A chance for an early manned Mars mission

Mars by 1980 can be a national goal by fully exploiting the most advantageous flight profiles, Apollo and orbiting-laboratory resources, and advanced chemical propulsion

By ROBERT L. SOHN
TRW/Space Technology Laboratories

Once a successful manned lunar landing has been achieved, there will be strong incentives, scientific and national, to press on with exploration of the planets. Mars will be especially attractive. It is relatively near, appears not too hostile, and may reveal native life forms. Already the Space Science Board of the National Academy of Sciences has urged that the major post-Apollo effort be devoted to searching for life on Mars. Unmanned probes are of course required. But manned flight will be even more important than in the exploration of the Moon. The presence of men will be necessary for most of the experiments needed to determine the existence and nature of life on Mars.

As with Apollo, preparations for manned interplanetary flights will have to begin many years before the launches. It seems essential that realistic planning begin now to permit an orderly step from the Moon to Mars without waste or slumps. With aerodynamic entry at Mars and its consequent lowering of propulsion requirements, the step to Mars does not necessitate post-Apollo propulsion systems or, in fact, any basic enhancement of space technology beyond Apollo. An integrated, detailed plan for an early manned flight to Mars can be prepared now—must be prepared now if the nation is to make efficient use of the manned space programs which precede planetary missions.

Apollo represents a capability for space exploration far beyond missions to the Moon. We have only recently started detailed design studies of orbiting research laboratory (ORL) programs based on Apollo equipment and procedures, but it is already evident that many ORL goals can be met at an early date with direct Apollo derivatives. Strong possibilities exist for using major elements of Apollo-derivative and medium-ORL programs in early manned Mars missions, with many consequent advantages. The orbiting laboratories can be used to develop, test, and qualify major elements of planetary vehicles, and to gain operating experience before an actual mission.

This article outlines a possible approach to an early manned Mars flight. In brief, the approach, relying heavily on the application of existing capability, proposes a four-step sequence of events leading to manned landing on Mars in the 1980s:

1. Apollo system is developed, yielding the command module, a life-support system, an orbital-rendezvous technique, Saturn V launch system.
2. Extended-duration Apollo command module, life-support system, and mission module (which replaces the Lunar Excursion Module) are developed as an early manned orbiting laboratory, yielding design criteria for flight times of about a year.
3. A medium orbiting research laboratory (MORL) is developed using an enlarged mission module and a crew of six to eight men. Concurrently the Saturn V will be uprated.
4. A manned Mars stopover vehicle is developed, using an Apollo-type command module, the MORL life-support system and mission module, and a new Mars-excursion module. Assembled in Earth orbit, it would require the launch of four to five uprated Saturn Vs.

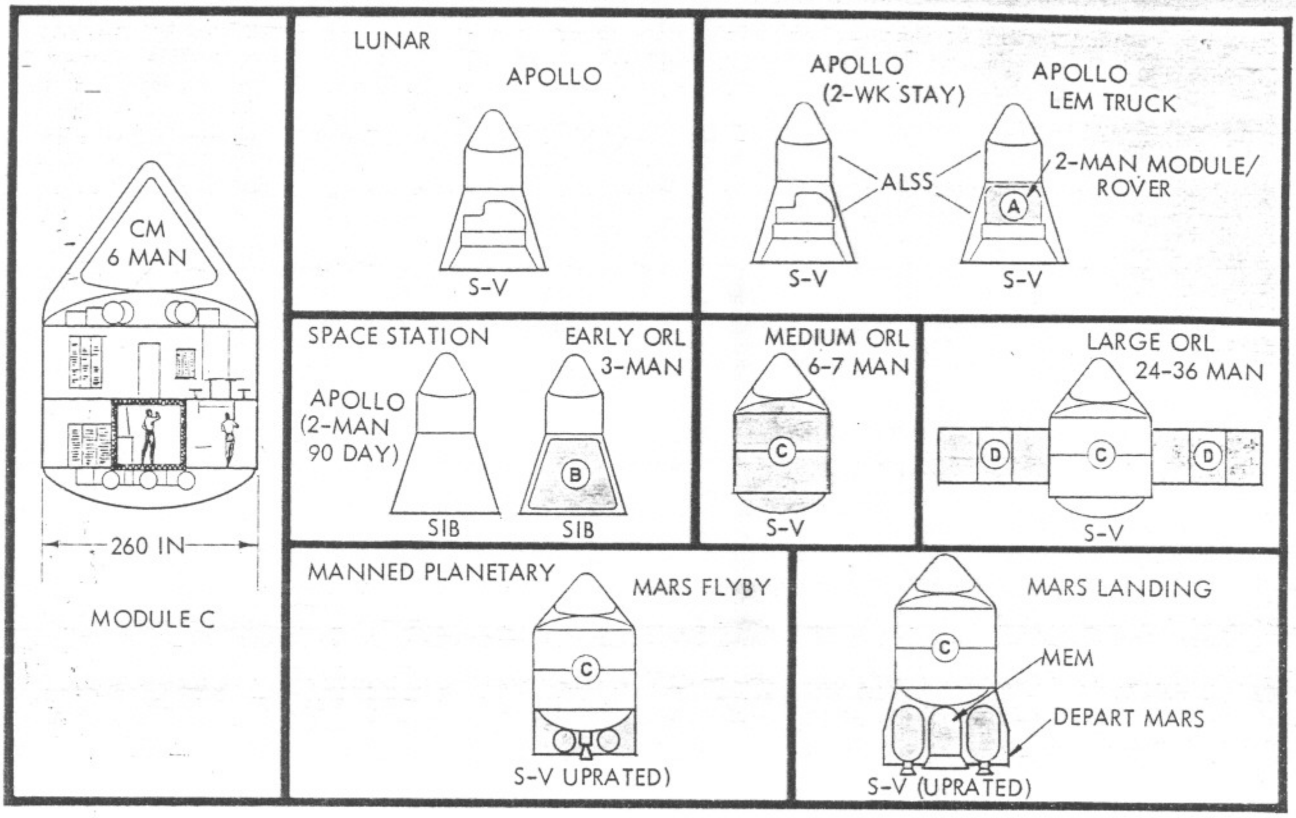
Integrating the Missions. Along with continued exploration of the lunar surface, basic goals of the post-Apollo manned programs would emphasize—

- Early ORL programs, based pri-

ROBERT L. SOHN

head of STL's Technical Requirements Staff, has directed numerous studies of advanced systems, including communication satellites, electrically powered spacecraft, an advanced orbiting solar observatory, launch vehicles, mobile ICBM systems, and, recently, manned Mars vehicles. A graduate of Iowa State Univ. with an M.S. from USC, his 15 years experience in the field includes aircraft, missile, satellite, and spacecraft design work. He lectures in propulsion at UCLA, holds five patents, and has published numerous papers.

POST-APOLLO MANNED MISSIONS—SCHEME FOR INTEGRATION



marily on Apollo adaptations.

• Early manned Mars missions, with short-duration landings, employing equipment and techniques developed during the lunar and ORL programs.

The modules of the three programs could be related as indicated in the illustration at the top here.

The Apollo program, it should be noted, will be followed by extended-stay landings, using the basic Lunar Excursion Module (LEM) equipped for explorations of two to three weeks. The manned lunar landings will be supported by a LEM truck, carrying a two-man life-support module and/or a surface rover. This approach permits considerable exploration of the lunar surface, while introducing the need for only a limited development of new systems. The manned expeditions will, of course, continue to be supported by unmanned flights.

The early manned orbiting research laboratories, based on Apollo, are indicated in the second line in the illustration at the top. Initial launches may be limited to two-man systems incorporating the Apollo command and service modules, capable of remaining in orbit for periods of several weeks. Logistic or ferry support systems would not be required for these early flights. Subsequent versions of the Apollo orbiting research laboratory (AORL) might use the volume in the LEM adapter section, which is adequate for housing and supporting at least a three-man crew. With logistics and crew-rotation support, this module would be capable of operating in orbit for several months. This orbiting research laboratory would be vital for evaluating the reactions of man to extended operations in space and for proof testing the functions of long-duration life-support equipment.

The key new item beyond the early Apollo orbiting research laboratories will be the medium-class orbiting research laboratory. It will draw upon the results of the AORL program and serve as the crucial link between the Earth-orbiting-laboratory programs and the early manned Mars mission. The medium-class orbiting research laboratory (MORL) should be capable with few major modifications, of serving as the main module for the manned Mars mission. It should have a capacity for supporting a six- to eight-man crew for at least a year, with resupply, and be able to demonstrate the operational feasibility of long-duration life support, power, communications, in-flight test and maintenance equipment, and all other systems and subsystems vital to 400-day manned planetary missions. With careful planning, the MORL can serve as a demonstration of the manned interplanetary spacecraft system.

The manned planetary program is indicated in the third line of the illustration at the top. Modules for two missions are shown—a Mars flyby, which may not be necessary if unmanned precursor programs are fully successful, and a Mars landing mission, based on a Mars Orbiting Rendezvous (MOR) mode analogous to that used for the lunar landings. A Mars Excursion Module (MEM) is carried aboard the main spacecraft for the landing. The main spacecraft is derived from the MORL program, with suitable modifications to give subsystems the additional functions and maintenance spares required for the planetary missions.

The chart on page 30 shows a possible schedule for the post-Apollo manned missions. With full utilization of precursor programs, a manned landing on Mars can be made in the early 1980s. Every effort should be bent to achieving landings in the 1980s because launch-propulsion requirements will be at a minimum then.

For close integration with Apollo programs, the manned planetary program must follow these general guidelines in the selection of mission modules, Earth launch systems, and operational modes:

• Apollo-type Earth entry system, suitably modified.

• Medium-class orbiting research laboratory module.

• Saturn V launch system, uprated for greater payload performance.

• Chemical launch systems for initial missions.

• Simple in-orbit assembly techniques for the manned planetary spacecraft.

• Simple, reliable approach to provisions for artificial gravity.

Vehicle Design. The illustration on page 32 depicts an approach to the design of the manned Mars spacecraft that follows these guidelines. The cone-cylinder-flare shape of the vehicle permits an efficient combination of the aero-entry system and various functional systems — crew modules, Mars-excursion modules, Mars-departure stage, and the Earth-entry module. The Earth-departure tank joins the main spacecraft aft. The flared skirt serves to decelerate and stabilize the vehicle during Mars entry and houses the Mars-departure tanks. Hydrogen-fluorine propellants are used in both the Earth-departure and Mars-departure propulsion systems because they have high bulk density (compared to hydrogen and oxygen). The flare shape can generate lift-to-drag ratios up to about 0.4, with appropriate center-of-gravity offset.

This system assumes a partially-closed life support system; water and atmosphere are processed and reused, but food is not. Systems of this type are within the state of the art, and are approximately equal in weight to fully closed ecological systems, which are beyond the state of the art.

Electric-power requirements are about 7-10 kw, which is in the range suitable for solar static (or solar dynamic) power sources. Solar systems, shown on the spacecraft design illustrated on page 32, are competitive in terms of weight and don't have many of the operational problems associated with nuclear systems. A fuel cell can be used as a power source during eclipse in the Earth and Mars orbits.

Engines in the design, selected on the basis of yielding near-minimum spacecraft gross weights with an engine-out condition, are J-2s for Earth departure and RL-10s for Mars departure; conversion to hydrogen-fluorine propellants would offer several advantages.

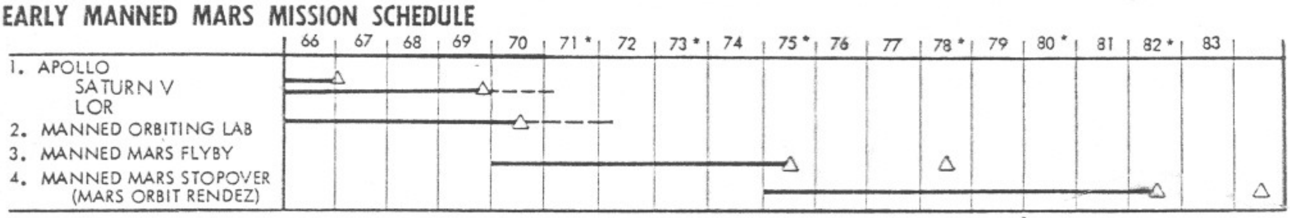
The MEM is designed to land two men on the surface and support their activities for 10 to 15 days. Aerodynamic entry and deceleration in the Mars atmosphere is used for the MEM. Terminal touchdown uses a parachute together with a retrorocket for final braking. A hydrogen-fluorine propulsion stage returns the MEM to orbit.

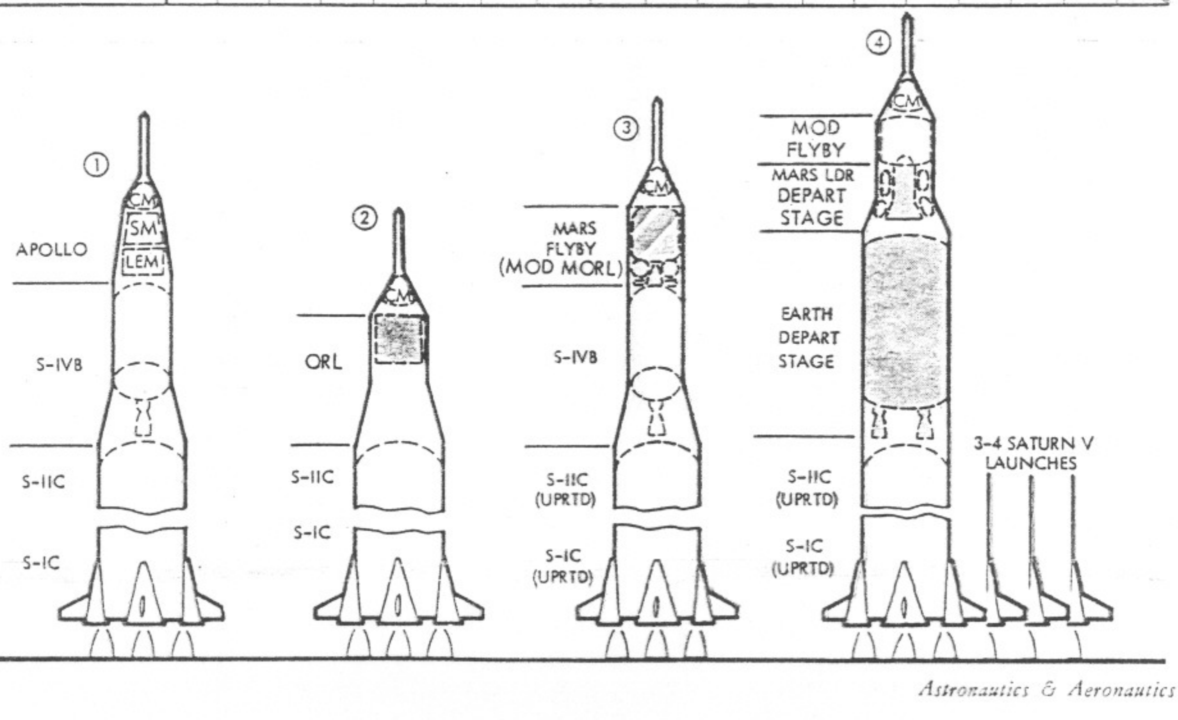
Artificial gravity (1/6 g) during the long transit flight would be provided by spinning the complete vehicle, spent propellant tanks being suspended from the main spacecraft by cables as counterweights. This configuration has been verified for dynamic and long-term stability on a nine-degree-of-freedom computer program developed for space-station analyses at NASA Langley Research Center. One arrangement illustrated on page 32 allows the main mission module to remain intact during transit, so that extensible crew modules are not required.

Aero-Entry. The manned Mars missions are characterized by large propulsion requirements, which lead to large spacecraft weights and formidable requirements for Earth-launch vehicles. Aerodynamic braking at Mars and Earth must be given serious consideration as a means of reducing gross weights. Entry velocities at Mars are not excessive, and can be dealt with by conventional design techniques. Earth-entry velocities, on the other hand, can range up to 70,000 fps during the unfavorable years; this may exceed practical design capabilities.

From a study of aerodynamic capture trajectories in the Martian atmosphere, it was determined that entry corridors of 30 km could be achieved with vehicle lift-to-drag ratios of 0.1.

EARLY MANNED MARS MISSION SCHEDULE





This corridor is more than adequate for present-day navigation systems, and lift-to-drag ratios of 0.2 to 0.3 should be adequate to accommodate uncertainties in the Martian environment. Low lift-to-drag ratio permits a symmetrical vehicle shape, which can achieve the necessary angle of attack by center-of-gravity offset or slight asymmetry of the flare aft. A relatively pointed forebody minimizes radiant heating, which may be a problem if the Mars atmosphere has a relatively high concentration of carbon dioxide. Aerodynamic shielding represents less than 10% of the gross weight of the vehicle entering the Mars atmosphere.

Similar analyses of Earth-entry maneuvers indicate that practical upper limits in terms of usable corridors are reached at 65,000-70,000 fps. Advanced navigation techniques are required at these velocities, even for vehicles with lift-to-drag ratios of 1.0 and above. Although protection against aerodynamic heating does not appear to constitute an insurmountable problem, practical considerations of guidance and control, deceleration loads, and development testing may reduce the upper limits on entry velocity to 50,000-55,000 fps.

Since Earth-entry velocities can range up to 70,000 fps during the favorable missions, retro-brakes must decelerate the module before Earth entry. Since 75-80% of the spacecraft weight is jettisoned prior to entry (with a capsule), over-all weight penalties due to retrobraking at Earth are not completely out of reason.

An alternate mission mode suggested by the author as a general method for reducing Earth-entry velocities for all opportunities would be Venus swingby—using the gravitational field of the planet to reduce Earth-entry velocity below 50,000 fps. The Venus-swingby mode is now receiving considerable study, and appears to have no basic limitations in navigation, launch delay, or other factors.

With this mode, the spacecraft can also be accelerated by the gravitational field of Venus as it passes by the planet on the outbound trip to Mars. This outbound maneuver similarly gives favorable return to Earth, with lower Earth-entry velocities, as outlined in the table at bottom. Making Venus rendezvous before perihelion passage extends trip time to about 500 days. Making rendezvous after perihelion passage extends trip time little. Spacecraft gross weight is essentially unaffected.

In certain cases it is possible to reduce the spacecraft-gross-weight penalty associated with the unfavorable years by proper selection of trajectory paths. In 1980, for example, using a Venus swingby on the outbound leg, total propulsion ΔV (to leave Earth and to leave Mars) is 23,000 fps, which compares with 27,500 fps for the 1971 opportunity and 29,500 fps for an optimum direct mode in 1980. By use of the Venus outbound swingby in 1980, spacecraft gross weight can be reduced by 36% compared to the direct mode in 1980 and by 23% compared to the direct mode in the most favorable year, 1986! Mission duration is extended by less than 16%. Essentially, the Venus-swingby mode approximates a triple Hohmann, in which the gravity field of Venus adds impulse at the intermediate transfer point. Swingby converts the year 1980 from an unfavorable to a very favorable mission.

Navigation. Navigation studies for direct-mode flights from Earth to Mars and return have been completed employing optical and radio onboard-observation models. A 1978 mission was chosen for analysis because of its relatively long duration and characteristicly high entry-velocities. The criteria for evaluating the effectiveness of onboard tracking was cross-range uncertainty at perifocal passage at the target planet. The table on page 33 gives results.

Navigation into the Martian atmosphere is entirely feasible with present-day sensor capabilities. However, navigation into Earth corridors at very high velocities requires an advance in sensor capabilities and/or an integration with the advanced DSIF network. The corridors are rendered more marginal by diurnal variations in the atmosphere and the possible requirement to roll the vehicle during entry.

Launch Vehicles. In this approach to the Mars mission, what will the launch-vehicle requirements be? The chart on page 32 outlines recently computed gross weights of spacecraft in Earth orbit for each mission opportunity commencing in 1980 and extending through 1990, assuming hydrogen and fluorine propellants for both Earth and Mars departures. The gross weights range from 1.33-million lb in the favorable year, 1986, to 1.88-

RELIANCE OF MANNED MARS PROGRAM ON APOLLO AND ORL

Mission Element	Source: Apollo	Source: AORL/MORL	Source: New	Remarks
1. Main Mission Module				
Life-support system		x		Partially closed (water and atmosphere).
Communications		x	x	Advanced data-handling techniques beneficial.
Power		x		Conventional solar arrays applicable, reliable.
Guidance and navigation			x	Close integration with DSIF for Earth entry.
Artificial gravity		x		Requirements and techniques established by ORL.
Propulsion		x		J-2 and RL-10 engines adequate; H_2-F_2 desirable.
Micrometeoroid protection		x		Additional environmental data mandatory.
Nuclear radiation shield		x		Additional environmental data mandatory.
Mars aero-capture			x	Full-scale simulation difficult.
2. Earth Entry Module	x		x	Apollo shape; entry velocities to 50,000 fps.
3. Mars Excursion Module			x	Major new development.
4. Operations				
Mars orbit rendezvous	x			Full-scale simulation during ORL program.
Earth orbit rendezvous		x		Practical for three to five launches. Uprated Saturn V desirable.
Maintenance and reliability		x		Increased Mean Time Before Failure required.
5. Launch vehicle	x			Uprated Saturn V.

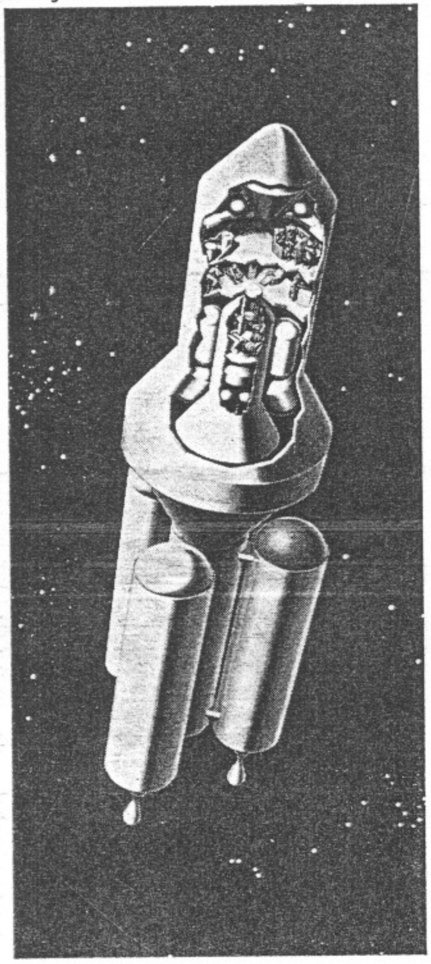
EARTH-ENTRY VELOCITIES WITH VENUS SWINGBY

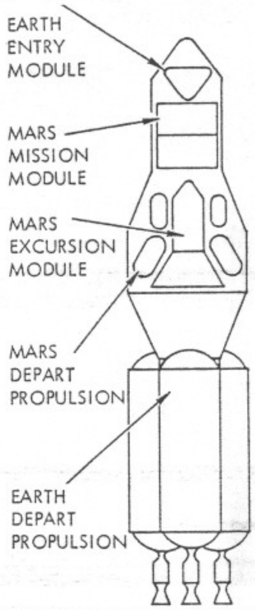
Mission	Earth-arrival Velocity, 10^3 fps: Direct	Earth-arrival Velocity, 10^3 fps: Venus Swingby
1980	66.0	41.8*
1982	58.2	45.8
1984	53.0	44.7
1986	46.9	42.9*
1988	54.0	40.0
1990	64.7	41.9
1993	68.1	44.0*
1995	65.7	44.?
1997	60.2	51.2

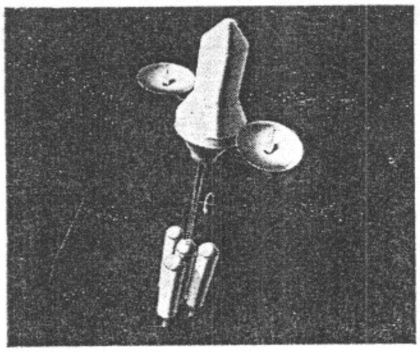
*Outbound swingby; others are return swingby.

EARLY MARS MISSION SPACECRAFT CONCEPT

Sketch identifies spacecraft systems. Top illustration shows configuration at Earth-orbit launch. Illustration below shows rotating configuration after orbital launch to give artificial gravity.

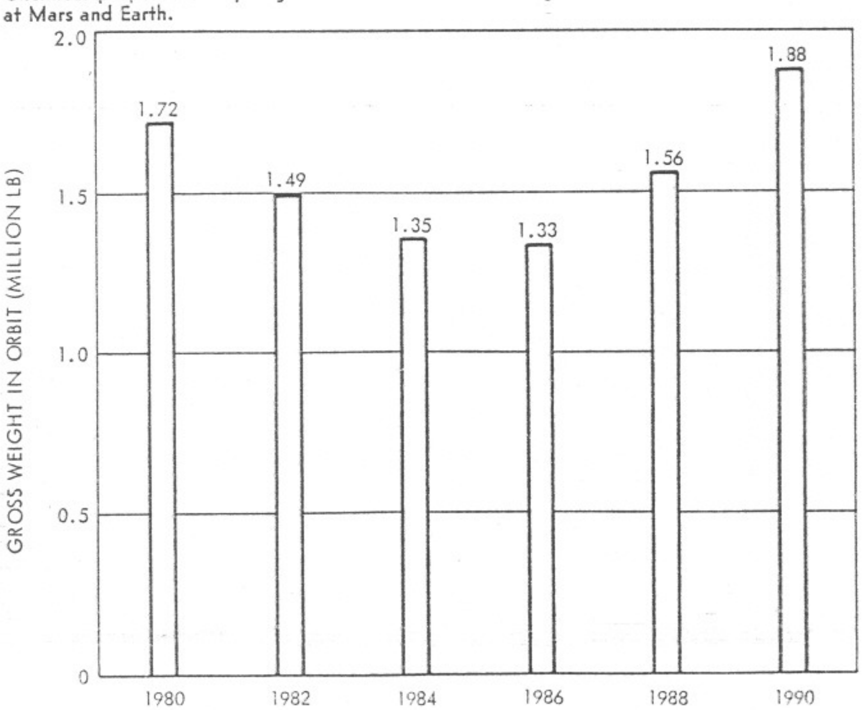






MARS ORBIT RENDEZVOUS MODE CONDITIONS

Chemical propellants: Hydrogen and fluorine. Aerobraking at Mars and Earth.



million lb in the unfavorable years. As can be seen, the 1980 decade is a favorable period for performing the manned Mars mission. The 1984 and 1986 missions are especially attractive.

Assuming that uprating can increase the Earth-orbit payload of Saturn V to about 400,000 lb by the late 1970s, four or five launches of an uprated vehicle will be required to insert the manned Mars spacecraft into Earth orbit—one launch for the mission module plus Mars-departure stage and the remaining launches for the Earth-departure propulsion modules. Fully preassembled propulsion modules, of the kind illustrated at the left, would lessen risks in Earth-orbit assembly operations, as compared with tanker operations and complex construction in orbit. Using developed Saturn S-IVB stages for the propulsion modules would further reduce operational risks.

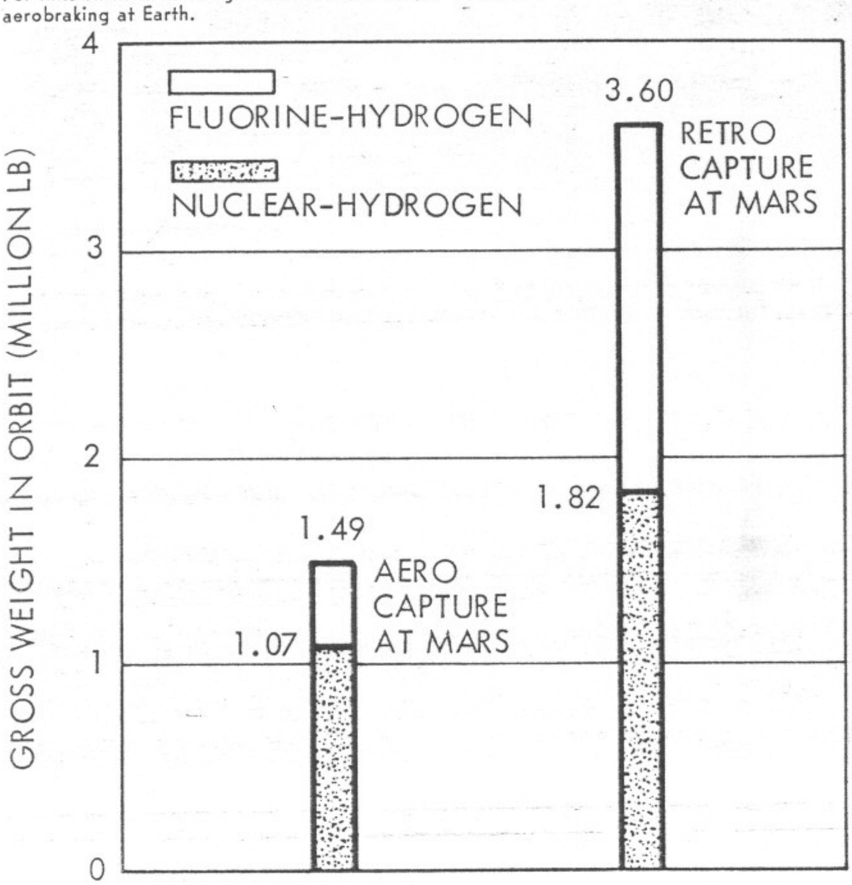
Mission Factors. Aerodynamic braking at Mars constitutes the most important factor involved in meeting these launch-vehicle payload constraints. Using aerodynamic rather than retrorocket braking at Mars can reduce the gross weight of the spacecraft in Earth orbit by a factor of two; and this makes the use of conventional chemical rather than nuclear propulsion practical for the mission, within the payload range of uprated Saturn V. Without aerodynamic braking at Mars, the gross weight of the spacecraft at departure from Earth orbit grows to the point where nuclear or other launch vehicles beyond Saturn V become mandatory. Such an approach would delay the manned planetary mission by at least a decade, disrupting the continuity of the post-Apollo manned program. Fortunately, this will not be necessary.

Although the characteristics of Mars' atmosphere are not completely known as yet (particularly density), aerodynamic braking works for all models of the atmospheres that have been postulated. It is essential to know which model is the correct one, however, because a single spacecraft design cannot accommodate the present range of uncertainties in the Martian environment. Fortunately, Mariner flights to Mars will almost certainly reduce these uncertainties to acceptable limits.

Solid-core nuclear-propulsion systems for Earth departure can reduce the gross weight of the manned Mars spacecraft at Earth departure, as indicated in bar chart on page 33, and should be considered for incorporation into the manned Mars mission before the unfavorable 1990 decade. A nuclear stage for this 1990 decade would

NUCLEAR PROPULSION ADVANTAGE

For mission in 1982 using Mars orbit rendezvous mode with aerobraking at Earth.



eliminate one Saturn V (uprated) launch per mission or permit a larger payload to be transported to Mars.

Concluding Remarks. Assuming successful conclusion of the Apollo program and satisfactory demonstration of man's tolerance to long-duration space missions in our Earth orbiting laboratory programs, I see no basic roadblocks to the manned Mars mission. Substantially improved system reliabilities will be required, but recent studies indicate that this problem can be approached successfully by manned maintenance and repair techniques and judicious provisioning of spares. Aerodynamic braking at Mars appear feasible for the range of atmospheres now considered possible, although it is mandatory to determine the actual atmosphere model before final design of the spacecraft. Testing the entry system under simulated mission conditions may prove difficult. This problem has not been studied completely. Guidance and control into the Mars aerodynamic corridors should not prove difficult. On the other hand, entry into the Earth's atmosphere at 70,000 fps is a difficult guidance task, and may require the use of retro-thrust or a Venus swing-by. In any case, high Earth-entry velocities will not be encountered until the 1990 decade.

The table on page 31 suggests the relation of the equipment of Apollo and the orbiting laboratories to manned Mars flight, and indicates how extensively such a program can be built on preceding development.

This approach to the manned Mars mission, drawing heavily on Apollo and ORL equipments, will permit mounting the manned planetary mission early in the 1980s. ••

NAVIGATION IN THE MARS MISSION

Based on DSIF near Earth and Star/Sun sensor system near Mars.

	Tracking uncertainty, km	Corridor, km
Earth-Mars		
Star/Sun sensors	0.9 (1σ)	5.4 (3σ)
Star/Star sensors	0.2	1.1
Mars-Earth		
Star/Sun sensors	3.4 (1σ)	20.4 (3σ)
Star/Star sensors	0.7	4.2
DSIF (at 210 days)	0.67	4.0
Correction velocities		
Earth-Mars	345 fps (3σ)	
Mars-Earth	300	
	645	