MISSION AND SPACE VEHICLE CONCEPTS

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ABSTRACT

This paper discusses a number of top-level considerations which affect Mars and vehicle selection. Indications are provided of the nature and severity of the impact of these considerations on missions and vehicles. The paper identifies and discusses various types of missions, such as Mars fly-bys, Mars orbiting and landing missions, and missions to the moons of Mars. Mission trajectories and opportunities are discussed briefly.

The paper also discusses the different types of vehicles required in a Mars program. Discussion includes several potential Earth-to-Orbit (ETO) vehicles, Mars surface vehicles, and 2 types of Orbit-to-Orbit (OTO) vehicles. Indications are provided as to preference for some of the concepts discussed.

OVERALL CONSIDERATIONS

The exploration of Mars will require multiple manned (and/or unmanned) missions. Furthermore, the utilization of Mars as a science outpost, a resource production site, or as a site for colonization experiments, etc., adds a significant level of increase in quantity and sophistication of missions. The initial Mars mission usually receives the greatest interest and definition activity, but this mission should not be considered an end in itself. The technology and design concepts selected for the initial mission should be chosen so as to allow their utilization and evolution to occur in subsequent missions.

Some of the key top-level considerations which will determine the nature of mission and vehicle concepts for a manned mission to Mars are 1) the desired launch timeframe, 2) the desired stopover time at Mars, 3) the nature and location of the science to be conducted, 4) design implications implied by the physiological effects of long-term zero-g environments, 5) contamination considerations, and 6) cost.

Launch Timeframe

The two launch timeframes of interest for study activities have been specified broadly as an "early" (pre-2000) timeframe and a later (post-2000) timeframe. The main effects of specifying the earlier launch timeframe are to constrain technology selection to that which is more near-term and to restrict more severely the options for shaping the cost envelope. Also, the scope and complexity of the science associated with the initial mission would probably be more limited if the mission were in an early timeframe rather than in a later one. For one thing, earlier technology would be less efficient, making weight more critical and hence, not as much science (or other) equipment could be transported. Also, any international prestige factor ("race to Mars" context) associated with an early mission might be a forcing function towards ensuring that mission (and science) complexity remained low, lest it jeopardize the schedule.

Mars Stopover Time

Within either of the broad launch timeframes, there are only a limited number of practical opportunities for launch, due to the severity of the energy requirements for a launch at any but the optimal planetary alignments (References 9 & 10). These practical opportunities occur roughly every 2 years, but the energy requirements can vary by a factor of 2 to 1 between successive opportunities for some trajectories. Hence, selection of a specific launch date can have significant implications for sizing of the propulsive vehicle. The vehicle size is fairly sensitive to launch window size, with a 30-day launch window requiring about a 6-10% increase in propellant, compared to a 10-day window.

The choice of stopover time at Mars is pre-set by the selection of the trajectory to be used, and vice versa. There are basically two choices of stopover times: 1) about 60 days, and 2) about a year, corresponding to total mission times of 1) about 2 years ("opposition"-type trajectory), and 2) about 3 years (conjunction-type trajectory). The wide variation in these times can have a significant effect on the mission and vehicle concepts. There are systems technologies and concepts which might be usable for a 60-day stopover, but which might not be usable for the longer stopover. The longer mission time also implies the need for greater lifetime and reliability of systems, for more expendables, and for more science equipment (to make the longer stopover productive).

Science Activity Nature and Location

The nature and location of the science activity to be conducted has a fairly significant bearing on the mission and vehicle concepts. Science activities are planned for all phases of the missions (in transit, in the Earth vicinity, in the Mars vicinity, and on the Mars surface), but that planned for the Mars surface is likely to be the most demanding and to also have the greatest implications for mission and vehicle concepts. For example, some form of surface traverse capability will be necessary for efficient exploration. Concepts vary from short-range lunar-rover-type vehicles to mobile laboratories with ranges up to hundreds of kilometers and several days' duration. The location of the desired surface science activity can vary from the polar regions to the equator, from rocky fields to sand dunes, and from mountainous regions to smooth plains. Each of these imposes some different requirements on the mission (particularly the trajectory) and on the vehicles and equipment (particularly the surface infrastructure elements). Ideally, the mission and vehicle concepts should be able to accommodate any of the desired landing locations and science activities, since separate locations will probably be desired on different missions (particularly the early missions).

Physiological Effects

Physiological considerations (particularly the long-term zero-g effects which can incapacitate astronauts) can have significant impacts on mission and vehicle concepts. Research must be done to understand more fully the physiological mechanisms involved, and to discover preventive or corrective measures. It is possible that diet supplements can offer significant help in this regard, for example, in aiding fixation of calcium in the bones. Exercise, also, will probably be part of the solution. Major questions remain, however, in regard to 1) whether there must be a gravity field provided during the long transit periods or not, 2) the level of the g-forces required, 3) the consistency of the g-forces required (constant vs. intermittent, and unidirectional vs. reciprocating), etc. The greatest impact on the vehicle design would occur if there were a requirement to spin the entire vehicle, or a major portion thereof. A lesser impact would occur if, for example, a reciprocating sled arrangement might be available for occasional astronaut use. For spinning vehicles, arrangements must be made to despin some science equipment and any vehicle systems equipment needing preferential orientations (solar arrays, radiators, antennas etc.). Some vehicle system concepts must be able to operate in the LEO environment (during assembly), in the Earth-Mars transit phase, in Mars orbit, and on the Martian surface; the g-levels vary from zero-g to about one-third g across these mission phases, even before consideration of any additional effects due to spinning vehicles. Reference 5 and papers in Section VI provide further discussion of this subject.

Contamination

Contamination considerations can be major drivers of mission and vehicle concepts. In addition to the usual concerns of contamination due to the natural and induced environments associated with the mission and vehicle, there are two special areas of concern which can have far-reaching impacts. One is the potential for biological contamination of Mars and Earth. Some of the more significant potential impacts are sterilization of equipment, use of bio-locks and facilities, and quarantine periods. The other special area of concern is the potential for radiological contamination of Earth and Mars, if nuclear power and/or propulsion concepts are used. There are reasons to believe that these concerns might not result in major impacts, but considerable attention must be given to them in future studies to further determine this. Convincing the general public of their safety is a major part of considerations in this area.

Cost

Cost will be one of the most important governing paramenters of a Mars mission. We are, in the respects of knowledge, proven technology, and flight experience, well ahead of the place where we were when we began the Apollo lunar landing program. There will be a significant base of Space Station technology, designs, hardware, and operations experience, and even an in-orbit Space Station at Earth, for potential support of a Mars landing program. Also, there will likely be an Earth-to-orbit heavy-payload-capability vehicle available for use. Many of the challenges of a Mars mission (long durations, great distances, difficult environments, and more sophisticated science requirements) will be demanding, on but by comparison to our situation at initiation of the Apollo program, they are less demanding than the challenges were then. Reference 11 discusses this subject, also.

MISSION TYPES

The simplest and nearest-term type of manned mission to Mars which might be envisioned is a manned fly-by of Mars, in which case there is no injection into Mars orbit, nor landing, of any manned elements (although unmanned probes would probably be ejected from the passing Space Vehicle (SV) to do both of these things). Such a mission could be accomplished, using then-existing technology, in the late 1990's. A short mission duration (about a year) would probably be required for such a mission. This would require a "hot" trajectory, and the total delta velocity from LEO to Mars and return would be about 13.64 km/sec. A preliminary estimate of the total SV weight in LEO (assuming cryogenic chemical propulsion) would be about 1.35M lbs., but this might be reduced by as much as 50% if mission time is extended by about 20% (these weights assume that only a small module is returned to Earth orbit).

The next easiest type of manned mission to accomplish, and one which could also be done before the end of the century, would be a manned mission to Mars orbit, with an alternate mission being a manned landing on one of the moons (Phobos or Deimos) of Mars. Practical trajectories for this type of mission fall into two categories, depending on planetary alignments: 1) conjunction-type missions, which have a total mission time of about 3 years (including a 1-year stopover), and 2) opposition-type missions, which have a mission time of about 2 years (including a 60-day stopover). Depending on the type of trajectory and the type of braking (aero or propulsive), these missions require a total delta velocity of about 4.65 to 12.53 km/sec., and a total SV weight in LEO of 1.3M (conjunction/aerobraking) to 3.6M (opposition/propulsive) on some of these missions, all habitable modules could be returned to Earth orbit for re-use.

The manned Mars landing type of mission is more complex and costly than either of the others mentioned previously, but it provides greater science return, a greater capability for buildup of Mars surface elements towards a Mars base capability, greater international prestige, etc.

This type of mission, like the others previously mentioned, could be accomplished before the end of the century. The mission trajectory and duration options would be the same as for the Mars orbit missions. The total delta velocity requirements would be about 7.2 km/sec higher than those, to effect the descent and ascent at Mars. Both oppostion and conjuction types of missions might be desireable during a Mars program, the opposition type for early low-risk missions and/or for later unmanned cargo missions the conjuction type for more extensive science/exploration and/or for Mars base activities. As mentioned previously, the energy requirements vary considerably from one opportunity to another for opposition trajecories. The 2001 opportunity (Mars arrival date) offers considerable improvement in energy requirements over earlier or later opportunities, and would be an attractive year if an early opposition mission were desired. References 9 and 10 provide more details on performance analyses of these missions.

TRANSPORTATION APPROACHES

For the initial manned mission to Mars, no matter what type of mission is chosen, it would seem that the simplest, cheapest, and most reliable way to transport the people and equipment would be to transport them all together in one vehicle. Another possibility is to utilize two or more separate vehicles which are very similar and which would travel along together; this has some advantages but also adds some complexity and cost to the mission, and so would probably be best considered for later missions. Data applicable to this concept are provided and discussed briefly in reference 1.

A variation of the multiple-vehicle, simultaneous-travel approach is to have separate vehicles for cargo and for people. Some parametric sizing data for such vehicles have been generated and are discussed in reference 1. A fourth approach is to have separate vehicles for cargo and people, but to not constrain the vehicles to travel together. This allows for utilization of a "slow freighter" cargo vehicle concept and a "fast-track" manned vehicle concept, although when practical constraints are imposed, this approach may evolve back towards the third approach. A fifth option (reference 14) is a "loop vehicle" approach, wherein a large transportation vehicle continuously traverses a loop between Earth and Mars, on a fly-by trajectory at each planet. Smaller crew and cargo "commuter" vehicles would ascend to and descend from the loop vehicle at Earth and Mars proximities. Several (3-5) of such loop vehicles might be necessary to provide adequate encounter opportunities without exhorbitant gaps in the program. One of the potential difficulties associated with this concept would be that the need to occasionally replace/refurbish systems hardware on the loop vehicle might necessitate periodically returning it to Earth orbit for a "dry-dock" period, which might cause the Earth departure dates to get out of synchronization with the planetary alignments. Rendezvous windows would also be very critical with the loop vehicle concept.

A loop-vehicle concept has been proposed for the Earth-Lunar system and was assessed briefly by MSFC (reference 15). In that case, the loop mission time is only a few days, whereas in the Earth-Mars case, loop mission times of 2 - 3 years would be minimum. Due to these longer mission times, a dry-dock operation would probably be necessary after each loop, which would necessitate having a second loop vehicle available to alternate missions with the first vehicle. In this event, the loop vehicle approach essentially evolves back to the dedicated mission approaches discussed previously.

VEHICLE CONCEPTS

The basic types of vehicles required for a manned Mars mission are an ETO vehicle, an SV, Mars surface vehicles (included as part of the SV), and OTO vehicles. The ETO vehicle is utilized to launch the SV elements into low Earth orbit (LEO) in the vicinity of the Space Station. Because of the size of the SV (greater than 1M lbs.), it will be necessary to assemble it in orbit, and a number of flights of ETO vehicles will be required to deliver it there (reference 12). An assembly system may be required for on-orbit buildup of the SV. A concept of such an element is discussed in references 2 and 5.

Earth-To-Orbit Vehicles

The Space Transportation System (STS) would be utilized for launch of the crew and some of the smaller elements of the Mars SV. ETO's of the proposed Shuttle-Derived Vehicle (SDV) class (<200K lbs. of payload to LEO) and the Heavy Lift Launch Vehicle (HLLV) class (about 400-500K lbs. of payload to LEO) would be candidates for Mars missions. These have been studied extensively by MSFC and others for a number of years and a considerable amount of work is still in progress in this area. Reference 3 provides some updated data on vehicles. Figure 1 shows the concepts which were utilized in this study as typical ETO's. More than likely, some such vehicles will already exist, having been developed by NASA or DoD (or jointly) by the time frame being discussed for Mars missions.

Space Vehicle

The Space Vehicle as discussed herein is the vehicle which travels to Mars. Figure 2 shows a typical SV. It consists of a Transportation Vehicle and a Spacecraft. Their key elements and different options for each are discussed briefly below.

Transportation Vehicle

The types of propulsion which have most often been suggested are chemical (cryogenic, liquid storable, or solid storable), ion-drive (solar-electric or nuclear-electric), nuclear-thermal, solar sail, and hybrids of these. Each of these has been studied in the past, and a discussion and comparison of some of them is provided in reference 4 and in several papers in Section II of this report. Chemical propulsion with aerobraking is presently the most developed technology, and would probably be the choice for an early Mars mission. More data and discussion are provided on chemical propulsion concepts than on others in this paper.

The very-low-thrust systems (nuclear-electric, solar-electric, solar sail, etc.) can spiral out of LEO, given sufficient time (months), but they spend a significant amount of time in the trapped radiation belts, in addition to adding significantly to the mission time. This approach would not be acceptable for manned travel. Even for "cargo ships", the radiation is detrimental to some systems hardware, such as solid state electronics and solar arrays (if used). Shielding of sensitive systems against trapped radiation would have to be provided in the very-low-thrust systems' designs. Practical consideration of very-low-thrust systems should probably be as a part of a hybrid system, with chemical stages used to deliver the crew to Earth-departure nodes (such as Earth-Moon libration points) beyond the belts. Nuclear-thermal systems (such as the NERVA) several standpoints, but their development

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FIGURE 1. TYPICAL EARTH-TO-ORBIT VEHICLES

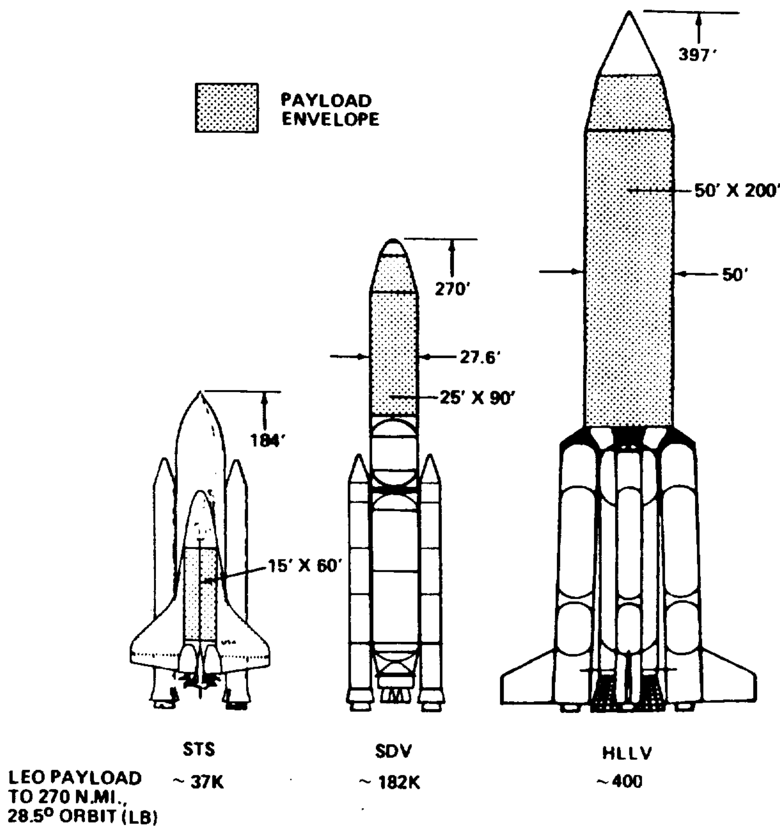

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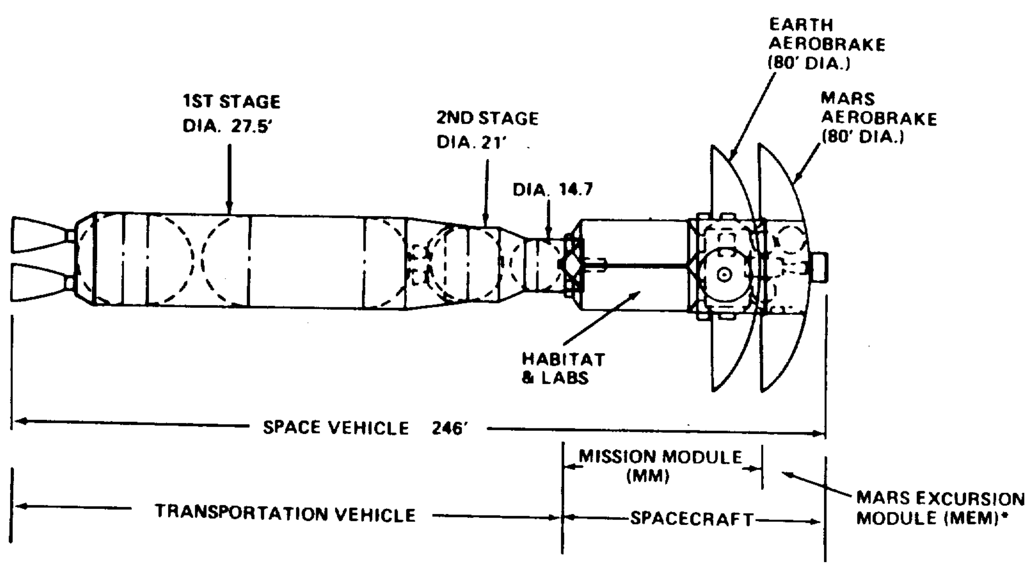
FIGURE 2. TYPICAL CHEMICAL PROPULSION/AEROBRAKING SPACE VEHICLE FOR MANNED MARS MISSION 2001 OPPOSITION



* CONTAINS ASCENT/DESCENT PROPULSIVE SYSTEMS FOR MARS LANDING

appear to be further downstream and more costly than chemical propulsion systems.

Some of the options for a chemical all-propulsive transportation vehicle are shown in Figure 3 (not to scale). These concepts vary from single-stage to 3-stage vehicles. One of the features stressed in these concepts is commonality of design among the stages, with tank length being a variable to accommodate differences in sizing.

On the STS External Tank (ET)-derived vehicle, it probably would be difficult to design the third stage tanks with as large a diameter as the ET, since the required propellant quantity may not be that large. The first and second stages, however, could probably make use of this commonality. The single-stage concept does not appear to be as good as some of the others from several standpoints. For one thing, it would be difficult to cover the required thrust range with only one engine concept. The engines would have to be fairly large and heavy (approximately 7,000 lbs. each) to accommodate the first stage requirements, and would have to be carried along for the entire mission, which adds a significant weight penalty. The 2-stage and 3-stage vehicles alleviate these problems, but at the expense of some cost and complexity. On these concepts, empty tanks and/or expended stages are jettisoned to save weight. There is a tradeoff between the propellant weight savings accrued by jettison of dead weight, and the cost, complexity, and weight associated with the additional stages. A preliminary design was developed for a modified version of the 3-stage concept shown here, and is described in reference 5.

An all-propulsive vehicle would probably not be utilized, especially for opposition missions, due to excessive propellant weight penalties; a more attractive approach would be to utilize a vehicle capable of aerobraking at Earth and Mars. Research and development is already underway on aerobraking concepts, as part of OTV technology work, and the technology should be supportive of Mars vehicle needs and should be available in the timeframe needed for Mars applications. As mentioned previously, multiple missions will be needed for Mars exploration and utilization. The variation of energy requirements across the opportunities of interest implies that the SV must have the capability of accomplishing missions across the range of worst to best-case

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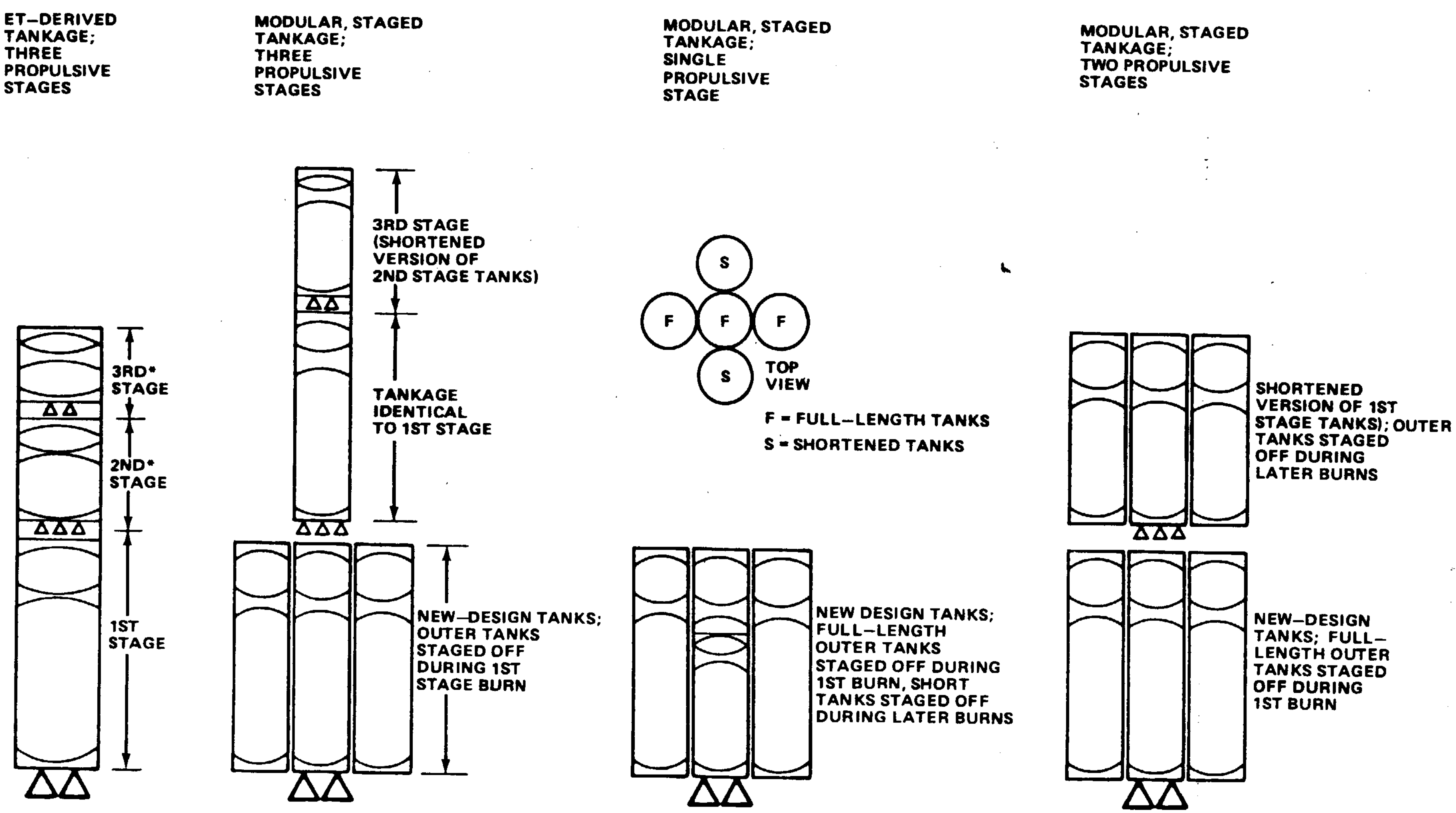
FIGURE 3. CHEMICAL–PROPULSION TRANSPORTATION VEHICLE OPTIONS FOR MANNED MARS MISSIONS



* SHORTENED VERSIONS OF 1ST STAGE TANKS (LIGHT–WEIGHTED ET DERIVATIVES)

opportunities. For maxium versatility and cost-effectiveness, a transportation "system" should be developed which allows accomplishment of a wide range of missions over a wide range of opportunities. One approach to such a system is described in reference 5. In this system, an aerobraking, cryogenic-propulsion SV is used for either opposition or conjunction missions at any opportunity. Elements of this system can be used for an early Mars fly-by mission as well as for more demanding later landing missions, with modular additions to the elements. No costly dead-ended concepts would be involved in this type of approach. The elements and associated systems would incorporate "technology transparency" to the degree feasible, for efficient upgrading of capability over long time periods.

Spacecraft

The nature of the spacecraft is dependent on the nature of the mission. Some missions would have only an orbiter, some only a lander, and some both. For unmanned "cargo" missions, no habitable elements would be necessary. Some of the concepts which have been proposed as orbiters are shown (not to scale) in Figure 4. The terminology most frequently used for this element is "Mission Module" (MM).

The MM concepts could be elements derived from Space Station (SS) modules (14 ft. diameter X 35-45 ft. long) or could be larger-diameter modules of a new design. The former approach would have cost, experience, and logistics advantages. The latter approach may have internal packaging and weight advantages. Multiple pressurizable habitable volumes will probably be necessary for safe-haven reasons, hence a large-diameter module will probably need to have separate pressurizable compartments. There are some limitations on the MM configuration, but generally, these are not as restrictive as those on the Mars Excursion Module (MEM) discussed later. Since the MM can be assembled in orbit, it does not have to withstand (as a whole) the ETO launch environment nor be constrained to the ETO shroud dimensions. A large-diameter (approximately 80 ft.) aeroshell will probably be needed for aerocapture at Mars, and this also permits a good bit of freedom in configuration of the equipment (MM and other) located behind the aeroshell (the areoshell would be assembled or deployed in LEO, because of its large size). Some

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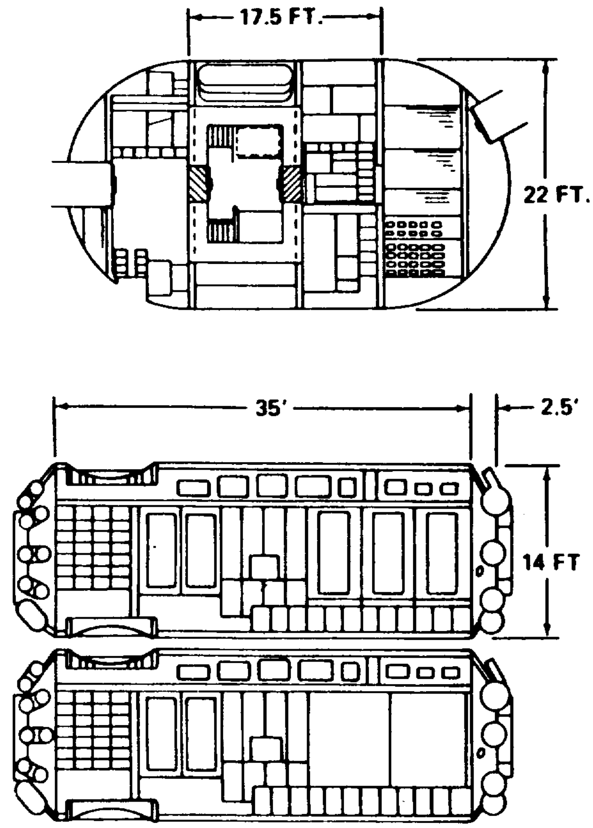
FIGURE 4. MISSION MODULE OPTIONS



LARGE MODULE

VOLUME = 12,250 FT^3
*WEIGHT = 13,050 LB.**

SPACE STATION MODULES

VOLUME (2 MODULES) = 11,488 FT^3
* WEIGHT (2 MODULES) = 22,762 LB.**

** WEIGHTS ARE REFERENCED TO EARTH

* PRIMARY STRUCTURE ONLY

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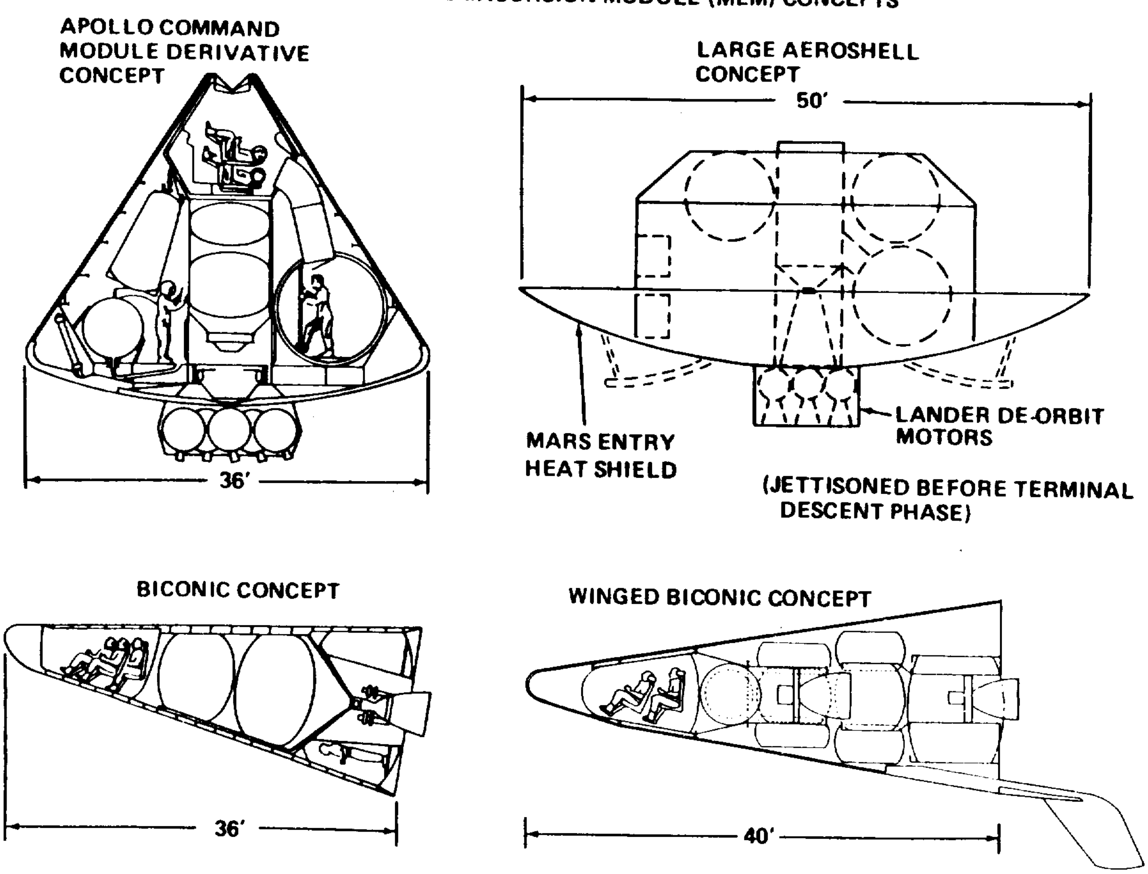
FIGURE 5 . MARS EXCURSION MODULE (MEM) CONCEPTS



of the concepts which have been proposed as landers, or MEM's, are shown in Figure 5. Some of these are discussed in reference 13.

The MEM design is heavily dependent on the concept of entry into the Mars atmosphere. Most concepts have utilized aerobraking for partial descent. In addition, some have utilized parachutes and some have utilized propulsive braking. Some MEM concepts have utilized a biconic shape, and others have utilized a conical shape. Both of these approaches impose rather severe limitations on the configuration and quantity of equipment which can be taken to the surface, since the equipment must be conformable to the conic or biconic envelope dimensions. A large diameter (approximately 50 ft.) aeroshell seems to be required for aerobraking of the MEM during descent to the surface. Such a large diameter shell would probably allow freedom to package equipment of various sizes and shapes behind it if the MEM configuration were not constrained to a conical envelope. This allows development of a delivery "system" concept, in which the size and shape of the equipment behind the aeroshell can vary considerably from mission to mission, affording a high degree of adaptability and versatility for surface delivery of men and equipment. Such a concept is discussed more fully in reference 5.

Mars surface transportation vehicles (such as land rovers, "pogo" propulsive vehicles, airplanes, etc.) would be transported to the Martian surface in the MEM. Concepts of these are discussed more fully in reference 6.

Orbit-To-Orbit Vehicles

Orbital Transfer Vehicles

The Orbital Transfer Vehicle (OTV) (reference 7) should be an operational vehicle in the mid-to-late 1990s. One or more orbit-based OTVs is planned to be a part of the advanced SS infrastructure. OTV studies are in progress, and no selection has yet been made of a preferred concept. However, one concept is shown in Figure 6 to aid familiarization with this class of vehicle.

For all Mars mission options, a LEO-based OTV (possibly one on loan from the SS) can be used to circularize the orbit of the elements returned from Mars (which would probably have been injected into an elliptical Earth orbit having a perigee equal to the SS orbit). Compared

4196–85

FIGURE 6.
S-4 CORE PROPELLANT MODULAR OTV THREE & SEVEN TANK ASSEMBLIES

	3 tank	7 tank
Propellants	O_2/H_2	
Engine(s)/no.	Adv Eng/2	
Isp & mixture ratio (sec)	482/6:1	
Thrust level	7.5 Klb/engine	
Avionics	Baseline	
Payload available length	—	
Propellant capability	63,780	148,820 lb
Burnout weight	7,290	12,530 lb
ASE weight	TBD	
Payload capability	—	
• GEO transfer	TBD	
• GEO circular delivery		
— Expendable	TBD	
— Reusable	27	72 Klb
• GEO roundtrip	14	37 Klb
• 12 hour, 63 deg	TBD	
• C_3 of 85 km^2/sec^2	TBD	
Source of data	GDC-1985	

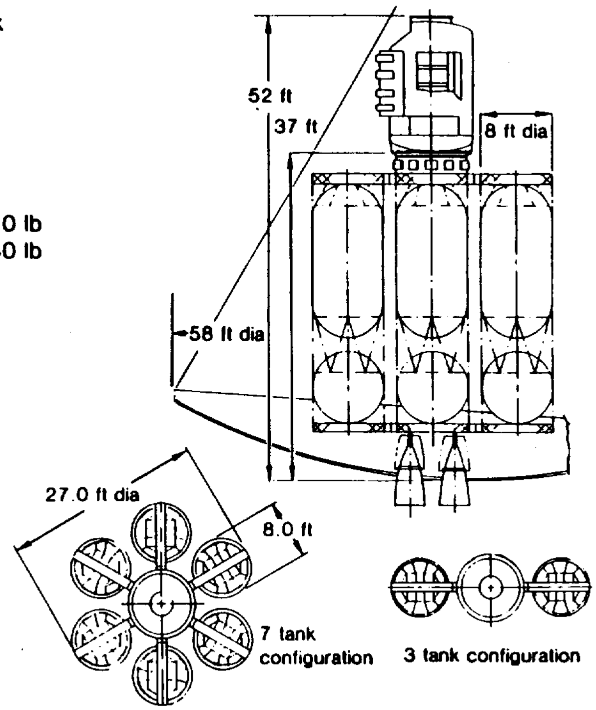


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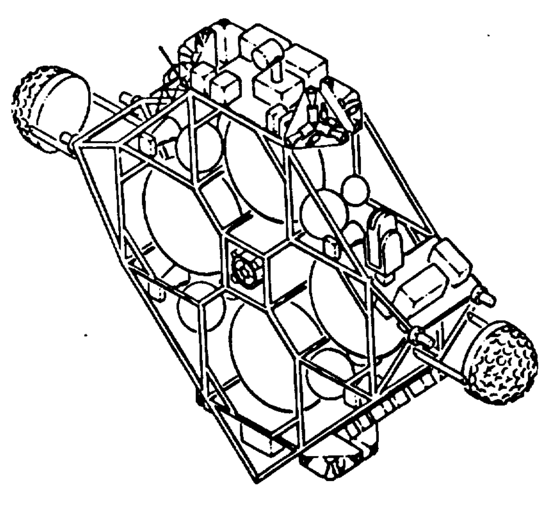
FIGURE 7. TYPICAL OMV



DIMENSIONS:

37 X 178 INCHES

WEIGHT LOADED:

10,496 LBS.

PROPELLANTS:

6700 LBS. NTO/MMH
200 LBS. GN_2

to the case of having to transport a circularization stage to Mars and back, this would allow significant savings of weight on the SV.

For Mars missions using very-low-thrust vehicles, a new orbit-to-orbit vehicle development would be required for the chemical portion of the hybrid propulsion system, in addition to the new development require for the very-low-thrust portion. This vehicle could possibly be a derivative of the OTV.

Orbital Maneuvering Vehicles

The Orbital Maneuvering Vehicle (OMV) (reference 8) should be an operational vehicle in the early-to-mid 1990's. OMV studies are in progress, and no selection has yet been made of a preferred concept. A generic concept is shown in Figure 7 to aid familiarization with this class of vehicle.

One or more orbit-based OMVs is planned to be a part of the early SS infrastructure. An OMV (possibly on loan from the SS) will be useful in on-orbit assembly of the SV, and in ferrying men and equipment between the STS, SV, and SS (especially if the SV and SS are co-orbiting with each other in the SV assembly phase).

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