N87-17783

MARS LANDING MISSION: A STRUCTURAL APPROACH

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ABSTRACT

A Mars landing mission in the 2000 opportunity presents a structural challenge. Earlier studies have indicated that a Mars landing was then feasible using current structural techniques. Since these earlier studies, technology advances have been made to enhance the capability. Lighter and stronger materials, large structures programs, and super computers now exist and even greater advances are expected.

The feasibility of a Mars landing does not depend on the structure. If the space travelers can withstand the trip, the necessary structures can be provided to deliver them. If artificial gravity is required the structure can also provide for it.

The structural challenge is to provide structural designs that are lightweight with high reliability. In order to do this advanced technology must be utilized to the fullest on all structural elements.

LOADS ENVIRONMENT

Shown in Figure 1 are the load conditions imposed on the structure during the course of a manned Mars landing mission. It is obvious the Earth launch condition is the most severe load condition the structure will encounter for the entire Mars mission.

PRIMARY MISSION OPTIONS

The classical Mars landing mission of past studies has considered propulsive stages for braking into Mars orbit and for braking into Earth orbit. Development in the understanding of aero-braking technology has led to the concept of placing aerodynamic brakes and heat shields on the spacecraft to provide the delta-V necessary to brake the spacecraft into Mars and Earth orbit. The propulsive stages are replaced by these structural/thermal shields. Shown on Figures 1a and 1b are representative configurations for the propulsive and aero-braking concepts respectively.

FIGURE 1

STRUCTURAL LOAD ENVIRONMENT FOR MARS LANDING MISSION

- o EARTH LAUNCH
  (Most severe structural loads)
  - -Aero, Thrust, bending, max q Liftoff
  - o EARTH ORBIT ASSEMBLY
    - -Docking Loads
    - -Manuvering Loads
    - o EARTH DEPARTURE
      - -Thrust Loads (well defined)
      - o BRAKING
        - -Thrust Loads
        - -Aero Braking
        - o MARS LANDING
          - -Aero
          - -Landing
          - o ASCENT
            - -Thrust Loads
            - -Mars Launch Loads
            - o MARS DEPARTURE
              - -Thrust Loads
              - o EARTH BRAKING
                - -Propulsive Loads
                - -Aero Braking

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FIGURE 1a.
MANNED MARS MISSION
1999 OPPOSITION
ALL PROPULSIVE OPTION

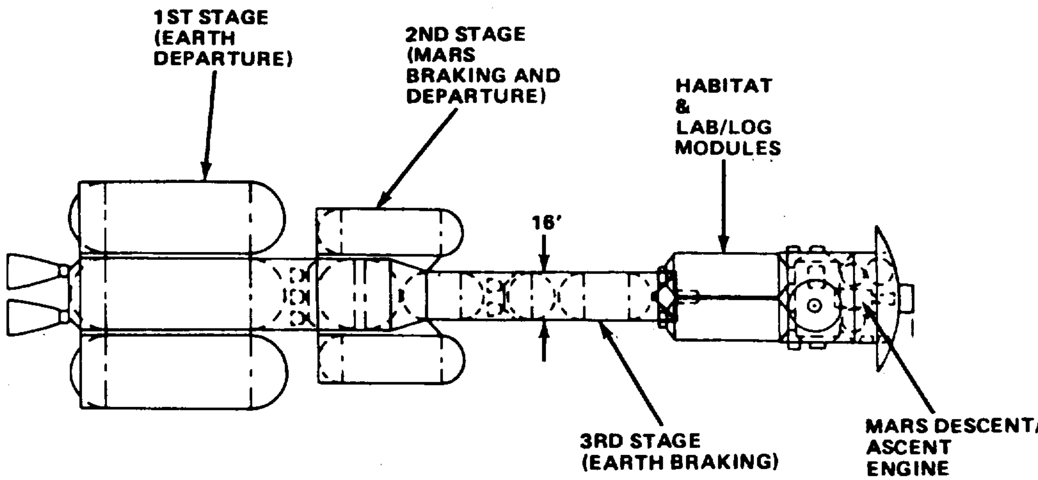
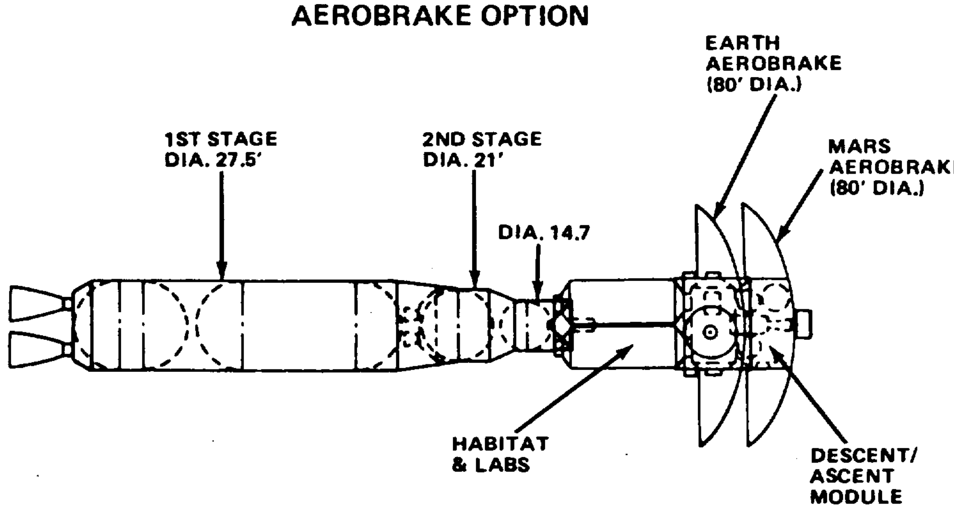


FIGURE 1b.
2001 OPPOSITION
MANNED MARS MISSION
AEROBRAKE OPTION



EARTH LAUNCH PHASE

All elements of any trans-Mars injection configuration are required to endure the Earth launch condition. The launch condition includes vehicle bending and acceleration loads, liftoff loads, and max q conditions. Shown in Figure 2b is an assumed launch vehicle. All structural elements are required to reflect the launch environment. It is important the Earth launch vehicle relieve the Mars stages from as much load as possible. Since the launch vehicle is in the early phases of selection this phase of the Mars study should define requirements imposed on the launch vehicle by the Mars landing mission. Shown in Figure 2a are the Shuttle Derived Vehicle (SDV) and the Heavy Lift Launch Vehicle (HLLV) compared to the current Shuttle configuration. A larger vehicle will allow for more efficient structural elements.

STRUCTURAL ELEMENTS

Shown on Figure 3a and 3b are representative configurations of all the propulsive and aero-braking configurations respectively.

The following major structural elements have been identified:

(1) Trans-Mars Injection Stage - LO_2/LH_2 stage that required multiple launches (smaller stage required for aerobraking)

(2) Mars Braking (*) / Departure Stage

(3) Earth Braking Stage (*)

(4) Mars Excursion Module (MEM) - Landing Stage; Pressurized Habitat and Lab; Departure Stage

(5) Interstages - The interstages are light weight; no launch loads are carried thru them.

(*) Indicates Aero-braking option

TRANS-MARS INJECTION STAGE

The trans-Mars injection stage puts more requirements on the selection of the Earth launch vehicle than any of the Mars stages because of the massive size of the stage and the amount of propellant it must hold. Since the stage is separated after the trans-Mars burn, the trans-Mars injection stage is less technology critical than other elements. As seen from Figures 3a and 3b the injection stage for the aerobraking concept is smaller than the stage for the all-propulsive option. The structural loads are primarily due to launch and to LEO environments.

FIGURE 2a. SHUTTLE–DERIVED VEHICLE

PAYLOAD	182K LBS
ORBIT	
ALTITUDE	270 NMI
INCLINATION	28.5 DEGREES

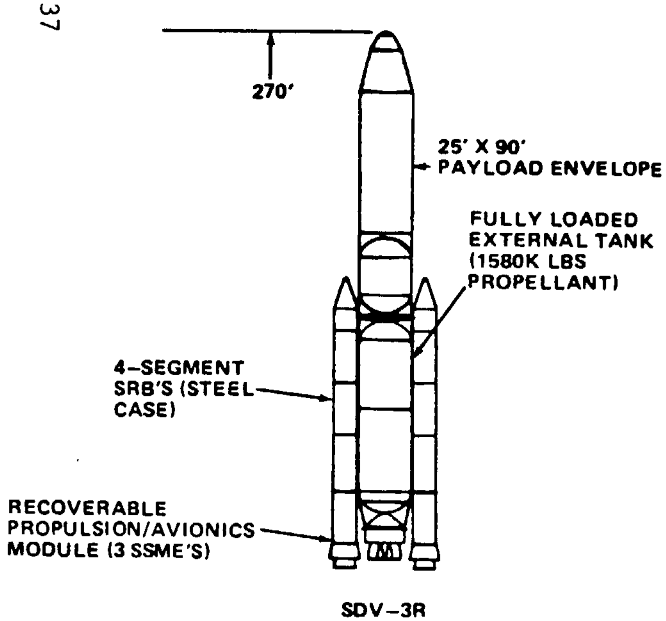


FIGURE 2b. TYPICAL EARTH–TO–ORBIT VEHICLES

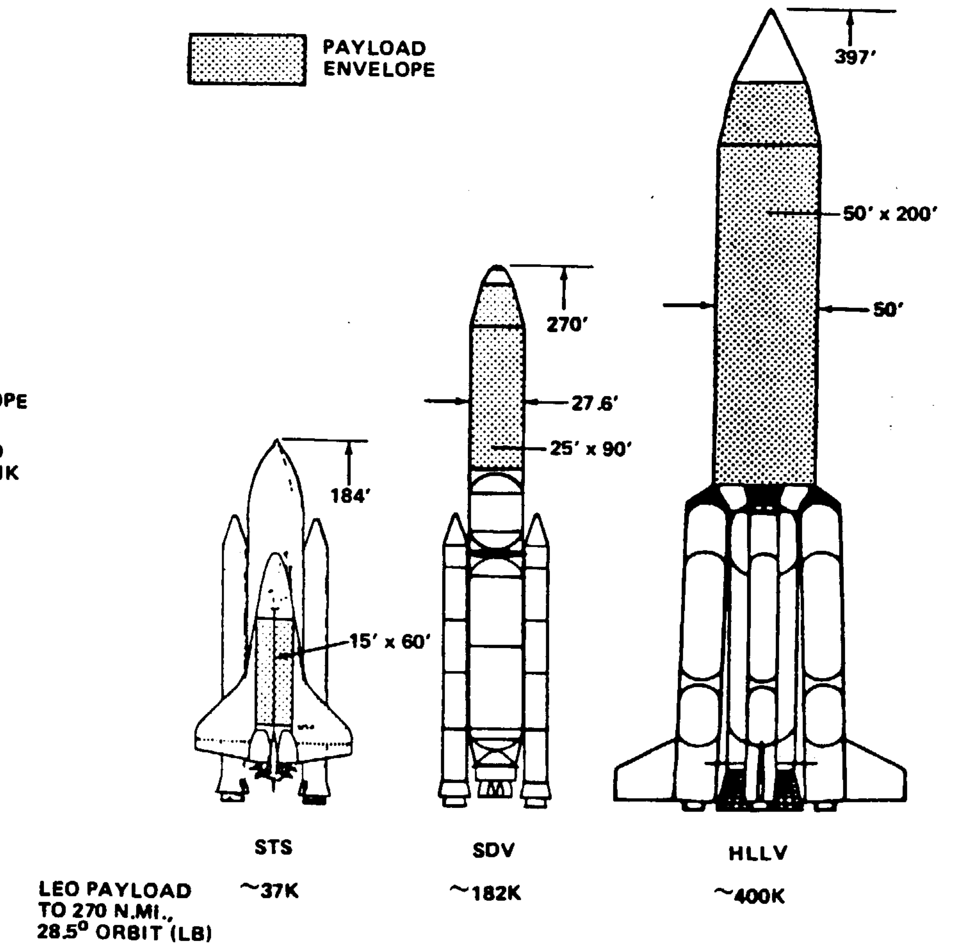


FIGURE 3a. ALL–PROPULSIVE CONFIGURATION

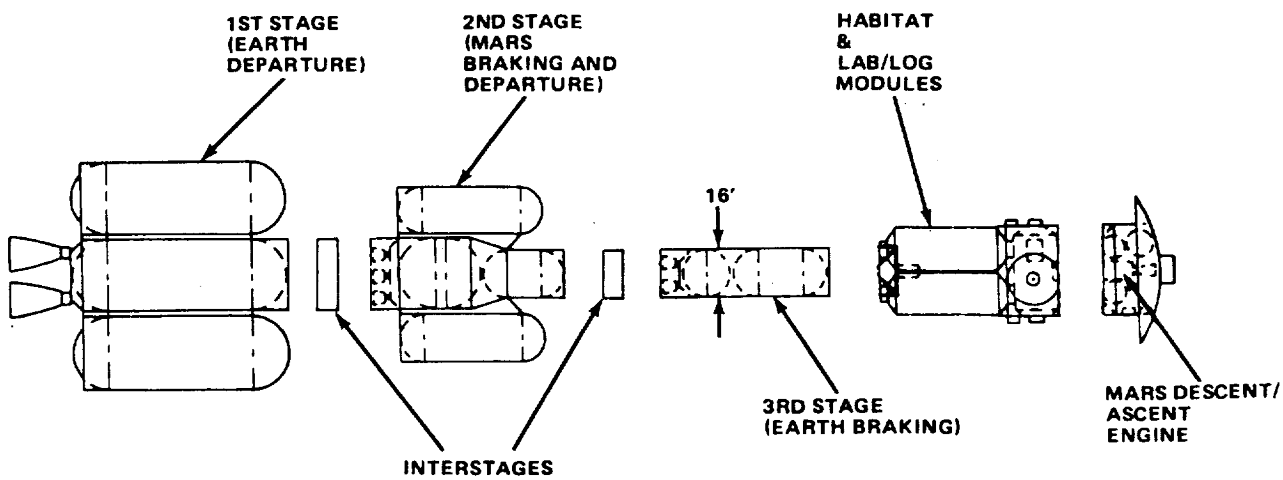
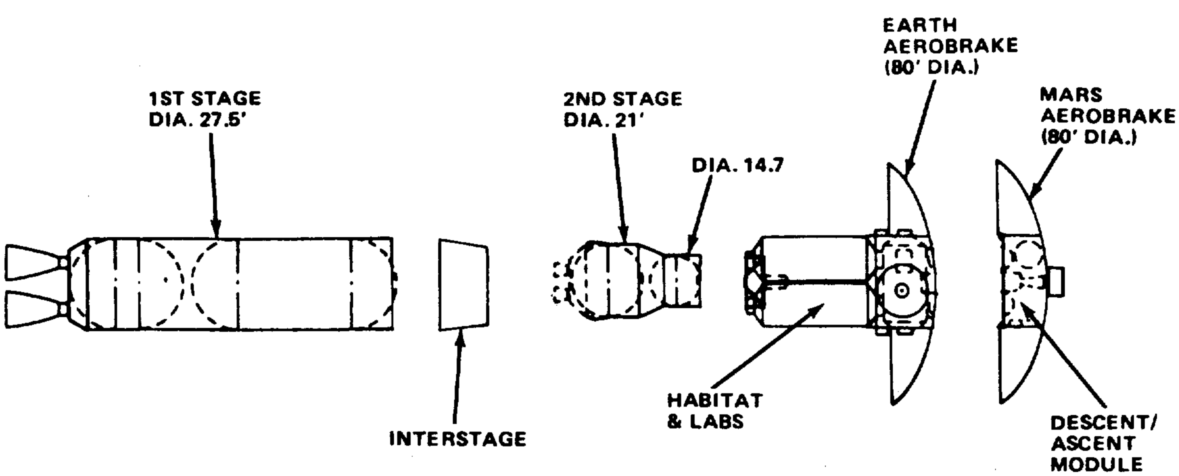


FIGURE 3b. AEROBRAKING CONFIGURATION



The propulsive stage is a LO_2/LH_2 stage launched in three separate launches. The core stage contains the engines and LOX tanks. Much of the propellant will be launched after the stage is launched.

A definite advantage of having an all aero-braking configuration is the reduced size of the trans-Mars stage. Even with the reduced size the stage will have to be launched partially full with the balance of the propellant to be launched later; therefore, a propellant "tanker" concept is required to support the Mars landing mission.

MARS BRAKING STAGE

Mars braking can be provided by propulsion or by an aero-braking shield. The all-propulsive option utilizes the braking stage combined with the Earth return stage. The structural approach for the braking/return stage is to employ maximum technology to reduce the stage weight. The aerobraking concept utilizes an aero-shield to provide the braking. The diameter of the Mars braking shield will require assembly in Earth orbit unless it is a slender shape which can be launched intact. Though the braking concept is estimated to be much lighter than a propulsive stage the loading conditions and temperature considerations will require the maximum use of high technology materials and analysis.

Earth Braking Stage

Braking at Earth is provided by a propulsive stage or an aero-braking stage. In either case the technology requirements are high. This stage weight impacts the structural weights of the trans-Mars stage, Mars braking and departure stage. The aero-braking shield may require assembly in LEO whereas the propulsive braking stage and propellant can be carried to LEO on one launch without requiring LEO assembly. The aerobraking concept is estimated to be much lighter than a propulsive stage; however, the loading conditions and temperature considerations will require the maximum use of high technology materials and analysis.

MARS MISSION MODULE (MMM)

The Mars Mission Module goes through every phase except landing. It must protect the space travelers throughout the entire mission. There are two concepts considered; the single MM and the multiple concept which utilizes the Space Station type modules to build up to the MM. Shown in Figure 4 are weight comparisons between two concepts. Since the single large module is much lighter the structural preference is the single

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FIGURE 4a.

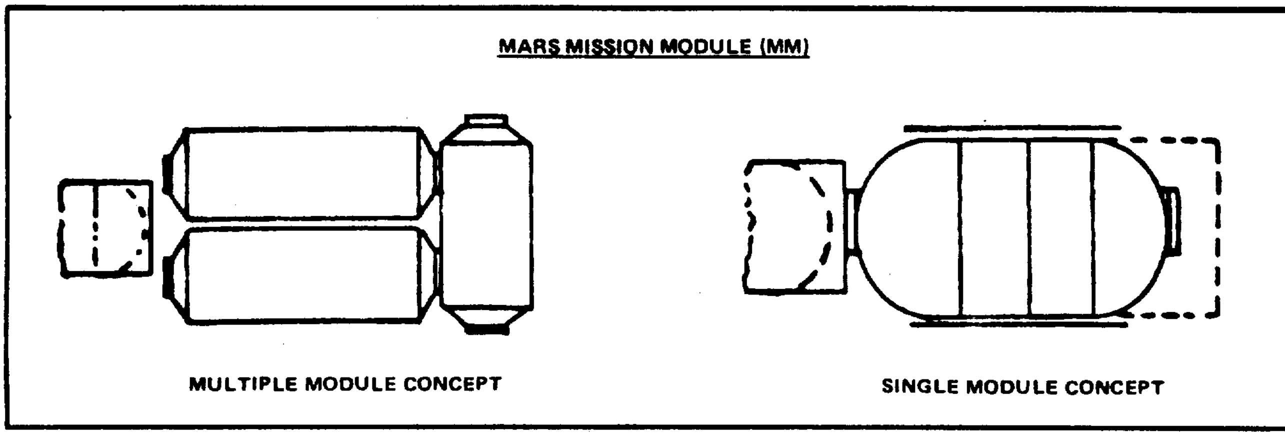
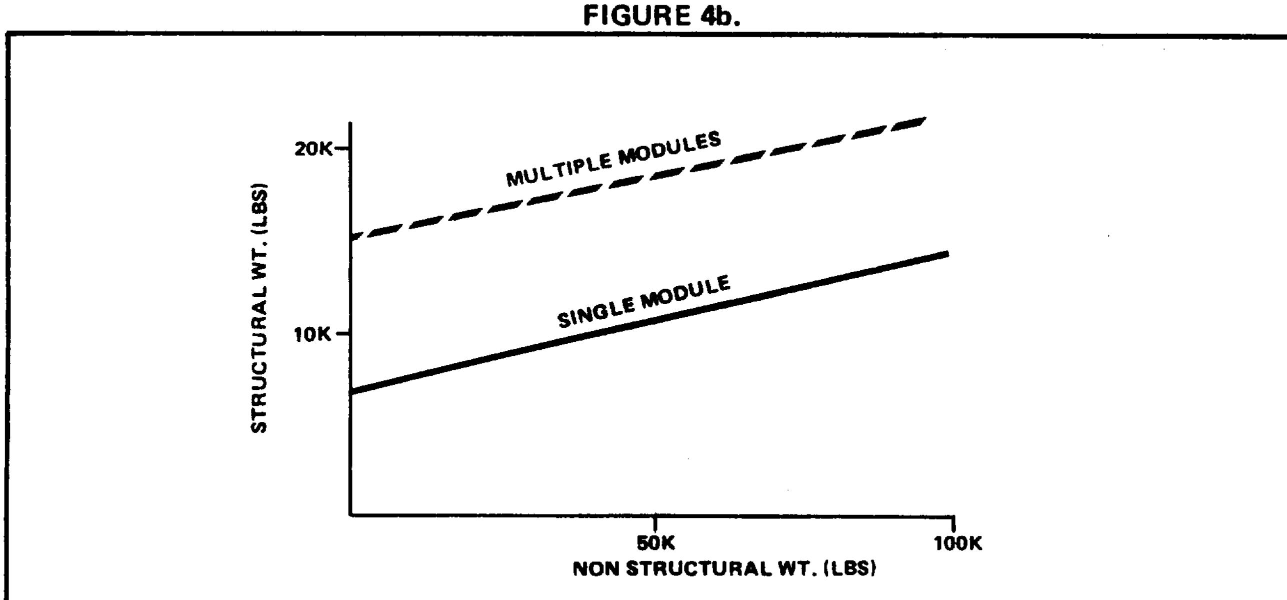


FIGURE 4b.



module. Every stage weight is impacted by the Mission Module, therefore, the MM is constructed of the highest technology material available.

MARS EXCURSION MODULE (MEM)

The MEM goes through every loads environment except the Earth return and braking, and the ascent stage must experience those environments in some mission scenarios. The MEM structure faces more unknown conditions than any of the other elements. The MEM consist of four primary elements: (1) Aero-brake; (2) Propulsive landing stage; (3) Ascent stage; and (4) Pressurized Habitat. Also, the MEM must deliver several independent sets of equipment such as Mars rover vehicle, and Mars surface test equipment along with providing the capability to return with samples. The MEM has to be as light as possible and still meet the Mars mission requirements. Also, the MEM impacts the Mars braking and the trans-Mars injection stages. Since the aero-braking shield will not be tested after assembly the structural approach and materials must provide for a light-weight structure with high reliability. It is therefore necessary that a high technology approach for the entire MEM structure be taken.

Because of the complexity of the design requirements and loading conditions proper structural analyses have not been made to determine the MEM structural weights.

INTERSTAGES

The interstages will be supported for Earth launch such that the only loads they see are self-induced loads. The design loads for the interstages then are the trans-Mars propulsion or braking loads. They will be constructed of lightweight material.

TECHNOLOGY REQUIREMENTS

Figure 5 shows the relative technology ranking for the various structural elements. The ranking is from 1 through 10 where 10 is the highest technology requirement. The various structural elements do not have the same sensitivity to improvements over current technology. The purpose of Figure 5 is to determine where the structural technology emphasis needs to be.

FIGURE 5

TECHNOLOGY EMPHASIS

Item	all propulsive	aero-braking
trans-mars injection stage	3	2
Mars braking stage	5	7
Mars departure stage	6	6
Earth braking stage	9	10
Mission Module(MM)	10	10
Mars Excursion Module(MEM)	10	10

STRUCTURAL TECHNOLOGY PROJECTION

The primary focus on structural technology is to reduce the structural weight. Much advancement with composite materials has been made that allow for lighter and stronger structures. Shown on Figure 6a is a projection of weight reductions that can be expected through the year 2000. Also, shown on Figures 6b and 6c are specific characteristics for some composite materials. These type material advances when applied to the MEM and MM have much potential to enhance the Mars landing mission.

FIGURE 6a.

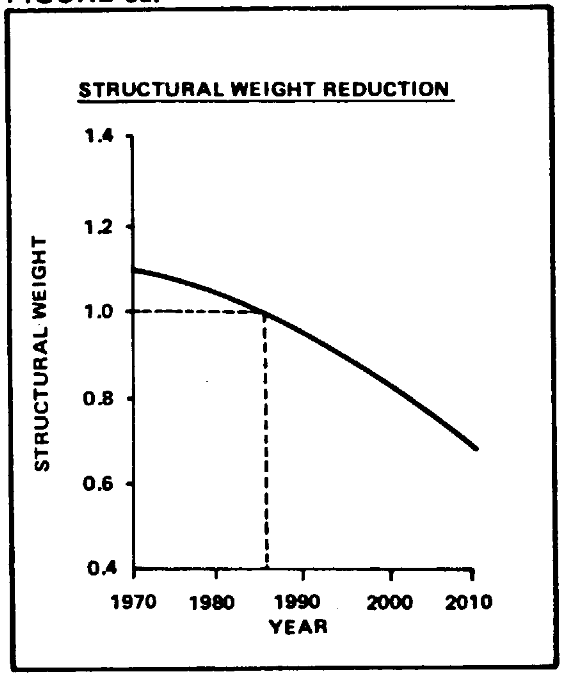


FIGURE 6b.

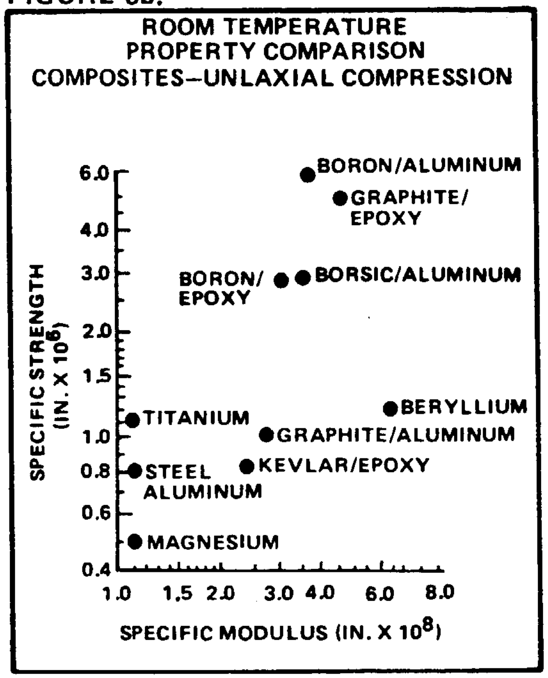
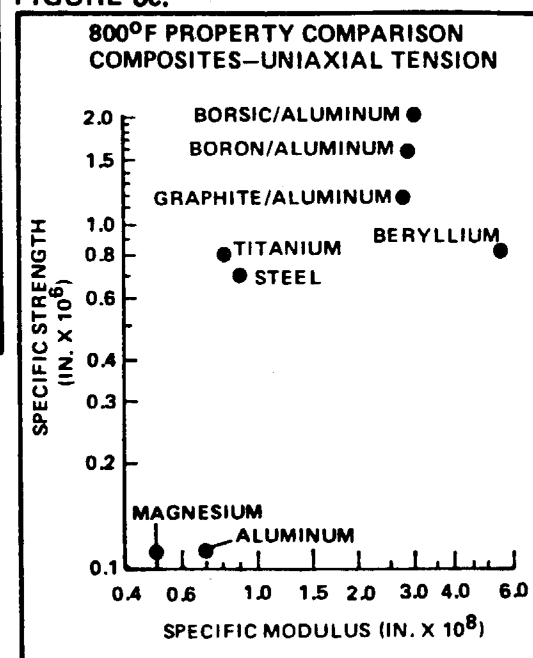


FIGURE 6c.



MICROMETEOROID PROTECTION

Meteoroid protection must be provided during all phases of the Mars landing mission. The following table shows the considerations for the various structural elements.

Item	Exposed Area	Mission Time	Probability of no Penetrations (Po)
Trans-Mars Injection Stage			.99
Mars Braking Stage			.995 (*)1.000
Mars Departure Stage			.995
Earth Braking			.995 (*)1.000
MM			.999
MEM			
Aero-brake			1.000
Landing stage			.99
Ascent stage			.9999
Habitat			.995

(*) Aero-braking Shield

The overall mission requirement for micrometeoroid protection has not been established. Flux models are required for near Earth, the trans-Mars orbit, and near Mars. The above probabilities are estimates. The total probability of penetration of all structural elements should equal the overall mission requirement. An estimate for the overall requirement is .995 for the mission duration.

SUMMARY

A manned Mars landing presents a number of challenges in the area of structural design; however, it appears that the structure is not the critical element for a Mars mission. The structural approach is to utilize advanced technology to make the mission more reliable and cost effective. The purpose of this paper is to present a survey of structural considerations in order to focus thinking on future work.