Early Manned Exploration of the Planets

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This paper outlines a means of performing early manned flyby and stopover missions to Mars and Venus with chemical propulsion and the Saturn V booster. With conventional mission modes, these missions have high and varying initial mass requirements. By using an alternative mission mode, these mass requirements can be stabilized and reduced to within the launch capability of two Saturn V boosters for most launch opportunities, and such commonality between all Mars and Venus missions can be provided that a single spacecraft with clustered off-the-shelf propellant tanks and engines can be devised. The alternative mode is based on round-trip flybys with the planetary stopover being performed by a relatively small excursion module which separates from the spacecraft prior to the flyby and later rendezvous with it during the flyby. This concept eliminates the planetary capture and escape maneuvers for the basic spacecraft and thus saves gross amounts of propellant. This concept could reduce the cost of early manned planetary exploration by a large percentage, compared to the presently planned development of a nuclear rocket, a shuttle vehicle for launch to orbit, and the associated program for orbital assembly.

Introduction

In recent months there has been renewed governmental interest in the area of manned planetary exploration, and plans are being formulated for the post-Apollo space activities. These activities include the erection of an orbital space station, the development of a reusable space shuttle, the development of a space station module (many of which will comprise the space station), development of a space tug, and later the development of a nuclear shuttle to be used from Earth orbit to synchronous orbit and to the moon. Finally, these developments will be used to formulate the basis of an interplanetary vehicle for a manned landing on the surface of Mars in 1986. The proposed mission will require a total duration of about 680 days with 80 days at Mars. This is a very ambitious plan for early exploration and will probably require well over 100 billion dollars up to the first Mars trip. It may be advisable to undertake less ambitious and less costly exploration until it is established that extensive exploration is desirable.

The sophisticated hardware developments stem from the basic energy requirements of the mission mode envisioned. This paper shows how alternative modes can be used to such advantage that a complete system of manned missions to Mars and Venus can be performed with chemical propulsion and the Saturn V booster, simultaneously eliminating any requirement for Earth orbital assembly.

Analysis

This paper summarizes and extends the prior work by the author on alternative mission modes.[1–6] All missions are assumed to be manned, with the objective planets being Venus and Mars. These missions include both round-trip flybys and orbital stopovers. For the stopovers, the stay time is ten days.

A range of opposition and conjunction years was chosen such that the entire range of energy requirements would be included. For Mars, the opposition years are 1971, 1973, 1975, 1978, and 1980, thus representing at least half of the 17-yr cycle for Mars. Similarly, the Venus conjunction years are 1972, 1974, 1975, 1977, and 1978, representing the 8-yr cycle for Venus. These years are not suggested launch dates, but were chosen since much previous work has been performed for them.

Energy Requirements

The energy requirements for the various mission modes and operations are derived from a trajectory program which considers the eccentricities and mutual inclinations of the planetary orbits of concern. Transfer trajectories are computed as a three-body problem. The velocities are computed as hyperbolic excess velocities and are then converted to ΔV's by considering the planet's physical characteristics and the selected planetary parking orbits.

For ballistic flybys, only an Earth-escape impulse is required. Two types of multiple-impulse flybys are considered: powered flybys,[1] which require an Earth-escape impulse plus an additional impulse at the target planet to define a valid return trajectory to Earth, and flybys that employ a major midcourse maneuver on the outbound leg.[2] The latter maneuver allows a low Earth-escape ΔV and a ballistic return to Earth after the midcourse maneuver. These flybys are optimized by minimizing the sum of the Earth-escape and target or midcourse ΔV's.

The energy requirements for standard stopovers are also minimized by selecting the characteristic dates such that the

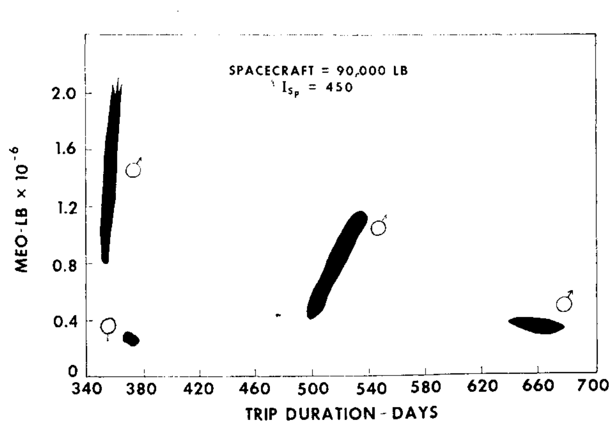

Fig. 1 **Operational domains for Mars and Venus ballistic flybys.**

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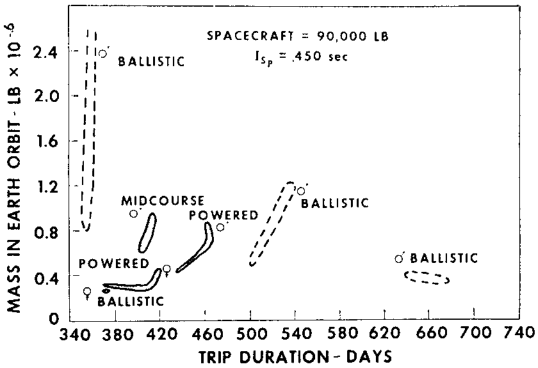

Fig. 2 Operational domains for Mars and Venus flybys.

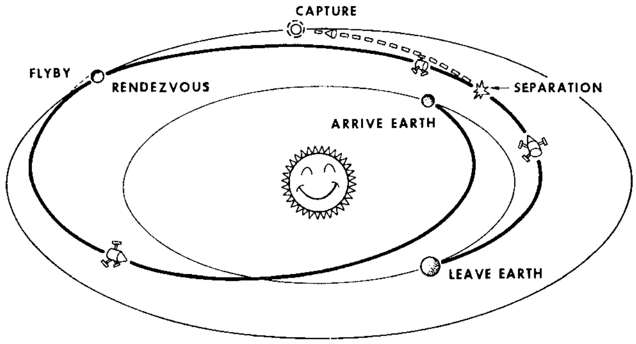

Fig. 4 Flyby-landing excursion mode.

sum of the Earth-escape, planetary-capture, and planetary-escape ΔV's are minimized. The energy requirements for the unique alternative mission mode, the Flyby-Landing Excursion Mode (FLEM),[3] are determined by integrating the excursion module stopover ΔV's, separation ΔV's, and Earth-escape ΔV's. Since the FLEM uses flybys as the basic mode, optimal flyby trajectories are determined for FLEM applications.

Hardware Definitions

Since this study is concerned with the potential use of Saturn V boosters and existing chemical propulsion for manned interplanetary missions, a hypothetical spacecraft is defined to establish a baseline vehicle from which perturbations can be performed. This spacecraft was formulated from its major subsystems, as shown in Table 1. The dry spacecraft weight is then assumed to be 60,000–90,000 lb. The planetary excursion module (PEM) weighs 10,000 lb (dry). This vehicle provides no artificial gravity since the total time away from the spacecraft is only 60–90 days. It provides for a three-man crew.

All stages use LOX/H_2 with an I_{SP} of 450 sec. The tank inerts are defined in Ref. 4.

Discussion

Flybys

Manned ballistic flybys of Mars and Venus, unlike our unmanned Mariner flybys, cannot utilize the minimum-energy approach. Rather, these missions are determined by unique sets of launch dates, flyby dates, and flyby distances which define the energy requirements.[5] For the Mars case, there are three distinct classes of trips (Fig. 1) whereas for Venus one can establish one region of desirable missions (lower left corner of Fig. 1).

One class of Mars flybys requires an MEO (mass in Earth orbit) of only 300,000–400,000 lb, but the trips are nearly two years in duration. This is the class that NASA proposed for a post-Apollo activity. Besides the long duration, the aphelions of these flybys extend well into the "asteriod belt." Also, the flyby velocities are quite high, thus greatly complicating the soft landing of a probe and its subsequent retrieval, as suggested. The second class of Mars flybys has durations of ~1.5 yr, with the desirable MEO's occurring in 1971 (1988, etc.). The third class requires only a year to complete, but how do you put 10^6 lb in orbit?

The Venus flybys are the most attractive, with 1-yr durations and total mass requirements of about 250,000 lb for all conjunction years, which suggests use of a single Saturn V launch vehicle. Moreover, powered flybys offer no mass or duration reduction, because the Venus ballistic flybys depart Earth very near the minimum-ΔV regions.

In contrast, multiple-impulse Mars flybys offer large advantages over ballistic flybys (Fig. 2). The powered flybys reduce the mass requirements drastically in the unfavorable years while reducing the trip durations by about 90 days for all years. The midcourse flybys have even shorter durations, saving another 40 days, but the MEO's are somewhat higher in the favorable years.

Stopovers

Inherently, planetary stopovers require more initial mass than flybys, and they have appeared beyond the capability of chemical propulsion. It has been suggested that nuclear propulsion will be required. As a point of reference, Fig. 3 compares the mass requirements for Mars and Venus 10-day orbital stopovers. If one assumes that circular parking orbits are used at the planets, the MEO's for Mars will vary between 2 and 6 million pounds, whereas comparable Venus missions require $2\frac{1}{2}$ million pounds. Not only does the magnitude of the mass requirements support the nuclear argument, but the wide variation for Mars makes it difficult to plan a space

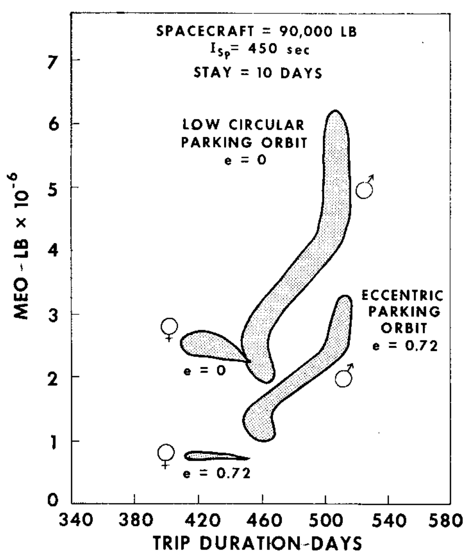

Fig. 3 Operational domains for Mars and Venus standard stopovers.

Table 1 Major spacecraft components

Command module (entry vehicle)	18,000 to 30,000 lb
Service module	7,000 to 10,000 lb
Life support (5 men)	11,000 to 20,000 lb
Power supply (8 kw)	1,500 to 3,000 lb
Structure	8,500 to 10,000 lb
Solar shelter	11,000 to 13,000 lb
Miscellaneous	3,000 to 4,000 lb
Totals	60,000 to 90,000 lb

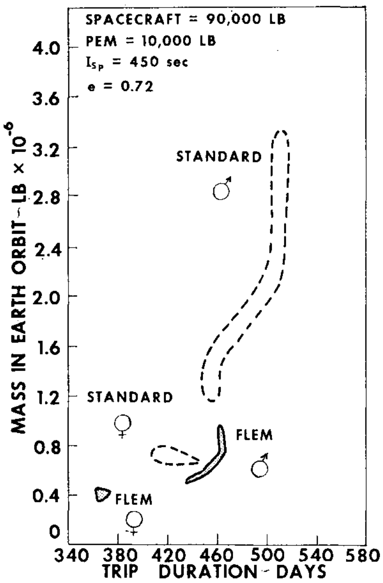

Fig. 5 Operational domains for Mars and Venus stopovers.

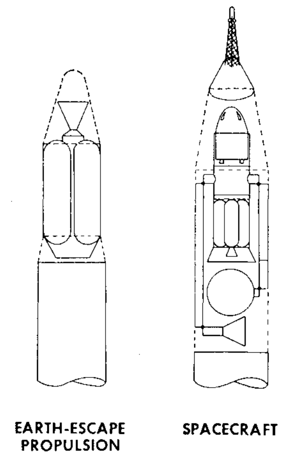

Fig. 7 Dual launch to orbit.

program for *all* years. However, use of elliptical parking orbits can reduce the ΔV or MEO requirements (Fig. 3). With a parking orbit eccentricity e of 0.72 and a pericenter distance of 1.1 planet radii, the mass requirements are reduced 40% to 45% for Mars and about 70% for Venus. The larger sensitivity for Venus reflects its larger mass. With these parking orbits, Venus trips now require 700,000 to 800,000 lb, whereas the best Mars year requires 1,000,000 lb. Even though these weights are relatively low, it would still require a larger number of Saturn V launches to place the spacecraft in orbit, to say nothing of the required assembly and fabrication.

Further reductions in mass requirements are possible using FLEM (Fig. 4), which uses round-trip flybys as the basic trajectory. Prior to the planetary encounter, an excursion module (PEM) separates from the parent craft and proceeds ahead to the planet where it establishes a parking orbit and performs the scientific experiments. At the end of a predetermined stay time, the parent craft arrives on its original flyby trajectory. The excursion module departs the planet and performs a hyperbolic rendezvous with the parent craft for the return to Earth. Because only the PEM performs planetary operations, MEO is greatly reduced as compared to standard stopovers (Fig. 5). The FLEM, using powered flybys, reduces the MEO from 3,300,000 lb to 1,000,000 lb for Mars missions in the unfavorable years and from 1,100,000 to 520,000 lb in the favorable years. The MEO's for the Venus case also are halved. It now appears that many Mars and Venus missions are within the capability of two Saturn V launches, especially in uprated versions.

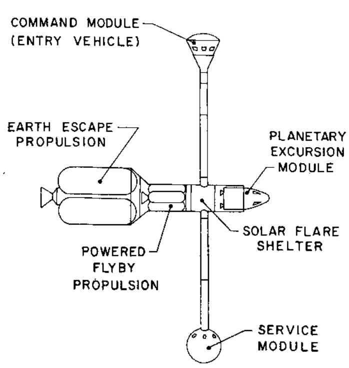

Fig. 6 Basic spacecraft concept.

Booster Capability

Presently, Saturn V can orbit a payload of 206,000 to 242,000 lb, depending upon orbital inclination. If high-pressure (H.P.) engines are used in the SII and SIVB stages, this payload can be increased to 277,000 to 320,000 lb. Finally, with the addition of uprated F-1 engines in the SIC stage, the payload is 332,000 to 380,000 lb.

Upon examining the mass breakdown of each transportation system, it was determined that a logical interface is between the Earth-escape stage and the remainder of the vehicle. Now, the Earth-escape stage can constitute the payload for a second Saturn V. The entire vehicle can now be readied in Earth orbit by two Saturn V launches with a subsequent rendezvous and docking at the interface juncture; thus, all *orbital assembly* is eliminated.

Spacecraft Concept

In analyzing the mass breakdown of the transportation system and the capability of launch boosters, it is desirable to formulate a conceptual spacecraft to enable one to determine the physical size of the systems and to determine the stowability for Saturn V application. Figure 6 is a concept of the basic spacecraft required for a Mars stopover mission using the FLEM concept. This particular configuration shows the Earth-escape propulsion mated to the spacecraft ready for launch. The command and service modules can be partially retracted for launch to reduce the effects of acceleration on the connecting transport arms. It is intended that this basic spacecraft will suffice for all Mars and Venus flybys and stopovers. For Venus stopovers, the powered flyby propulsion is eliminated since ballistic flybys are used

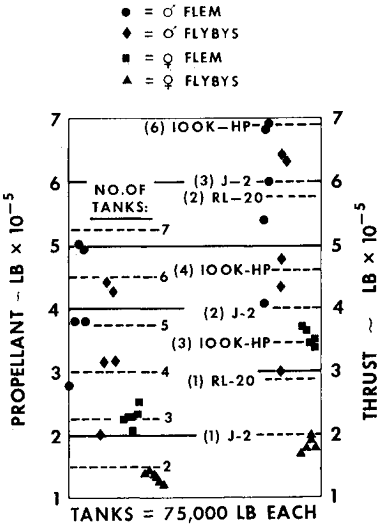

Fig. 8 Earth-escape propellant requirements.

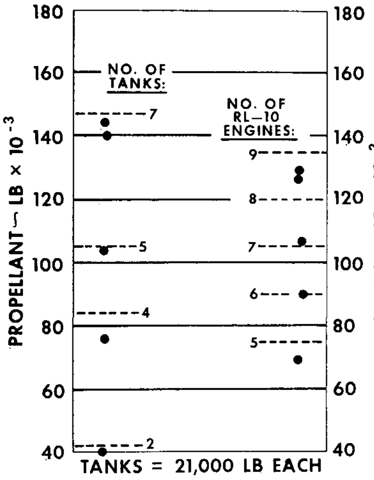

Fig. 9 Requirements for powered-flyby stages.

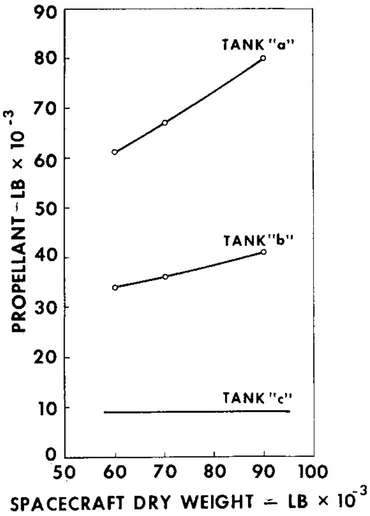

Fig. 11 Propellant tank capacities.

with FLEM. Likewise, for Mars flybys the powered-flyby stage is retained, whereas Venus flybys would require only the basic spacecraft plus the Earth-escape stage.

Figure 7 illustrates the concept of the double launch for placing the transportation system into Earth orbit. The left side shows the Earth-escape stage mounted on a Saturn V with aerodynamic fairings for the ascent phase. On the right, the spacecraft is stowed for launch on a Saturn V. During launch, the crew occupies the command module which is fitted with the launch-abort rockets. The transport arms are folded to allow an aerodynamically clean upper stage configuration, aided by appropriate fairings.

Once in orbit, the fairings are jettisoned, the transport arms are erected, and the command module is rotated into the receptical at the end of one arm. After systems checkout, the rendezvous is made with the Earth-escape stage which is stabilized by command from the spacecraft. The docking maneuver is performed, which includes an automatic locking and aligning sequence. Again systems check-out is performed, and the vehicle is readied for the Earth-escape phase.

Propellant-Tank Commonality

The computer program used for the mass calculations is designed to optimize each propulsive stage. Gravity losses are computed for those maneuvers which are performed within the domain of a gravitational field. The propellant weights and stage inert weights are determined along with the optimum initial acceleration to minimize gravity losses. The corresponding thrust levels and engine weights are also computed. To tailor each hydrogen and oxygen tank for each propulsive maneuver for each mission to each planet would necessitate customs sizing and fabrication, and result in high design and fabrication costs. It was determined, upon examination of the entire spectrum of propulsive requirements, that the propellant tank capacities could be grouped to represent all mission requirements by selecting a few basic sizes and clustering to provide the total requirement. Figure 8 presents the Earth-escape propellant requirements for all of the candidate Mars and Venus missions utilizing the 90,000-lb spacecraft. It is now assumed that, instead of fabricating many customsized tanks, only tanks with a 75,000-lb capacity will be manufactured. Thus, the advantages of volume production will be realized.

To perform Venus ballistic flybys, two such tanks will suffice; for Venus stopovers, 3 tanks; and for Mars stopovers in the unfavorable years, 7 tanks. The thrust required can also be treated in a manner similar to tank sizing. Figure 8 also illustrates that the thrust required for Venus flybys can be provided with a single J-2 engine of 200,000 pounds thrust, whereas combinations of Pratt & Whitney's 100 K-HP engine can be used for various other missions. Pratt & Whitney's RL-20 engine performance is also shown for reference.

Clustering of existing engines and propellant tanks of 75,000-lb-capacity each can fulfill the Earth-escape requirements for all missions. For some missions, extra propellant will be available due to this modular concept. However, this excess can be used to broaden the launch windows.

Figure 9 presents the propellant and thrust requirements for the powered flyby stage used for Mars missions. Again, combinations of tanks containing 21,000 lb of propellant will suffice for all missions. The engines shown are Pratt & Whitney's RL-10 A-3 units, clustered up to nine for the unfavorable years. The excursion-module propulsion consists of the planetary capture and escape stages. Assuming individual staging for these maneuvers, the tank sizes are as

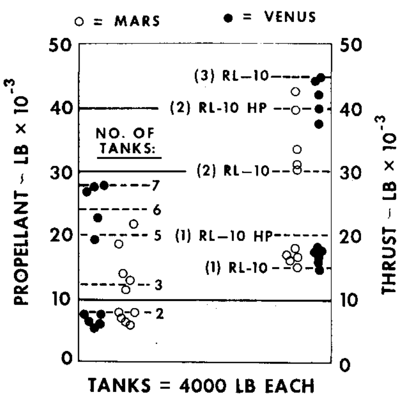

Fig. 10 Stage requirements for planetary excursion module.

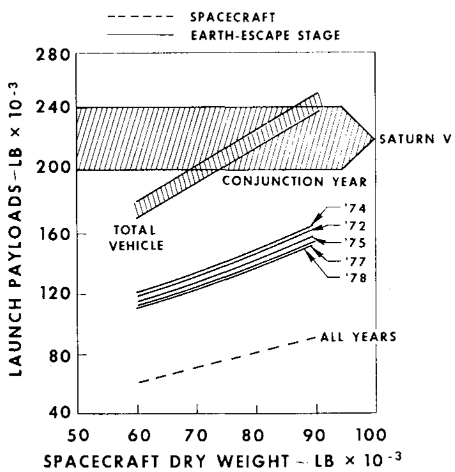

Fig. 12 Saturn V payloads for Venus flybys.

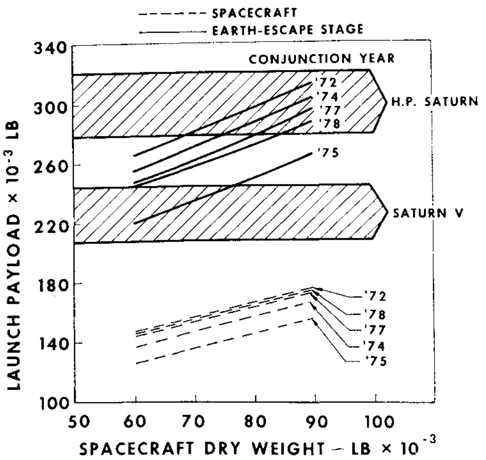

Fig. 13 **Saturn V payloads for Venus stopovers.**

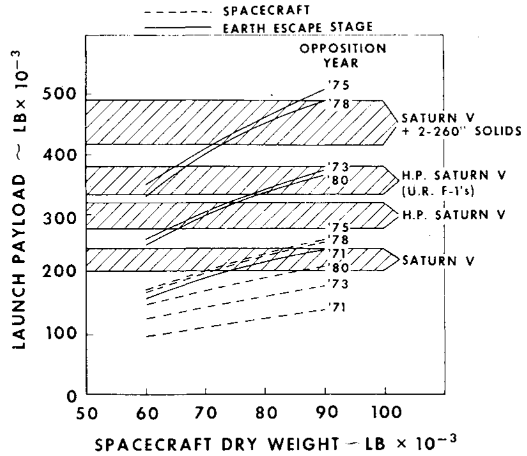

Fig. 14 **Saturn V payloads for Mars flybys.**

shown in Fig. 10. Here, combinations of tanks containing 4000 lb of propellant are used along with RL-10 or up-rated RL-10 engines. In practice, the excursion module maneuvers may be performed by restart of a single propulsion source, thus eliminating the staging between maneuvers. For this case, the propellant tanks and thrust levels would be combined and re-defined.

It is conceivable that a single spacecraft can be designed to perform all Mars and Venus flybys and stopovers outlined herein, while incorporating the modular concept for the propulsive units and engines.

Figure 11 presents the variation of the propellant tank capacities with spacecraft dry weight. Because of the increased inert weights associated with the clustering of tanks to achieve a given total capacity, the size of each tank must be slightly increased as reflected in this figure.

One can then catalog the propellant tank requirements for all missions to Mars and Venus as shown in Table 2. For each opposition or conjunction year, the requirements are immediately defined. By the proper clustering of tanks and engines, one can assemble the propulson units with "off-the-shelf" ease and economy.

Payload Requirements

The final Saturn V payload requirements are illustrated in Figs. 12–15 for Mars and Venus flybys and orbital stopover missions. The over-all applicability of the Saturn V booster to Mars and Venus exploration is illustrated in Table 3 for the 90,000-lb spacecraft. The Saturn V will suffice for 55% of all launch requirements, whereas an uprated version will suffice for another 30%. Thus, 85% of all launches of the spacecraft and the Earth-escape stage can be accomplished with Saturn V. The remaining 15% would require a larger booster, such as the strap-on concept. The S1-C first stage can be off-loaded and fitted with two-260-in. solid-propellant rockets. This combination would raise the payload capability to almost 500,000 lb.

For the 60,000-lb spacecraft, Saturn V could fulfill 93% of all launch requirements.

Long-Range Program

The use of alternative mission modes could greatly influence the planning of a national space program. Powered flybys and midcourse flybys provide missions of 400–460 days, whereas comparable ballistic flybys require 500–540 days or 640–680 days, depending upon the class chosen. More important may be the way the total ΔV requirements vary throughout the years. Since Mars' orbit is relatively eccentric, the total variation in the propulsion requirements is considerable; multiple-impulse flybys tend to minimize this variation. For planetary stopovers to Mars, the use of the FLEM concept greatly reduces MEO requirements and the variation with opposition year. Now one can plan missions for most any opposition or conjunction year.

Figure 16 presents a typical launch schedule encompassing Mars and Venus missions between 1975 and the year 2000. Since the stopovers use flybys with the FLEM concept, this schedule will suffice for both manned flybys and stopovers. Venus opportunities occur every 19 months, whereas trips to Mars can be initiated every 25 months. Since the Venus trips are about 12 months in total duration, 7 months would be available between the termination of one flight and the initiation of the next. For Mars, this time lapse would be about 10 months, thus providing time for debriefing, scientific analysis, data reduction, etc., for all missions to a given planet.

Conclusions

1) The FLEM concept of planetary stopovers is a very effective means of reducing the initial mass requirements, due to performing the planetary operations with a minimal size vehicle while the main spacecraft is on a flyby trajectory.

2) The FLEM concept, coupled with eccentric planetary parking orbits, reduces the initial mass requirements for Mars

Table 2 Clustering requirements

	Spacecraft dry weight = 90,000 lb																			
	Mars stopovers					Mars flybys					Venus stopovers					Venus flybys				
	71	73	75	78	80	71	73	75	78	80	72	74	75	77	78	72	74	75	77	78
Depart Earth	4a[a]	6a	7a	7a	6a	3a	5a	6a	6a	5a	7b	7b	6b	7b	7b	4b	4b	4b	4b	4b
Flyby planet	1b[b]	2b	4b	4b	3b	1b	2b	4b	4b	3b	—	—	—	—	—	—	—	—	—	—
Capture planet	4c[c]	2c	2c	2c	3c	—	—	—	—	—	6c	6c	5c	6c	6c	—	—	—	—	—
Depart planet	1c	1c	1c	1c	1c	—	—	—	—	—	1c	1c	1c	1c	1c	—	—	—	—	—
Separation	Included in capture stages																			

[a] = 80,000-lb tank.
[b] = 41 000-lb tank.
[c] = 9000-lb-tank.

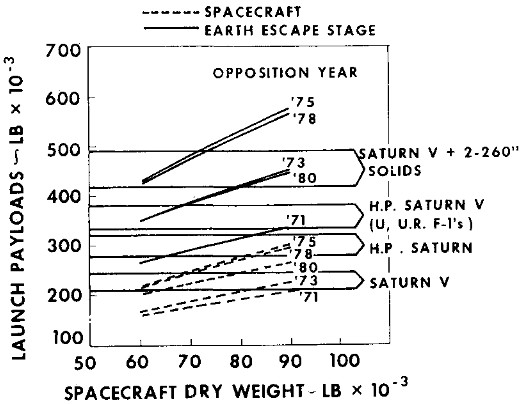

Fig. 15 Saturn V payloads for Mars stopovers.

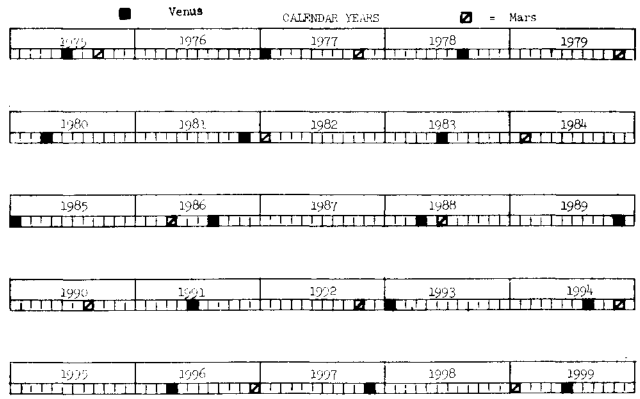

Fig. 16 Interplanetary launch schedule.

and Venus missions to within the launch capability of two Saturn V rockets or up-rated versions thereof.

3) The breakdown of the initial mass requirements is such that the Earth-escape propulsion can constitute the payload for one Saturn V, while the spacecraft constitutes the payload for the second booster. This concept then allows the entire interplanetary transportation system to be placed in orbit and readied for Earth escape by a simple rendezvous and docking maneuver, thus eliminating in-orbit assembly and fabrication.

4) The use of clustered propellant tanks and engines of specified sizes eliminates the need for custom design and fabrication for each mission, thus greatly reducing the costs of the space program, while providing "off-the-shelf" building block simplicity.

5) Saturn V rockets in the existing version could provide for a large percent of the launches required for Mars and Venus flybys and stopovers. In an up-rated version, these percentages increase to encompass most all missions. Saturn V with two-260-in. solid propellant strap-ons will provide the launch capability for the remainder of the missions.

6) A national space program could be formulated and implemented at an early date, using existing propellants, engines, launch boosters, and overall technology. This approach would allow inexpensive early exploration to determine the feasibility and practicability of extensive planetary exploration.

Table 3 Launch vehicle summary

PLANETARY FLYBYS

W_{SC} = 90,000 LB w_{PEM} = 10,000 LB I_{SP} = 450 SEC

	MARS		VENUS		
OPPOSITION YEAR	EARTH ESCAPE PROPULSION	EARTH ESCAPE PAYLOAD	EARTH ESCAPE PROPULSION	EARTH ESCAPE PAYLOAD	CONJUNCTION YEAR
1971	S V	S V	S V	S V	1972
1973	H.P S V	S V	S V	S V	1974
1975		H.P. S V	S V	S V	1975
1978		H.P. S V	S V	S V	1977
1980	H.P. S V	S V	S V	S V	1978

PLANETARY ORBITAL STOPOVERS

	MARS		VENUS		
OPPOSITION YEAR	EARTH ESCAPE PROPULSION	EARTH ESCAPE PAYLOAD	EARTH ESCAPE PROPULSION	EARTH ESCAPE PAYLOAD	CONJUNCTION YEAR
1971	H.P. S V	S V	H.P. S V	S V	1972
1973		S V	H.P. S V	S V	1974
1975		H.P. S V	H.P. S V	S V	1975
1978		H.P. S V	H.P. S V	S V	1977
1980		H.P. S V	S V	S V	1978

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