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AN INITIAL CONCEPT OF A MANNED MARS EXCURSION VEHICLE FOR A TENOUS MARS ATMOSPHERE

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Huntsville, Alabama

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ABSTRACT

This report summarizes a preliminary investigation of the requirements and characteristics of a manned Mars landing vehicle to:

1. Establish how much aerodynamic braking might be feasible with thin atmosphere;

2. Determine if parachutes appear feasible and, if not, how can aerodynamic braking be phased into rocket braking for a landing;

3. Establish a rough estimate of the total mass of a Mars landing vehicle.

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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ADVANCED SYSTEMS OFFICE
RESEARCH AND DEVELOPMENT OPERATIONS

LIST OF ILLUSTRATIONS

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LIST OF SYMBOLS

Symbol	Definition
C_D	drag coefficient
D	Aerodynamic drag
f	Dependent parameters in Newton's divided difference formula
F	Force
g	Acceleration of gravity at a planetary surface
L	Aerodynamic lift
m	mass
r	radius from center of planet
S	Aerodynamic Reference area
t	time
V	velocity
x	Independent parameter in Newton's divided difference formula (equations 7-10).
x, y	position of vehicle, rectangular co-ordinates (see equations 3 and 4)
γ	Relative path angle
ρ	atmosphere density
θ	range angle

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SUMMARY

The following conclusions and recommendations were developed:

1. An Apollo-shape entry and landing vehicle provides a reasonable solution to the problems of aerodynamic braking at Mars.

2. Entry and landing on Mars should be accomplished by aerodynamic braking with modest lift, followed by rocket braking. The mass penalty for rocket braking is not great and this represents a much more conservative approach than any attempts to use supersonic parachutes or similar devices.

3. Entry should be made from a Mars orbit. Whereas a satisfactory entry from parabolic or higher-energy conditions is theoretically feasible, the entry corridor is very small and this entry mode would lead to undue risks.

4. Fully loaded system mass for a 4-man lander with ascent vehicle will be on the order of 50 metric tons.

5. Size of such a lander would probably be larger than the diameter of the Saturn V launch vehicle; a hammer-head configuration would then be necessary to launch the lander to Earth orbit by means of the Saturn V.

6. Performance available from cryogenic propellants is extremely desirable for the ascent stage. Lox methane appears to be an attractive choice as a compromise between performance and cryogenics storage problems.

7. An alternate configuration of the landing vehicle, without the ascent stage, could provide a reasonably effective cargo lander or shelter system for extended Mars exploration.

8. It is recommended that a more detailed design study of this type of vehicle be carried out to confirm the design approach and the rough-order-of-magnitude weights.

9. It is recommended that a study be carried out to ascertain the degree to which Mars entry simulations with this vehicle type could be carried out in an Earth atmosphere environment. This would be desirable to avoid the necessity of an unmanned test at Mars.

10. A simulation study is recommended to ascertain the degree to which a Mars entry and landing of the type discussed herein could be controlled by a human pilot.

SECTION I. INTRODUCTION

A manned landing on Mars will require a special purpose space vehicle designed and developed for this purpose. In a typical mission profile [1], the Mars landing vehicle will be transported to Mars by an interplanetary space vehicle which will deliver the mission from Earth orbit to Mars orbit. The function of the Mars landing vehicle will be (a) to land an exploration crew on the planet and at a later time return them to Mars orbit for rendezvous with the interplanetary vehicle, or (b) to deliver exploratory cargo to the Mars surface, with no provision for reascent to Mars orbit. Its function therefore is quite analogous to the lunar excursion module being developed for the Apollo program. However, orbital velocities at Mars are substantially higher than at the moon, such that a Mars excursion module designed for entirely propulsive braking and landing would be very large and heavy. Mars, however, unlike the Moon, has enough atmosphere to provide some atmospheric braking.

Earlier studies of manned Mars landing vehicles were generally based on a nominal Mars atmosphere model assuming roughly 25 millibars of pressure at Mars surface and a scale height of 20 kilometers or more. With this atmosphere model, it appeared feasible to fly a lifting entry which would bring the landing vehicle to a subsonic flight velocity at a nominal distance from Mars surface. At this point parachutes were to be deployed for final letdown, with a very modest provision for terminal rocket braking to reduce the impact velocity.

In July of 1965, the Mariner 4 spacecraft executed a flyby of Mars during which an occultation experiment was performed. As viewed from the Earth, the spacecraft flew behind the planet and its radio signal was occulted by the atmosphere, and then by the planet itself. Measurements made during this occultation provided new and more accurate information on the structure of Mars' atmosphere. This experiment indicated the surface pressure to be only about 6 millibars and the scale height to be only 8 kilometers. This new information has made it desirable to take another look at the requirements and characteristics of a manned Mars landing vehicle, to establish, first, how much aerodynamic braking might be feasible with this thin atmosphere, secondly, do parachutes appear feasible (and if not, how can aerodynamic braking be phased into rocket braking for a landing), and thirdly, a rough estimate of the total mass of such a Mars landing vehicle. These results are needed for analyses of overall mission profiles for manned Mars exploratory missions.

The purpose of this report is to record results of a preliminary investigation into these matters.

SECTION II. SELECTION OF ATMOSPHERE MODEL

The Mariner IV occultation experiment provided both the motivation for the investigation described in this report and the atmosphere model which was used. The Mariner IV experiment was performed by observing the fade-out of radio signals from the Mariner IV space probe as it passed behind the planet Mars [2]. This radio signal was phase-locked with a ground transmitter and receiver. Consequently it was possible to observe, as well as fade-out in intensity, the total relative phase shift of the signal passing through the atmosphere as it faded out. Based on plausible assumptions of the constituents of the Mars atmosphere, it was then possible from these data to determine the density scale height of the atmosphere as well as the atmosphere density at the surface at the instant of final fade-out, when the solid body of the planet became interposed between the transmitter and receiver. Atmosphere models could then be constructed, based on this density scale height and again assumptions regarding the constituency of the Mars atmosphere.

The measured scale height was small compared to what had been expected: i.e. about 8 kilometers. With the strength of Mars' gravity field, this requires assumption of an atmosphere which is both very cold and of relatively high molecular weight. The atmosphere used in this study was based on a value of indicated surface density from the Mariner measurements, 0.019 kilograms per cubic meter, and on an assumed mean molecular weight of 40 for the atmosphere. Mean atmospheric temperature could then be calculated from the measured scale height, the assumed molecular weight and the known surface gravity strength. Whereas later work with the Mariner IV data may provide improved knowledge of the atmosphere structure, very little was available to the writer at the time of conduct of this study. Consequently some speculation was employed and it was assumed that above approximately 30 kilometers altitude, the atmosphere temperature increased due to heating by the solar wind. In fact, structure of the upper atmosphere has relatively little effect on the analysis since the bulk of the braking as well as the terminal velocity occur in the atmosphere below 50 km.

Surface pressure of the atmosphere model used was calculated to be 5.69 millibars. A tabulation of the atmosphere model is given in Table 1. Values for the atmosphere above 100 kilometers are extremely speculative; they have essentially no effect on the entry simulation; but it was necessary to provide atmosphere data for the table-lookup computer routine over the range of flight altitudes to be investigated. Consequently, the atmosphere table was extended to 1000 kilometers altitude.

Since the analysis was conducted, there have come to the writer's attention several atmosphere models proposed by JPL based on the Mariner IV measurements [3]. Density versus geometric altitude for two of these models, as well as for the model used in this study, are shown in Figure 1.

TABLE 1. ATMOSPHERE MODEL

Altitude, Meters	Density, KG/Cu. Meter	Temperature, Deg. K	Speed of Sound, Meters/Second
0.0	1.9×10^{-2}	143	196
5.0×10^{3}	1.02×10^{-2}	143	196
1.0×10^{4}	2.92×10^{-3}	143	196
2.0×10^{4}	8.37×10^{-4}	143	196
3.0×10^{4}	2.4×10^{-4}	143	196
4.0×10^{4}	6.86×10^{-5}	143	196
5.0×10^{4}	2.26×10^{-5}	161	208
7.5×10^{4}	2.33×10^{-6}	197	230
1.0×10^{5}	4.4×10^{-7}	268	269
1.5×10^{5}	3.61×10^{-8}	358	310
2.0×10^{5}	2.96×10^{-9}	358	310
3.0×10^{5}	1.98×10^{-11}	358	310
4.0×10^{5}	1.32×10^{-13}	358	310
5.0×10^{5}	6.78×10^{-16}	358	310
6.0×10^{5}	3.14×10^{-17}	540	310
7.0×10^{5}	2.26×10^{-18}	715	310
8.0×10^{5}	3.53×10^{-19}	890	310
9.0×10^{5}	8.33×10^{-20}	1250	310
1.0×10^{6}	3.06×10^{-20}	1800	310
1.1×10^{6}	1.13×10^{-20}	1800	310
1.2×10^{6}	3.71×10^{-21}	1800	310
1.3×10^{6}	1.35×10^{-21}	1800	310

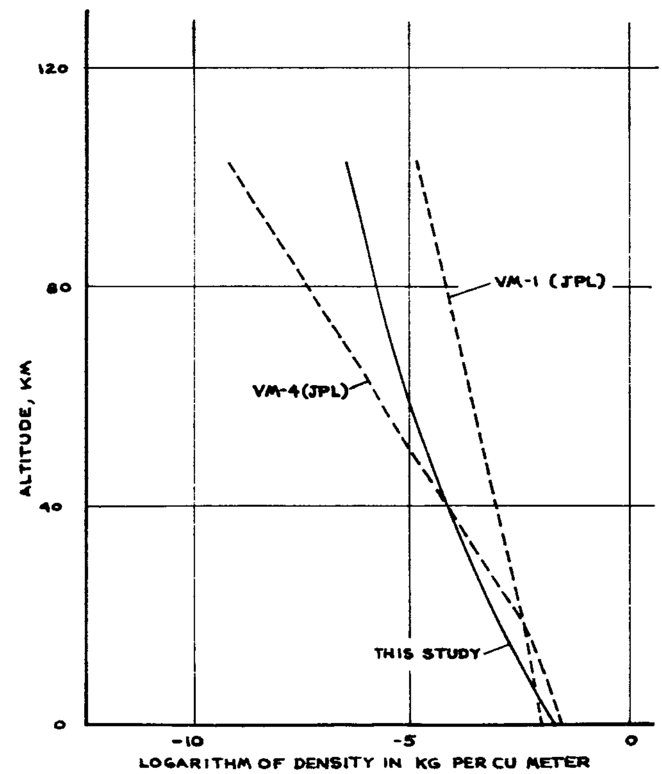


FIGURE 1. MARS ATMOSPHERE MODELS

SECTION III. CONFIGURATION CONSIDERATION

Early designs of Mars landing vehicles [4] were based on an assumed Mars atmosphere with a surface pressure of roughly 85 milibars and a scale height of roughly 15 kilometers. In the early 1950's very little work had been done on entry physics or on the various blunted ballistic and lifting shapes which are now common knowledge. Consequently these early designs were winged gliders which were assumed to land horizontally like aircraft. A later concept, [5] investigated in some detail under a NASA contract, employed a lifting body shape similar to the M-2 shape but was also based on an atmosphere model more dense than that derived from the Mariner IV experiment; a surface pressure of roughly 25 milibars was assumed as a lower limit. The terminal glide was subsonic and parachutes were deployed to accomplish the final letdown. These parachutes rotated the vehicle in pitch attitude so that it landed tail first, using retro rockets for final braking. The ascent stage was contained within the lander such that with the vehicle vertically positioned, the ascent stage was ready for launch.

Entry simulations (to be discussed in the following sections), based on a nominal Mariner IV atmosphere model with 6 millibars surface pressure and on reasonable weights and dimensions for a manned Mars excursion vehicle, indicate that the terminal glide is supersonic; consequently parachute braking appears questionable. A conservative design approach would therefore require that all terminal braking be accomplished by retro rockets. With rocket braking, if a lifting body shape of the type described were to be used, two alternatives present themselves:

a. Use the retro rocket system to perform deceleration to zero relative velocity and then perform a final vertical descent to landing in a horizontal attitude, or,

b. A pitch maneuver to turn the vehicle tail first, combined with deceleration, in order to make a tail first landing.

The first alternative would require either an unusual ascent stage configuration, or erection of the ascent stage after landing, in order to be prepared for launch. The second alternative requires maneuvering as well as presuambly multiple rocket thrust chamber arrangements, which in the writer's opinion are undesirable under the circumstances of a first manned landing on Mars.

For this reason it was deemed desirable to investigate alternate vehicle shapes to accomplish the landing. A semi-ballistic shape similar to the Apollo command module was chosen for investigation. If such a shape could provide suitable aerodynamic braking, it would appear to have several advantages:

a. General aerodynamic characteristics well understood for an Earth-type atmosphere, and, because of the simple geometry, readily obtainable for other atmospheric characteristics.

b. Relatively high volumetric efficiency.

c. Assuming a landing with the blunt end downward, a relatively low center of gravity and wide footprint.

d. Geometry amenable to a relatively simple arrangement of deceleration and letdown thrust chambers, also not requiring unusual maneuvering to attain a landing attitude.

e. Geometry amenable to packaging of an ascent stage with conventional configuration.

The choice of an Apollo shape then appeared appropriate, provided that a lift to drag ratio on the order of 0.4 would be sufficient for accomplishing aerodynamic entry and deceleration.

SECTION IV. MARS ENTRY SIMULATION: METHOD OF ANALYSIS

The key to definition of this initial concept was mathematical simulation of Mars entry trajectories to establish (a) how much aerodynamic braking could be obtained from the Mars atmosphere, and (b) how much aerodynamic lift is needed to make the most of aerodynamic braking. The latter question is, of course, pertinent to the choice of configuration for the lander.

The model chosen for the simulations was two-dimensional, with a non rotating planet but including variation of gravity force with altitude. The previously-described atmosphere model was employed. Gravity, lift, and drag were the only forces assumed acting on the vehicle, with the resulting force equations in polar co-ordinates:

$$F_r = L \cos \gamma - D \sin \gamma - m\, g_{\mars} \left(\frac{r_{\mars}}{r}\right)^2 \tag{1}$$

$$F_\theta = - L \sin \gamma - D \cos \gamma \tag{2}$$

L/D and C_D were fixed at initial values for each case, a reasonable assumption since subsonic speeds did not occur.

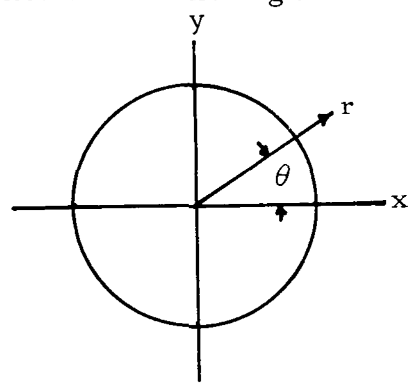
These were converted to rectangular co-ordinates for integration according to the standard convention sketched at the right: therefore,

$$x = r \cos \theta \tag{3}$$

$$y = r \sin \theta \tag{4}$$

$$F_x = F_r \cos \theta - F_\theta \sin \theta \tag{5}$$

$$F_y = F_r \sin \theta + F_\theta \cos \theta \tag{6}$$



Integration was carried out by Newton's divided difference formula [6], third order.* This amounts to fitting a cubic polynomial to four successive points of the parameter to be integrated, and then integrating the polynomial approximation.

Newton's Divided Difference Equation for interpolation to third order is given by:

$$f(x) = f(x_0) + (x-x_0)\, f(x_0, x_1) + (x-x_0)(x-x_1)\, f(x_0, x_1, x_2)$$

$$+ (x-x_0)(x-x_1)(x-x_2)\, f(x_0, x_1, x_2, x_3) \tag{7}$$

where: $f(x_0, x_1, x_2, x_3) = \left[f(x_0, x_1, x_2) - f(x_1, x_2, x_3)\right] / (x_0 - x_3)$ (8)

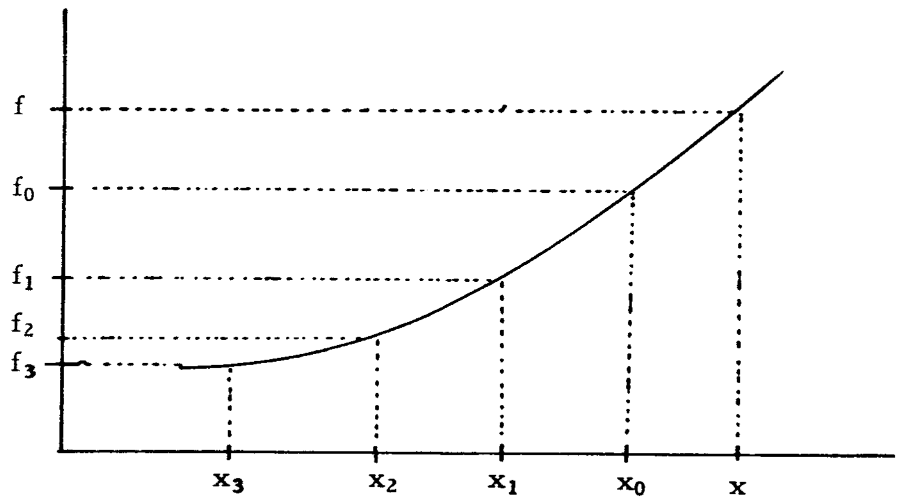
---

*One should not assume that a higher order is automatically better. In the simulations conducted here, parameters to be integrated varied slowly and smoothly with time, and third order was quite satisfactory. Third order fits can be, however, intractable (worse than first order), for example, for parameters which tend to vary stepwise.

$$f(x_0, x_1, x_2) = [f(x_0, x_1) - f(x_1, x_2)]/(x_0 - x_2) \tag{9}$$

$$f(x_0, x_1) = [f(x_0) - f(x_1)]/(x_0 - x_1) \tag{10}$$

Where parameters are as sketched below.



Integration were, in essence:

$$V_x = V_{xa} + \int_a^b F_{x/m}\, dt \tag{11}$$

$$V_y = V_{ya} + \int_a^b F_{y/m}\, dt \tag{12}$$

$$x = x_a + \int_a^b V_x\, dt \tag{13}$$

$$y = y_a + \int_a^b V_y\, dt \tag{14}$$

Conversion back to polar co-ordinates was then made:

$$\theta = \tan^{-1} y/x \tag{15}$$

$$V_\theta = V_y \cos\theta - V_x \sin\theta \tag{16}$$

$$V_r = V_x \cos\theta + V_y \sin\theta \tag{17}$$

$$r = (x^2 + y^2)^{\frac{1}{2}} \tag{18}$$

$$V = (V_x{}^2 + V_y{}^2)^{\frac{1}{2}} \tag{19}$$

$$\gamma = \tan^{-1} V_r/V_\theta \tag{20}$$

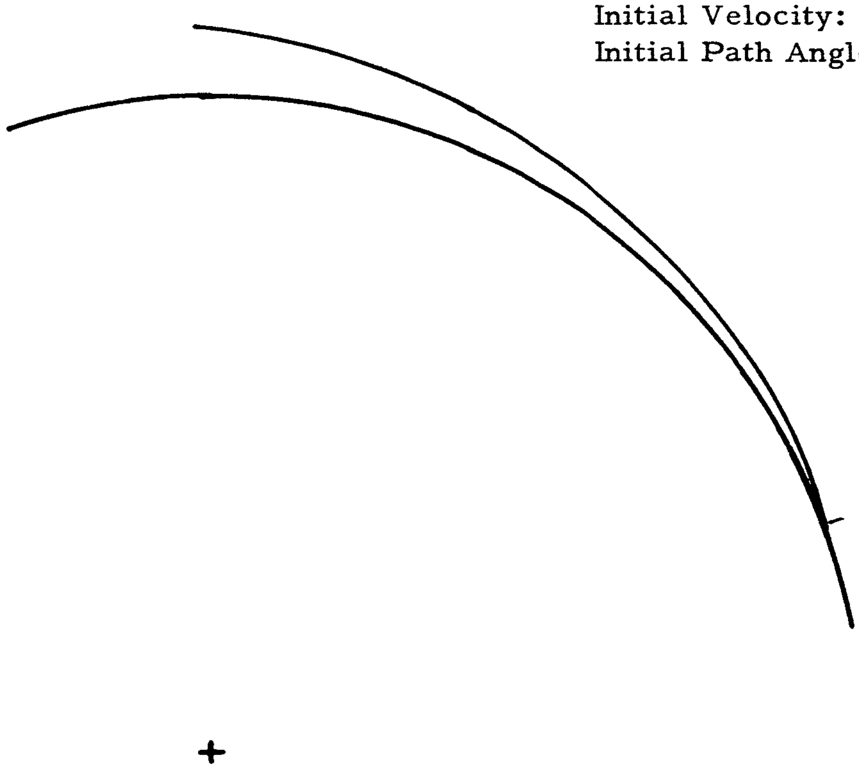
Interpolation of the atmosphere table also employed the third-order Newton's divided difference method. Density was put in logarithmic form prior to interpolation; i.e. $q_i = \ln \rho_i$. The interpolated result was then converted back to density, and drag found from $D = C_D S \rho V^2/2$.

Computations were performed by a simple Fortran IV digital program for the IBM 7094. Initial conditions of altitude, velocity, path angle, mass, drag coefficient, L/D etc. were entered and the program performed the integrations either (a) 10,000 times, or (b) until zero altitude was reached. The usual time interval of integration was 1 second; this was switched by the program to a smaller value, usually 0.2 seconds, when drag exceeded 1 percent of the weight of the vehicle. Accuracy of the integration routine was checked by simulating an elliptical descent from a circular orbit at 1000-km altitude. About 1/3 of an orbit was covered before drag became appreciable. Such a path, of course, has a readily obtained closed form solution, which was used as a check. After 1/3 of an orbit, altitude error was less than 3 km, and velocity error less than 1 m/sec; this was deemed adequate for the purposes at hand.

SECTION V. RESULTS OF SIMULATIONS

The principal simulation effort was devoted to simulation of very shallow entries from Mars orbit at a 1000-kilometer orbit altitude. A Mars mission based on high-thrust interplanetary propulsion would presumably enter into such an orbit prior to descent of the Mars surface excursion vehicle. Some effort also was expended on simulation of entries from parabolic conditions. The entry-from-orbit simulations had two principal objectives; first, to determine what lift-to-drag ratio range would be required to realize effective use of the atmosphere for aerodynamic braking, and second, to obtain an estimate of the speed at which it would be necessary to switch to retro rocket braking. Initial efforts carried the simulation from 1000-kilometer altitude, immediately following the entry retro impulse, to Mars surface, with no lift; i.e. ballistic entry. Examination of this simulation allowed choice of a starting point for subsequent runs which was just prior to first noticeable effects of the atmosphere; this served to reduce computer run time. Simulations were run for a constant drag coefficient of 0.9 and lift-to-drag ratios ranging from 0 to 0.4. Other vehicle characteristics were as tabulated on Figure 3. Following this, simulations were run for varying entry angles, to determine the sensitivity of terminal conditions to the entry angle.

Initial Altitude: 343.4 km
Initial Velocity: 3461 m/sec.
Initial Path Angle: -0.12 radians



Entry Path Shown to Scale
(1 inch = 1000 km)

FIGURE 2. RESULTS OF MARS ENTRY SIMULATION
NON-LIFTING ENTRY

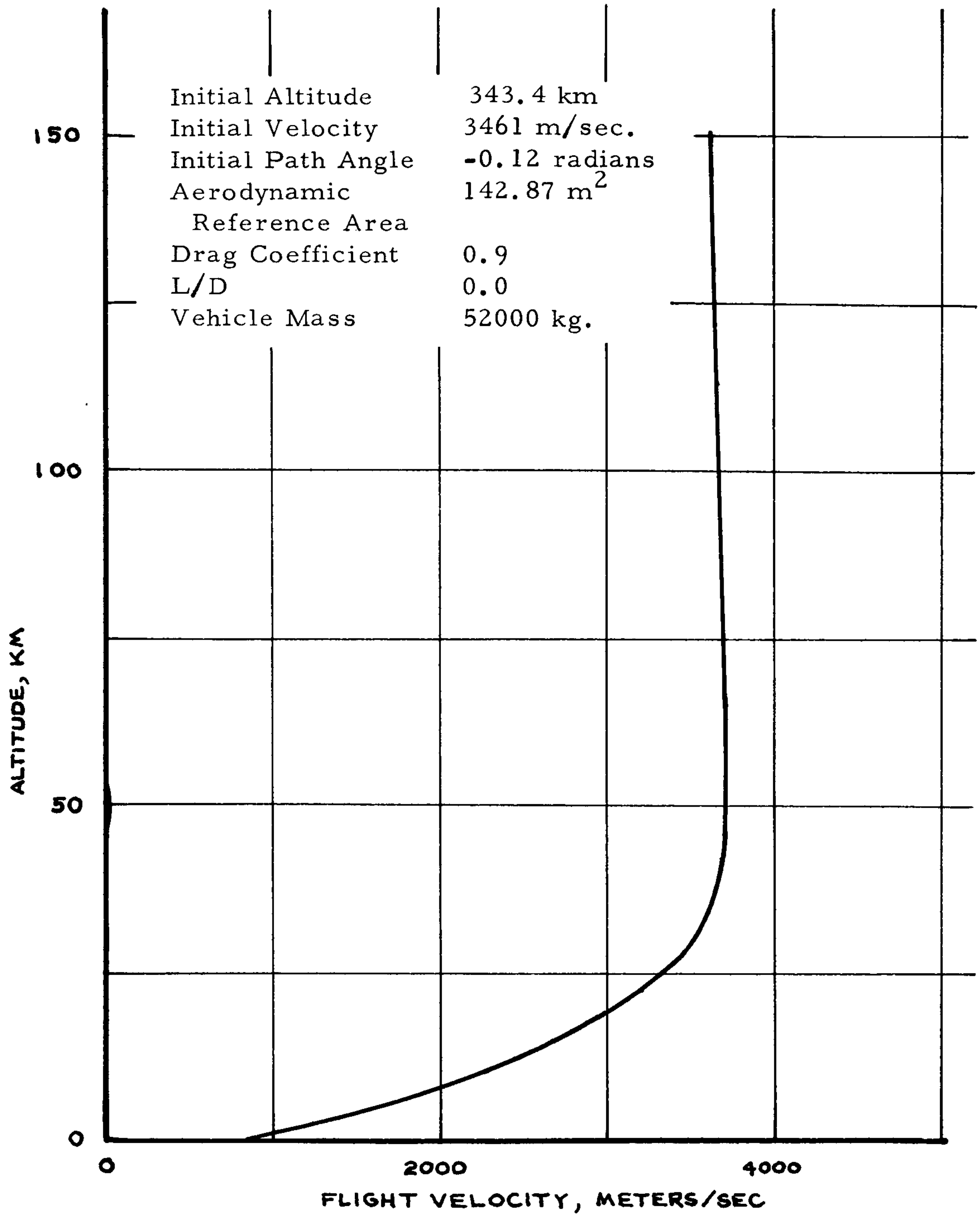


FIGURE 3. RESULTS OF MARS ENTRY SIMULATION NON-LIFTING ENTRY

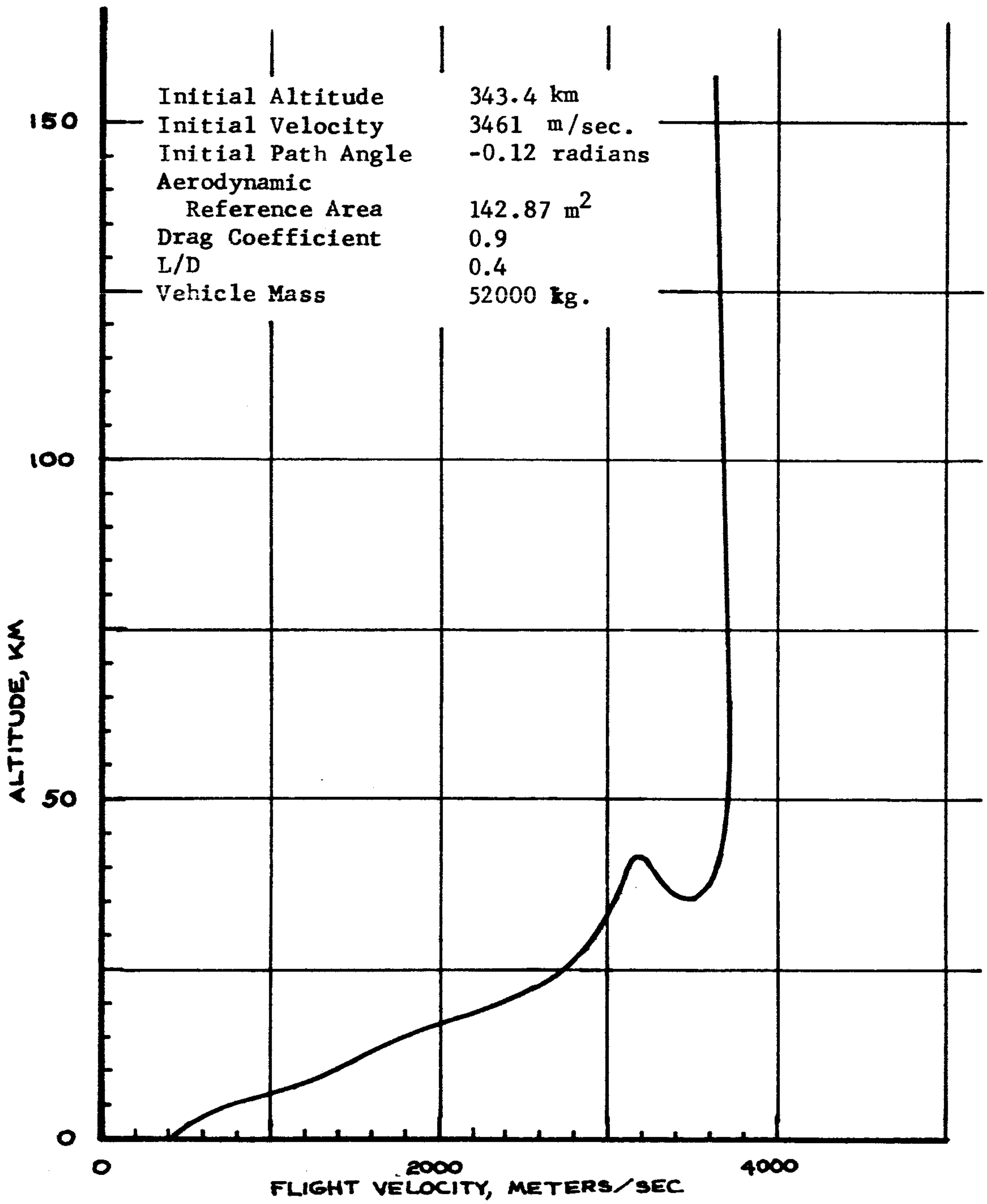


FIGURE 4. RESULTS OF MARS ENTRY SIMULATION
LIFTING ENTRY

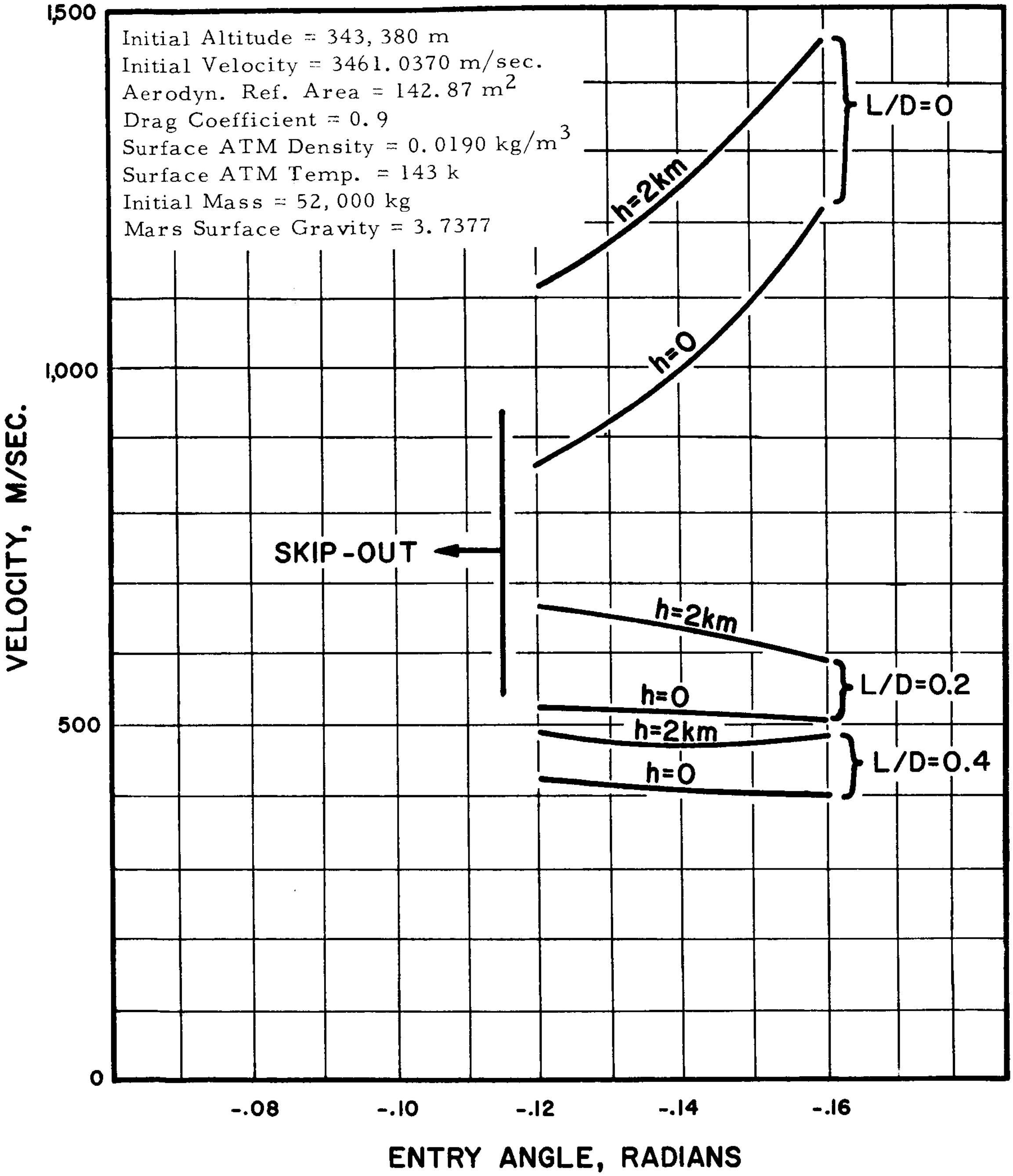


FIGURE 5. RESULTS OF MARS ENTRY SIMULATIONS

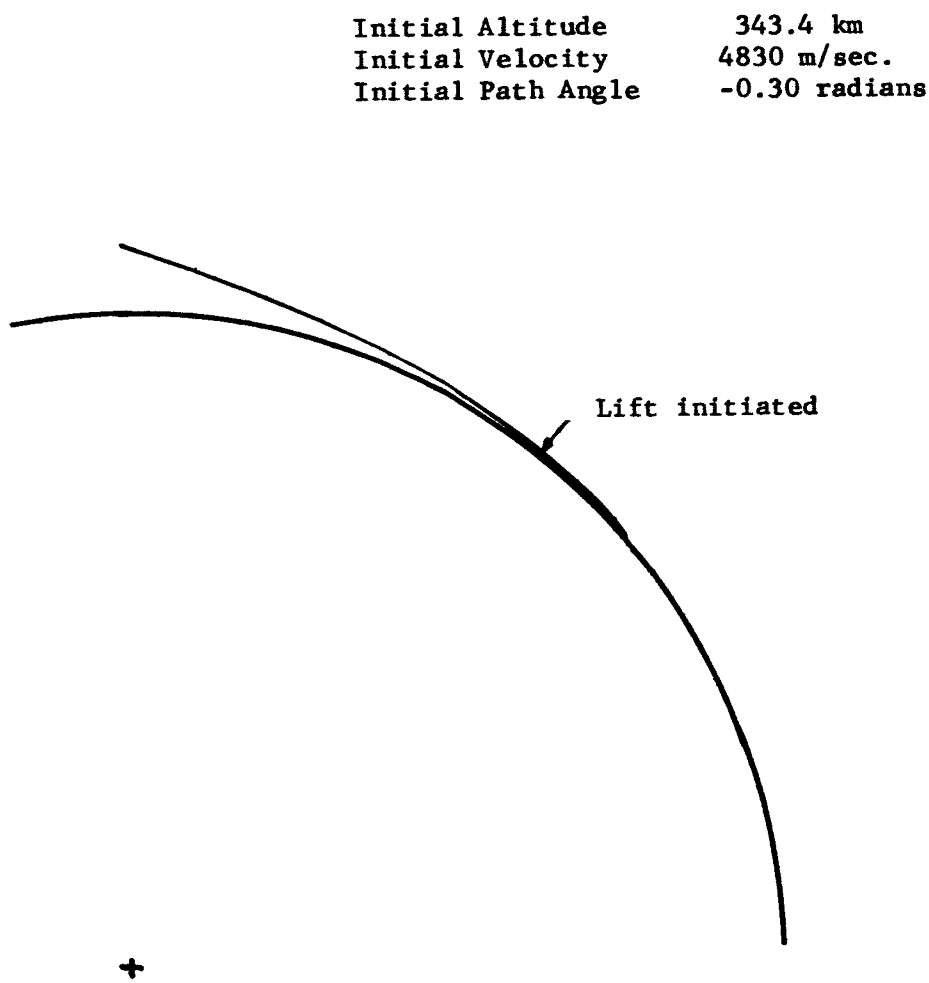


FIGURE 6. RESULTS OF MARS ENTRY SIMULATION: PARABOLIC LIFT-MODULATED ENTRY

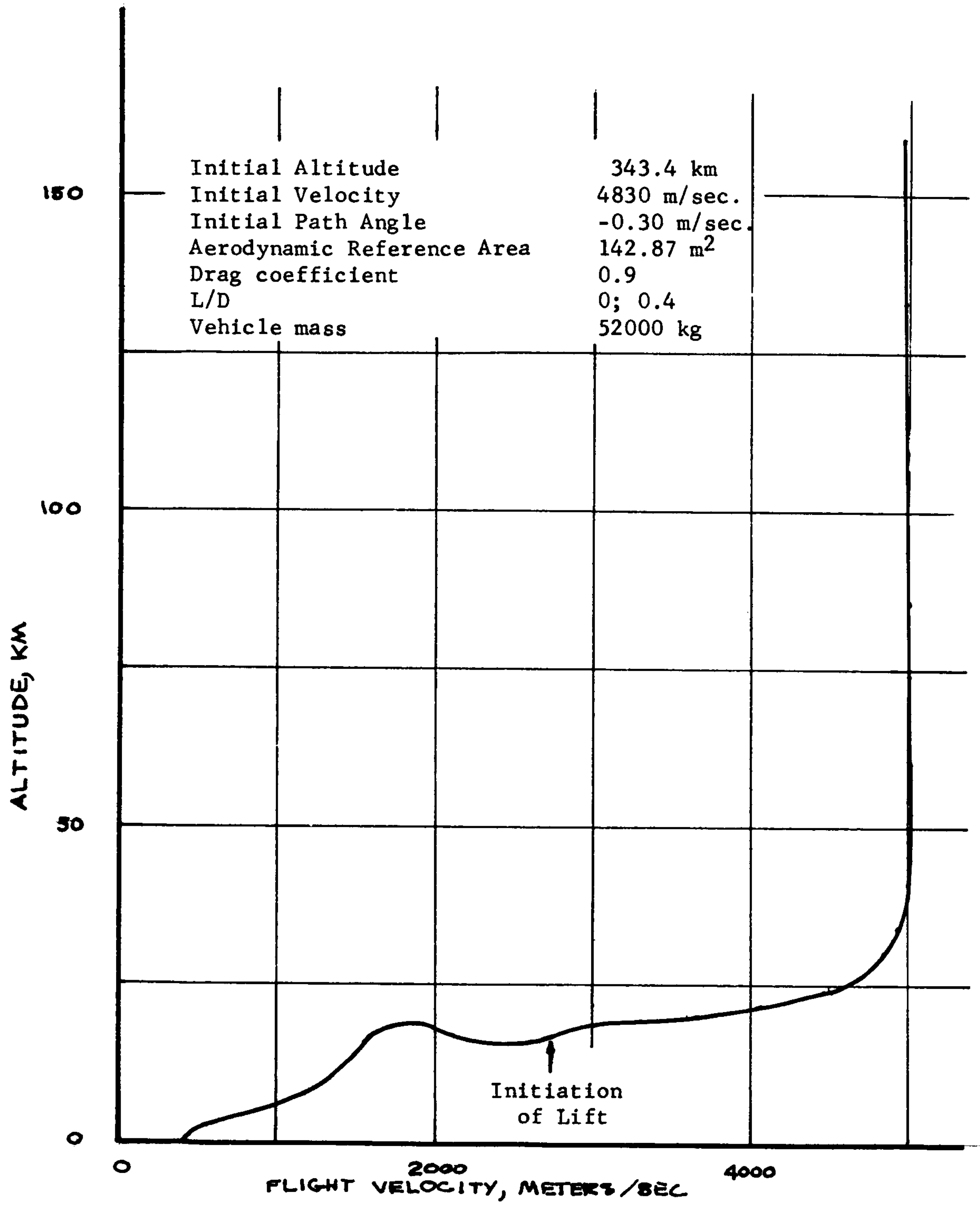


FIGURE 7. RESULTS OF MARS ENTRY SIMULATION: PARABOLIC ENTRY WITH LIFT MODULATION

Principal results of the simulations are shown on Figures 2 through 7. Figures 2 and 3 show real space and phase space plots of the ballistic entry from orbit. Figure 4 shows a phase space plot of a 0.4 L/D entry. Figure 5 illustrates the effect of entry angle on terminal conditions for three representative lift-to-drag ratios. Figures 6 and 7 show real space and phase space plots of the simulated parabolic entry. This entry takes place at zero lift-to-drag ratio until velocity is slowed down to 2.7 kilometers per second, at which point lift is modulated to 0.4 lift-to-drag ratio until terminal conditions. Other simulation attempts from parabolic conditions indicated that the entry corridor for these conditions is very narrow; probably only a few kilometers in height. The nature of the rudimentry simulation technique utilized was such that an accurate estimate of the corridor height could not be obtained. An example of an entry simulation is given in the appendix.

The following principal conclusions were drawn from this analysis:

1. A lift-to-drag ratio on the order of 0.4, such as available with Apollo shapes, is adequate to provide effective braking for Mars entry from an orbit.

2. Terminal conditions for the vehicle analyzed were such that 500 meters per second could be considered a reasonable velocity at which to initiate retro rocket braking.

3. Terminal conditions were supersonic, about Mach 2, thus making very questionable the feasibility of utilizing parachutes or similar devices for aerodynamic braking.

4. Modest lift-to-drag ratios are very effective in reducing the sensitivity of terminal conditions to entry angle.

5. The entry corridor for entry from parabolic conditions is very narrow and would require sophisticated guidance techniques. This conclusion would be even more true for the case of utilization of Mars' atmosphere for arrival braking from hyperbolic conditions.

Based on these simulations and the resulting conclusions, an Apollo-shape entry vehicle was selected for this initial concept investigation.

SECTION VI. ASCENT VEHICLE

The ascent stage of the Mars lander was required to fly from Mars' surface to a 1000-km altitude orbit, carrying a crew of four astronauts. A velocity budget for this maneuver was assigned as given in Table 2 below:

TABLE 2. MARS ASCENT VELOCITY BUDGET

Element	V, km/sec.
Impulsive requirement	3.9
Drag loss	0.1
Rotational gain	-0.1
Gravity loss	0.6
Rendezvous	0.1
Launch window	0.1
Plane change	0.15
Flight performance reserve	0.15
Total	5.0

Payload was assumed to consist of the following elements:

1.	Crew of four	400 kg.
2.	Ascent cabin pressure vessel and forward skirt structure	1000 kg.
3.	Airlock and access hatch	100 kg.
4.	Environmental control and life support system	600 kg.
5.	Communications	100 kg.
6.	Guidance and equipment navigation	100 kg.
7.	Scientific payload	400 kg.
	(TOTAL)	2700 kg.

The propulsion system was assumed to employ liquid oxygen and methane as propellants. This choice was viewed as an acceptable compromise between the desire for high performance and the desire to avoid severe problems with cryogenic storage. Since liquid oxygen and methane have overlapping liquid ranges, a single thermal insulation envelope could be employed with an uninsulated common bulkhead between the propellants.

Engines were assumed to be RL-10's with a 60:1 area ratio, modified for lox-methane operation. Three engines were employed to provide engine-out capability. Predicted Isp was 356 sec (3500 m/sec effective exhaust velocity). Each engine was assumed to deliver 67,000 newtons of thrust, providing 134,000 newtons with two engines operating.

Table 3 gives a rough-order-of-magnitude weight breakdown for the vehicle.

TABLE 3. WEIGHT BREAKDOWN

Engines (3)	600 kg.
Tankage	900 kg.
Insulation	400 kg.
Pressurization system	400 kg.
Feed system	100 kg.
Thrust structure	300 kg.
Aft skirt	200 kg.
Astrionics	100 kg.
Residuals	400 kg.
(payload)	2700 kg.
Cutoff mass	6100 kg.
Impulse Propellant	19300 kg.
Liftoff mass	25400 kg.
Allowance for propellant boiloff	1900 kg.
Landed mass	27300 kg.

Ullage volume of 10 percent was assumed, based on landed propellant mass. Propellant mixture ratio (O/F) was assumed to be 4.16; resulting tank volumes were: 15.7 cubic meters for liquid oxygen and 12.73 cubic meters for methane. A tank internal diameter of 3 meters was selected, resulting in an ascent stage configuration as shown in Figure 8. Detailed design sketches were not developed.

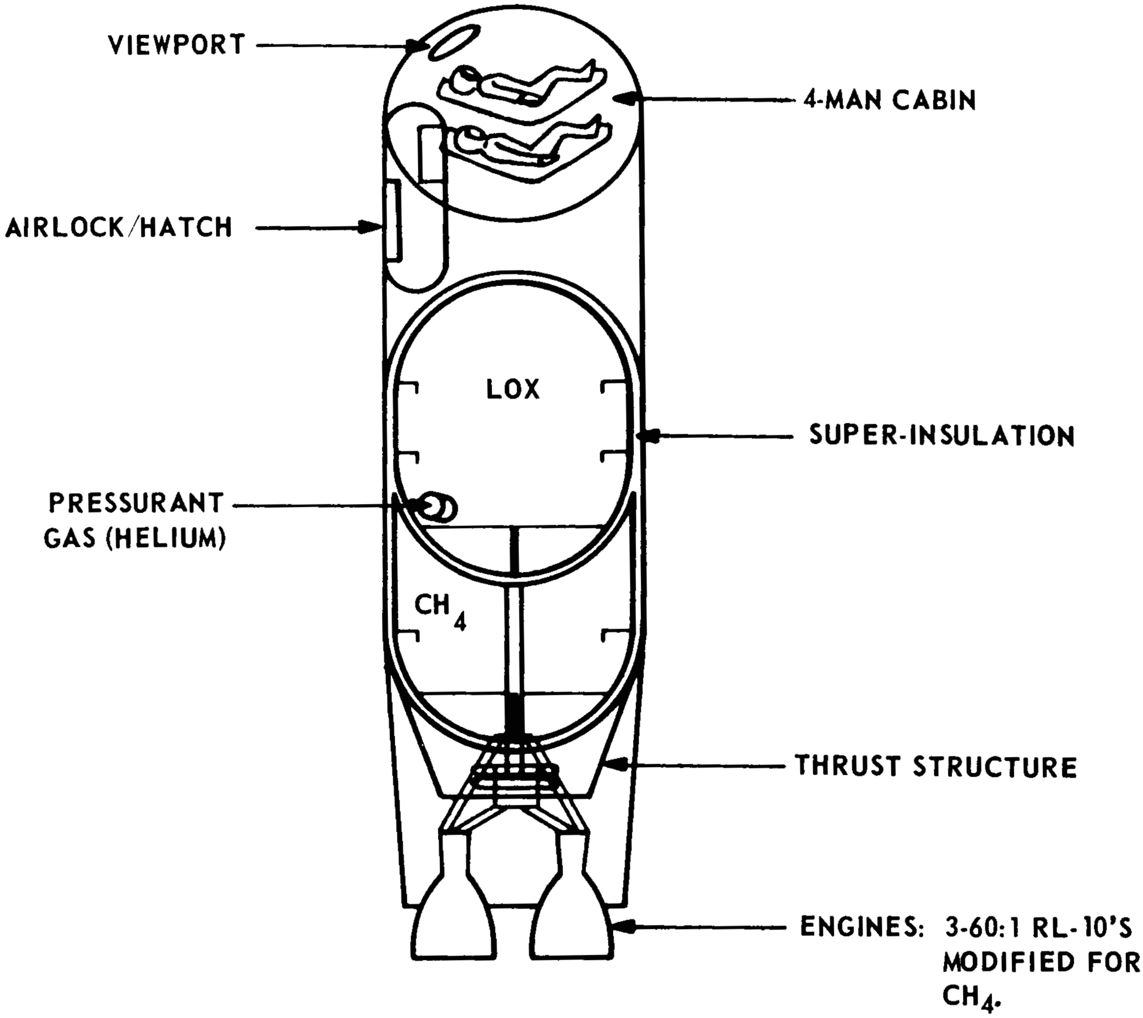


FIGURE 8. MARS EXCURSION VEHICLE ASCENT STAGE

SECTION VII. DESCENT VEHICLE

As previously discussed, an Apollo shape was selected for the descent vehicle. This vehicle is required to protect the ascent vehicle during landing, to provide for its launch when required, and to provide shelter for the four astronauts during a short duration surface stay. In addition, there is the obvious requirement of executing the landing.

Figure 9 shows the general arrangement of the descent vehicle with the ascent stage as its payload, positioned so that it will be ready for launch after the descent stage has landed. Storable propellants were assumed for the landing stage, because the relatively small Δv required did not strongly favor cryogenics, and the tank geometry chosen was not as amenable to super-insulation as were the tanks for the ascent-stage.

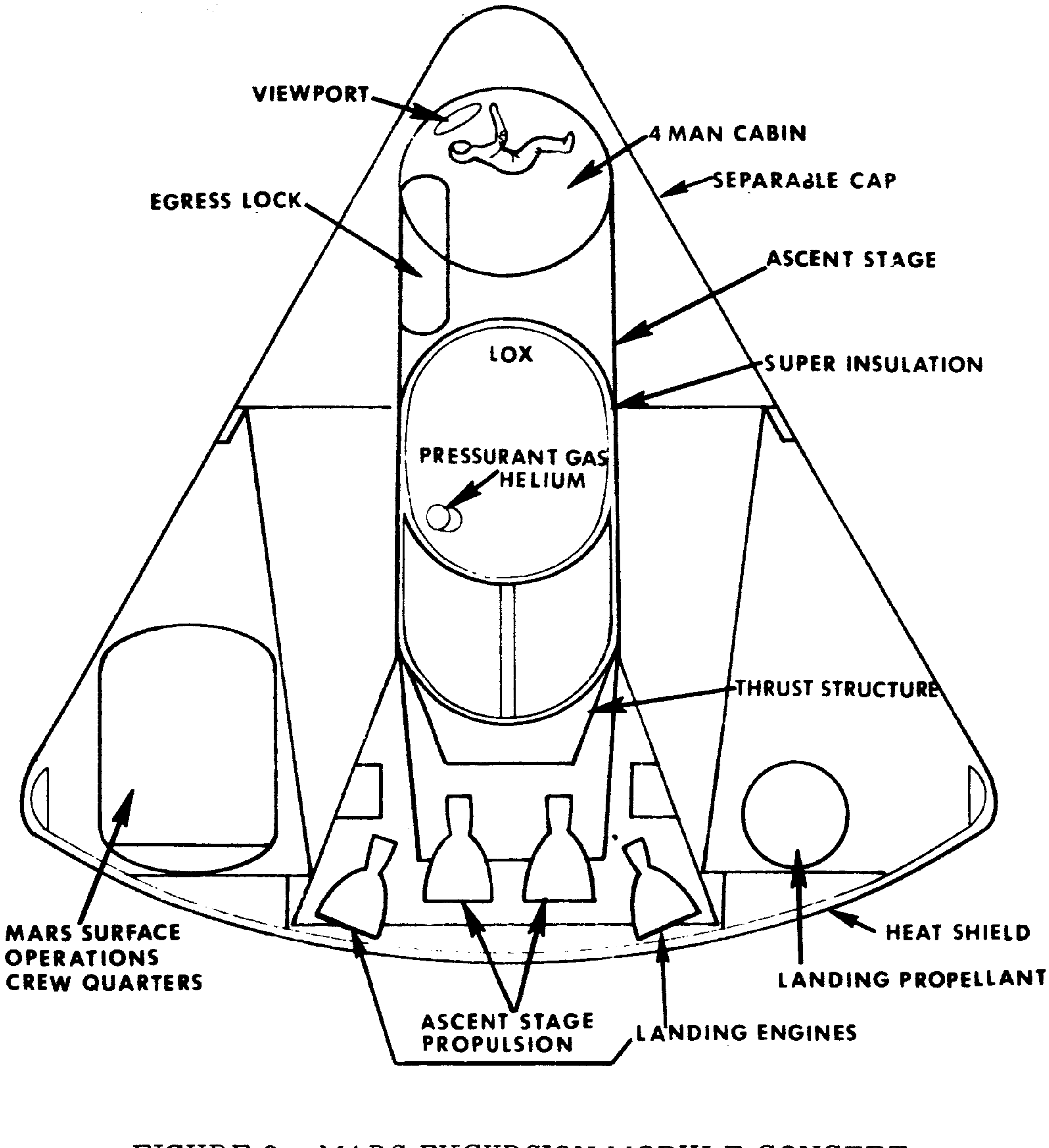


FIGURE 9. MARS EXCURSION MODULE CONCEPT

Configurations for the landing propellant tanks and the surface operations shelter pressure vessel were chosen such that without significant changes in configuration design concept, these elements could be located as required to trim the lander for the desired L/D (presumably 0.4). The surface operations shelter and the propellant tanks were toroidal segments, the tanks being of circular cross section, and the shelter nearly rectangular.

Four landing engines, each of 100,000 newtons thrust, were assumed. Specific impulse was estimated as 320 sec. These estimates lead to a weight statement as given in Table 4.

TABLE 4. WEIGHT BREAKDOWN FOR LANDING VEHICLE

Landed payload (ascent vehicle)		27,300 kg.
Outer conical shell		3,000 kg.
Internal Structure		4,800 kg.
Crew cabin, including airlock		1,000 kg.
Life Support and environmental control		840 kg.
Heat shield skin and insulation		1,600 kg.
Ablator		4,000 kg.
Reaction control system		500 kg.
Landing engines		800 kg.
Tankage and Feed system		1,200 kg.
Astrionics		100 kg.
Propellant Residuals		300 kg.
	TOTAL INERTS	45,440 kg.
Less ablator and forward shell (dropped at landing engine ignition)		4,500 kg.
LANDED WEIGHT		40,940 kg.
Impulse propellant		10,700 kg.
	TOTAL MASS AT ABLATOR JETTISON	51,640 kg.
Ablator and forward shell		4,500 kg.
	TOTAL ENTRY MASS	56,140 kg.

The landing sequence begins in Mars orbit, where a propulsive impulse is required to initiate entry. The crew are housed in the ascent stage during entry and landing. (Retro rockets were not sized and their weight is not included in any of the weight statements). Figure 10 shows an artists' concept of an early phase of entry. Aerodynamic deceleration continues until the vehicle has slowed to about 500 meters/sec. (Figure 11). Landing engines are ignited; at this time the ablation heat shield and the upper fairing are jettisoned (Figure 12). Final letdown and landing occur under rocket power; 100 seconds of hover time are provided (Figures 13 and 14). During the final descent, with the upper fairing jettisoned, the pilot can see the ground through a window in the ascent stage cabin. Also, in the event an abort is necessary, the ascent stages can be ignited and flown back to Mars orbit. Upon landing, the crew leaves the ascent vehicle to live in the surface operations shelter. When surface operations are complete, the crew return to the ascent stage and depart for Mars orbit (Figure 15).

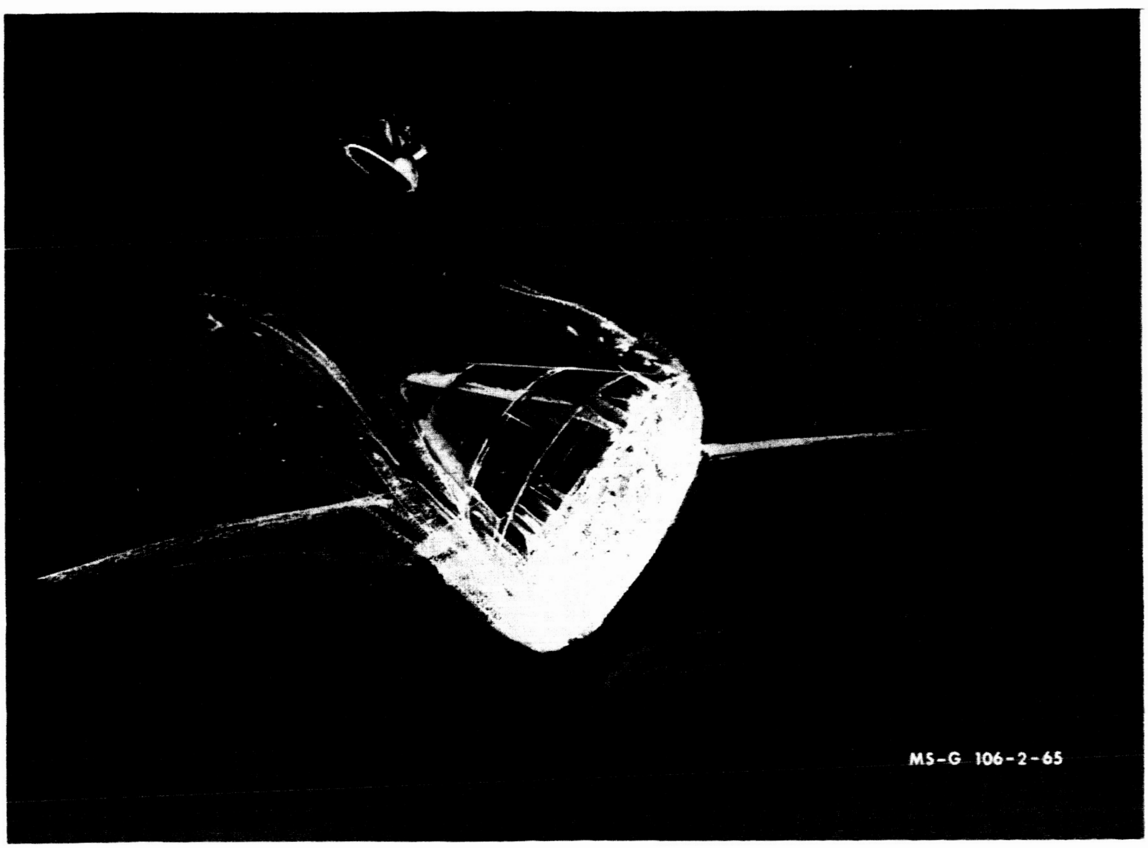


FIGURE 10. MARS EXCURSION MODULE LANDING SEQUENCE: ARTIST'S CONCEPT

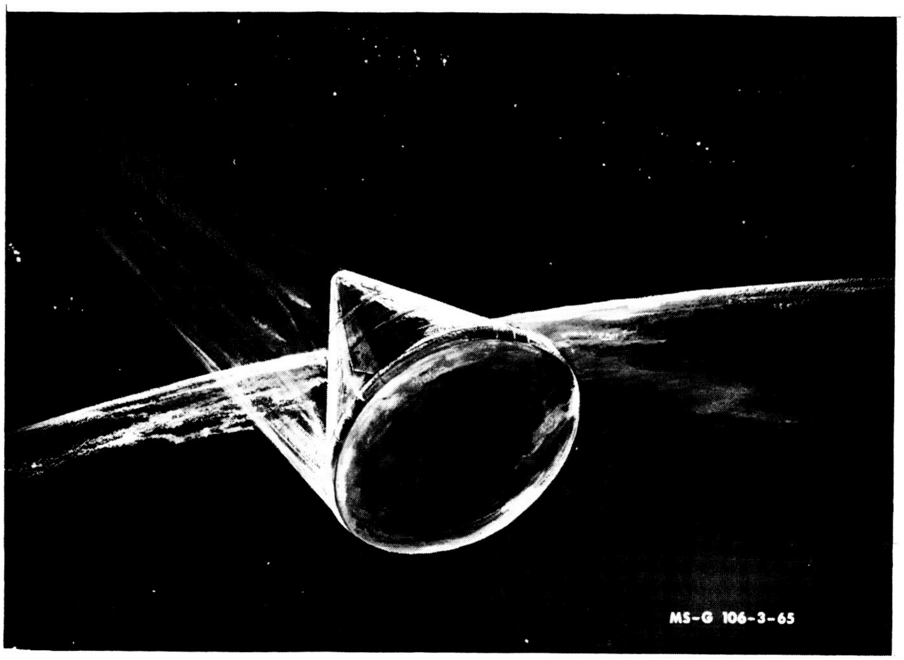


FIGURE 11. MARS EXCURSION MODULE LANDING SEQUENCE: ARTIST'S CONCEPT

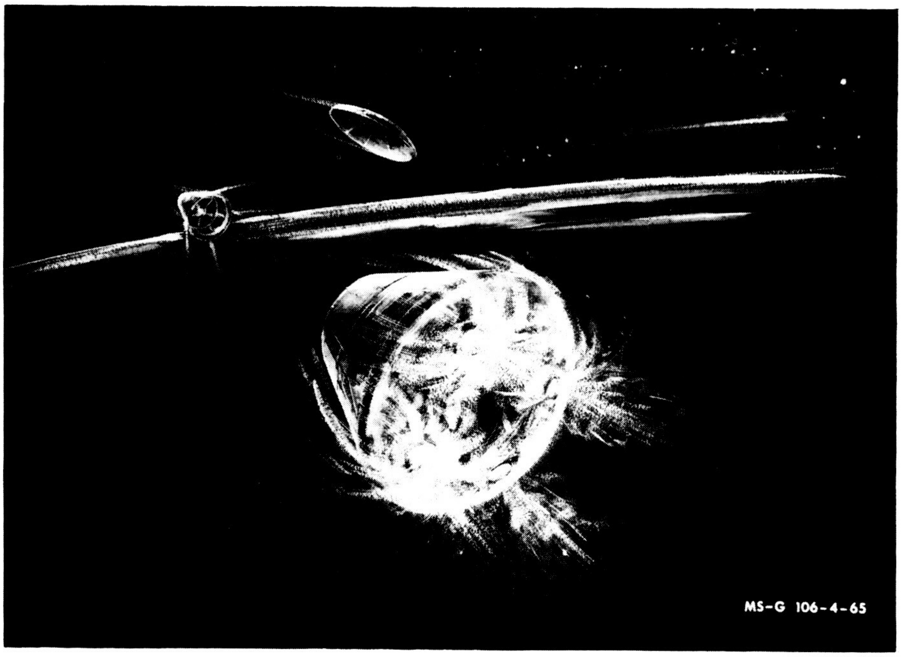


FIGURE 12. MARS EXCURSION MODULE LANDING SEQUENCE: ARTIST'S CONCEPT

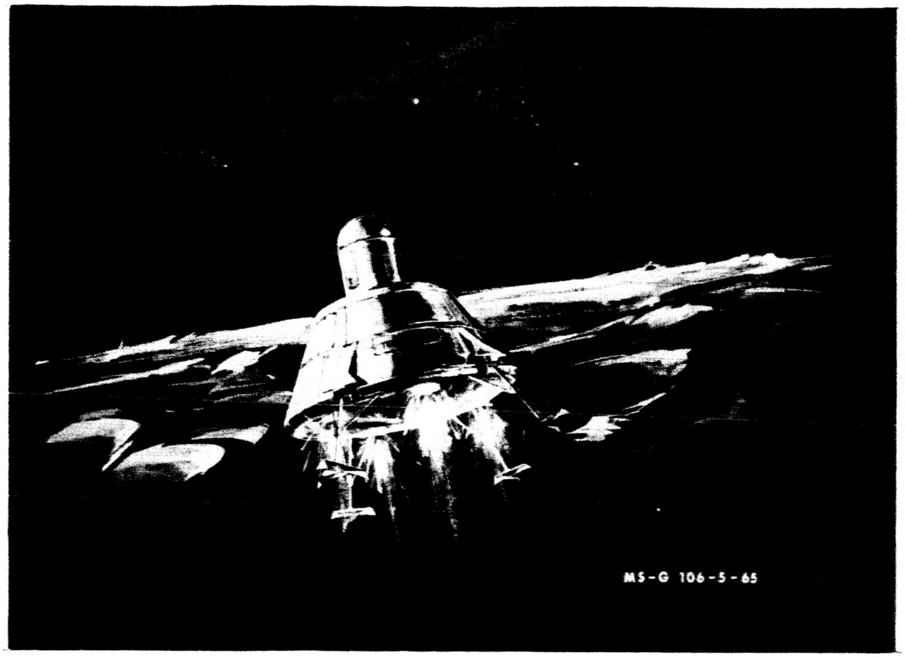


FIGURE 13. MARS EXCURSION MODULE LANDING SEQUENCE: ARTIST'S CONCEPT

FIGURE 14. MARS EXCURSION MODULE LANDING SEQUENCE: ARTIST'S CONCEPT

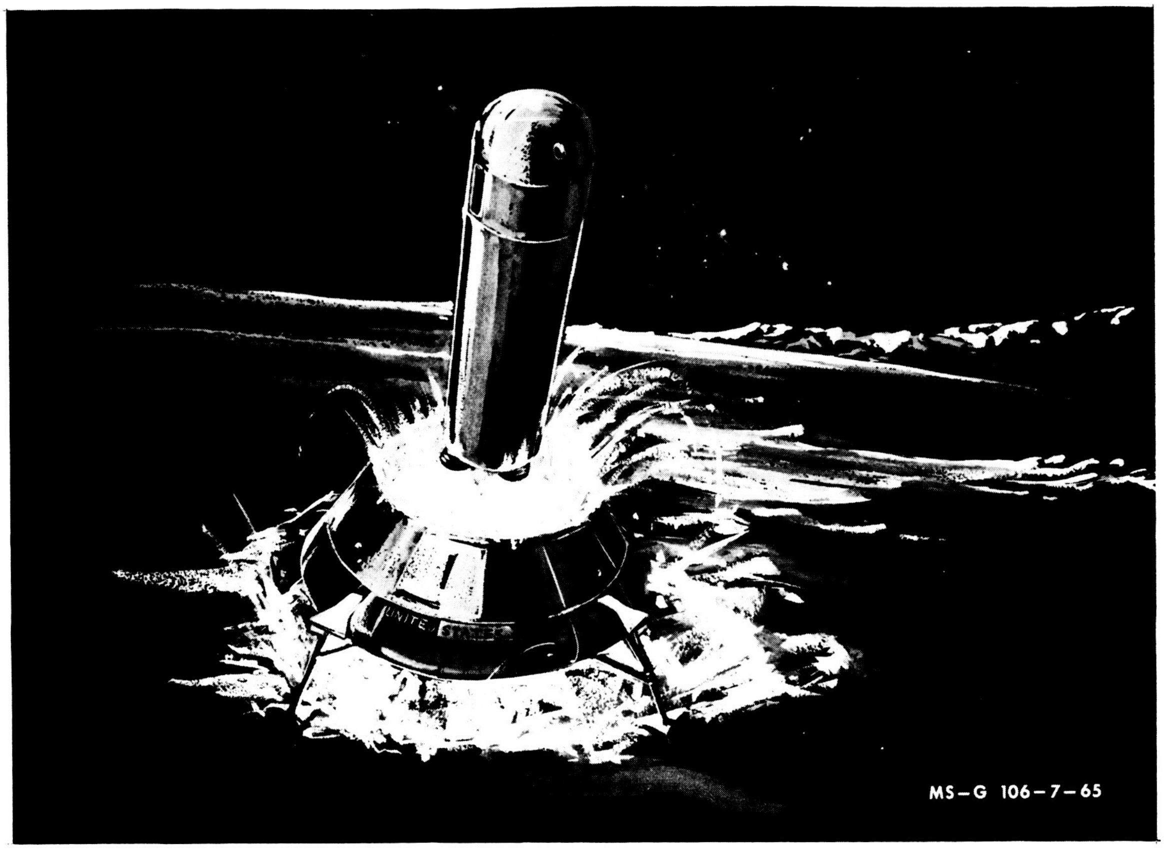


FIGURE 15. MARS EXCURSION MODULE LAUNCH FROM MARS

SECTION VIII. LOGISTICS AND MANNED SHELTER APPLICATIONS

The Mars landing vehicle as discussed so far in this report would be applicable to an early manned Mars landing mission (e.g. an initial landing). Later manned landings would require a more extensive mission support capability in order to make possible significant scientific exploration of the planet. It appears feasible to use, for an extended Mars surface exploration mission, essentially the same interplanetary transfer flight systems as would be used for an initial landing, but with an altered mission mode to provide for a larger crew and extended stay time. This has been discussed elsewhere[1,7]. Since the landed payload delivered by the Mars lander (the 27-ton ascent vehicle) is quite substantial, it is appropriate to consider modifications of the landing vehicle wherein the ascent vehicle would be replaced by a mission logistics payload; or by an internal modification of the landing vehicle to convert it to a long-duration crew shelter, complete with environmental control and life support systems and necessary expendables. This section of this report will describe some concepts for such utilization of the landing vehicle.

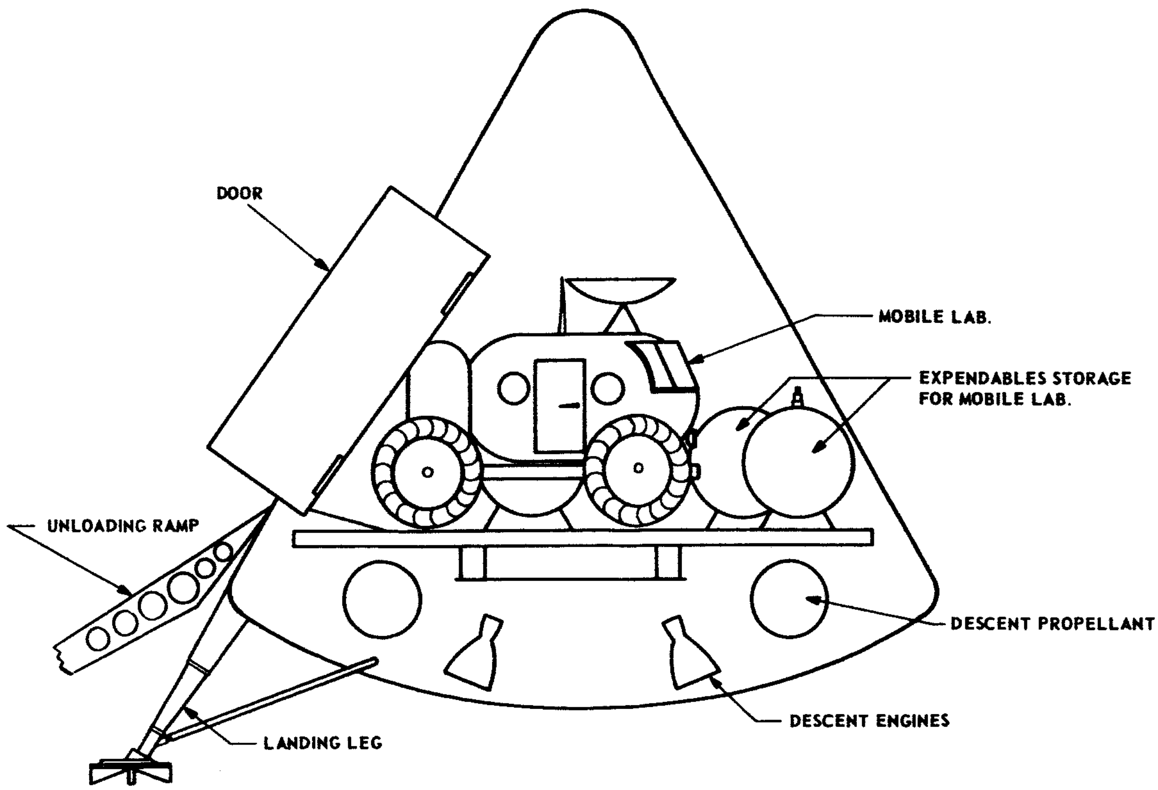


FIGURE 16. MARS EXCURSION MODULE: LOGISTICS LANDER

Structural modifications to the landing vehicle to outfit it as a logistics lander will depend on the nature of the payload to be delivered. In general, it is likely that fairly extensive internal structural modifications will be required, since it is unlikely that a logistics payload will fit conveniently into the space normally allocated to the ascent vehicle. Figure 16 is a conceptual sketch of a logistics carrier version in the landed configuration. This particular concept delivers a long-range surface mobility vehicle, plus expendables and spares for the vehicle. It may be expected that structural modifications to the landing vehicle, as implied by Figure 16, will reduce the landed payload to roughly 22 to 24 metric tons.

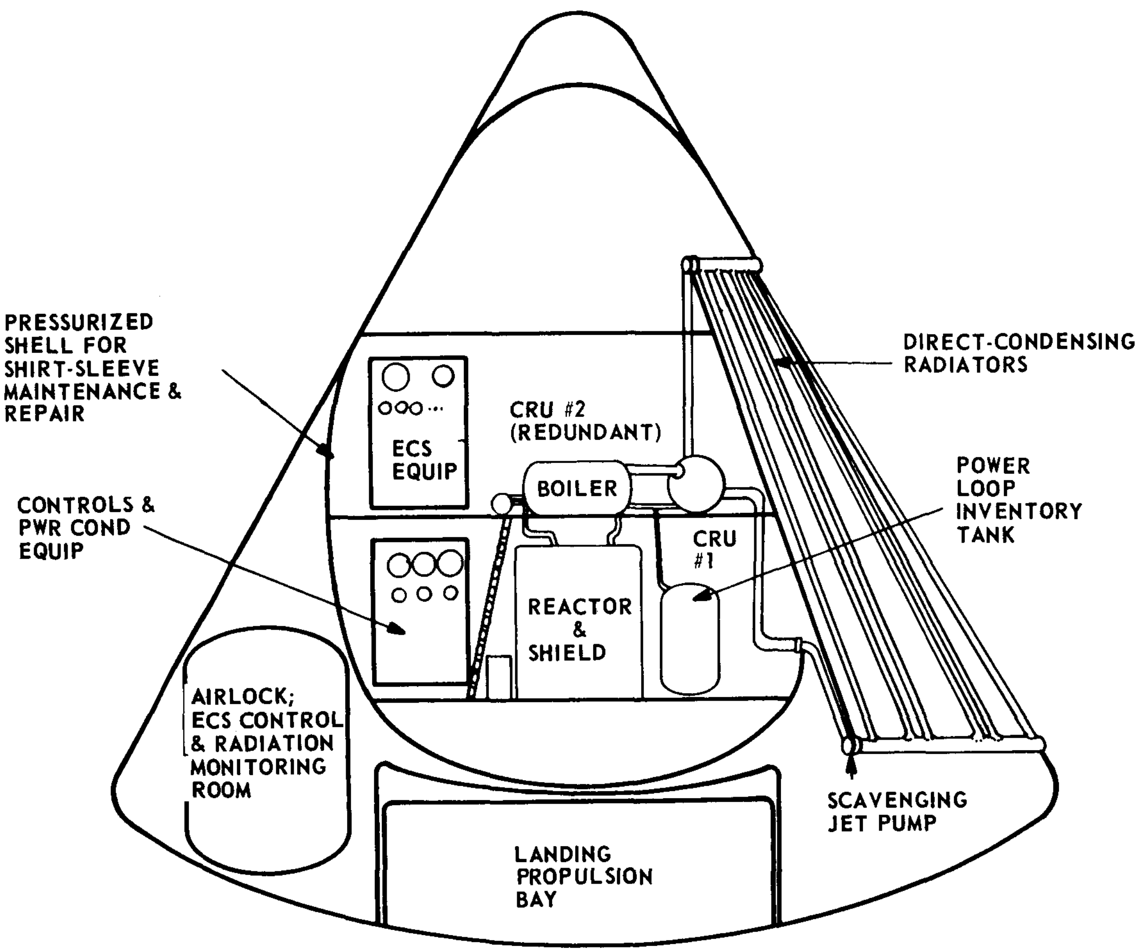


FIGURE 17. MARS EXCRUSION MODULE: NUCLEAR POWER MODULE

It is very likely that an extended-stay manned exploration mission at Mars will require a reactor power system to supply the electric power required for base operations. The landing vehicle would in this regard also be required to serve as a landable nuclear power module. Figure 17 shows a rough conceptual sketch of this application. Internal structural modifications to the lander are similar to those required for conversion to a shelter. It is assumed that the shelter pressure vessel would be used to provide a shirt-sleeve atmosphere around the reactor and equipment. It would also serve to limit radioactive contamination in the event of an accident.

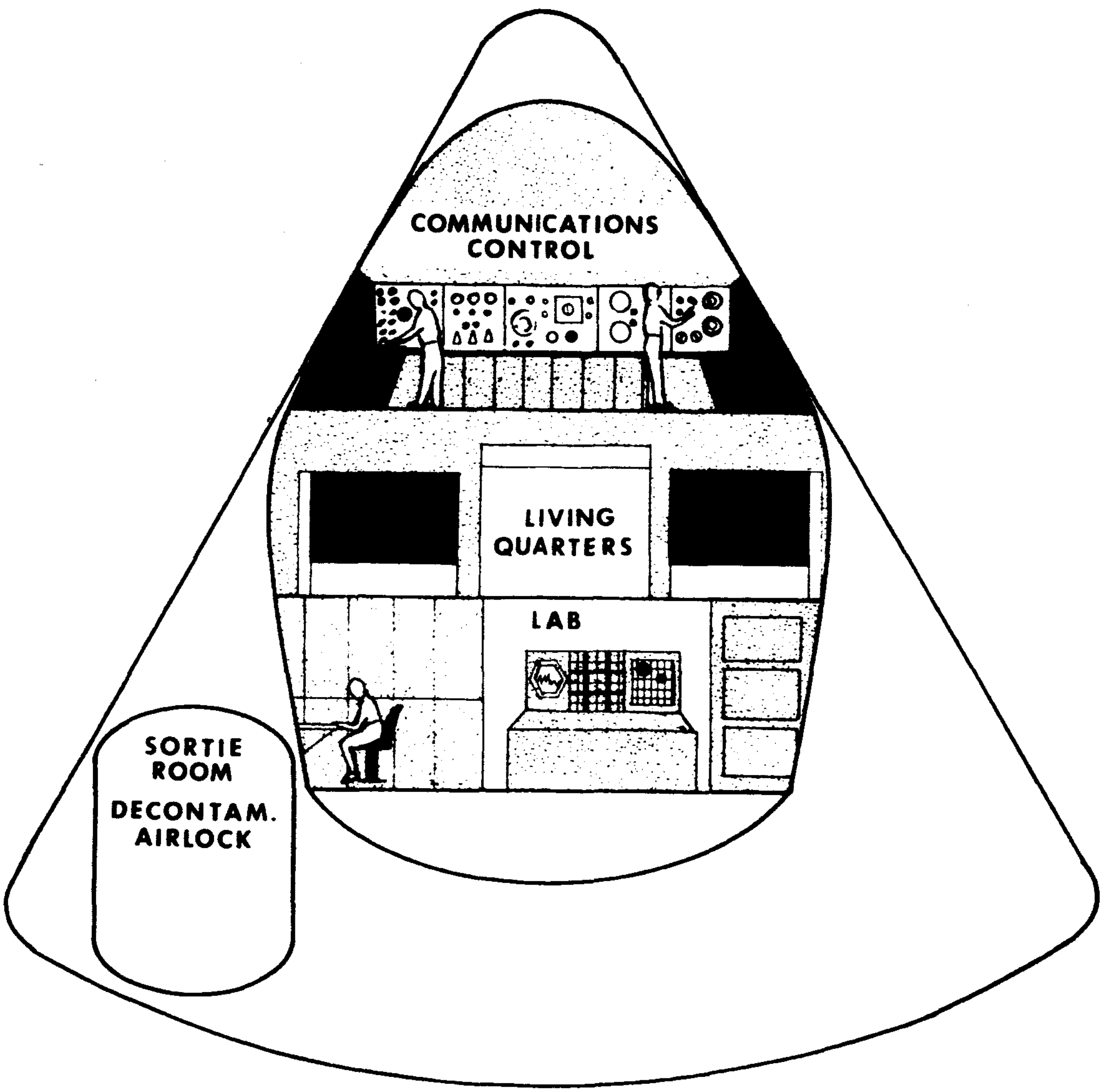


FIGURE 18. MARS EXCURSION MODULE: EXTENDED-STAY SHELTER

As previously noted, the lander must also serve as a shelter system for the exploration crew. Figure 18 is a preliminary concept of such a shelter version, indicating the feasibility of converting most of the upper section of the lander to a pressure vessel housing a three-deck shelter and laboratory module, adequate for extended-duration housing of a crew of 5 to 6 men. Table 6 is a rough-order-of-magnitude weight statement for such a shelter version, designed to house a crew of 5 for a 500-day stay on the Mars surface. Environmental control and life support system weights are based on a study of such systems for lunar surface applications (which are directly comparable) [8]. The weight statement indicates the feasibility of such a self-contained shelter, including all life support and environmental control expendables, for a 500 day period. Electrical power required is assumed to be provided by an external power module such as previously noted.

It has been implicitly assumed in the foregoing discussions that the standard version of this Mars excursion vehicle concept (incorporating the ascent stage) would be landed on Mars in a piloted mode, whereas the logistics and shelter versions would be landed in an unmanned mode. Differences in astrionics systems are thereby implied.

TABLE 6. PAYLOAD BREAKDOWN FOR SHELTER VERSION OF MARS LANDER

Added Internal Structure (Includes "Furniture", etc.)		5000 kg.
Life Support & Environmental Control Subsystems		4000 kg.
Communications & Control Subsystems		1000 kg.
	for 5-man crew: kg/day	
Water	6	
Food	7	
Metabolic O_2	5	
Repressurization Allowance	0.5	
Lockages (5 per day, 80% air recovery)	1.7	
Leakage	1.0	
	21.2 kg/day	
Total Expendables for 500 days		10,600 kg.
Reserve		4000 kg.
Lab equipment & scientific payload		2700 kg.
TOTAL LANDED PAYLOAD		27,300 kg.

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2. Kliore, Arvydas, et. al., "Mariner IV Measurements near Mars: Initial Results," Science, Vol. 149 (Aug. 1965) pp. 1226-1248.

3. "Physical Characteristics and Atmospheric Data for Mars," report # SID 65-1684, N. A. A. (Nov. 1965).

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6. Wylie, C. R., Jr. Advanced Engineering Mathematics, McGraw-Hill, 1951.

7. Woodcock, G. R., "Capability of Saturn V to Support Planetary Exploration," Planetology and Space Mission Planning, (Conference Monograph), New York Academy of Sciences (to be published).

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APPENDIX

EXAMPLE OF COMPUTER ENTRY SIMULATION RESULTS

The following pages are computer output for one of the entry simulations performed for this study. SI units were used as follows:

Masses - Kilograms

Forces - newtons

Lengths - meters

Angles - radians

Atmosphere density - kg per cubic meter

Load factor - Earth g's

The data shown represent every 20th step in the numerical integration.

BEGIN CASE 5

INPUT DATA

INITIAL ALTITUDE = 343380.0000

INITIAL VELØCITY = 3461.0370

INITIAL PATH ANGLE = -0.1600

L ØVER D = 0.4000

AERØDYNAMIC REFERENCE AREA = 142.8700

DRAG CØEFFICIENT = 0.9000

SURFACE ATM. DENSITY = 0.0190

SURFACE ATM. TEMPERATURE = 143.0000

INITIAL MASS = 52000.0000

MARS SURFACE GRAVITY = 3.7377

THE DATA TØ FØLLØW ARE ARRANGED IN BLØCKS AS NØTED

ELAPSED TIME DELTA TIME TØTAL LØAD FACTØR	VELØCITY PATH ANGLE AERØDYNAMIC Q	LIFT L/D ATMØSPHERE DENSITY	ALTITUDE RANGE ANGLE	DRAG MACH NØ.
20.0000 20.0000 0.0000	3470.8827 -0.1601 0.0000	0.0012 0.4000 0.0000	332363.0938 0.0184	0.0030 11.1948
40.0000 20.0000 0.0000	3480.7362 -0.1593 0.0000	0.0021 0.4000 0.0000	321372.1250 0.0369	0.0052 11.2266
60.0000 20.0000 0.0000	3490.5938 -0.1584 0.0001	0.0036 0.4000 0.0000	310411.0000 0.0555	0.0091 11.2584
80.0000 20.0000 0.0000	3500.4520 -0.1574 0.0001	0.0063 0.4000 0.0000	299483.6250 0.0743	0.0158 11.2902
100.0000 20.0000 0.0000	3510.3069 -0.1564 0.0002	0.0110 0.4000 0.0000	288594.1563 0.0931	0.0274 11.3220
120.0000 20.0000 0.0000	3520.1548 -0.1553 0.0004	0.0190 0.4000 0.0000	277746.6875 0.1121	0.0474 11.3538
140.0000 20.0000 0.0000	3529.9919 -0.1542 0.0006	0.0328 0.4000 0.0000	266945.3750 0.1311	0.0819 11.3855

160.0000	3539.8140	0.0565	256194.4375	0.1412
20.0000	-0.1530	0.4000	0.1503	11.4172
0.0000	0.0011	0.0000		
180.0000	3549.6171	0.0970	245498.2813	0.2426
20.0000	-0.1518	0.4000	0.1696	11.4488
0.0000	0.0019	0.0000		
200.0000	3559.3969	0.1662	234861.2813	0.4155
20.0000	-0.1505	0.4000	0.1890	11.4804
0.0000	0.0032	0.0000		
220.0000	3569.1492	0.2837	224287.6250	0.7093
20.0000	-0.1492	0.4000	0.2086	11.5118
0.0000	0.0055	0.0000		
240.0000	3578.8695	0.4827	213781.9063	1.2067
20.0000	-0.1478	0.4000	0.2282	11.5432
0.0000	0.0094	0.0000		
260.0000	3588.5531	0.8182	203348.5938	2.0454
20.0000	-0.1463	0.4000	0.2480	11.5744
0.0000	0.0159	0.0000		
280.0000	3598.1953	1.3812	192992.1250	3.4531
20.0000	-0.1448	0.4000	0.2678	11.5579
0.0000	0.0269	0.0000		
300.0000	3607.7913	2.3220	182717.1563	5.8050
20.0000	-0.1433	0.4000	0.2878	11.5362
0.0000	0.0451	0.0000		
320.0000	3617.3356	3.8865	172528.2188	9.7162
20.0000	-0.1417	0.4000	0.3079	11.5468
0.0000	0.0756	0.0000		
340.0000	3626.8226	6.4751	162430.1250	16.1877
20.0000	-0.1400	0.4000	0.3281	11.5982
0.0000	0.1259	0.0000		
360.0000	3636.2462	10.7356	152427.4375	26.8389
20.0000	-0.1383	0.4000	0.3485	11.6995
0.0001	0.2087	0.0000		
380.0000	3645.5992	17.1606	142525.0625	42.9016
20.0000	-0.1365	0.4000	0.3689	11.8795
0.0001	0.3336	0.0000		
400.0000	3654.8739	27.1770	132727.5938	67.9426
20.0000	-0.1347	0.4000	0.3895	12.1352
0.0001	0.5284	0.0000		
420.0000	3664.0602	43.5573	123040.0938	108.8932
20.0000	-0.1328	0.4000	0.4101	12.4686
0.0002	0.8469	0.0000		
440.0000	3673.1446	71.2669	113467.3750	178.1673
20.0000	-0.1309	0.4000	0.4309	12.8917
0.0004	1.3856	0.0000		
460.0000	3682.1061	119.9898	104014.4688	299.9745
20.0000	-0.1289	0.4000	0.4518	13.4208
0.0006	2.3329	0.0000		

480.0000	3690.9102	208.4090	94686.7188	521.0226
20.0000	-0.1269	0.4000	0.4728	14.1528
0.0011	4.0520	0.0000		
500.0000	3699.4949	378.0012	85489.7500	945.0029
20.0000	-0.1248	0.4000	0.4940	15.0419
0.0020	7.3494	0.0000		
520.0000	3707.7327	725.9301	76429.9063	1814.8252
20.0000	-0.1226	0.4000	0.5152	15.9596
0.0038	14.1140	0.0000		
524.7999	3709.6265	869.4653	74276.4688	2173.6632
4.0000	-0.1212	0.4000	0.5203	16.1750
0.0046	16.9047	0.0000		
528.7999	3711.1723	1002.8735	72488.4375	2507.1838
4.0000	-0.1207	0.4000	0.5246	16.3016
0.0053	19.4986	0.0000		
532.7998	3712.6855	1159.8340	70706.3438	2899.5851
4.0000	-0.1203	0.4000	0.5289	16.4246
0.0061	22.5503	0.0000		
536.7998	3714.1611	1344.9510	68930.2813	3362.3775
4.0000	-0.1198	0.4000	0.5331	16.5448
0.0071	26.1495	0.0000		
540.7997	3715.5928	1563.7962	67160.4375	3909.4904
4.0000	-0.1193	0.4000	0.5374	16.6628
0.0083	30.4044	0.0000		
544.7996	3716.9735	1823.1301	65396.8750	4557.8253
4.0000	-0.1189	0.4000	0.5417	16.7796
0.0096	35.4466	0.0000		
548.7996	3718.2946	2131.1748	63639.6875	5327.9370
4.0000	-0.1184	0.4000	0.5460	16.8959
0.0113	41.4358	0.0000		
552.7995	3719.5453	2497.9440	61889.0313	6244.8602
4.0000	-0.1179	0.4000	0.5503	17.0127
0.0132	48.5668	0.0000		
556.7995	3720.7133	2935.6363	60145.1563	7339.0908
4.0000	-0.1174	0.4000	0.5546	17.1308
0.0155	57.0767	0.0000		
560.7994	3721.7833	3459.1592	58408.2500	8647.8981
4.0000	-0.1169	0.4000	0.5589	17.2512
0.0183	67.2554	0.0000		
564.7993	3722.7366	4086.7453	56678.4688	10216.8633
4.0000	-0.1164	0.4000	0.5632	17.3747
0.0216	79.4573	0.0000		
568.7993	3723.5510	4840.7466	54956.0625	12101.8667
4.0000	-0.1158	0.4000	0.5675	17.5023
0.0256	94.1172	0.0000		
572.7992	3724.1992	5748.4878	53241.4063	14371.2196
4.0000	-0.1153	0.4000	0.5718	17.6348
0.0304	111.7661	0.0000		

576.7991	3724.6480	6843.4560	51534.8438	17108.6401
4.0000	-0.1147	0.4000	0.5761	17.7733
0.0361	133.0552	0.0000		
580.7991	3724.8571	8166.4610	49836.7813	20416.1526
4.0000	-0.1141	0.4000	0.5804	17.9235
0.0431	158.7780	0.0000		
584.7990	3724.7780	9763.2039	48147.8125	24408.0100
4.0000	-0.1135	0.4000	0.5847	18.1385
0.0516	189.8230	0.0000		
588.7990	3724.3509	11700.2543	46468.4063	29250.6360
4.0000	-0.1128	0.4000	0.5890	18.3444
0.0618	227.4845	0.0000		
592.7989	3723.5023	14053.9690	44799.3750	35134.9229
4.0000	-0.1121	0.4000	0.5933	18.5362
0.0742	273.2470	0.0000		
596.7988	3722.1424	16917.5803	43141.6875	42293.9512
4.0000	-0.1114	0.4000	0.5977	18.7087
0.0893	328.9234	0.0000		
600.7988	3720.1609	20405.5757	41496.1875	51013.9399
4.0000	-0.1106	0.4000	0.6020	18.8565
0.1078	396.7394	0.0001		
604.7987	3717.4234	24662.6267	39864.3750	61656.5674
4.0000	-0.1097	0.4000	0.6063	18.9709
0.1302	479.5079	0.0001		
608.7987	3713.7519	29971.3552	38247.6563	74928.3887
4.0000	-0.1087	0.4000	0.6106	18.9991
0.1583	582.7239	0.0001		
612.7986	3708.9326	36435.4014	36647.9375	91088.5049
4.0000	-0.1076	0.4000	0.6149	18.9962
0.1924	708.4024	0.0001		
616.7985	3702.7212	44258.8721	35067.6563	110647.1807
4.0000	-0.1064	0.4000	0.6193	18.9663
0.2337	860.5117	0.0001		
620.7985	3694.8321	53658.2168	33509.5938	134145.5430
4.0000	-0.1050	0.4000	0.6236	18.9133
0.2834	1043.2603	0.0002		
624.7984	3684.9377	64849.1274	31977.0313	162122.8203
4.0000	-0.1034	0.4000	0.6279	18.8407
0.3425	1260.8418	0.0002		
628.7984	3672.6702	78028.2910	30473.9375	195070.7285
4.0000	-0.1016	0.4000	0.6322	18.7513
0.4121	1517.0802	0.0002		
632.7983	3657.6417	93127.6094	29004.9375	232819.0254
4.0000	-0.0995	0.4000	0.6364	18.6656
0.4918	1810.6517	0.0003		
636.7982	3639.4790	110270.0244	27575.0625	275675.0625
4.0000	-0.0971	0.4000	0.6407	18.5738
0.5823	2143.9464	0.0003		

640.7982	3617.7649	129572.5908	26190.1875	323931.4805
4.0000	-0.0943	0.4000	0.6449	18.4640
0.6843	2519.2404	0.0004		
644.7981	3592.0862	150937.1504	24856.6250	377342.8789
4.0000	-0.0912	0.4000	0.6491	18.3340
0.7971	2934.6249	0.0005		
648.7980	3562.0630	174108.7227	23581.3438	435271.8125
4.0000	-0.0876	0.4000	0.6533	18.1820
0.9195	3385.1428	0.0005		
652.7980	3527.3820	198652.1816	22371.5625	496630.4570
4.0000	-0.0835	0.4000	0.6575	18.0063
1.0491	3862.3337	0.0006		
656.7979	3487.8328	223935.2695	21234.7500	559838.1797
4.0000	-0.0790	0.4000	0.6616	17.8058
1.1826	4353.9052	0.0007		
660.7979	3443.3450	249145.7227	20178.1875	622864.3125
4.0000	-0.0739	0.4000	0.6657	17.5800
1.3157	4844.0643	0.0008		
664.7978	3394.5726	266548.2422	19208.3750	666370.6172
4.0000	-0.0683	0.4000	0.6697	17.3321
1.4076	5182.4162	0.0009		
668.7977	3342.8362	280615.0625	18329.3750	701537.6641
4.0000	-0.0625	0.4000	0.6736	17.0688
1.4819	5455.9130	0.0010		
672.7977	3288.4840	292898.8477	17543.2813	732247.1250
4.0000	-0.0564	0.4000	0.6775	16.7921
1.5468	5694.7429	0.0011		
676.7976	3231.8797	303135.0664	16851.4063	757837.6719
4.0000	-0.0500	0.4000	0.6814	16.5039
1.6009	5893.7626	0.0011		
680.7976	3173.4471	310988.1563	16254.2500	777470.3984
4.0000	-0.0435	0.4000	0.6851	16.2061
1.6423	6046.4478	0.0012		
684.7975	3113.6764	316120.1953	15751.2188	790300.5000
4.0000	-0.0368	0.4000	0.6888	15.9015
1.6694	6146.2285	0.0013		
688.7974	3053.1184	318261.2422	15340.6563	795653.1094
4.0000	-0.0300	0.4000	0.6924	15.5926
1.6807	6187.8562	0.0013		
692.7974	2992.3632	317278.4883	15019.8438	793196.2266
4.0000	-0.0233	0.4000	0.6960	15.2826
1.6756	6168.7488	0.0014		
696.7973	2932.0107	313212.2813	14785.1250	783030.7109
4.0000	-0.0166	0.4000	0.6995	14.9745
1.6541	6089.6908	0.0014		
700.7973	2872.6357	306285.6758	14631.9375	765714.1953
4.0000	-0.0101	0.4000	0.7029	14.6713
1.6175	5955.0189	0.0014		

704.7972	2814.7545	296882.1602	14554.7500	742205.4063
4.0000	-0.0038	0.4000	0.7063	14.3755
1.5678	5772.1893	0.0015		
708.7971	2758.7997	285482.3828	14547.8438	713705.9609
4.0000	0.0022	0.4000	0.7095	14.0895
1.5076	5550.5468	0.0015		
712.7971	2705.1051	272636.2617	14604.5938	681590.6641
4.0000	0.0079	0.4000	0.7128	13.8150
1.4398	5300.7837	0.0014		
716.7970	2653.9016	258863.2793	14718.7813	647158.2031
4.0000	0.0131	0.4000	0.7159	13.5531
1.3671	5032.9998	0.0014		
720.7970	2605.3232	244650.5352	14883.9063	611626.3438
4.0000	0.0180	0.4000	0.7190	13.3045
1.2920	4756.6657	0.0014		
724.7969	2559.4181	230410.6816	15093.3750	576026.7109
4.0000	0.0223	0.4000	0.7221	13.0696
1.2168	4479.8046	0.0014		
728.7968	2516.1647	216460.9980	15341.2500	541152.5000
4.0000	0.0262	0.4000	0.7250	12.8483
1.1431	4208.5851	0.0013		
732.7968	2475.4893	203034.0000	15621.8750	507585.0039
4.0000	0.0297	0.4000	0.7280	12.6401
1.0722	3947.5281	0.0013		
736.7967	2437.2812	190286.8359	15929.8438	475717.0938
4.0000	0.0327	0.4000	0.7309	12.4446
1.0049	3699.6889	0.0012		
740.7966	2401.4057	178313.2793	16260.1250	445783.2031
4.0000	0.0353	0.4000	0.7337	12.2610
0.9417	3466.8907	0.0012		
744.7966	2367.7156	167154.5664	16608.2813	417886.4180
4.0000	0.0375	0.4000	0.7365	12.0885
0.8827	3249.9352	0.0012		
748.7965	2336.0594	156815.2012	16970.1563	392038.0078
4.0000	0.0392	0.4000	0.7393	11.9265
0.8281	3048.9101	0.0011		
752.7965	2306.2870	147275.1621	17341.8750	368187.9102
4.0000	0.0406	0.4000	0.7420	11.7741
0.7778	2863.4261	0.0011		
756.7964	2278.2537	138496.1328	17720.0313	346240.3359
4.0000	0.0417	0.4000	0.7447	11.6307
0.7314	2692.7381	0.0010		
760.7963	2251.8232	130429.6035	18101.5313	326074.0117
4.0000	0.0424	0.4000	0.7474	11.4955
0.6888	2535.9030	0.0010		
764.7963	2226.8682	123025.1631	18483.5625	307562.9102
4.0000	0.0427	0.4000	0.7500	11.3678
0.6497	2391.9407	0.0010		

768.7962	2203.2718	116228.9463	18863.4375	290572.3672
4.0000	0.0428	0.4000	0.7526	11.2470
0.6138	2259.8039	0.0009		
772.7962	2180.9259	109991.0537	19238.8125	274977.6367
4.0000	0.0426	0.4000	0.7552	11.1327
0.5809	2138.5225	0.0009		
776.7961	2159.7325	104262.5840	19607.5938	260656.4609
4.0000	0.0422	0.4000	0.7577	11.0243
0.5506	2027.1456	0.0009		
780.7960	2139.6017	99000.5176	19967.8125	247501.2949
4.0000	0.0415	0.4000	0.7603	10.9213
0.5228	1924.8368	0.0008		
784.7960	2120.5396	93207.9121	20317.6250	233019.7813
4.0000	0.0405	0.4000	0.7628	10.8238
0.4922	1812.2130	0.0008		
788.7959	2102.5748	87845.8604	20655.1563	219614.6523
4.0000	0.0393	0.4000	0.7653	10.7319
0.4639	1707.9603	0.0008		
792.7959	2085.6077	83003.8740	20978.7188	207509.6875
4.0000	0.0378	0.4000	0.7677	10.6451
0.4383	1613.8190	0.0007		
796.7958	2069.5461	78639.7539	21286.7188	196599.3867
4.0000	0.0361	0.4000	0.7702	10.5629
0.4153	1528.9687	0.0007		
800.7957	2054.3052	74713.7676	21577.7500	186784.4219
4.0000	0.0343	0.4000	0.7726	10.4849
0.3946	1452.6370	0.0007		
804.7957	2039.8073	71189.6660	21850.5313	177974.1660
4.0000	0.0322	0.4000	0.7750	10.4108
0.3760	1384.1189	0.0007		
808.7956	2025.9812	68034.2266	22103.9375	170085.5684
4.0000	0.0300	0.4000	0.7774	10.3401
0.3593	1322.7687	0.0006		
812.7955	2012.7614	65217.8599	22336.9375	163044.6504
4.0000	0.0276	0.4000	0.7797	10.2725
0.3444	1268.0109	0.0006		
816.7955	2000.0878	62714.0728	22548.5313	156785.1836
4.0000	0.0250	0.4000	0.7821	10.2077
0.3312	1219.3306	0.0006		
820.7954	1987.9049	60497.8345	22738.0625	151244.5879
4.0000	0.0223	0.4000	0.7844	10.1454
0.3195	1176.2409	0.0006		
824.7954	1976.1613	58548.5166	22904.6875	146371.2930
4.0000	0.0195	0.4000	0.7868	10.0854
0.3092	1138.3409	0.0006		
828.7953	1964.8095	56847.8525	23047.7500	142119.6328
4.0000	0.0166	0.4000	0.7891	10.0274
0.3002	1105.2755	0.0006		

832.7952	1953.8049	55378.6611	23166.7500	138446.6543
4.0000	0.0136	0.4000	0.7914	9.9712
0.2925	1076.7104	0.0006		
836.7952	1943.1059	54128.4238	23261.0000	135321.0605
4.0000	0.0105	0.4000	0.7937	9.9165
0.2859	1052.4024	0.0006		
840.7951	1932.6732	53082.5869	23330.2813	132706.4688
4.0000	0.0073	0.4000	0.7960	9.8632
0.2803	1032.0685	0.0006		
844.7951	1922.4696	52231.7310	23374.2188	130579.3281
4.0000	0.0040	0.4000	0.7982	9.8111
0.2758	1015.5256	0.0005		
848.7950	1912.4597	51566.9219	23392.4688	128917.3057
4.0000	0.0006	0.4000	0.8005	9.7600
0.2723	1002.5999	0.0005		
852.7949	1902.6093	51081.8389	23384.7188	127704.5977
4.0000	-0.0028	0.4000	0.8027	9.7097
0.2698	993.1686	0.0005		
856.7949	1892.8855	50771.0552	23350.8750	126927.6387
4.0000	-0.0063	0.4000	0.8049	9.6600
0.2681	987.1261	0.0006		
860.7948	1883.2558	50630.1597	23290.7188	126575.4004
4.0000	-0.0098	0.4000	0.8072	9.6109
0.2674	984.3867	0.0006		
864.7948	1873.6886	50657.4424	23204.2500	126643.6064
4.0000	-0.0134	0.4000	0.8094	9.5621
0.2675	984.9172	0.0006		
868.7947	1864.1523	50851.0767	23091.3125	127127.6924
4.0000	-0.0170	0.4000	0.8116	9.5134
0.2685	988.6820	0.0006		
872.7946	1854.6153	51211.2192	22952.0625	128028.0488
4.0000	-0.0206	0.4000	0.8137	9.4648
0.2704	995.6841	0.0006		
876.7946	1845.0460	51738.9766	22786.4688	129347.4424
4.0000	-0.0243	0.4000	0.8159	9.4159
0.2732	1005.9451	0.0006		
880.7945	1835.4122	52436.5361	22594.7813	131091.3418
4.0000	-0.0279	0.4000	0.8181	9.3668
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884.7944	1825.6811	53307.3501	22377.1875	133268.3770
4.0000	-0.0316	0.4000	0.8202	9.3172
0.2815	1036.4386	0.0006		
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0.2871	1056.8246	0.0006		
892.7943	1805.7915	55587.6978	21865.2500	138969.2461
4.0000	-0.0390	0.4000	0.8245	9.2158
0.2936	1080.7746	0.0007		

896.7943	1795.5623	57008.0317	21571.7188	142520.0801
4.0000	-0.0426	0.4000	0.8266	9.1637
0.3011	1108.3898	0.0007		
900.7942	1785.0944	58624.8052	21253.6875	146562.0137
4.0000	-0.0463	0.4000	0.8287	9.1103
0.3096	1139.8242	0.0007		
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4.0000	-0.0499	0.4000	0.8308	9.0556
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908.7941	1763.2854	62478.2661	20546.1875	156195.6660
4.0000	-0.0535	0.4000	0.8329	8.9992
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912.7940	1751.8615	64731.3604	20158.0313	161828.4023
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916.7940	1740.0659	66676.8447	19747.9063	166692.1133
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0.3613	1330.0506	0.0009		
924.7938	1715.6155	70307.5215	18864.2500	175768.8047
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0.3713	1366.9677	0.0009		
928.7938	1702.9083	72393.4639	18391.9375	180983.6621
4.0000	-0.0709	0.4000	0.8431	8.6916
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0.3945	1452.2229	0.0010		
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0.4079	1501.6826	0.0011		
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4.0000	-0.0808	0.4000	0.8490	8.4851
0.4228	1556.6509	0.0011		
944.7935	1647.8773	83220.6484	16317.1563	208051.6230
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0.4793	1764.5042	0.0013		
956.7934	1600.4684	95270.8340	14594.5625	238177.0879
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0.5302	1951.9770	0.0016		
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0.6813	2508.1409	0.0022		
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4.0000	-0.1051	0.4000	0.8675	7.5437
0.7324	2696.5543	0.0025		
984.7929	1451.1282	149557.4121	10289.8750	373893.5352
4.0000	-0.1059	0.4000	0.8692	7.4107
0.7898	2907.7991	0.0028		
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992.7928	1390.4798	184288.1543	9086.7813	460720.3906
4.0000	-0.1054	0.4000	0.8726	7.1029
0.9732	3583.0583	0.0037		
996.7927	1354.6365	203559.5566	8513.2813	508898.8945
4.0000	-0.1037	0.4000	0.8742	6.9210
1.0750	3957.7463	0.0043		
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1.1697	4306.2518	0.0050		
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1008.7926	1227.0727	248542.6953	6981.3125	621356.7422
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1.3126	4832.3398	0.0064		
1012.7925	1179.7977	255942.9570	6548.5625	639857.3984
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1016.7924	1131.4745	258830.3984	6158.3125	647076.0000
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1044.7920	820.1808	199849.0547	4413.0625	499622.6406
4.0000	-0.0505	0.4000	0.8895	4.1942
1.0554	3885.6042	0.0115		
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4.0000	-0.0496	0.4000	0.8904	4.0074
0.9942	3660.2363	0.0119		
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4.0000	-0.0498	0.4000	0.8913	3.8316
0.9357	3444.8642	0.0122		
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0.8807	3242.5539	0.0126		
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0.8297	3054.6719	0.0129		
1064.7917	658.2972	148218.2598	3654.6875	370545.6523
4.0000	-0.0579	0.4000	0.8938	3.3657
0.7827	2881.7624	0.0132		
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0.7398	2723.6440	0.0136		
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0.6651	2448.4814	0.0144		
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4.0000	-0.0859	0.4000	0.8967	2.8638
0.6327	2329.2367	0.0148		
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0.5761	2121.0268	0.0157		
1092.7913	500.3624	104377.0566	2329.2500	260942.6426
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0.5512	2029.3712	0.0162		
1096.7912	482.6163	99997.5273	2081.1250	249993.8203
4.0000	-0.1333	0.4000	0.8991	2.4667
0.5281	1944.2214	0.0166		
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1104.7911	450.1697	91971.6543	1530.2813	229929.1387
4.0000	-0.1640	0.4000	0.9002	2.3007
0.4857	1788.1768	0.0176		
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0.4657	1714.7107	0.0180		
1112.7910	421.6623	84486.8525	901.8438	211217.1328
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4.0000	-0.2395	0.4000	0.9022	2.0290
0.4069	1497.9700	0.0189		

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AN INITIAL CONCEPT OF A MANNED MARS EXCURSION VEHICLE FOR A TENUOUS MARS ATMOSPHERE

By

G. R. Woodcock

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