LEAP - A ONE-MAN
LUNAR ESCAPE AMBULANCE PACK

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ABSTRACT

Seeks to anticipate an accident or medical emergency during the early phases of lunar exploration. The ambulance described lifts the patient alone from the surface and into rendezvous with a waiting hospital ship in close orbit. Such a mission largely predetermines the minimum size of vehicle and its layout. LEAP is in consequence a constant attitude vehicle with a two position thrust vector produced by a rotating nozzle or combustion chamber. The influence of the vehicle scaling constants, of initial acceleration and rendezvous height upon vehicle size for both solid and liquid propellant propulsion systems are described.

INTRODUCTION

LEAP is a one-man vehicle intended for operation from the lunar surface. The concept involves the launching of the LEAP payload into a trajectory that will place it close to an orbiting space station. A "soft" rendezvous will permit the transfer of the payload into the space station. As foreseen at the moment, the orbiting space station will be of an Apollo type, but with only two men on board. A "normal" Apollo and three-man crew will be on the lunar surface for an extended exploration (1).[2] See Fig.1.

In the event of an emergency (i.e., the occurrence of an anticipated but nonpredictable serious accident or illness), the affected crew member is transferred to the waiting space station. This vehicle will have a special emphasis on medicine and surgery and will perform the hospital function if its

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Presented at the ARS Lunar Missions Meeting, Cleveland, Ohio, July 17-19, 1962. This study has been supported entirely by LEAP's own efflux.

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[2] Numbers in parentheses indicate References at end of paper.

normal duties are interrupted. (The normal duties of a lunar orbiting space station during a period of manned exploration are seen as possibly navigational aids, communication links, advisory and command post, research control center, and extended physiological zero "g" studies.)

If LEAP is not made available at the time in question (during the early lunar exploration phase), then alternative arrangements will be required in order to maintain the emergency service at the proposed level. The only possible alternative to something like LEAP will require, in the event of an emergency, the launching of the surfaced vehicle. A rendezvous in close lunar orbit and transfer of the patient to the hospital vehicle will follow. It appears certain that the necessity of supplying to the two Apollo Earth return vehicles the potential ability to rendezvous and transfer the patient will involve penalties in the sense of mass allocation and also problems in guidance and control much more severe and delicate than arise with LEAP.

This paper describes the salient features of a supposedly finalized complete LEAP system. Particular point is made to emphasize the manner in which the definition of the mission and mission philosophy themselves direct the logical build-up. At a number of places, problems are considered in some detail in order to clarify decisions made with respect to operation. It represents a part of a study undertaken by the author upon the effect of finite propulsion systems and mission philosophy upon vehicles and payload.

MISSION

The LEAP mission is to lift from the lunar surface a 240 lb payload (of one noncompos-mentis human plus equipment) and to place this in the vicinity of a waiting vehicle, which is in a close lunar orbit.

The waiting hospital vehicle is in a carefully controlled circular orbit at a height 2×10^5 ft (38 miles) above mean mare level. The LEAP vehicle possesses excess propellant and can deliver to the payload a velocity of 5400 fps. This is slightly greater than circular velocity. The excess, which is 5% in energy terms, is to permit the propulsive maneuvers for the rendezvous and docking procedures. No maneuver is required from the waiting vehicle.

The LEAP propulsion requirement is specified in terms of an energy height of 3×10^6 ft, of which 93.3% is put into the payload in the horizontal sense.

MISSION PHILOSOPHY

LEAP, with its human payload, is considered as a last ditch operation. There is no secondary layer of safety processes and no abort machinery. It follows, therefore, that a very high reliability is demanded of the complete system.

The over-all philosophy has therefore been 1) wherever possible, to simplify; 2) wherever possible, to use one component instead of two, even at some mass sacrifice; and 3) wherever possible, to place equipment in the hospital vehicle.

MISSION CONSTRAINTS : GENERAL

No controlling activity at all is required, or needed, from the human payload. In fact, once the "countdown" has been initiated, the payload is unable to interfere with the procedure at all. Command problems require solution at this point. These are particularly vexatious when the commander of the landed forces ends up as the payload.

Countdown initiation, which can only be operated after payload has been secured, will normally be operated by the personnel remaining behind.

Exceptionally the whole process of LEAP assembly, payload "tucking-in", and countdown initiation may be done by the payload. The process from tuck-in is irreversible!

GUIDANCE

It is not possible for the initial phase of LEAP launch to be observed closely by the waiting space vehicle. At the moment of ignition of LEAP, the distance between the vehicles exceeds 50 miles. In consequence, it would not have been possible to use radio from LEAP to space station or the reverse as part of a take-off guidance system. Nor would it have been possible for the space station to have detected the initial LEAP trajectory by any means. In consequence, the initial phase of the launch has had to be guided independently of either space station or lunar surface. In fact, LEAP uses an elementary two-gyroscope inertial guidance for a large part of its flight. This involves a certain minimum of prelaunch setting-up in order to define the local vertical and also the planned "turn down" direction.

With LEAP, a simple rigging system is used. The vertical sense is determined by centralization of a plumb-bob. The turn-down direction is obtained by sighting visible land marks already located upon a lunar grid. The precise relationship between grid master line and hospital vehicle flight path will be determined by the flight vehicle and remain a constant for a given phase of the exploration. Final offset angle will depend on the perpendicular distance from flight path to launch point.

The final phase of the trajectory, leading to rendezvous and docking, cannot economically and reliably be guided by an automatic sensing system within LEAP. In consequence, the final guidance is commanded by the space station using visual techniques. (This procedure is the inverse of that reported by Houbolt, Ref.2, of the work by Lineberry and Kurbjun, Ref.3.) Velocity and trajectory changes are made by LEAP to the external commands.

INITIATION OF LAUNCHING SEQUENCE

It is essential that the liftoff of LEAP occurs at an exact time relationship with respect to the orbiting vehicle. Since no communication can occur between vehicles at liftoff or immediately before this, synchronization must occur one revolution of the orbiting vehicle prior to liftoff. With LEAP, the first step in the setting up sequence involves the erection of a very light aerial. This picks up the "overhead" signal from the space station. A clock mechanism is thereby triggered which counts off one orbit to zero. If the launch initiation circuit is not completed, the clock mechanism will be reset at each pass of the space station. If the "launch" circuit is completed, then a countdown to ignition and accurately timed liftoff will occur. Obviously, a simple time mechanism will prevent liftoff occurring if insufficient time is given for warm-up procedure.

TRAJECTORY

Although the minimum energy trajectory to a given altitude involves a tangential departure from the launching point, LEAP takes off vertically. This is dictated from fairly obvious aspects of safety. Obviously the "pure" tangential departure results in the launching vehicle remaining very close to the lunar surface for an unpleasantly long time. In consequence, even if the launching took place from the top of a convenient rise, the vehicle would still only possess a few thousand feet of altitude at the end of burning. In addition the flight line would need careful selection so that the trajectory took the vehicle through valleys rather than through mountains.

In fact, the possible presence of a precipitous surface close to the launching site predetermines an initial vertical phase that is maintained for several thousand feet.

HANDLING ON THE LUNAR SURFACE

LEAP, enclosed within an environmental control capsule, is carried at a fixed location within the lunar landing stage of the main Earth launching vehicle. Upon landing on the lunar surface, it is kept within the "command module" with adequate environment control. If a command post is to be set up away from the command module, the LEAP will be transferred as one of the essential items. Such a transfer will normally be carried out with the LEAP components still contained within the environmental control capsule. This has a total mass of some 475 lb which, in the lunar environment, can be managed by two men. Nevertheless, should circumstances dictate, the separate components of LEAP may be moved, erected, filled, and fired by one man.

At the conclusion of an expedition, if LEAP has not been used in the emergency sense, some 175 Earth-lb of selenological samples are transferred instead.

LEAP - DESCRIPTION AND OPERATION

There are only two methods by which a single main propulsion system operating continuously can be used to fulfil the requirements of LEAP. The first of these uses fixed geometry and a planned rotation through the flight of both vehicle and thrust vector. Such a proceedings requiring a fairly elaborate guidance system within the take-off vehicle. LEAP on the other hand maintains a constant attitude with respect to the lunar surface. The vehicle leaves the surface under vertical acceleration only. This is maintained until the energy in the vertical sense is sufficient to carry the payload to the rendezvous altitude. At this moment the thrust vector is rotated through 90° to produce the required horizontal acceleration to orbital velocity. This is achieved by the physical rotation of the nozzle in the solid propellant vehicle example, and by the rotation of the complete combustion chamber in the liquid propellant vehicle. The reason for the selection of this arrangement is due to the simplification of the guidance problem. The guidance requirement being the maintenance of the vehicle at a constant attitude : the rotation of the thrust line occurring at a fixed time from liftoff.

LEAP layout is shown in Fig.2A. Problems of dynamic instability are simplified, and attitude control firces minimised by disposing payload and two propellant spheres about the thrust line so that the center of mass coincides with the thrust line in both positions of nozzle or combustion chamber throughout the firing time. Neither the solid propellant swivelling nozzle a detail of which is shown in Fig.2B (4), nor the swivelling combustion chamber for the liquid propellant unit is a severe engineering problem.

ANALYSIS

The question of selection of operating conditions to produce a minimum vehicle for the LEAP studies depends very much on the scaling parameters used (5). In this paper it has been assumed that the liquid propellant system is working at a combustion pressure of 15 atm. resulting in an effective exhaust velocity of 8000 fps. The solid propellant combustion pressure is 68 atm. and the same effective exhaust velocity. The effect of the size of scaling parameters upon the layload ratio are presented in Figs. 3A and 3B. The values actually considered are, for the pressurized liquid propellant system $Mt/Mp = 0.05$ and $Me/m_p = 2.5$ and for the solid propellant system $Mt/Mp = 0.1$ and $Me/m_p = 1$.

The assumed distribution of mass of payload and other non scaling items is given in Table 1. The results of the analysis are in Table 2. Initial accelerations of 5 and 6 lunar g absolute (about 0.8 and 0.97 Earth g's) have been considered for the liquid and solid systems respectively. These are not quite optimum but have been selected in order to minimize acceleration on the patient. The change in acceleration throughout the operation is not large as the overall mass ratio is 2.4 in each case. The resulting all burnt accelerations are 12 and 14.4 lunar g absolute (about 1.9 and 2.3 Earth g's).

The analysis so far discussed has been based on a rendezvous altitude of 2×10^5 ft. The effect of reducing this height upon the payload ratio for various system scaling constants is presented in Fig.4. In fact the unmanned LEAP mass which is 469 lb at 2×10^5 ft is reduced to 435 lb at 10^5 ft and to 384 lb at 2×10^4 ft.

Were the selection of altitude a free choice, then a considerable advantage could be obtained by significantly reducing the rendezvous height. Unfortunately, this is a problem involving the limitations of the orbiting vehicle guidance and control, and in addition the possible hazard of some mountains of the order 3×10^4 ft. In consequence, although orbiting heights of 5×10^4 may perhaps be possible in the future, it is thought the 2 x 10^5 represents a confidently achievable maximum for the described operations.

CONCLUSIONS

LEAP is one of a number of possible solutions to the real problem of making available a medical/surgical facility in case of need. The problem will be of greater magnitude during the immediate build-up period of lunar exploration. A decision to provide LEAP as an exploration emergency ambulance service will be possible without major changes in designs already commenced. It will involve a nonreturnable mass of less than 500 lb in the lunar landing vehicle.

The finally achievable figure for LEAP mass is very sensitive to rendezvous altitude, to the propulsion system used, and to the design values achieved for the scaling constant of vehicle and propulsion. The mass is less sensitive to the vehicle initial acceleration. Quite modest maximum accelerations may be used (to the benefit of the payloads health) without a large inherent effect on payload ratio. The difference between achievable payload ratio with liquid propellant and solid propellant is not large. The selection of a liquid system is based on its better behavior in exposed lunar daylight.

Table 1 LEAP payload : distribution of mass

Payload details	
Man	175 lb
Pressurized stretcher plus breathing kit	25 lb
Attachment structure	5 lb
Power supply; communication pack	10 lb
Vehicle details	
Guidance gyro platform	5 lb
Control attitude	10 lb
Control thrust vector rotation	10 lb
Total	240 lb

Table 2 LEAP details

Rendezvous height = 2×10^5 ft; payload + disposable load = 240 lb

	Pressurized liquid	Solid propellant
M_t/M_p	= 0.05	= 0.1
$M_e/\dot{m}_p$	= 2.5 sec	= 1.0 sec
X_α	= 5 g_L absolute	= 6 g_L absolute
a_α	= 26 ft/sec^2 absolute	= 31.15 ft/sec^2 absolute
M_L/M_α	= 0.373	= 0.358
M_p/M_α	= 0.582	= 0.581
M_α	= 644 lb	= 670 lb
M_p	= 374 lb	= 389 lb
M_t	= 19 lb	= 20 lb
F	= 16700 poundal	= 20860 poundal
	= 520 lbf	= 648 lbf
$\mathring{m}_p$	= 2.087 lb/sec	= 2.61 lb/sec
M_e	= 5.1 lb	= 2.6 lb
t_b	= 179.8 sec 55.8 sec vertical	= 152 sec
M_α - man	= 469 lb	= 495 lb
	= 76 Earth lb	= 80 Earth lb

NOMENCLATURE

a = absolute acceleration, ft/sec^2
c = effective exhaust velocity, fps
g_L = acceleration due to local gravitational field, ft/sec^2
g_c = nondimensional ratio, 1 slug mass/1 lb and 1 lbf/1 pdl
h = altitude above surface, ft
h_x = rendezvous altitude, ft
H_e = energy height based on lunar surface, ft
M = mass, lb
$\dot{m}$ = mass flow rate, lb/sec
t = time, sec

v = velocity, fps
v_x = circular velocity at height h_x
X = absolute acceleration in g_L units

Subscripts

α = start of burning
e = engine
h = horizontal acceleration phase of trajectory
i = end of vertical acceleration phase
t = tanks
v = vertical acceleration phase of trajectory
ω = end of burning
p = propellant
L = payload

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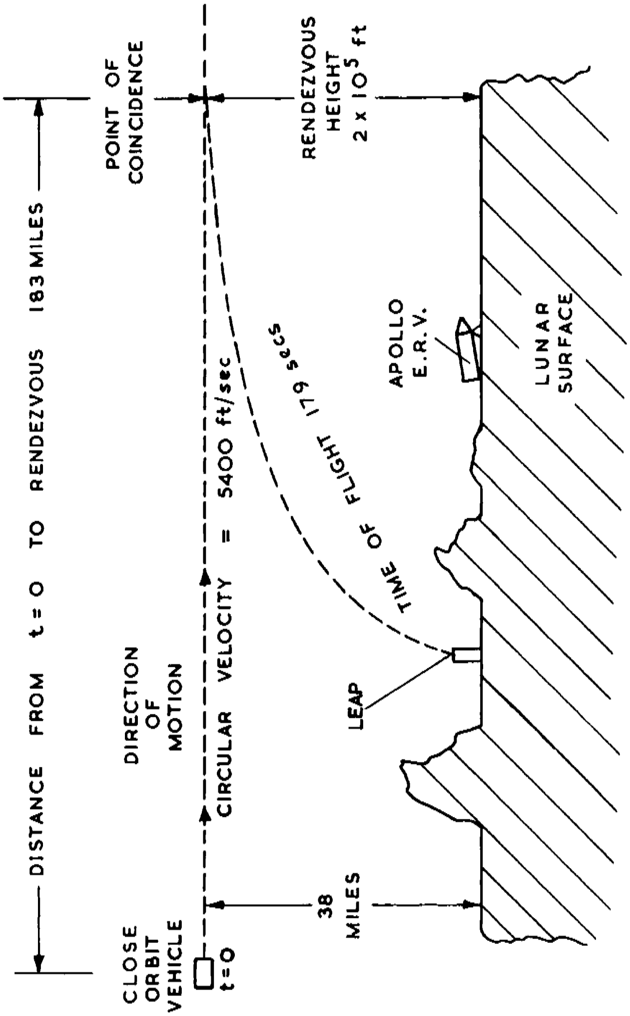

Fig. 1 Lunar escape ambulance and close orbit pickup

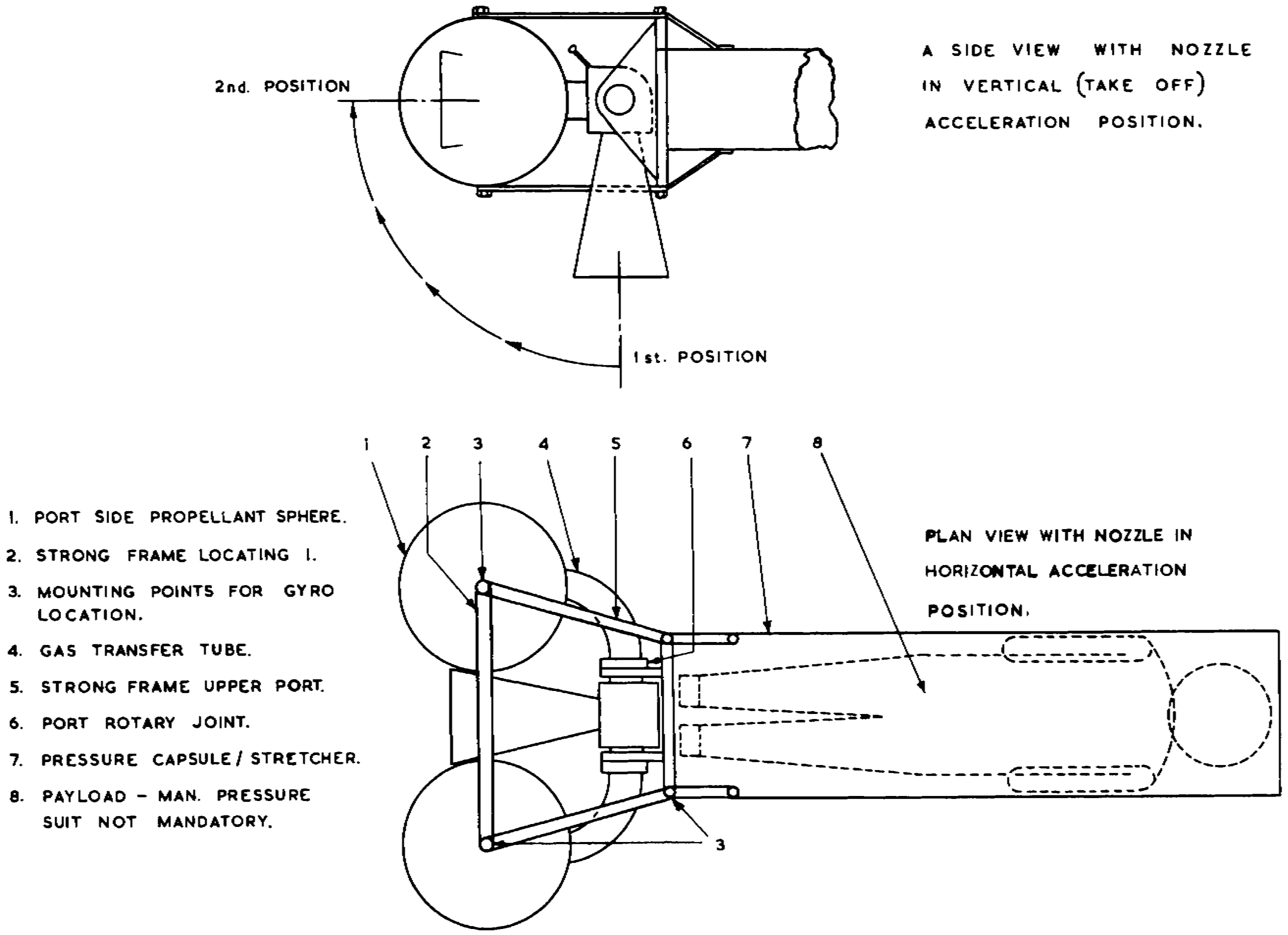

Fig. 2a LEAP layout with solid propellant motor

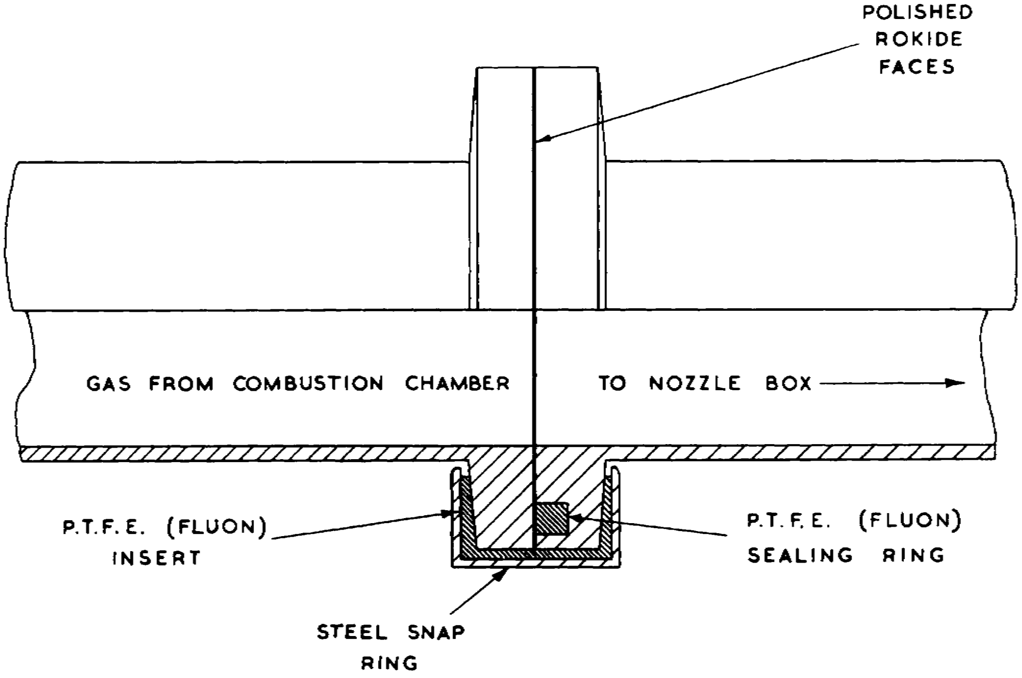

Fig. 2b Detail of rotary transfer tube of solid propellant layout

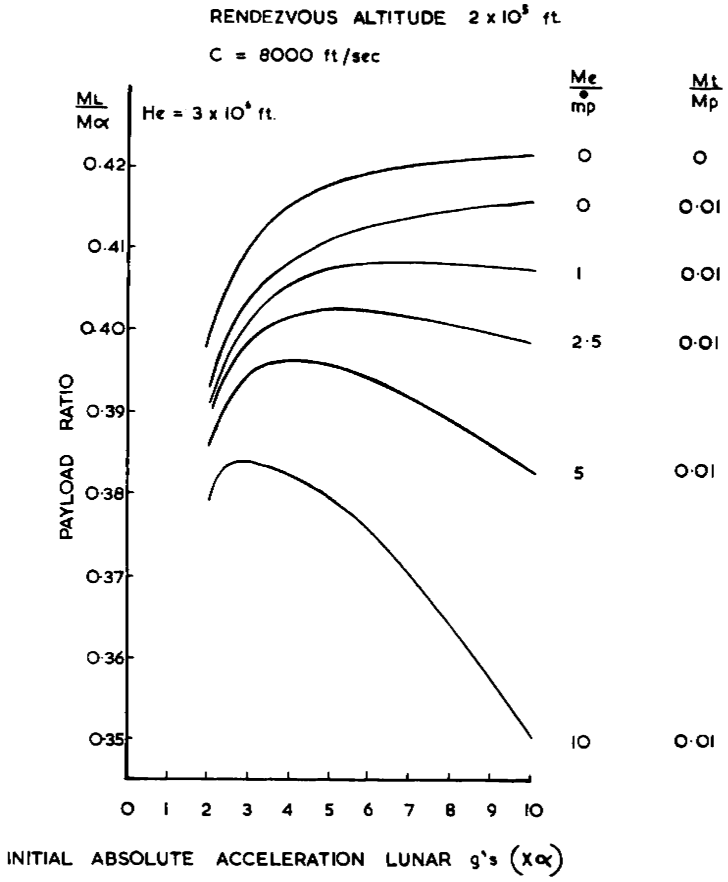

Fig. 3a Effect of scaling parameters

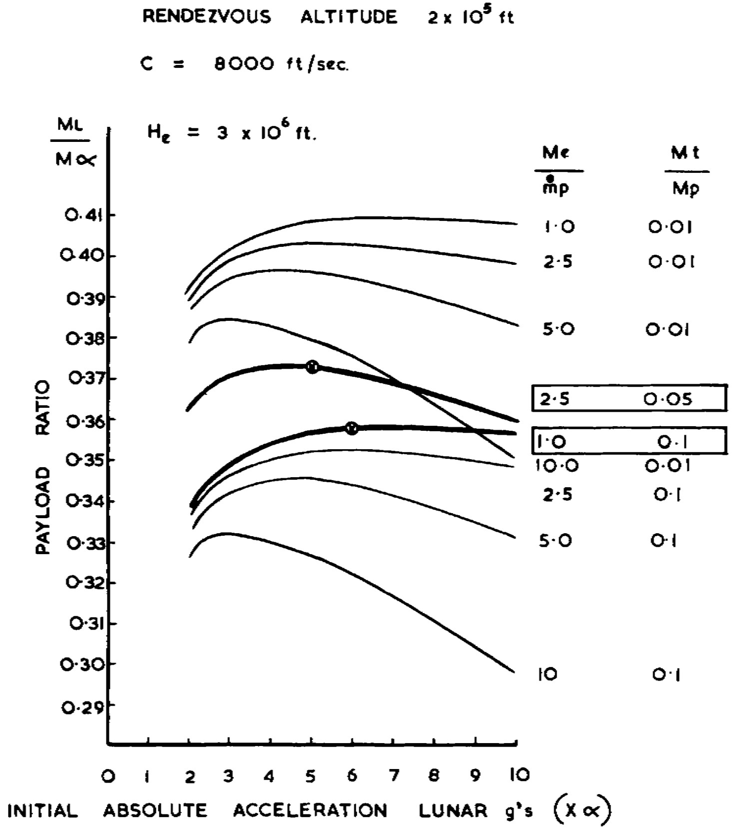

Fig. 3b Effect of scaling parameters

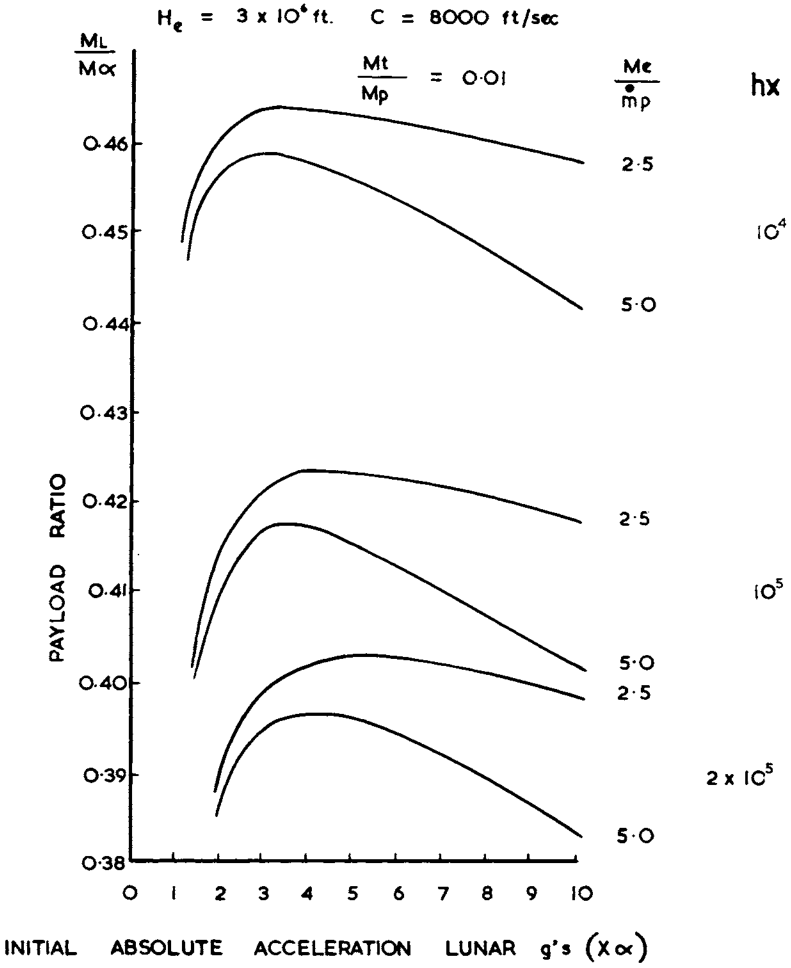

Fig. 4 Effect of rendezvous height