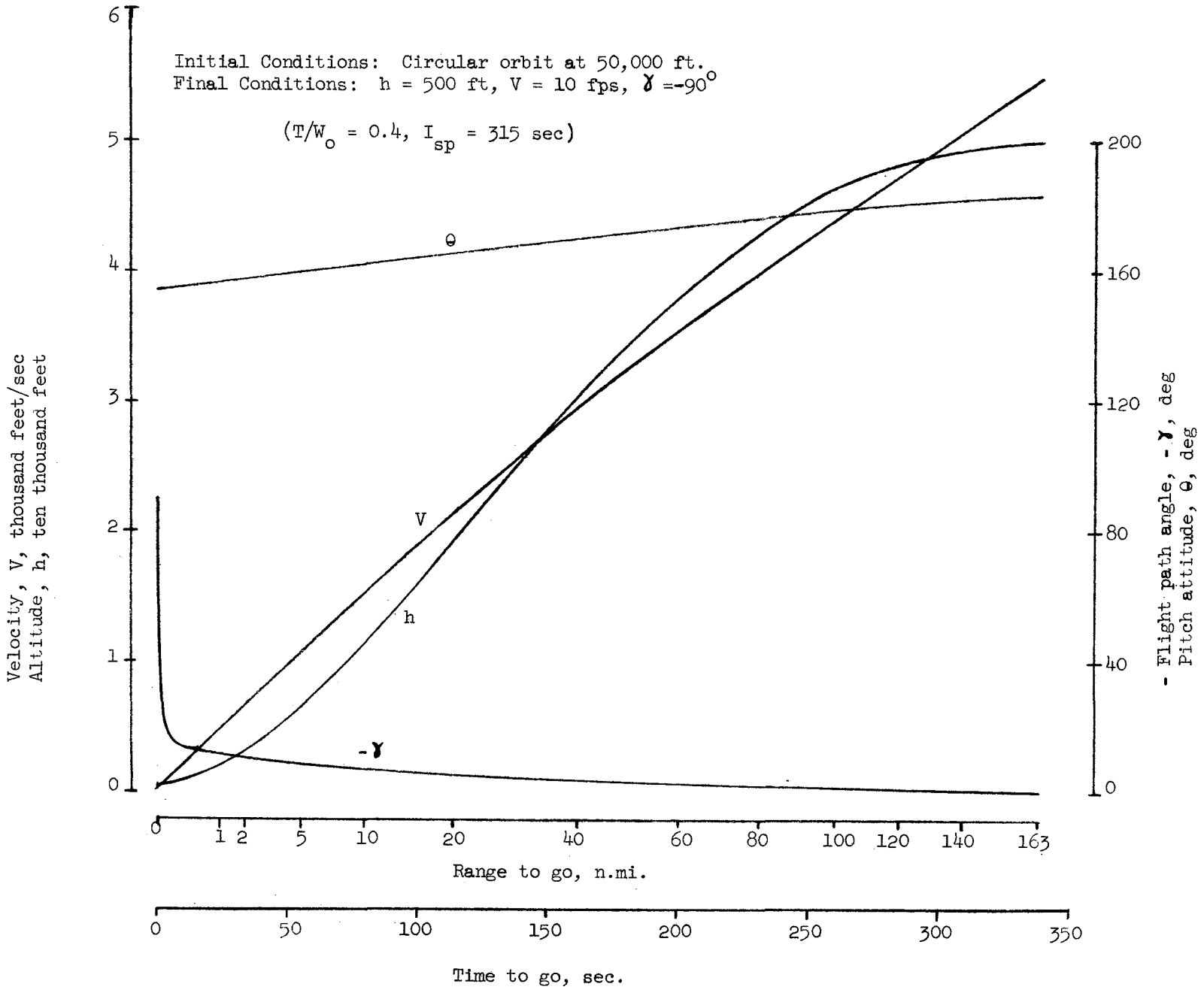

Figure 3. Characteristics of fuel optimum, constant thrust descent.

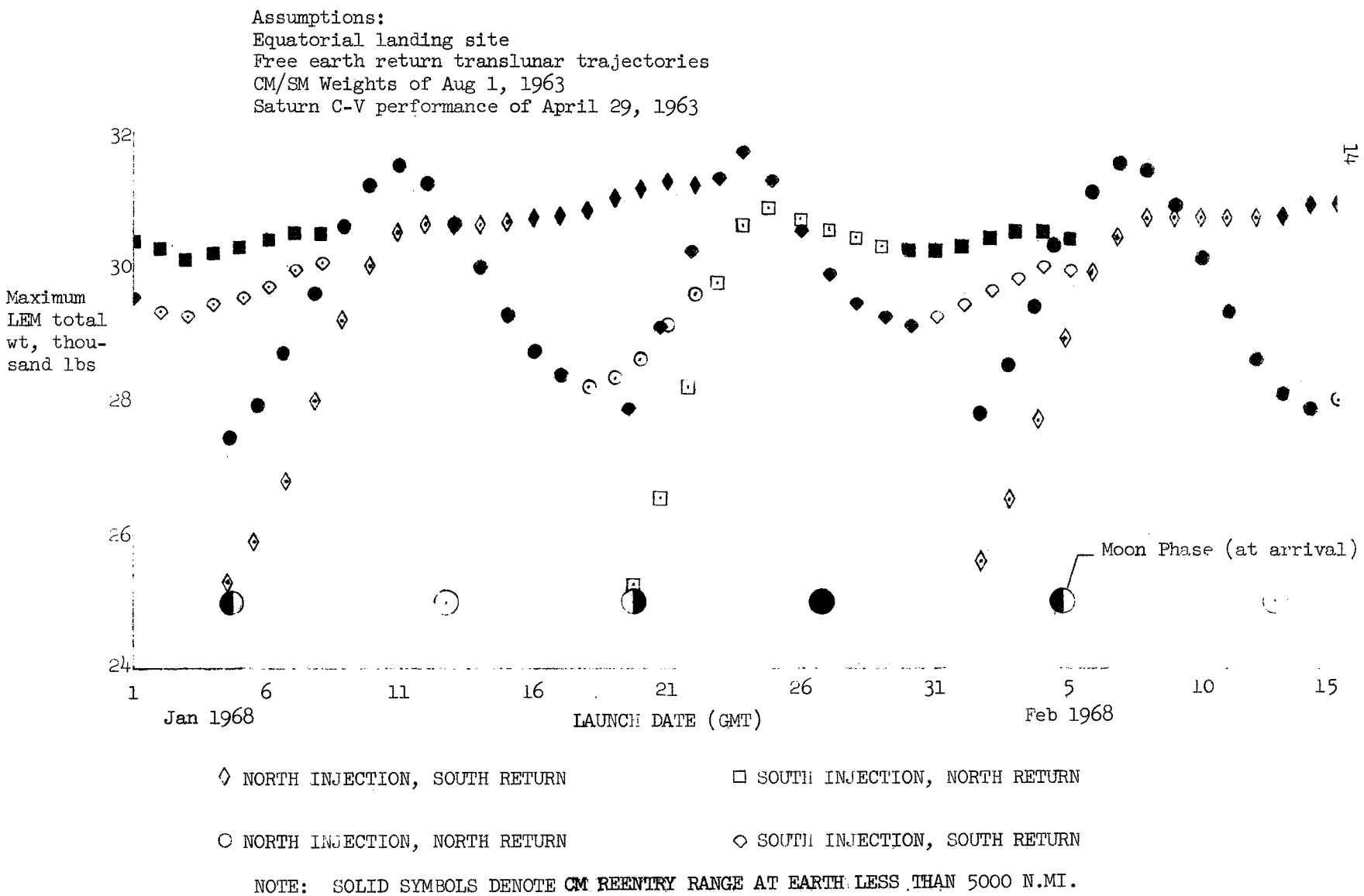

FIGURE 4. Typical variation of maximum LEM total weight with launch date for unmanned lunar landing.

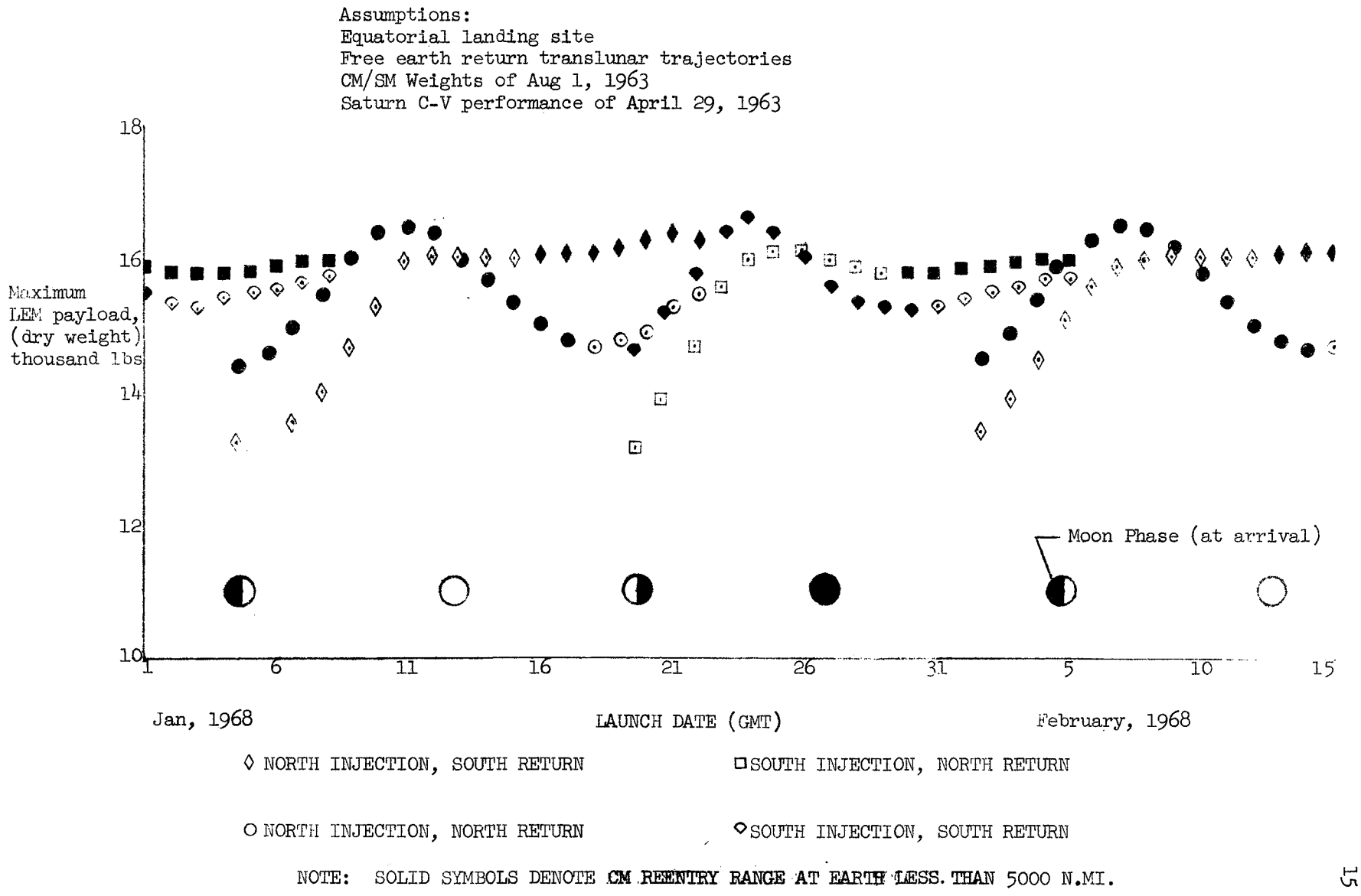

FIGURE 5. Typical variation of maximum LEM payload (including structure) with launch date for unmanned lunar landing.