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Chapter 1

EMPIRE: Background and Initial Dual-Planet Mission Studies*

Frederick I. Ordway, III,† Mitchell R. Sharpe,‡ and Ronald C. Wakeford**

Introduction

For millennia Mars has intrigued man. Not only does it move across the skies and thus differ from the apparently "fixed" stars, but it exhibits a distinct reddish color. In *Scipio's Dream* published in 52 B.C. by Marcus Tullius Cicero, the sleeping hero tells of the "seven globes" beneath the sphere of the heavens including Mars "gleaming red and hateful." A thousand years later, Robert Anglicus would describe it as being "of hot and dry nature which consumes by burning."

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* Presented at the Twenty-Fourth History Symposium of the International Academy of Astronautics, Dresden, Germany, 1990. Note: This being an historical essay, the units employed are those from the original documents. All books, reports and journals listed in the references at the end are located with the Ordway Collection, U.S. Space & Rocket Center, Huntsville, Alabama, U.S.A.

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Like the ancients, modern man is attracted to the planet but for rather different reasons: he wants to *go there*. But why? What is it that makes Mars the target of our ambitions?

Mars Studies

For one thing, it is not too far away: astronomically speaking, Mars is the next planet out from the Sun after our Earth. Also, it possesses a thin atmosphere, something our Moon clearly lacks. Moreover, the Martian atmosphere is generally transparent so we can make out surface markings and speculate as to their nature. Although its diameter is only half that of Earth and its surface area a little more than a quarter of ours, since Mars has no oceans there is actually more land area to explore there than on our own world. It is the combination of being relatively close to Earth, possessing an atmosphere of sorts, and revealing a varied, interesting, and extensive surface that leads us to look upon Mars with keen exploratory interest.

The nature of the Martian surface has long intrigued astronomers and laymen. The earliest drawings based on telescopic observations are attributed to the Italian observer Francisco Fontana. In 1636, he described "the disk of Mars [as] not uniform in nature, but it appears fiery in the concave part." A couple of years later, he found that the planet exhibited a gibbous phase, characteristic of a planetary body revolving around the Sun as seen from Earth. Then, in 1659, with an improved telescope, Christian Huygens discovered a major feature on Mars, the *Syrtis Major*. His drawings included the south polar cap as well. The famed Dutch scientist also demonstrated that Mars rotates around a north-south axis much like the Earth. Several years later, Giovanni Domenico Cassini confirmed the rotation and determined that the Martian day is 24 hours 40 minutes long, remarkably close to the modern value of 24 hours 37 minutes 22.6 seconds.

William Herschel repeatedly observed Mars between 1777 and 1783, and worked out—among other things—its axial inclination (23.98 degrees) and the fact that the planet's atmosphere is at best very tenuous. During the following century, remarkable drawings were made by Wilhelm Beer and Johann H. von Madler in Germany, by the Reverend William R. Dawes in England, and by many others. In 1867, the British astronomer and author Richard A. Procter published a map based on observations made to that date, and provided names for numerous features.

About a century ago, long-smoldering debates on the possibilities of intelligent life beyond planet Earth began to heat up. They were given impetus from reports published in 1877 by the Italian astronomer Giovanni Virginio Schiaparelli.[1]

When Mars approached Earth during the late summer opposition of that year, the respected observer—using a relatively small 22-centimeter telescope at the Brera Observatory in Milan—detected a network of fine lines on the planet. He termed them *canali*, which meant simply channels or grooves. The curious markings were seen—and reported—during the subsequent oppositions of 1879-1880 and 1881-82. The Italian astronomer studiously avoided any suggestion that the canal-like markings were other than naturally occurring geographic features.

For a while, no one else could detect them. Then, in the spring of 1886, they were reported by H. C. Wilson at the Cincinnati Observatory and Henri J. A. Perrotin of the Nice Observatory. But others, try as they might, never did see the Schiaparellian markings.

One fervent believer in *canali* not as channels or grooves but as the handiwork of intelligent beings was the French astronomer and popularizer Camille Flammarion.[2] "The considerable variations observed in the network of waterways," he suggested, "testified that this planet is the seat of an energetic vitality" (by which he meant intelligent beings). *Canali* were beginning to be described as artificially constructed *canals*.

All of this attracted the attention of Percival Lowell, member of one of America's most famous and wealthy families and a man well trained in science. During the years following Schiaparelli's discovery of *canali* on Mars, Lowell became increasingly interested in the growing debate as to their true nature. When, during the course of a trip to Japan in 1892-93, he learned that Schiaparelli was giving up observing due to his failing eyesight, Lowell resolved to carry on his work.

His first task was to build and outfit a brand new observatory, one dedicated in large part to the study of Mars. Lowell wanted it ready for operation within a year—by October 1894—when the red planet would come into favorable opposition for viewing. He selected a site on the high Coconino Plateau near Flagstaff in the Arizona Territory. Then, with the help of associates and equipment from Harvard and elsewhere, he began construction. By late spring 1894, several months before the October opposition, he was ready.

As he trained his telescope on Mars, *canali* appeared not by the tens but by the hundreds! Some were single, others were double; some long, some not so long. Since the lines crisscrossing Mars were straight, argued Lowell, they could not be the result of random geological processes.[3] Then, too, he found them to be individually of uniform width, something unlikely in nature. He felt that, insofar as is known, physical processes do not give rise to "perfectly regular results; that is, results in which irregularity is not also discernible."

Lowell was especially drawn to what he called oases, which were " . . . not innocent of design. . . . For here in the oases we have an end and object for the existence of the canals, and the most natural one in the world, namely that the canals are constructed for the express purpose of fertilizing the oases. . . . The canals rendezvous so entirely in defiance of the doctrine of chance because they were constructed to that end. They are not purely natural developments, but cases of assisted nature."

Despite Lowell's intriguing theories, with the passing years, doubts about his canals grew. It was not until the advent of the Space Age, however, that their existence was finally shown to be illusory. Though the canal debate may seem to us to have been a waste of energy, there was a positive side to the whole affair, one well expressed by R. L. Waterfield in his *A Hundred Years of Astronomy*, published in 1940. "Now the story of the 'canals' is a long and sad one," he wrote, "fraught with backbitings and slanders; and many would have preferred that the whole theory of them had never been invented. Yet whatever harm was done was more than outweighed by the tremendous stimulus the theory gave to the study of Mars. . . ."[4]

Deliberations by Wernher von Braun

Wernher von Braun was one of many to feel this stimulus. It came to him by reading the scientific literature and press accounts of it, as well as by an occasional foray into science fiction. In an environment shaped partly by science, partly by exaggerated faith in an idea, and partly by writers of such fiction, he pondered how man might fly to other worlds. When he was brought to the United States from Germany following the end of World War II, he found the opportunity to put his thoughts on paper.[5] During spare time at Fort Bliss in Texas and the nearby White Sands Proving Ground in New Mexico, he developed plans for the manned exploration of Mars. The result: *Das Marsprojekt*, which appeared in 1952 in a special issue of the German journal *Weltraumfahrt*.[6] The following year, the work came out in English as *The Mars Project*, published by the University of Illinois Press.[7]

Von Braun warned his readers that space travel is an incredibly complex enterprise, one that "can be only achieved by the coordinated might of scientists, technicians, and organizers belonging to very nearly every branch of modern science and industry." He proceeded "to explode once and for all the theory of the solitary space rocket and its little band of bold interplanetary adventures. No such lonesome, extra-orbital thermos bottle," he predicted, "will ever escape Earth's gravity and drift towards Mars."

In *The Mars Project* von Braun described a flotilla of 10 spaceships manned by at least 70 men. "Each ship," he explained, "will be assembled in a two-hour orbital path around the Earth to which three-stage ferry rockets will deliver all the necessary components such as propellants, structures, and personnel. Once the vessels are assembled, fueled, and 'in all respects ready for space,' they will leave this 'orbit of departure' and begin a voyage that will take them out of the Earth's field of gravity and set them into an elliptical orbit around the Sun."

His spaceships were to be powered by chemical propellants; from the perspective of the early 1950s they offered the only feasible means of traversing interplanetary distances. Although von Braun did "not propose to deny the possibility that nuclear energy may someday propel space vessels," he felt that it was unlikely to become available for space applications for at least 25 years.

In preparing his readers for the Martian adventure, von Braun emphasized that it must be done "on a grand scale." He went on to explain that "Great numbers of professionals from many walks of life, trained to cooperate unfailingly, must be recruited. Such training will require years before each can fit his special ability into the pattern of the whole. . . . The whole expeditionary personnel, together with the inanimate objects required for the fulfillment of their purpose, must be distributed throughout a flotilla of space vessels traveling in close formation, so that help may be available in case of trouble or malfunction of a single ship. . . ."

Partly because it was published in Germany in a limited circulation journal and in the United States by a university press, *The Mars Project* did not enjoy wide distribution. Also, its timing was far from optimum; in the early 1950s, broad interest in space flight had yet to develop.

Von Braun was, of course, well aware of this. So, in 1954 with his friend Cornelius Ryan, he answered affirmatively in *Collier's* magazine the question, "Can we Get to Mars?"[8] But, he cautioned, " . . . it will be a century or more before he's [man's] ready." (He would change his mind about that within the next decade and a half.) Then, in 1956 he explained his ideas in *The Exploration of Mars*, written with another close associate, Willy Ley.[9] Enhanced with spectacular illustrations by Chesley Bonestell, the book included a chapter entitled "Expedition to Mars" that was, in effect, a revised, more developed and popularized version of themes earlier developed in *The Mars Project.*

Von Braun explained:

> Although it [*The Exploration of Mars*] envisions an expedition of only twelve men traveling in two ships, the total propellant requirement—a good

yardstick for the over-all logistic effort—is only 10 per cent of that found in *The Mars Project.* This enormous saving is due solely to the superior over-all plan, for the specific assumptions made with regard to rocket engine performance and construction weight factors have not been altered.

The following extracts demonstrate von Braun's enthusiasm for the subject:

For now the time has come—this is it. . . .

At X minus 4 seconds a deep rumble goes through the two ships—the rocket motors are burning at 'ignition stage.' Under a slight helium pressure, applied against the flexible displacement bags in the starter tanks, the two propellants are being fed at a comparatively slow rate into the twelve thrust chambers, where they ignite spontaneously. . . . At X minus 1 the ignition stage is well established, and at the zero moment the main stage goes on. . . . The rumble becomes a thunderous roar; the thrust very rapidly builds up to its full value of 396 tons. Ponderously the two large Mars ships begin to move visibly. The thunder and the reverberations of the rocket engines last for a little over 15 minutes. Then, as suddenly as it began, the roar subsides. The pitch of the whining gyros declines, and soon only the rustle of the ventilation blowers remains.

The 260-day coasting flight to Mars has begun. . . .

Only ten days remain before the second major power maneuver, the induced capture of the ships by Mars. The distance to the planet . . . has shrunk to 1,400,000 miles. The visible half-disk of Mars glows with an intense orange-red with greenish patches, and the naked eye can easily distinguish the white spot of the southern polar cap melting in the sunlight of the Martian summer. The opposite half is shrouded in night. . . .

The explorers' first task in Martian orbit is a thorough study of the surface of the planet. . . . The whole planet is surveyed, photographed, and mapped; surface temperatures are measured at various latitudes by day and by night; and cloud formations are studied. . . .

Clad in pressurized suits, the first nine human beings to set foot on Mars are grouped around the cabin door. One by one they enter the airlock and listen to the hiss of the escaping air as the lock is brought down to the low pressure outside. . . .

. . . [I]t has also been a year of exciting scientific discoveries, of profound satisfaction in being able to study meteorology and climate, rock formations

> and soil bacteria, plant life and seasonal changes on another planet. The explorers have sounded out the internal make-up of Mars by detonating explosive charges on the ground and measuring the propagation of shock waves with seismographs planted several miles around the blast. They have searched for possible remnants of higher forms of life that might have populated Mars in past geological ages, and for indications of whether Mars has ever been inhabited by intelligent beings. . . .

After more than 400 days the explorers ascend from the Martian surface to join their companions waiting in orbit above to begin the nearly 9-month return voyage to Earth.

During the years that followed publication of *The Exploration of Mars*, von Braun had little time to pursue his studies of the red planet. More immediately important was the task of developing ballistic missiles; and, beginning in October 1957, of rallying his team at the Army Ballistic Missile Agency in Huntsville, Alabama, to respond to the challenge of the Soviet *Sputnik* triumph.[10] A few years later, in the spring of 1961, President Kennedy announced the goal of landing man on the Moon within the decade. For von Braun, whose Army team in the meantime (July 1960) had been transferred to NASA to become the George C. Marshall Space Flight Center, this meant focusing the majority of his resources on the giant Saturn series of launch vehicles that were to make the lunar expeditions possible.

Nevertheless, as preparations for the Apollo program gained momentum, von Braun did assign members of his team to continue to study the feasibility of manned Mars exploration. After all, he reasoned, the conquest of the Moon would assuredly pave the way to that more ambitious goal. At about the same time, small groups were conducting similar studies at NASA's Ames Research Center in California; the Langley Research Center in Virginia; the Lewis Research Center in Ohio; and the Manned Spacecraft Center in Texas.

In October 1989, at the 40th International Astronautical Congress, Franklin P. Dixon presented a survey paper entitled "Manned Planetary Mission Studies From 1962 to 1968," in which he noted that "The logical beginning of this emphasis [e.g., planning manned planetary missions] was at the Future Projects Office . . . of the NASA Marshall Space Flight Center. . . ."[11] And, indeed, it was there, under Heinz Hermann Koelle and his deputy Harry O. Ruppe, that three contractor studies were soon to be sponsored.

To set the stage, in the spring of 1962 a work statement and a procurement request were prepared by NASA laying out tasks to be accomplished to determine the feasibility of manned scientific missions to Mars as well as to Venus during the 1970-72 period. The ground rules stated that the anticipated contractor-conducted studies would be based on projected state-of-the-art (as of the early 1970s) nuclear propulsion technology, and would consider a number of missions (Mars and Venus flybys, Mars and Venus orbital reconnaissance, and Mars orbital reconnaissance and eventual surface landing).

The total duration of any mission was not to exceed 1-1/2 years and nuclear propulsion was to be used for escape from Earth orbit, for braking into planetary orbit, and for any propulsive braking required when returning towards Earth. The studies were only to concern Earth launch vehicles insofar as they were dictated by spacecraft requirements. The crew was to be completely integrated into vehicular systems, and the spacecraft designs were to take into account experience gained in the American Mercury, Gemini, and Apollo programs as well as on-going space station studies. Mars surface landing missions were to be accomplished using a planetary excursion model. Preparations for the Mars initiative were duly reported in the trade literature.[12]

Implicit in the EMPIRE initiative, as it was called, was the use of nuclear propulsion. During the study period, the feasibility of such propulsion was being demonstrated by the joint NASA-Atomic Energy Commission NERVA (Nuclear Engine for Rocket Vehicle Application) solid core fission reactor program in which hydrogen was heated to high temperatures yielding exhaust velocities approximately twice those achievable from chemical engines. Building on the success of the Kiwi-A series of reactor tests, in July 1961 the NASA-AEC Space Nuclear Projects Office awarded a contract for engine development to the Aerojet-General Corporation; its principal subcontractor was the Westinghouse Astronuclear Laboratory, responsible for the flight reactor. During the course of the program thrust levels up to 200,000 pounds were realized.

Project EMPIRE:
Early Manned Planetary-Interplanetary Round-trip Expeditions

Building on studies conducted in the late 1950s and early 1960s by government, industrial and individual researchers, in May 1962 NASA's George C. Marshall Space Flight Center selected three contractors to undertake 6-month, 6,000 man-hour studies that became known as Project EMPIRE (Early Manned Planetary-Interplanetary Round-trip Expeditions).[13] The three were the Aeronutronic Division of the Ford Motor Company,* General Dynamics/Astronautics, and the Lockheed Missiles and Space Company.

* Prior to 1 July 1963, Aeronutronic was a division of Ford. On that date, it was placed under Ford's subsidiary, the Philco Corporation. Then, following Ford's sale of Philco, Aeronutronic was integrated into the Ford Aerospace & Communications Corporation. Then, in October 1990, the Loral Corporation purchased the entity from Ford and named it Space Systems/Loral.

Ruppe, who served as NASA-Marshall study director of the project, recalls that the acronym EMPIRE was suggested by his assistant Jerry Smith and that the enterprise itself originated from discussions held earlier with von Braun and Koelle. "The original requirement," according to Ruppe, "was to study the application of Apollo hardware for early manned planetary missions. Those were limited to fly-by missions. We assumed Saturn 5 [then often referred to as the C-5] and earth orbital operations (without a space station) as earth launchers." Ruppe added that "You might remember that at that time in the large assembly building at the Cape [Canaveral] we had a theoretical capability to process several Saturn 5 vehicles in parallel (I do not remember how many, maybe 3). This limitation was part of the input."[14]

The results of the EMPIRE studies, which were funded at U.S. $250,000 each, revealed that manned missions to the two planets appeared feasible during the early 1970s. As Ruppe noted, it was assumed that launch into orbit from the surface of the Earth would be accomplished by the Saturn C-5 (later, 5 or V, possibly with variations) booster configuration though some consideration was also given to the Nova then under study as well as the so-called Super Nova. Summaries of the three contract studies follow.

Aeronautics Division

Two company reports summarize work accomplished by the Aeronutronic Division: "EMPIRE, A Study of Early Manned Interplanetary Missions," by M. H. Caldwell, *et al.*;[15] and "The EMPIRE Dual Planet Flyby Mission," by Franklin P. Dixon.[16] At the same time, Dixon covered Aeronutronic's studies in the professional literature.[17]

In his introduction to that article, Dixon stressed that, "Much credit must be given to the forward thinking approach shown by the NASA effort on this program in 1962. By attacking the areas of interest at this early date," he added, "it was possible to obtain a clearer picture of the requirements for early manned planetary and interplanetary flight. Thus, the nation's resources, and the NASA and other United States space programs, can be oriented toward long range goals at an early date."

Several goals were established for the EMPIRE study including characterization of the contemplated Nova launch vehicle program, the then on-going nuclear rocket program, and advanced space operational concepts required for implementation of missions under study at the time. Table 1 lists the areas that Dixon and his associates at the Aeronutronic Division judged to be of particular importance.

Table 1

AREAS REQUIRING SPECIFIC ATTENTION

Trajectories
Propulsion: nuclear and/or chemical
Operations: orbital, mission staging, development requirements
Earth re-entry
Crew considerations, life support
Science payloads
Cryogenics
Subsystem definition: electronics, guidance, control, power
Emergency operations

After various approaches to early manned planetary-interplanetary flight had been examined in the Aeronutronic study, a so-called Nuclear Symmetric Mission of 1970 (named for the propulsion, trajectory option and target launch year selected) was felt to be more feasible. "This allowed," according to Dixon, "a more detailed subsystem and vehicle definition and provided a program for the operational analysis and the Development Plan and Funding Program." The lower part of Figure 1 depicts the Earth-orbit nuclear propulsion injection phase of Aeronutronic's complete interplanetary space vehicle while the upper part represents the portion remaining upon arrival at Mars. The unperturbed symmetrical trajectory it theoretically would follow is shown in Figure 2.

Design studies for dual-planet flybys were undertaken for several trajectories with the symmetric option being chosen that would pass close to Venus and Mars. Launch was to take place from a 300-kilometer Earth orbit between 19 July and 16 August 1970 leading to a total mission time of up to 21 months. Although all on-board systems were to be capable of operating under zero-gravity conditions, artificial gravity would be provided for the nominal crew of six. The space vehicle was to be protected against meteoroids and would incorporate a radiation shelter in which the crew would remain during severe solar flares.

Habitable space on board included 750 cubic feet of free volume per man (during short periods spent in the radiation shelter only 50 cubic feet each would be available). Attitude control was to be accomplished by a reaction control propulsion system and auxiliary power was to be furnished by a SNAP-8 nuclear reactor power system backed up by a single spare. Nuclear propulsion would serve to inject the spaceship onto its interplanetary trajectory; storable chemical systems would be relied upon to meet subsequent velocity change requirements. Subsystems and their weights are grouped in Table 2.

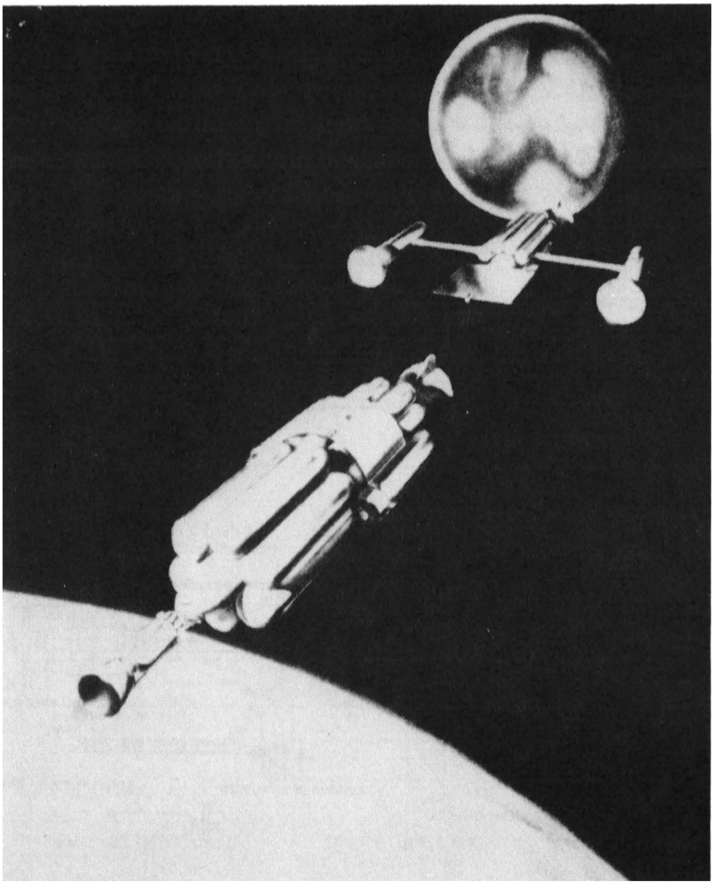


Figure 1 Aeronutronics design of interplanetary Mars-bound spacecraft.

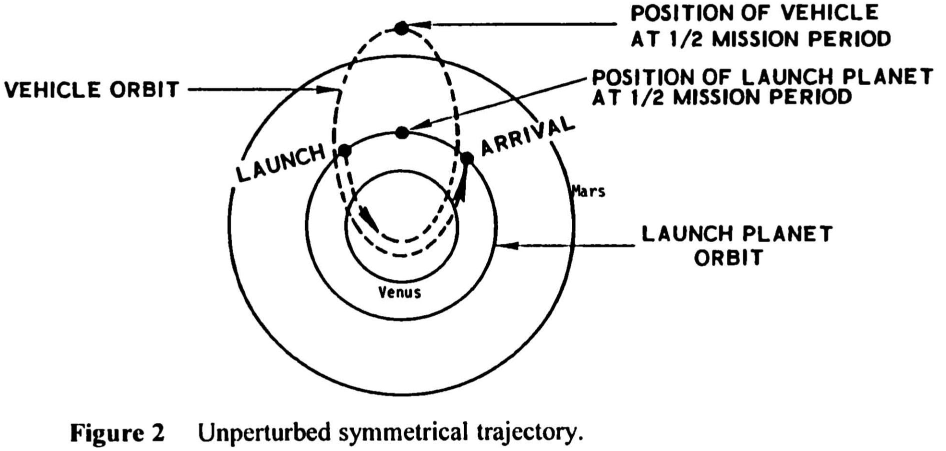


Figure 2 Unperturbed symmetrical trajectory.

Table 2
SUMMARY OF SUBSYSTEM WEIGHTS FOR SYMMETRIC TRAJECTORY

Subsystem	Weight, pounds
Life support	21,810
Thermal control	1,000
Power	10,000
Attitude control	1,000
Communications	300
Furnishings	500
Instrumentation	1,000
Emergency gear	1,200
Scientific payload	1,000
Total	37,810

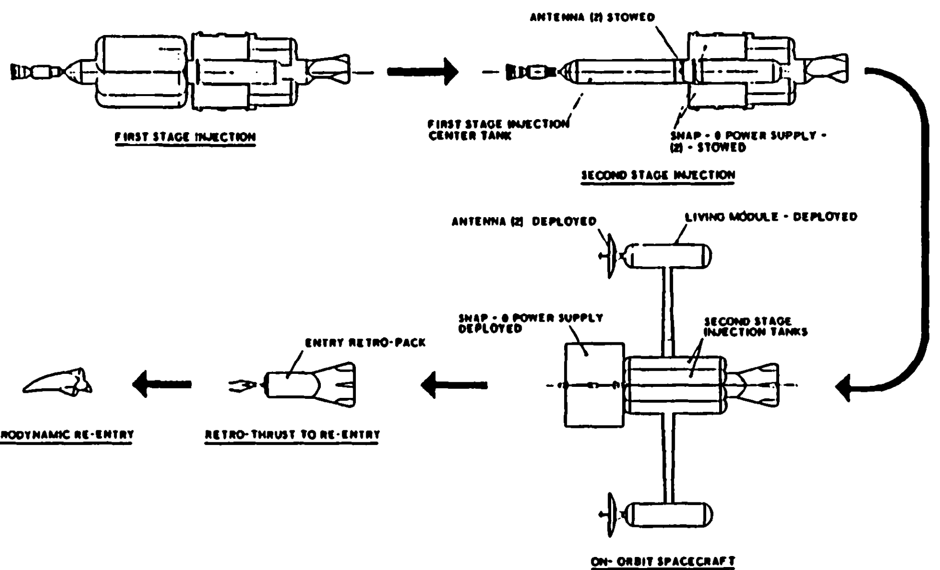


Figure 3 Aeronutronics EMPIRE spacecraft showing staging sequence for symmetrical trajectory nuclear injection mission.

Figure 3 illustrates the various elements of the space vehicle configuration proposed by the Aeronutronic team. Two living modules, stowed during first-stage injection, are extended through telescoping cylinders at the completion of the nuclear-powered injection phase. These modules incorporate command centers and the already cited radiation shelters.

At the top of the illustration we see the spaceship before and during first-stage injection. Propellants for first-stage injection are stored in seven cylindrical tanks, indicated in Figure 4, the center one also serving as structural support for the engine. Six of these tanks are jettisoned at the end of first-stage injection. During second-stage injection, propellant from the second-stage tanks flows to the main engine which, at burnout, is discarded along with the first-stage center tank.

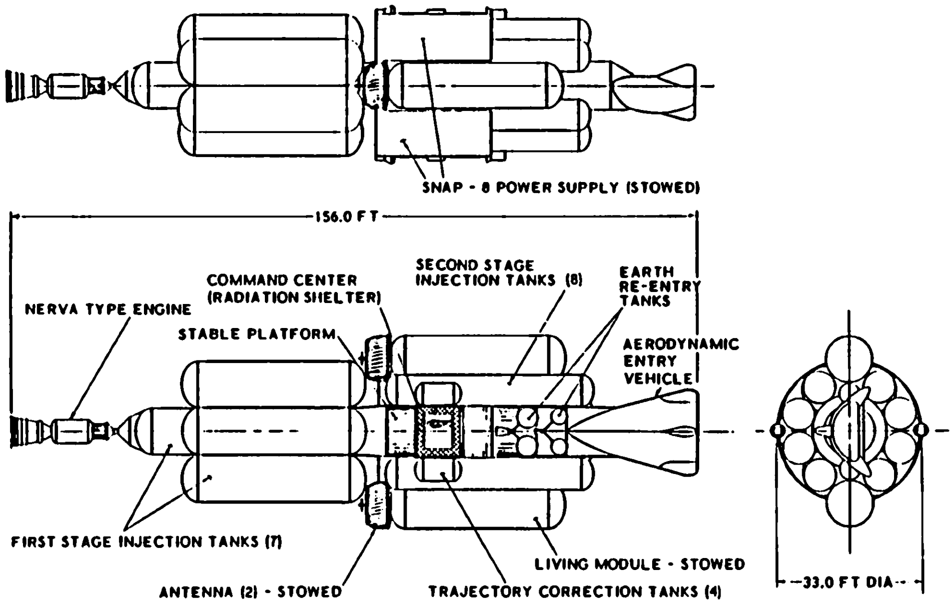


Figure 4 Cutaway of Aeronutronics EMPIRE spacecraft configuration.

Once the spaceship is progressing along its Earth-Mars transfer trajectory, the two living modules are deployed along with one of two SNAP-8s (the other—as already noted—to be held in reserve). By rotating the ship at approximately 3 revolutions per minute, a semblance of gravity relieves the weightlessness the crew would otherwise have to endure.

Figure 3 also shows the Earth re-entry retro-pack. Upon approaching our planet at the end of the mission, the crew transfers into this vehicle which is separated from the spaceship by small posi-grade solid propellant rockets. The retro-pack then decelerates the re-entry craft (see below), reducing velocity to the point where controlled atmospheric descent becomes possible.

For the 1970 mission, Dixon's ideal nuclear rocket engine would produce a thrust of 200,000 pounds for about 800 seconds. For the 1972 dual-planet flyby, an increase to some 1,000 seconds would be necessary. Before 1970, he foresaw at best the availability of smaller 50,000-pound thrust nuclear engines that would have to burn for nearly 2,900 seconds to accomplish their assigned missions. But this exceeded then-estimated maximum feasible burning times, which were limited by contemporary reactor materials and design considerations. Clearly, much had to be accomplished in this key area.

The Aeronutronic team examined three launch vehicle configurations that were being studied in the early 1960s, the Saturn C-5, the Nova, and the Super Nova. These were to be capable of lifting into low Earth orbit 200,000 to 240,000, 500,000 and 700,000 pounds, respectively. If the latter vehicle were to become available, the Aeronutronic interplanetary spaceship could be directly injected along the departure trajectory without the need of possibly unreliable nuclear propulsion.

Dixon concluded that "Saturn C-5's are practical ELV's [Earth Launch Vehicles] with the nuclear injection stage, and an all chemical mission is possible although it would require extensive orbital operations; abort capability in all phases is required to provide adequate manned survival probability, backup ELV's are required to allow for sufficient mission success probability, redundant nuclear injection units are desirable for these early missions, and accelerated nuclear engine development is desirable."

A number of trajectories were analyzed by Dixon and his associates. Their choice involved what they termed a symmetric mission of somewhat over 600 days duration; it was named from the fact that the Earth-launch and Earth-arrival positions enjoy symmetry with respect to the longitude positions of Mars at the midpoint of the spaceship's trajectory (Figure 2; planetary perturbations are neglected). Travel times along the legs of the interplanetary journey for a symmetric mission would be about 100 days Earth to Venus, nearly 200 days for Venus to Mars, and between approximately 310 and 340 days for Mars to Earth. The complete mission was calculated to take from 613 to 631 days to accomplish.

The proposed guidance subsystem would consist of a guidance control package, a star tracker and computer, and a Sun and planet (Earth) tracker. The control package would incorporate rate and displacement gyro sensors to yield attitude signals during the powered injection phase of flight, mid-course maneuvers, and planetary arrival (including re-entry back on Earth). The star tracker and computer subsystem would give the navigator the ability to determine ephemeris during the heliocentric transfer and planetary approach. This subsystem would back up ephemeris inputs received from the ground tracking network on Earth. As for the Sun and planet tracking tracker sensors, they would stabilize the omni-directional antenna to assure that the spaceship-to-Earth/Earth-to-spaceship communications links remained unbroken.

A thousand pounds of payload and an average power of 300 watts were assigned to the mission, though details of the scientific payload were not worked out as they were beyond the scope of work performed under the NASA-Marshall contract. Scientific studies were to be made during the interplanetary cruise, and at approach to and departure from Earth, Venus and Mars.

Three basic Earth-return designs, sized for a crew of six, were studied by Dixon and his team: High L/D (lift/drag), Apollo-type, and drag brake. These are illustrated, from bottom to top, in Figure 5. Nominal re-entry velocities considered ranged from 13.5 to 15.8 kilometers/second. The study concluded that "In the final analysis the High L/D vehicle with deepest entry corridor, widest latitude in site selection and conventional landing capability appeared to provide the best approach although all three vehicles are competitive in weight requirements. For this reason, the EMPIRE Earth Re-entry Vehicle used the High L/D configuration." Figure 6 shows the study's resulting High L/D design in its pitched-up entry mode with the crew visible in cutaway.

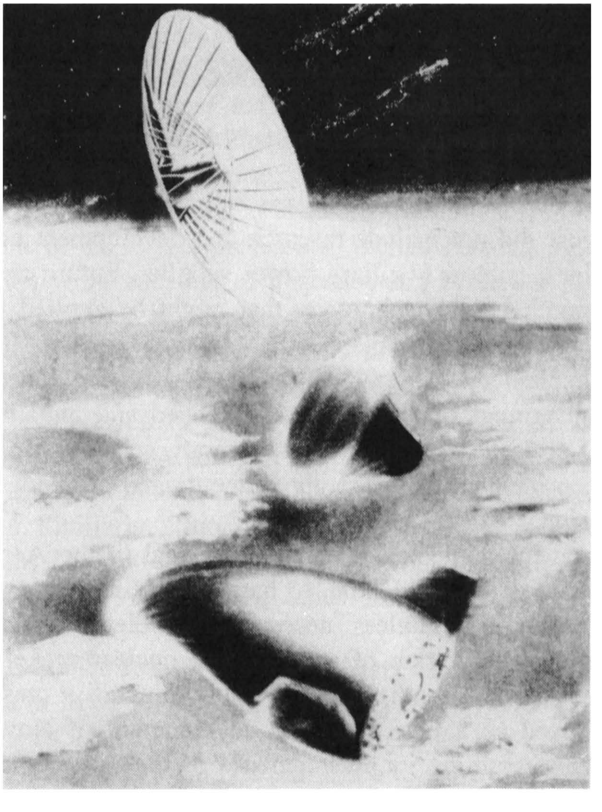


Figure 5 Types of Earth reentry vehicles studied by Aeronutronics.

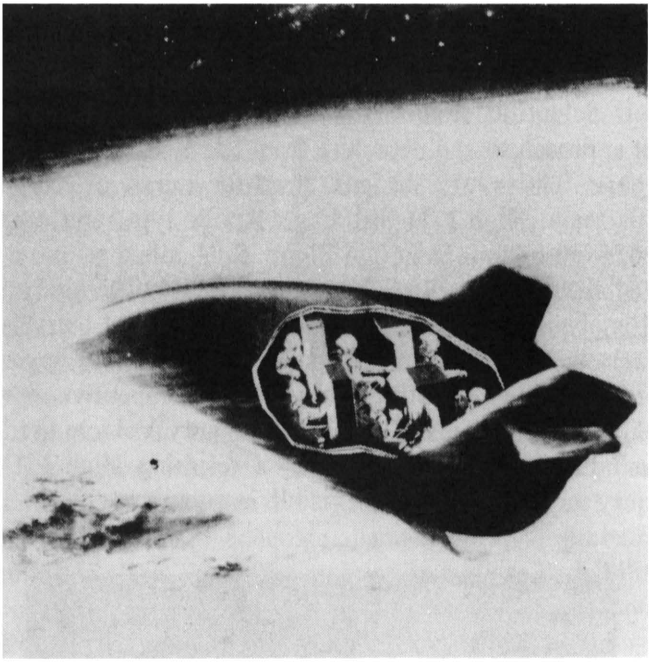


Figure 6 Aeronutronics High L/D reentry vehicle.

A total cost of U.S. $12.6 billion was estimated for the dual-planet flyby mission. This figure did not include research and development costs for the nuclear rocket engines, nuclear auxiliary power supplies, Saturn and Nova launch vehicle development, Apollo technology that might be applied to the mission, and ". . . other equipment under planned development for the 1970 time schedule." As Dixon explained, "Although it is necessary to expedite some of these developments, the ground rules have been followed and only the actual hardware and R & D costs for the EMPIRE spacecraft, subsystems, and production boosters have been included with the above mentioned program hardware costs for the 1970 mission."

The development of nuclear elements essential to the Aeronutronic EMPIRE study were, according to Dixon, to have started in January 1963 but, because of delays, would doubtless necessitate accelerated development. He stressed that the early definition of an advanced nuclear rocket engine should have gotten under way 6 months later (in July) to avoid a crash development program. If approved as a new start, the development of Nova was to have begun in mid-1964 assuming its clustered use of the same type of engines as those then being developed for the Saturn series. With considerations such as these in mind, Dixon ventured that "It would appear that even now [1963] a launch in July 1970 is within technological reach of a plausible development program—provided certain technological problems areas [such as noted above] are attacked immediately."

General Dynamics/Astronautics

General Dynamics/Astronautics (GDA), the second of the three industrial contractors selected to carry out EMPIRE studies during 1962 and 1963, published a number of reports.[18,19,20] Two were entitled "A Study of Early Manned Interplanetary Missions." The first, initiated in March 1962, appeared on 31 January 1963 while the second, undertaken during 1963, was published a year later. All three studies were directed by the late Krafft Ehricke, then head of GDA's Advanced Studies Office.

The description that follows covers the Mars capture mission only and does not include details of manned Venus and Mars flyby missions that were also evaluated in the GDA reports. The use of nuclear propulsion to achieve interplanetary objectives constituted a main thrust of the study effort. Unfortunately, most of this information was placed in a volume that remains classified. However, summary descriptions of nuclear rocket projects undertaken in the late 1950s and early 1960s were extracted from the open GDA studies.

It is interesting to note that Ehricke first considered nuclear rocket propulsion back in 1942. While an engineer at the German Peenemünde rocket research establishment he was asked to evaluate atomic research being undertaken at the time by one of his former professors, Werner Heisenberg, then at Leipzig. After studying his work and that of his associate, Professor H. Pose, on using the heat of disintegrating atoms to produce steam to drive turbines, Ehricke made a negative report on its possibilities for use as rocket propulsion.

Chemical launch systems were also considered by Ehricke and his GDA team, although downplayed in the reports as weak alternatives. The chemical propulsion aspect of the GDA study is not discussed herein because of the minimum emphasis accorded this means of launching the interplanetary vehicles under consideration. Similarly, although the number of crew members varied in the GDA studies from 2 to 16 to derive alternative vehicle configurations, they consistently emphasized 8. Accordingly, other crewing arrangements are not described.

The space vehicles considered for the Mars capture mission were based on the favorable Earth-Mars relationship occurring in the 1973-75 period. Mission energy requirements could thus be minimized during those years. For nuclear-powered spaceships, it was hypothesized that a round-trip mission period of between 400 and 450 days could be achieved. The planetary capture period was estimated to be 30-50 days, ample time, in the research team's view, for the deployment of auxiliary vehicles for scientific investigations without increasing the overall mission length.

Analysis of orbital departure weights of nuclear spaceships varied in the GDA study because of the many options to be considered. Some 30 differing configurations were evaluated; and, eventually, it was concluded that 1,200 to 1,400 metric tons would provide a realistic weight range at Earth departure. This conclusion was based on accommodating a crew of 8 and a payload of 100,000 pounds. The nuclear-powered vehicles would have specific impulses of about 800 seconds. Finally, it was concluded that the deployment of two interplanetary vehicles would most effectively meet Mars mission objectives.

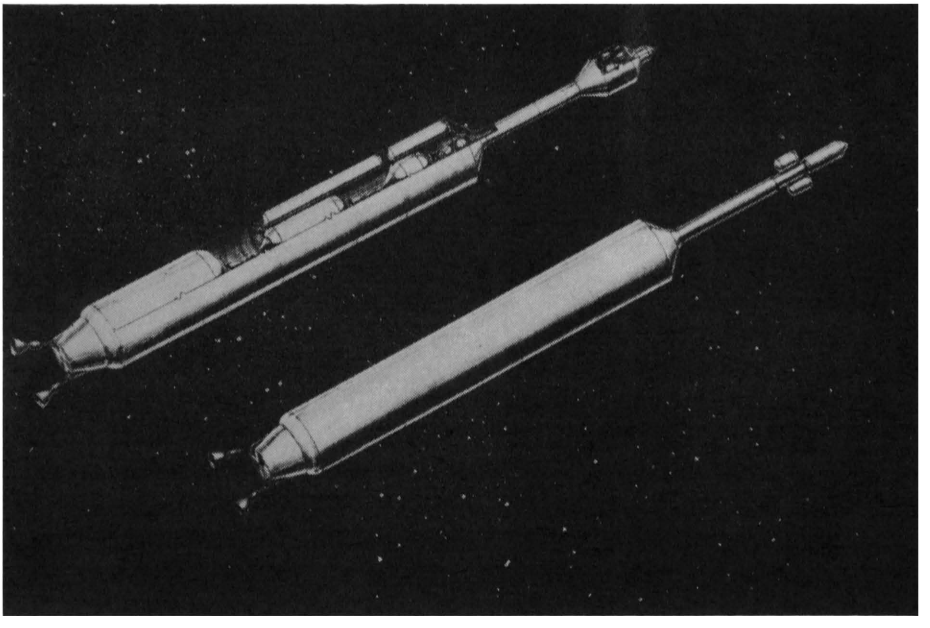


Figure 7 General Dynamics crew and service space vehicles.

Figure 7 depicts the proposed crew ship as well as its companion service ship that was designed to carry auxiliary craft and other destination payload. In this design, the crew compartment is transferable to the service ship in the event of an emergency. The crew ship was also to contain an Earth-entry module and a space taxi, which would serve as a commuter between convoy vehicles as well as operate as a tugboat. The assignments for the two convoy vehicles are shown in Table 3. As noted, the service vehicle would also incorporate a spare Earth-entry module and other crew quarters for emergency use.

In evaluating options, the GDA study group further considered the use of a duplex vehicle, which is pictured in Figure 8. In this configuration, the crew and service vehicles are coupled to form one spaceship. This approach was devised to simplify engine and flight control. In addition, the duplex vehicle would allow ready access by the crew to auxiliary craft and cargo.

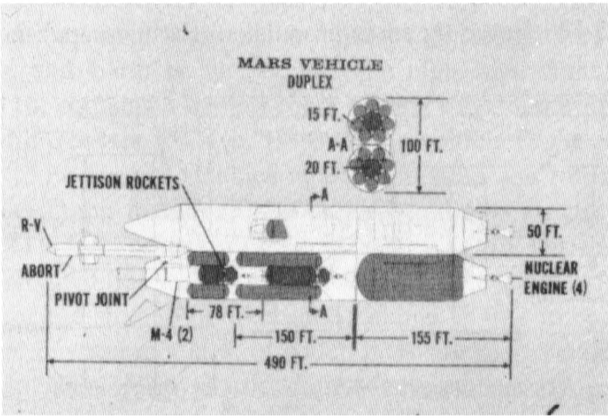


Figure 8 General Dynamics duplex Mars spacecraft.

Table 3

CONVOY VEHICLE ASSIGNMENTS

Crew Vehicle Task	Service Vehicle Task
Crew transport	Transport of auxiliary craft
Navigation	Transport of spares
Data processing and storage	Transport of make-up fuel
Communication	Transport of spare Earth-entry module
Control of auxiliary craft	Navigation assist
Injection of Earth-entry module into the correct atmospheric entry orbit	Back-up crew vehicle

The 8M-22 configuration is a prime example of the many designs evaluated by the GDA team for the manned mission to Mars. Shown in Figure 9, it relies on NERVA and Phoebus nuclear systems to accomplish various maneuvers. Both of these systems were in the exploratory development phase by the Atomic Energy Commission and NASA during the study period. Earth departure propulsion for the 8M-22 would use four Phoebus nuclear engines for interplanetary injection. Target planet arrival would be facilitated by retro-thrust generated by a single Phoebus engine. The propulsion system assigned the mission of Martian escape was an advanced NERVA. Earth arrival maneuvers would be carried out by a chemical liquid oxygen/liquid hydrogen system generating 75,000 pounds of thrust. The 8M-22 interplanetary vehicle was to be 420 feet long and some 120 feet at the main propulsion (Earth escape) module.

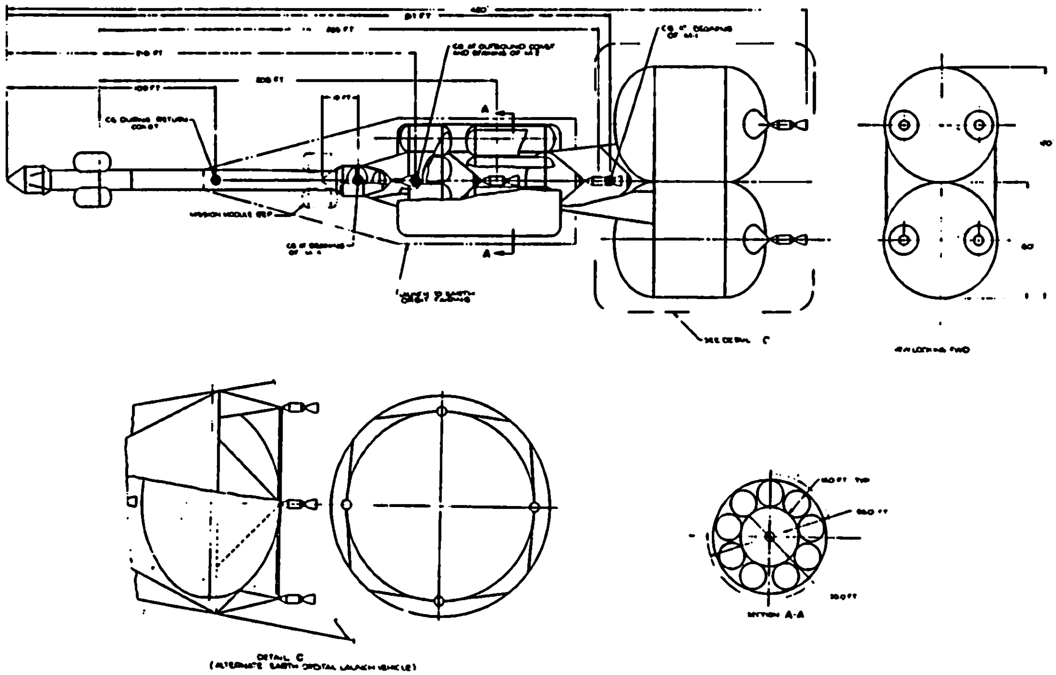


Figure 9 Cutaway of General Dynamics 8M-22 interplanetary space vehicle.

As mentioned above, an important aspect of the study was to evaluate and define potential options for the development of operational nuclear engines. Requirements and lead times were to be identified that could result in their use for the Mars mission. Confidence exhibited by the GDA group in the general feasibility of using nuclear propulsion was based on preliminary results of NERVA testing. Phoebus was a derivative of early nuclear rocket design activities.

The propulsion initiatives, whose origins dated from 1957 with a decision to proceed with the Kiwi reactor development program, were in full bloom by 1962. As noted earlier, nuclear engine contracts had been awarded; and, in parallel, a nuclear rocket development station had been established at Jackass Flats, Nevada. Hydrogen was soon identified as the most efficient working fluid with which to develop specific impulses in the 700- to 925-second range. From such a background, the Ehricke team was able to establish long-range mission goals. The resulting projections were to culminate in the production of nuclear engines able to propel large payloads to the orbit of Mars in an acceptable time span.

The living space designed into the interplanetary vehicles by the GDA team was divided into three sections: command module, internal and external mission modules, and Earth entry module. The eight-man command module, shown in Figure 10, contains a control room seating three and a lower compartment with sleeping quarters for five. Housing the vehicle flight control center, this module was to be heavily shielded against radiation and rotated to provide artificial gravity. Mission modules were divided into two groups: internal and external (Figure 11). Internal modules are identified as follows: module A was to contain the ecological life support system for the outbound voyage; module B was to be used for the storage of food; and module C was to contain a repair shop. The external mission modules, of which there are four, would house space taxis employed to accomplish shuttle duties between convoy vehicles. They would also serve as tugboats and commuter vehicles operating in Martian orbit. In addition, external modules would activate and deploy auxiliary vehicles stored in the service ship.

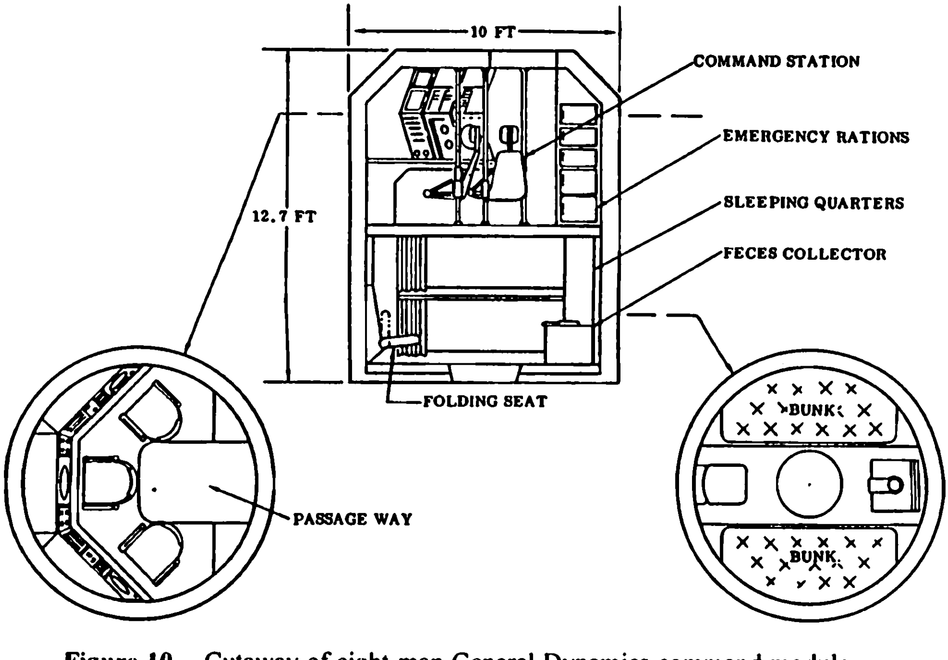


Figure 10 Cutaway of eight-man General Dynamics command module.

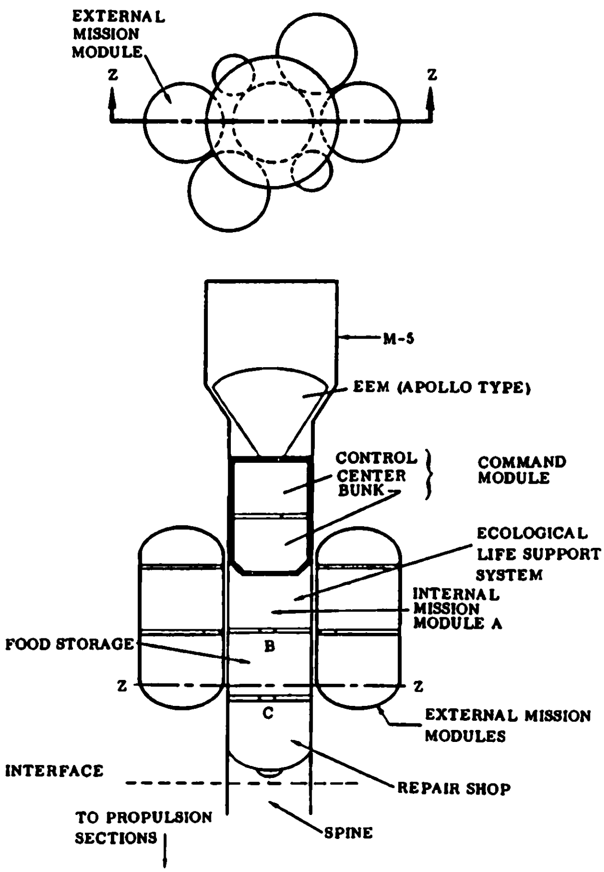


Figure 11 Cutaway of life support section of General Dynamics crew module.

The Earth entry module, depicted in Figure 12, was designed for departing Mars orbit and re-entering the terrestrial environment. As the illustration reveals, the design embodied an Apollo-type re-entry system and a liquid hydrogen-liquid oxygen propulsion system for Earth entry. This module would separate from the interplanetary vehicle after escaping from Mars and then employ chemical propulsion during the Earth re-entry maneuver. (The module would be re-deployed in Mars orbit by rotating to face the nuclear booster's spine.) The command module, together with mission modules, would be abandoned in orbit around Mars prior to departure of the returning spaceship.

The GDA team carefully studied crew criteria for the Mars' capture mission. As noted earlier, design criteria were established for crew sizes ranging from 2-16 persons. Since this relatively wide range caused considerable variation in establishing mission design objectives, most configurations were developed around crews numbering 8. Crew size and the associated life support system (LSS) assumed a shirtsleeve environment.

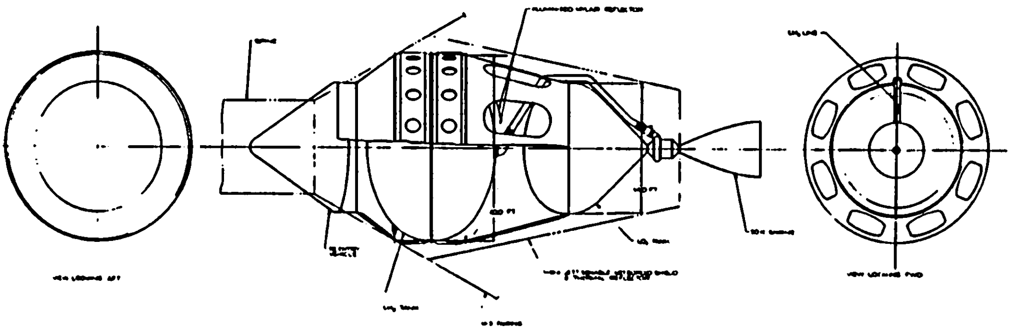


Figure 12 Cutaway of General Dynamics Earth M-4 reentry configuration powered by a liquid oxygen-liquid hydrogen 50K engine.

The major components of the ecological life support system designed by GDA included a detailed analysis of weight, volume, and power requirements. These factors for the main crew vehicle amounted to about 22,000 pounds, 750 cubic feet, and 4,600 watts, respectively. Water supply was of significant concern since it was estimated that consumption and sanitation would require some 10 pounds per person per day. Given the mission duration, a complex recovery system was designed to extract potable water from atmospheric condensate, urine, and wash water. Other innovative systems were also developed for environmental control, heat rejection, and food and waste management.

The crew composition selected by GDA for the Martian capture mission is shown in Table 4. Three members were to occupy the control room at all times, thereby ensuring maximum alert capability during the entire mission. The crew members' professions and specializations are also shown in the table together with their assigned responsibilities.

In evaluating build-up requirements for Earth orbital launch of interplanetary spaceships, the GDA team looked to a number of launch vehicle configurations. One was the Apollo version of the Saturn V under development for the lunar expeditions expected to begin before the end of the 1960 decade. Another was a configuration based on that booster but enlarged in diameter and called Saturn VM. It was felt that the principal restriction on the 'V' systems would be payload volume rather than payload weight. Finally, the GDA group selected a tanker version, again based on the Saturn V that would be used to replenish propellants and other supplies in orbit prior to the Mars launch. These three vehicles would each carry 250,000 pounds to the 325-kilometer Earth orbit.

Table 4
REPRESENTATIVE CREW COMPOSITION FOR THE MARTIAN CAPTURE MISSION

ASTRO-NAUT NO.	REPRESENTATIVE PROFESSIONS	SPECIALIZATION	PRIMARY TECHNICAL RESPONSIBILITY	ORGANIZATIONAL RESPONSIBILITY
1	Engineer	Mechanical	Structure; all mechanical equipment and subsystems.	One Commander
2	Engineer	Electrical	All electrical equipment and subsystems; wiring; power distribution.	One Deputy Commander
3	Engineer-Physicist	Nuclear-Electronic	Nuclear equipment; reactor control; isotope systems; radiation protection (in cooperation with the flight physician).	At least one of this group will be involved in the surface excursion (if any) and serves as Excursion Commander, if more than one person is involved.
4	Engineer-Astronomer	Electronic	Communication; navigation; guidance and navigation equipment; meteor radar; data processing equipment.	
5	Engineer-Physicist	Electronic		
6	Physicist-Geophysicist	Instrumentation Space Physics	On-board scientific instrumentation; on-board observatory; operational readiness of auxiliary vehicles prior to deployment.	Directs space physical research during transfer and capture period.
7	Astronomer-Geologist	Planetology Meteorology Geophysics		Directs scientific reconnaissance operations concerned with the target planet.
8	Physician Biologist	Medicine Surgery Dentistry Radiology Psychiatry Biology Medical Technology	Monitoring bio-technical systems in LSS; food and sanitary control; health and morale of crew; biological and astro-clinical research	Flight Surgeon; directs clinical and biological research en route; directs target-planet oriented biological research

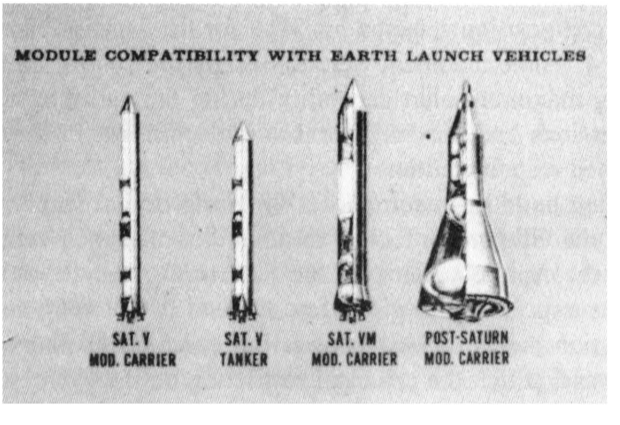


Figure 13 Post-Saturn V launch vehicles configurations studied by the General Dynamics/Astronautics team.

It was noted by the Ehricke team that a total of eight Saturn V launches and seven rendezvous operations would be needed to assemble in orbit the interplanetary vehicles planned for the manned Mars mission. On the other hand, only two launches of a proposed Post-Saturn Earth Launch vehicle (Figure 13), with a payload of 400 tons, would be required to place such a vehicle into Earth orbit. The development of this new booster was considered desirable and feasible within the proposed 1973-75 mission time boundaries that constrained the Ehricke team.

Considerable attention was paid in the study to crew training and preflight testing. An imaginative configuration for accomplishing these objectives is shown in Figure 14. The triangular space station was based on a collapsed system of spines with propulsion units attached. This launch arrangement would then be opened up in orbit. Design philosophy called for standardization of a system to support the integration of pre-mission ground and orbital operations. The GDA group considered not only study requirement specifics, but also the utilization of the station to support orbital launch, lunar base operations, and crew indoctrination in the space environment. Pre-launch, launch operations, and space mating were all considered in some depth by the GDA team. This effort included analysis of the transportation of major system components, launch complex requirements, and the use of space tugs to facilitate orbital assembly operations.

The GDA team contemplated that the Mars convoy would carry a sizable complement of auxiliary vehicles to conduct scientific experiments since the number of specific objectives for a manned planetary expedition would be large. In assessing optimum payloads for the Mars mission, seven auxiliary vehicles and a manned excursion system were proposed as most effectively meeting overall mission goals. The auxiliary vehicles were divided into two groups as seen in Table 5.

In evaluating various vehicular requirements, Ehricke and his teammates suggested that the Manned Excursion Vehicle (MEV), Lander, and Returner would be members of the same family. This determination was based on reasons of economy and reliability. It was felt that experience in developing contemporary unmanned Surveyor, Prospector, and Mariner systems would provide a firm design foundation for the three Mars vehicles described in the following subsections. Thus, an approach was formulated to maximize the use of modular concepts.

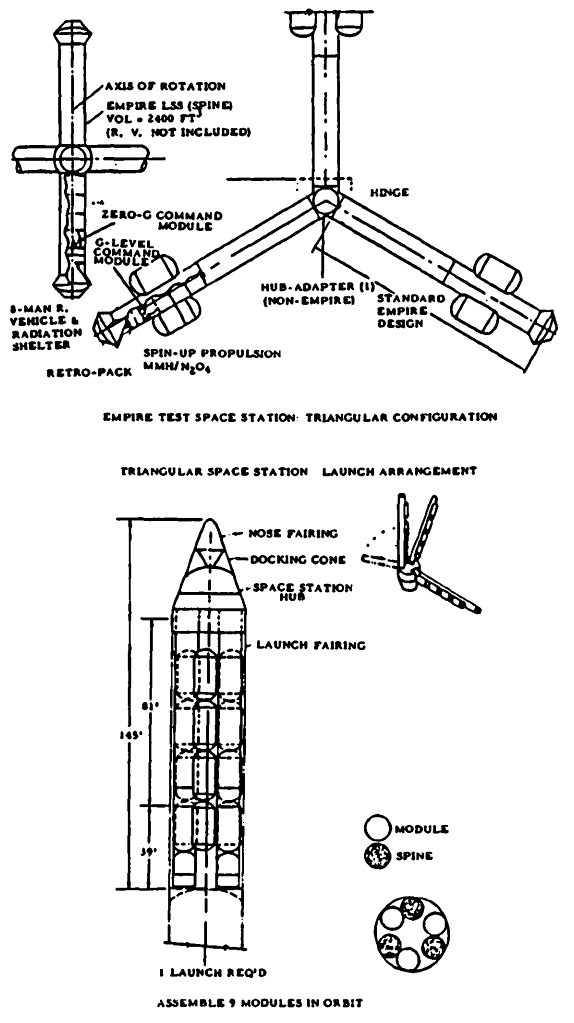


Figure 14 General Dynamics EMPIRE triangular test space station configuration.

Table 5
AUXILIARY VEHICLES

Surface Landing Vehicles	Unmanned Scientific Vehicles
Manned Excursion Vehicle	Mapper
Lander	Floater
Returner	Marens
	Phepro and Deipro

Design of the MEV was based on a crew of either one or two, and modularization as follows: propulsion, automatic instrumentation, and pilot. Figure 15 shows the basic design for the MEV as well as the Returner. The nose section would be interchangeable to accommodate either a manned or unmanned landing. Operationally, MEV excursions to the Martian surface would be preceded by several Lander vehicles to explore suitable sites. The performance requirement and weight break-down of the MEV is shown in Table 6.

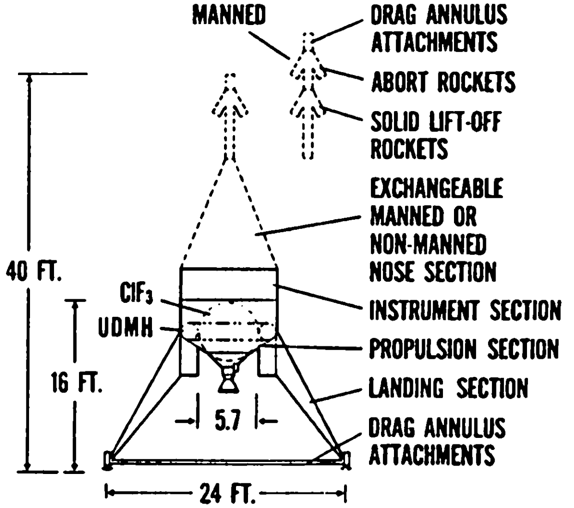


Figure 15 General Dynamics Mars Returner and Manned Excursion Vehicle.

Table 6

CHARACTERISTICS OF MANNED EXCURSION VEHICLE

Altitude of return orbit	1,070 km
Ideal velocity for return	4.5 km/sec
*Return payload	3,000 lb
*Useful propellants	14,000 lb
chlorine trifluoride	10,900 lb, r = 3.03, d = 1.38
unsymmetrical dimethyl hydrazine	3,600 lb, Isp = 280/325/(300)
*Wet inert weight	1,100 lb
Gross weight (takeoff)	*18,600 lb = 7,600 lb**
*Weight left on Mars	3,400 lb
Gross weight (descent)	22,000 lb = 9,000 lb**
*Transport weight	22,500 lb
Area of drag annulus	9,000 ft

* Earth ** Mars

An interesting feature of the MEV design was the use of a drag annulus to slow descent to the Martian surface. This system was to eliminate the need for retro-thrust and provide sufficient drag to limit descent velocity and bring the MEV to a soft touchdown. Figure 16 shows the deployed annulus during descent onto the Martian surface. The MEV was to be fitted with small nose rockets to provide initial lift from the surface at the end of the exploration mission. The main propulsion system would then propel MEV into orbit to mate with the waiting mother ship.

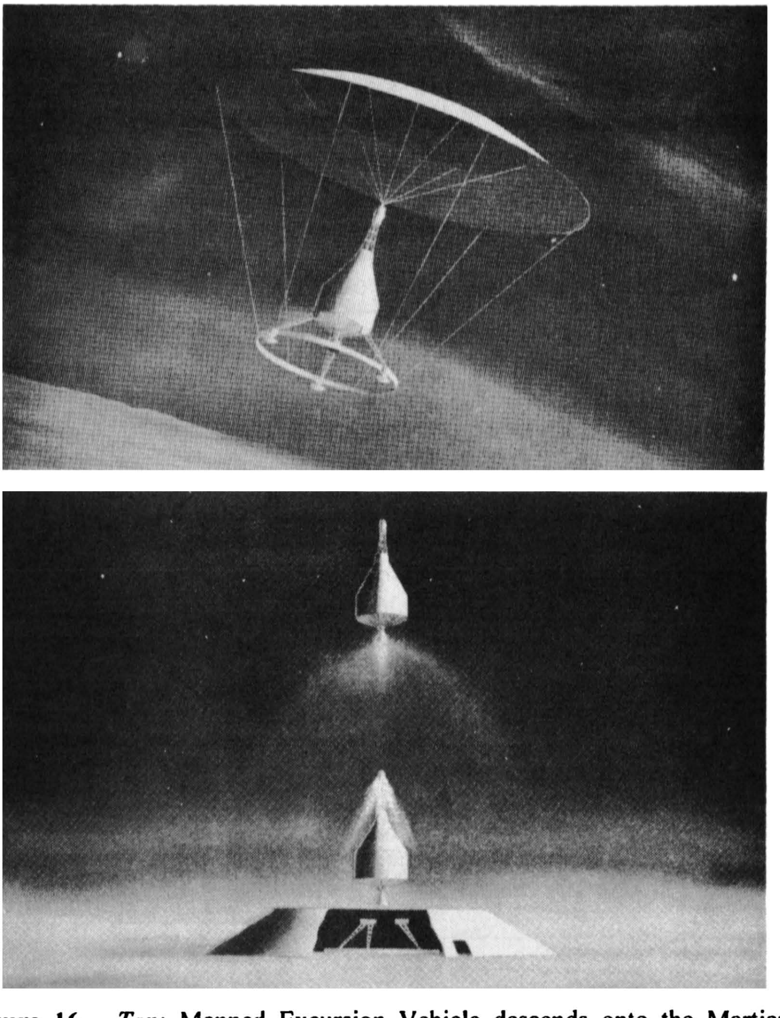


Figure 16 *Top:* Manned Excursion Vehicle descends onto the Martian surface with the annulus deployed; *bottom:* Mars propulsion system lifts the MEV towards orbit where it will rendezvous with the waiting mother ship.

Lander was to help determine the biological and planetological characteristics of Mars. Its scientific objectives are summarized in Table 7.

Table 7

SCIENTIFIC OBJECTIVES ESTABLISHED FOR THE LANDER

```
Undertake experiments to establish the existence of
 life and to define its chemistry and morphology

Conduct a variety of related surface investigations:
        Organic soil analysis
        High resolution photography
        Soil microscopy
        Biochemical soil analysis
        Culture studies
        Ultraviolet surface examinations
        Planetary biological contamination
        Chemistry of planetary organisms
```

It was proposed that the basic data collection system for the Lander would be a television camera system to take pictures of the surrounding landscape. In addition, the space vehicle crew would be expected to actuate core sampling drills and biological organism detectors remotely by means of the same visual system. The study team envisioned that three Landers would be deployed, one each in the following areas: (1) North or South Pole; (2) *Syrtis Major* or *Sinus Meridians* (typical dark green areas); and (3) *Lolis Lacus* (green to desert features).

The Returner, designed to accomplish the same basic missions as Lander, would possess similar physical characteristics to it and to the MEV. As a soft-landed instrumented surface probe, however, Returner would be capable of returning soil and air samples to the orbiting space vehicle's crew. It would further be capable of returning foreign and conceivably hostile biological organisms in a carefully constructed internal environment.

A family of five unmanned scientific vehicles was proposed for the Mars mission. Two members were to be orbiting satellites designated Mapper and Marens and one a balloon-born vehicle for atmospheric research called Floater. The final two were probes named Phepro and Deipro; both were to be instrumented to explore the tiny Martian moons.

Mapper was to carry out a number of tasks including orbital reconnaissance; visual mapping (high resolution); infrared mapping; altimetry; determination of planetary mass, shape, and dimension; and ultraviolet mapping. It was to be placed into a 662-kilometer polar orbit and would be equipped with television image tube systems (e.g., vidicons, image orthicons) to enable it to acquire non-overlapped still pictures along the orbital track. Mapper's control system would supply a strip of pictures one half of the planet's circumference in length. Varying widths would result for each orbit of the vehicle. In addition, data from both infrared and ultraviolet sensors would complement that obtained from the TV visual system.

The following design considerations were developed to enable Mapper to cover 100 per cent of the planet's surface:

1. The craft should be placed in a circular polar orbit such that synchronism with the Martian day would be achieved after a finite number of orbits.

2. The field of view of Mapper would be chosen to coincide exactly with the synchronous period. For example, if an orbit were attained such that synchronism would be achieved after 180 orbits, Mapper's field of view would have to be 2 degrees.

3. The control system would have to change the width of each picture automatically as Mapper changed latitude.

An interesting aspect of the GDA study was the concepts of balloon Floaters that would hover at different buoyancy levels to derive information on the Martian atmosphere at various altitudes. Their data collection objectives appear in Table 8.

Table 8

DATA COLLECTION OBJECTIVES FOR FLOATER

Wind direction and magnitude (obtained by observing the motion of the floater optically and/or by omnidirectional radio signals
Air pressure and density
Air composition at buoyancy altitude
Air temperature
Relative humidity
Sky and ground brightness and clouds
Spectral absorption of sunlight (especially ultraviolet intensity) at buoyancy altitude
Corpuscular radiation intensity

Another craft considered by Ehricke and his GDA team was an environmental satellite named Marens instrumented to investigate radiation and magnetic characteristics of Mars. Three Marens were proposed for equatorial, 45 degrees inclined, and polar orbit operations. The overall weight calculated for each Marens was 731 pounds, of which nine scientific experiments accounted for just under 80 pounds.

Two spacecraft designated Phepro and Deipro were proposed to explore the tiny Martian moons Phobos and Deimos. The primary purpose of each was to measure the space environment en route there and to obtain close-up surface pictures during the approach. On-board instrumentation would allow the probes to determine surface features (television mapping), seismic activity, surface radiation, and characteristics of magnetic fields. Since Phepro and Deipro were not soft-landers, all on-board instruments (TV cameras, magnetometers, and gamma ray spectrometers) except the seismometer would be destroyed upon impact. Consequently, only seismic activity would be reported from then on.

In analyzing the costs associated with the Mars capture mission, the Ehricke team divided its estimates into four major categories:

1. Direct development costs, including design and testing of all components and complete vehicles.

2. Costs associated with the establishment and maintenance of test facilities and test operations.

3. The cost of launch vehicles for flight and operational tests.

4. Modifications of the Saturn V leading to the development of the proposed Post Saturn Earth Launch Vehicle.

The direct cost estimate amounted to U.S. $18.5 billion over the proposed 1965-75 development period. Of this amount, some $4 billion would be earmarked for the Post Saturn Earth Launch Vehicle. Peripheral or indirect costs not directly associated with the Mars mission (e.g., scientific studies benefiting several programs) were also considered and were estimated to reach $6 billion.

Lockheed Missiles and Space Company

Before becoming contractually involved in the EMPIRE studies with the NASA-Marshall Space Flight Center, the Lockheed Aircraft Corporation (later the Lockheed Corporation) of Sunnyvale, California, had performed several in-house research studies germane to manned Venus and Mars fly-by missions. As early as 1960, the Lockheed Missiles and Space Division* produced a report on space mechanics by C. M. Petty.[22] Another pertinent study, published a month later by Leighton F. Koehler, concerned the orbital parameters of a manned satellite orbiting Mars.[23]

Detailed studies on interplanetary transportation systems supporting EMPIRE were conducted during 1962 and 1963 under contract NAS8-2469 by

* By the early 1960s, the Lockheed Missile and Space Division had become the Lockheed Missiles and Space Company whose acronym LMSC is used throughout the paper.

Lockheed Missiles and Space Company's (LMSC) Flight Mechanic Group, Aerospace Sciences Laboratory. Supervision was exercised by Marshall's Future Projects Office and Aero-Astrodynamics Laboratory. The final report, which was submitted on 30 April 1964, covered LMSC's study of analytic derivations and numerical data applicable to interplanetary and planetocentric flight mechanics, navigation, and guidance. In the words of the report, "the general information provides the background and means for extended *mission* studies; the specific [information] illustrates its use and significant applications."[24]

This study examined five areas of importance to EMPIRE planning: nonstop interplanetary round-trips, stopover interplanetary round-trips, missions launched normal to the ecliptic, nonstop trips passing Mars and Venus, and precise calculations and investigations of requisite guidance sensitivities.

EMPIRE studies conducted under NASA contract NAS8-5024 were directed to Marshall's Future Projects Office during 1962 and 1963. The first phase of this effort was concerned with spacecraft and launch vehicle sensitivities for manned flyby missions carried out during the Venus 1974 conjunction and the 1975 Mars opposition. The contract, which was subsequently extended from 1 April 1963 to 1 January 1964, emphasized missions most likely to be realized using launch vehicles proposed at the time. References 25 through 32 are selected reports issued during the period.

Study objectives established for LMSC by Marshall's Future Projects Office included:

1. A detailed definition of suitable mission profiles not requiring the development of major new chemical or nuclear propulsion systems.
2. Sufficient investigation of subsystems to delineate requirements and possible pacing items.
3. Preliminary design of spacecraft capable of undertaking early Venus and Mars round-trips based on the capabilities of the Saturn launch vehicle family.
4. Identification of launch vehicle requirements and comparison with current programs.
5. Development plan and funding schedule.

The method of approach was described in these terms:

> By an iterative process, mission velocities, and their effects on booster and re-entry requirements, were compared with mission times and their effects on life support and environmental control weights for 'nearly open' and 'nearly closed' systems for different crew sizes. When it became clear that Earth departure velocity was the dominating factor for the missions under considerations, the analysis to select missions of minimum mass on Earth

orbit was simplified to the selection of missions with minimum Earth departure velocities.

The many systems were investigated sufficiently to provide (within limits set by study fund limitations) an indication of applicability of the manned interplanetary program; development status; weight, size, and power characteristics; and cost. Vehicle concepts were developed and masses determined for different missions considering mission time and its effects on life support requirements, and also (with the influence of solar proximity) on shielding requirements. The spacecraft masses were compared with the velocity/payload performance capability of different Earth orbit boosters and the resulting combined weight effect for Earth surface launch boosters.

Principal assumptions developed for the EMPIRE study took account of a number of constraints. Among them:

1. The Earth surface launch vehicle was to be the Saturn V with the S-II serving as its second stage.

2. Systems carried to Earth orbit by the Saturn V were to rendezvous (where needed) to form the escape vehicle.

3. If possible, the mass required in Earth orbit was to be held to that achievable by two Saturn V launches (one rendezvous} so that a third launch pad could accommodate a backup launch vehicle and two payloads ready in the event either Saturn V launch were to fail.

4. The Earth orbit escape was to use a chemical propulsion system or a nuclear propulsion system developed from NERVA technology (either a single stage or a two stage configuration).

5. The spacecraft was to carry probes to gather direct data on planetary atmospheres and surface conditions.

6. Earth reentry was to be accomplished using an Apollo capsule modified to meet new mission requirements and increased entry speeds.

7. Unless and until it were established that an artificial gravity field was not required, vehicle systems capable of providing simulated gravity were to remain under investigation.

Study limitations were an important aspect of the LSMC effort. Considering the capability of the Saturn V, nuclear propulsion likely to be developed by then available technology, and the use of the Apollo spacecraft, the only interplanetary missions that appeared to be achievable were flybys. Limited funding precluded detailed investigations of the many subsystems such missions demanded.

LMSC made its first EMPIRE progress report on 6 August 1963 at the Marshall Center. A second report was delivered on 2 October 1963 at Lockheed's Palo Alto, California, facility. It was concluded that launch vehicle and spacecraft performance and design assumptions were valid and that major subsystems had been more clearly identified and delineated than had earlier been the case.

At the conclusion of the study, the LMSC team under the direction of Benjamin P. Martin delivered its final report to the Marshall Space Flight Center in several volumes. The first of these was an unclassified summary of the complete study. The second volume consisted of unabridged findings in two parts, Part A containing all unclassified material and Part B incorporating classified data on the nuclear propulsion systems and their associated launch vehicles. The third volume was a condensed, unclassified summary of the entire project.

The follow-on phase of the EMPIRE studies emphasized manned flyby missions of Venus and Mars during the 1974 conjunction of the former planet and the 1975 opposition of the latter. For the Venus mission, a departure on 11 November 1973 was proposed, a cruise duration of 370 days, and an approach to within 500 nautical miles of the planet. For the Mars mission, launch would occur on 24 September 1975; and, following a 670-day cruise, the spacecraft would also pass within 500 nautical miles of its target.

Martin and his associates stressed that such flyby missions would be very useful as precursors for later manned landings on the planets. Not only would landings provide the opportunity to gather valuable planetary data by on-board sensors and crew observations but would further define man-machine relationships and roles and crew requirements for long-term space voyages.

A number of conclusions were drawn from studies dealing with launch from parking orbit. Among them were:

1. The problem of launch window (the time available for launch from a particular parking orbit including plane-change requirements) must be a major consideration in selecting orbit launch systems and determining related operations. Launch windows would depend on the vehicle's ability to absorb a plane change and could range from several days to several hours.

2. A dual burn technique might be useful in reducing the plane change penalty.

3. The penalty of maintaining the departure asymptote with the orbital plane was found to be greater than that of absorbing the plane change during launch.

4. Selection of an orbit inclination slightly higher than the declination of the departure asymptote would keep the plane change penalty low over the longest period.

Most of the work involving crew utilization and requirements was accomplished in the first phase of the EMPIRE effort and was so reported in earlier documentation. However, general recommendations for life support and environmental control systems were made for a physico-chemical system of the "nearly closed" type shown in Figures 17 and 18. Assumptions supporting the selection are shown in Table 9. The crew compartment as a subsystem of the complete spacecraft and environment control system is shown in Figure 19. Food and water requirements for the subsystem are presented in Table 10, and the electric power requirements for various size crews are listed in Table 11. To protect the crew from ionizing radiation, sufficient shielding (consisting of aluminum and polyethylene) was felt to be necessary to limit the probability to 0.0001 of exceeding 200 rad to the blood-forming organs, with doses from cosmic and nuclear reactor sources both assumed to be 20 rad/hour.

In carrying out the guidance and control portion of the study, Martin and his associates divided the interplanetary mission into the following phases: (a) injection into the heliocentric trajectory; (b) midcourse; (c) planetary approach; and, where stopover missions were considered, (d) the stopover orbit. Depending on the mission, some phases would be repeated on the return leg as shown in Figure 20.

During the initial study period, navigation techniques, accuracy requirements, guidance procedures, and the conceptual development of an integrated spacecraft guidance system were considered for the injection, midcourse, and planetary approach phases. The follow-on study was directed toward a refinement of techniques, extending spacecraft guidance to include stopover capability as well as the development of an instrumented landing probe to aid in defining stopover orbit guidance requirements and surface reconnaissance techniques. A diagram of a proposed system is shown in Figure 21.

Estimated weight and power requirements are summarized in Table 12. It is noted that environmental control equipment and attitude torquers are not included. Computer memory and clock are continuous while other items operate intermittently.

Interplanetary reconnaissance as envisioned by Martin and his LMSC EMPIRE study team was to require a total, integrated system of data sensing, processing, correlation, and evaluation geared to supply planetary data for future designs related to manned landings on and exploration of Mars. It was anticipated that these data would supplement a logical sequence of earlier Earth-based astronomical and unmanned reconnaissance missions. However, the intimate knowledge of the landing site and its environment necessary to commit a manned lander appeared attainable only through the coordinating efforts of an on-board space crew. The crew was to perform this role only if it were possible to design an adequate, on-board, data processing and display system.

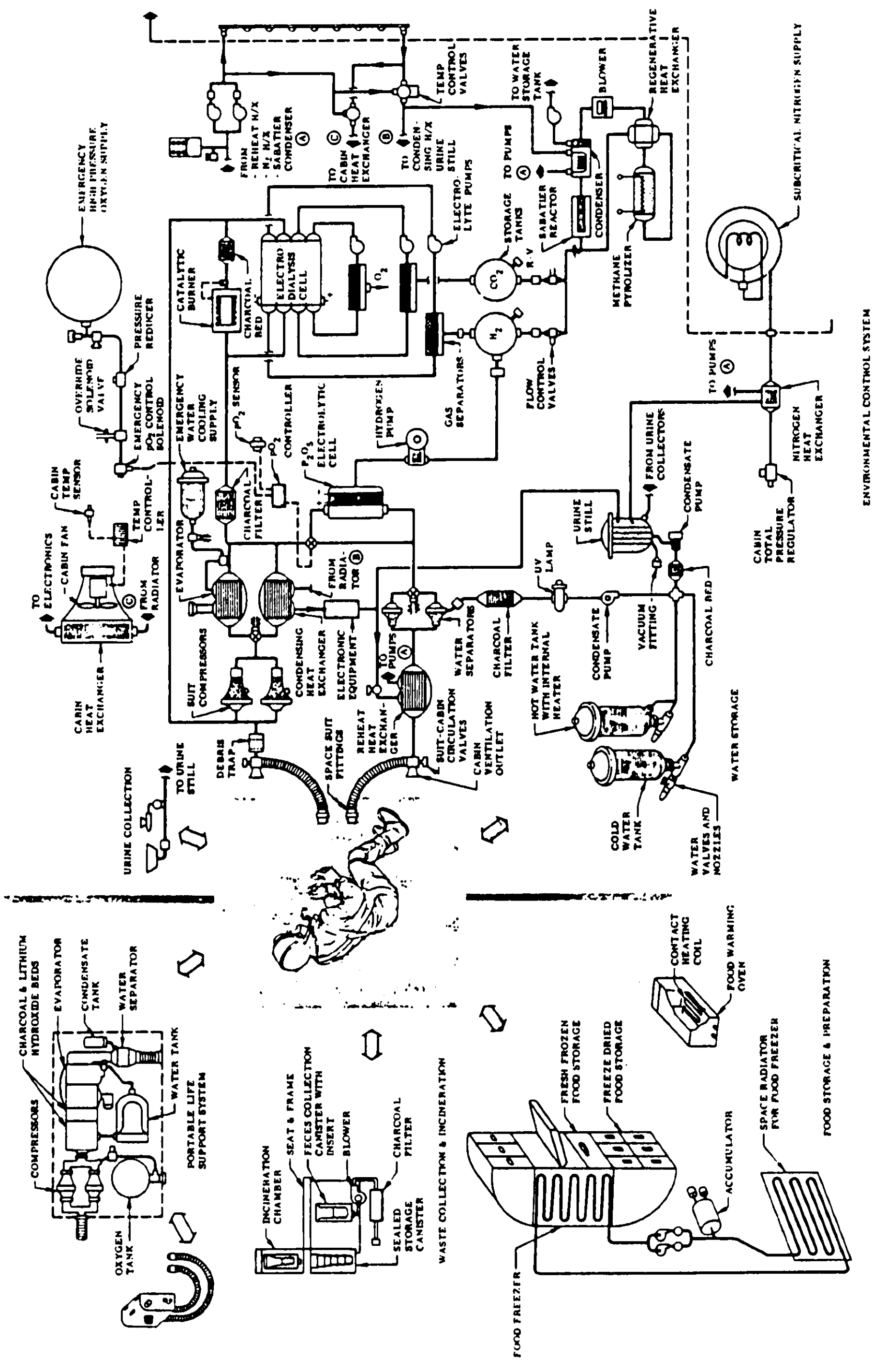


Figure 17 Schematic of Lockheed life support system.

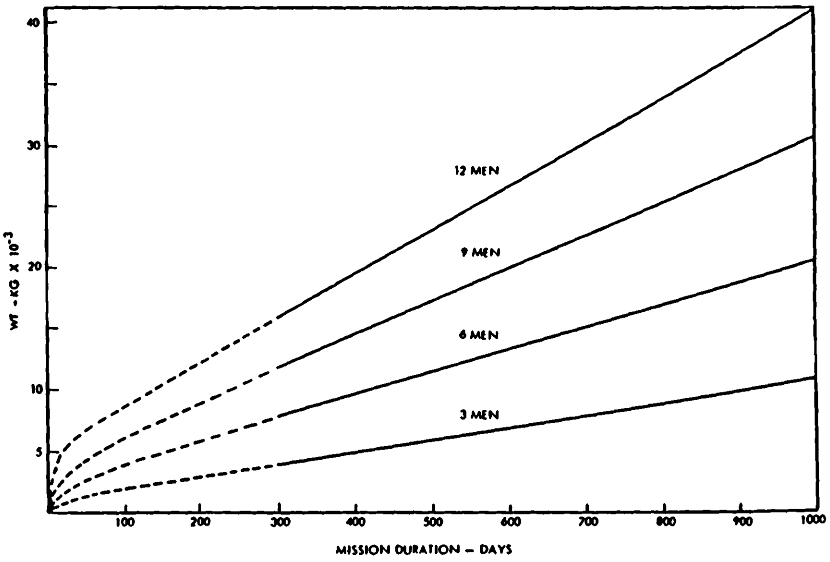


Figure 18 Lockheed semi-closed life support and environmental control system parameters.

Table 9

NOMINAL DESIGN VALUES FOR MANNED INTERPLANETARY MISSIONS

Parameter	Nominal Design Value
Temperature	24° C ± 3° C (75° F ± 5° F)
Relative humidity	50 percent ± 20 percent
Air velocity	12.7 cm sec^{-1} (25 ft min^{-1})
Cabin atmosphere	180 torr O_2 180 torr N_2
Suit atmosphere	180 torr O_2
Cabin $_pCO_2$	<3.8 torr
Cabin volume†	$113m^3$ + [$14m^3$ (C - 3)] or 4000 ft^3 + [500 ft^3 (C - 3)]
Lock volume	$1.4m^3$ (50 ft^3)
Lock usage	1 every 10 days
Cabin repressurizations	1 every 72 days
Cabin leakage‡	(C + 9) /12 kg day^{-1}
Angular velocity of rotating vehicle	< 0.4 radians sec^{-1}
Induced g acceleration	> 0.3 and < 0.85 g
Total radiation to blood forming organs with probability of 0.001	200 rads
Reentry acceleration stress	< 10 g
Water intake man^{-1} per day	3344 gm
O_2 intake man^{-1} per day	826 gm
Dry food intake man^{-1} per day	630 gm
Water of oxidation man^{-1} per day	356 gm
CO_2 produced man^{-1} per day	1015 gm
Feces produced man^{-1} per day	155 gm
Urine produced man^{-1} per day	1330 gm
Sweat produced man^{-1} per day	2300 gm
Total metabolism man^{-1} per day	2820 kcal
Latent heat loss	47 percent of total metabolism

†C = Number of men in crew.
‡Approximately proportional to area of pressurized cabin.

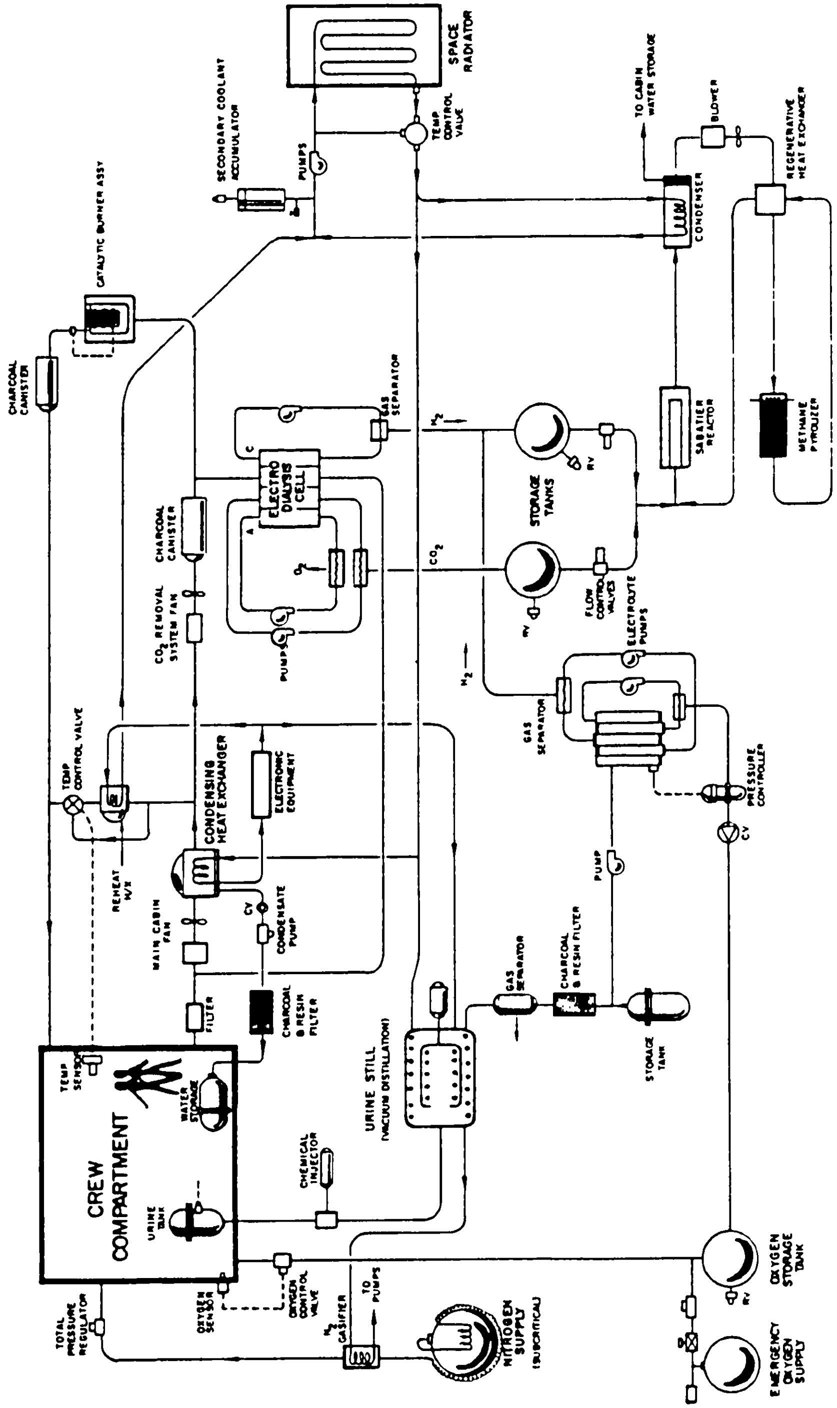


Figure 19 Schematic of Lockheed environmental control system.

Table 10
FOOD AND WATER WEIGHTS IN KILOGRAMS

	3 Men – 300 Days				3 Men – 1000 Days			
	Open		Closed		Open		Closed	
Dry Food	504		504		1680		1680	
Container	29		29		98		98	
Total		533		533		1778		1778
Hydrated Food (75% H_2O)	504		504		1680		1680	
Container	76		76		260		260	
Total		580		580		1940		1940
Water	2633		100		8730		100	
Container	338		13		1132		13	
Total		2971		113		9862		113
Refrigeration		200		200		500		500
Food Storage and Preparation		250		250		730		730
TOTAL		4534		1676		14,810		5061

Table 11
LIFE SUPPORT POWER REQUIREMENTS

	Open (Watts)				Semi-Closed (Watts)			
	3 Men	6 Men	9 Men	12 Men	3 Men	6 Men	9 Men	12 Men
CO_2 Removal	150	275	400	525	400	750	1,100	1,450
Atmosphere Purification	10	15	20	25	10	15	20	25
Refrigeration	250	450	650	850	250	450	650	850
Food Preparation	40	70	100	125	40	70	100	125
Thermal Control	680	900	1,100	1,300	840	1,320	1,820	2,400
Urine Distillation	-	-	-	-	30	60	90	120
CO_2 Reduction	-	-	-	-	100	200	300	400
CH_4 Pyrolysis	-	-	-	-	150	300	450	600
Utility Water Distillation	75	150	225	300	75	150	225	300
Utility Water Heating	50	90	130	170	50	90	130	170
Water Electrolysis	-	-	-	-	1,000	2,000	3,000	4,000
Waste Incineration	150	275	400	525	150	275	400	525
Lights	500	700	900	1,100	500	700	900	1,100
Gas Supply	30	45	60	75	30	45	60	75
Total (Average)	1,935	2,970	3,985	4,995	3,625	6,425	9,255	12,140
Total (Peak)	3,300	5,250	7,300	9,200	5,000	9,000	12,900	16,700

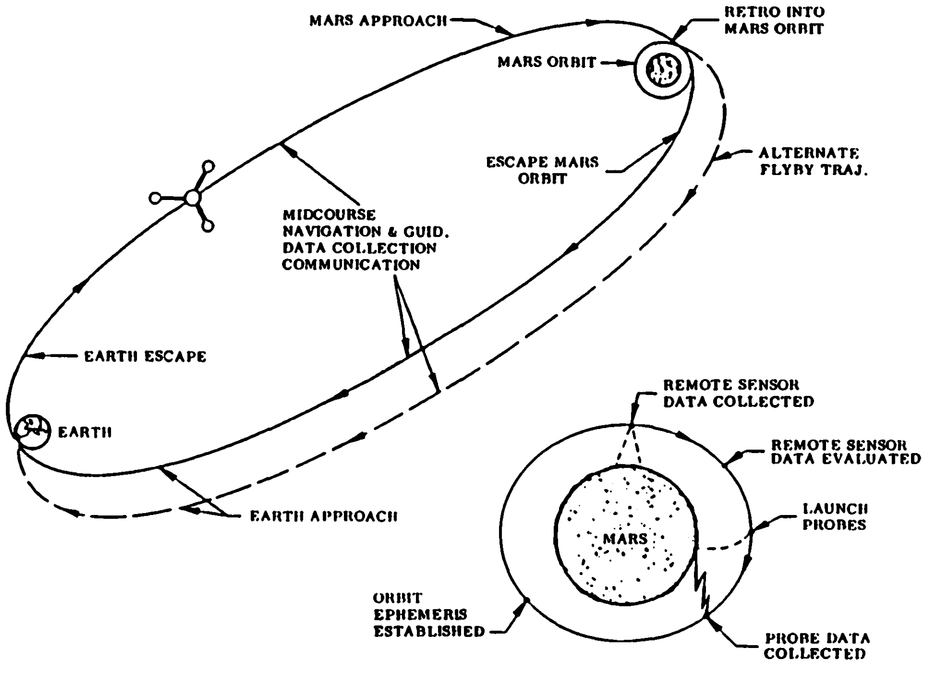


Figure 20 Lockheed guidance and data system mission phases, Earth to Mars.

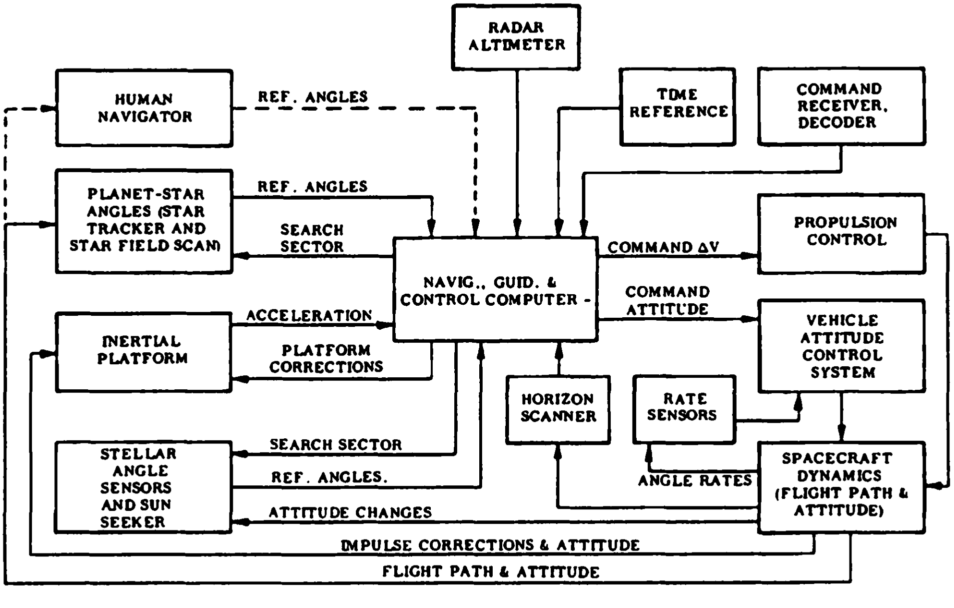


Figure 21 Lockheed spacecraft guidance and control system diagram.

Table 12

ESTIMATED WEIGHT AND POWER REQUIREMENTS

	Weight (lb)	Volume (cu ft))	Power (w)
Trajectory Determination System	145	5	200
Attitude Congrol System	50	2	25
Computer System	70	3	150
Command Link Equipment	5	0.3	5
Mars Orbit Determination	75	2	90
Totals	345	12.3	470

Preliminary review on the reconnaissance goals, capabilities, and problems of three interplanetary missions—flyby, orbiting, and landing—led to the following conclusions:

1. The flyby would be a limited, one-shot, narrow-swath reconnaissance tool, subject to continuous scale and angular-rate variation detrimental to optimum sensor design and to data interpretation. Its best use might be for operational testing of future-mission equipment and possibly for accurate insertion of a reliable unmanned reconnaissance orbiter and/or lander.

2. The manned orbiting mission would provide a stable reconnaissance platform, capable of mapping the complete planet, sensing vast quantities of detailed surface data at near-uniform scale, and—if properly equipped—collating atmospheric and surface data. Major problems were felt to involve mass-data handling, automatic processing and displays required to aid the crew in tracking, correlation, sensor control and evaluation.

3. The landing mission would require a higher order of data-handling and correlation sophistication than the orbiter. It was noted that in the course of repetitive orbits, preferred exploration areas would have to be located and landing site details (including the immediate environment) closely inspected by means of on-board and probe-borne sensors. The safety of manned landing operations would be judged from orbit. Furthermore, landing and return-rendezvous sensor systems would have to be provided along with surface exploration aids. The total equipment weight (including probes) was found to vary from 1,600 pounds for the flyby mission to 20,000 pounds (plus storage and transmission equipment) for the landing mission.

Studies of electric power requirements for three-man Venus/Mars flyby missions took into account nuclear and solar-activated primary systems as well as auxiliary or emergency systems and tradeoffs. Auxiliary power plant investigations considered Gemini- and Apollo-type hydrogen-oxygen fuel cells and reciprocating engines. A power output of 5 to 8 kilowatts was assumed for each such system. Among the nuclear options studied, the preference was for an 8-kilowatt nuclear/dynamic system using a SNAP 2/8 reactor and a Brayton gas-cycle energy conversion unit.

At the time the electric power supply and system portion of the LMSC EMPIRE study was completed, a number of observations could be made:

1. The leading candidate for the spacecraft was a nuclear power system.
2. No firm requirement for auxiliary power could be established in conjunction with the nuclear power plants.
3. There were weight penalties inherent in the nuclear power plant.
4. At the same time, there were several operational constraints in the solar/dynamic power plant.
5. It was felt that multiple solar/dynamic systems might be required.
6. An auxiliary power plant would be needed in conjunction with the use of a solar/dynamic primary power plant for Earth escape.

The LMSC investigators proposed a slowly rotating spacecraft that would produce an artificial gravity of 0.4 g. They reported that "two detailed spacecraft configurations were designed for the interplanetary flyby missions with differences brought about largely because of the electrical power system concepts. One design employs a solar dynamic power system, and the other a nuclear dynamic power system. The first configuration, which is a modification of the spacecraft described in the initial EMPIRE report, incorporates a larger, more spacious solar shelter in the hub and provides for a heavier Earth-entry system. The second configuration is a more detailed study of a spacecraft mentioned briefly in the initial report." In both cases, the spacecraft would comprise a command module, a mission module, a power system, and a midcourse propulsion unit.

The command module for the spacecraft fitted with a solar power system would be a modified Apollo with an internal volume of about 8.5 cubic meters. It would serve as the crew's launch vehicle, emergency escape vehicle during launch, Earth entry vehicle during an emergency in Earth orbit, command/control center during interplanetary cruise, and Earth entry vehicle at the completion of the mission. For one configuration using a nuclear power system, the command module would be a special purpose design integrating the command/control center with the solar shelter. A second configuration would employ a command module similar to the solar power system configuration's command module.

The mission module would house the crew's living quarters, the dining and recreational area, and the environmental control equipment, food, water, and spares for the spacecraft. Internal volume of the module would be 113 cubic meters.

The spacecraft was designed with a protective shelter to shield the crew from radiation during periods of intense solar activity.

This configuration, shown in Figure 22, consisted of command and mission modules connected by 25-meter rigid spokes to a hub. Crew access to the modules would be through these spokes. The command module would be a modified Apollo spacecraft with an attached retro-propulsion pack to decrease Earth entry velocity to design values. The mission module would be 3.66 meters in diameter and 12.1 meters long. The solar shelter, shown in Figure 23, would have an internal volume of approximately 5.6 cubic meters and would be located at the rotational hub with the electric power system and the midcourse propulsion unit.

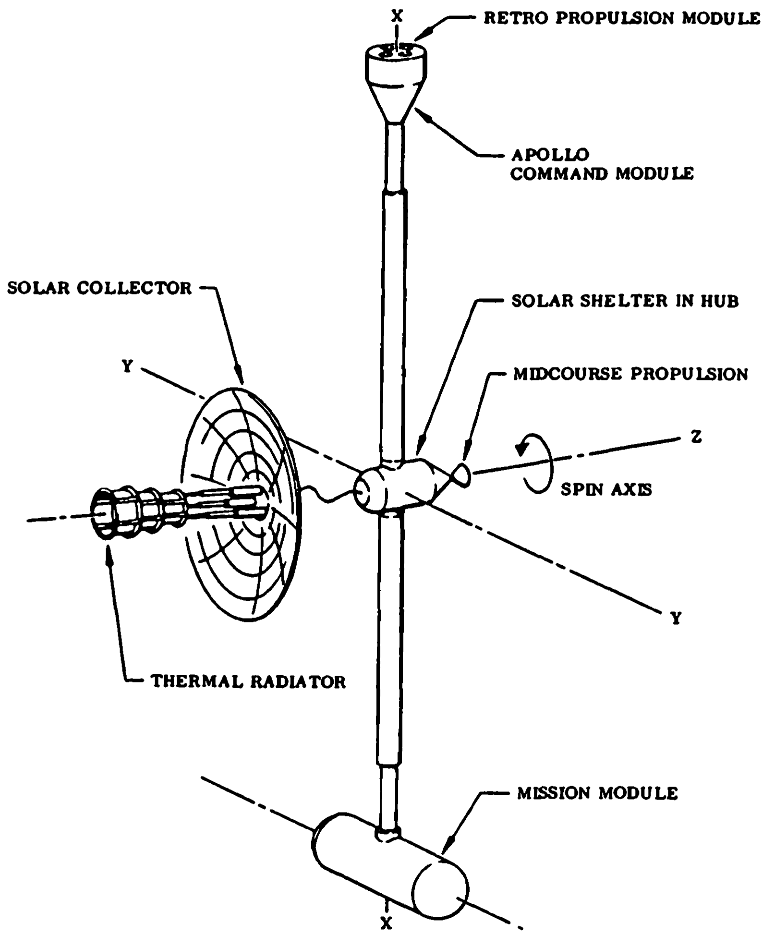


Figure 22 Lockheed manned interplanetary spacecraft solar power system.

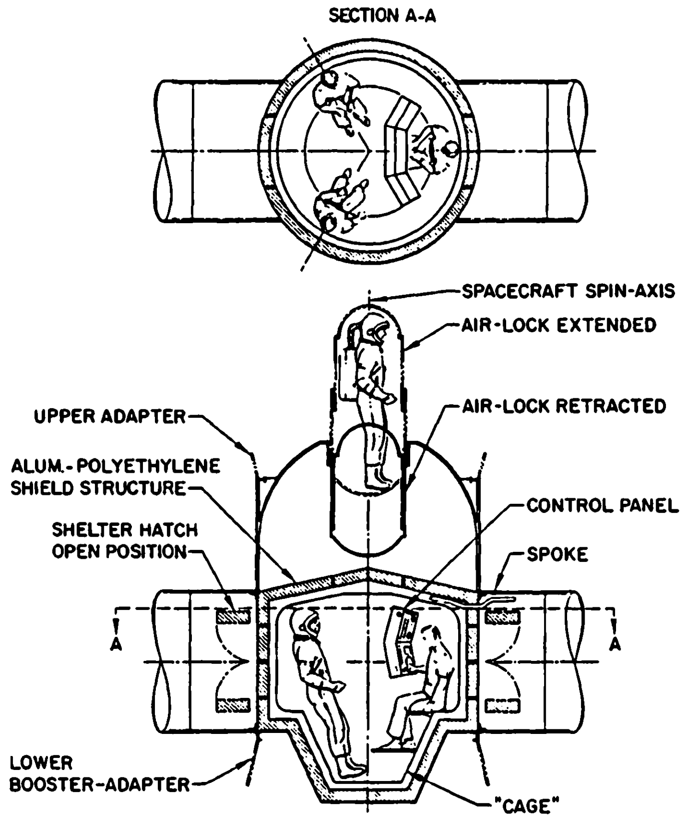


Figure 23 Cutaway of Lockheed solar shelter located in the spacecraft hull.

For launch, the spacecraft would be stowed as shown in Figure 24. The sequence for deploying the craft once in Earth orbit was described by the LMSC EMPIRE team thus:

> The spacecraft is launched as a compact package on the booster and then erected in Earth orbit. The crew is launched into orbit in the command module to which the emergency escape rocket is attached. This rocket is jettisoned at the end of the first stage burnout. In orbit, the sequence is as follows: (1) the fairings and interstage adapters are jettisoned, (2) the command module with the attached retrorocket is rotated 180 degrees and secured to its spoke, (3) this assembly is rotated 90 degrees and secured to the hub, (4) the opposite spoke with the mission module attached is rotated 90 degrees and secured to the hub, and then (5) the mission module is rotated and secured to the spoke. A cable system can be used to move the spokes and modules into proper position, one section of the system would 'pull' the modules into position and the other section would 'restrain' these modules from closing too rapidly.

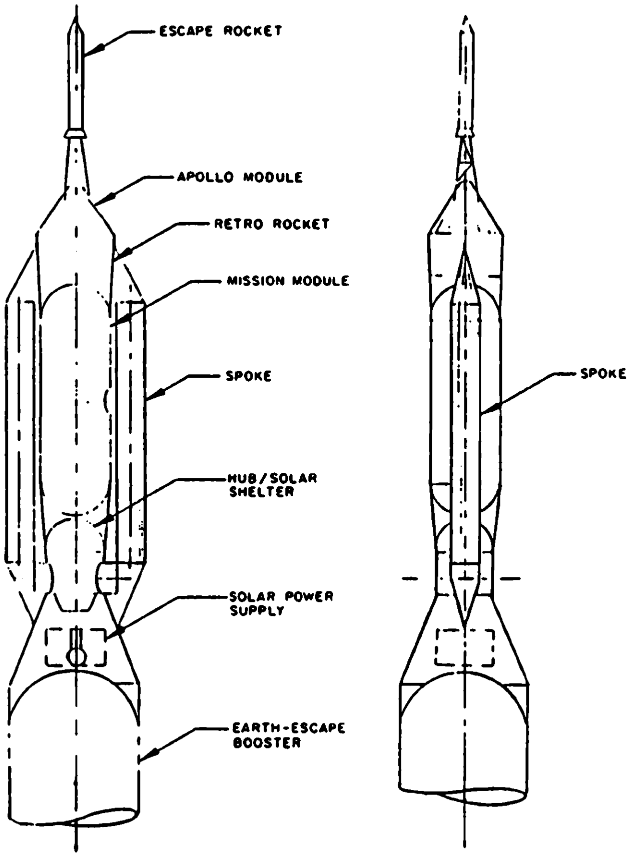


Figure 24 Lockheed solar power system launch configuration.

All systems within the spacecraft were to be checked out in Earth orbit before proceeding with the interplanetary cruise. Power during the checkout phase was to be supplied by an auxiliary chemical system, either a thermal piston or turbine system, which would operate on storable propellants from the midcourse propulsion system, or by fuel cells. The solar concentrator was not to be erected in Earth orbit because the large diameter reflector could not withstand escape loads during the injection phase.

The nuclear-powered configuration is shown in Figure 25. Basically, the arrangement of the modules is the same as that of the solar-powered version, except that a third spoke is required to support the nuclear-power system and a radiation shield is added. The solar shelter located in the hub, as seen in Figure 26, is of a somewhat different design. A variation shown in Figure 27 would shift the Apollo Earth-entry module to the hub. Its solar shield is illustrated in Figure 28.

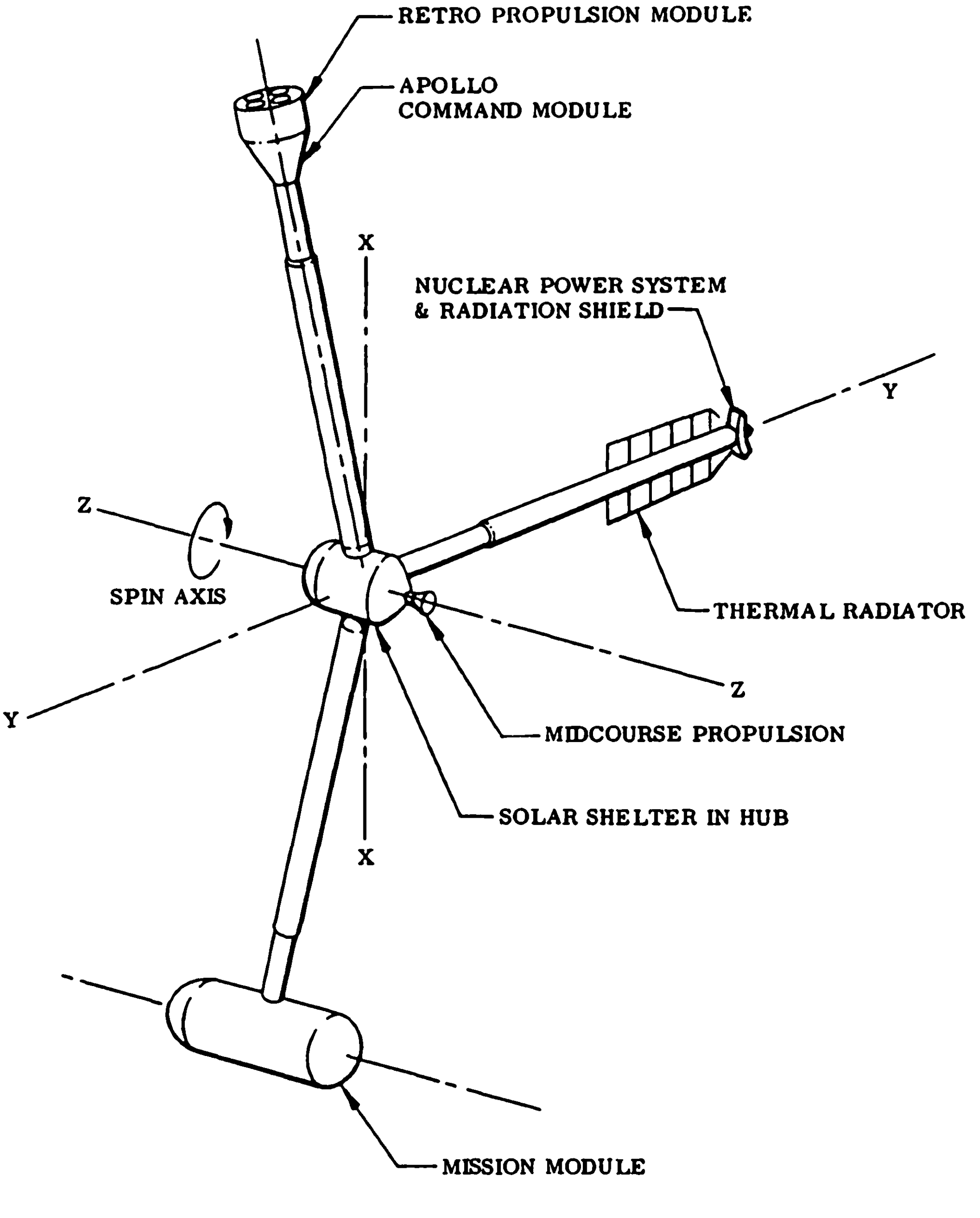


Figure 25 Lockheed manned interplanetary spacecraft nuclear power system.

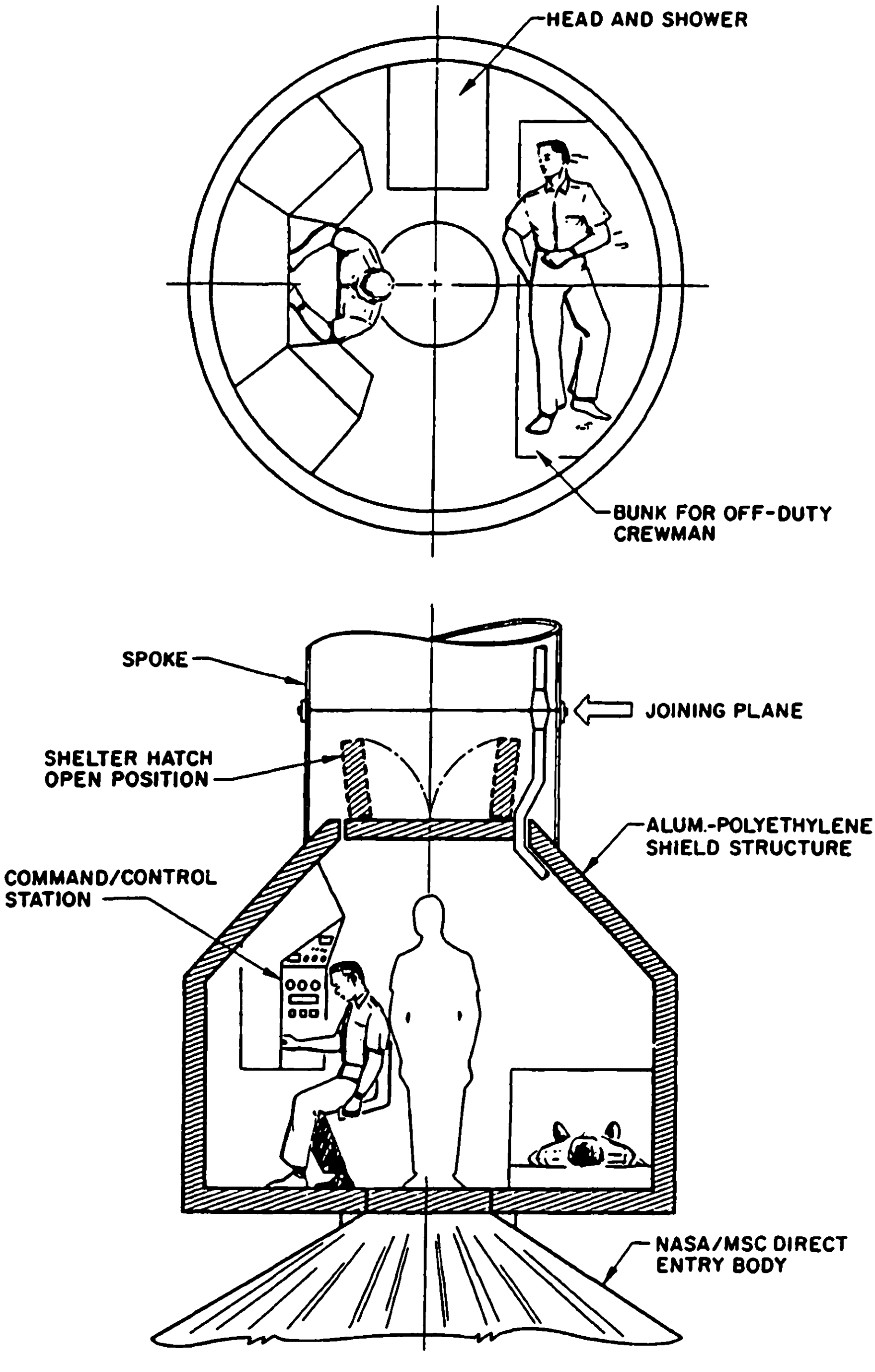


Figure 26 Cutaway of Lockheed solar shelter including command/control center.

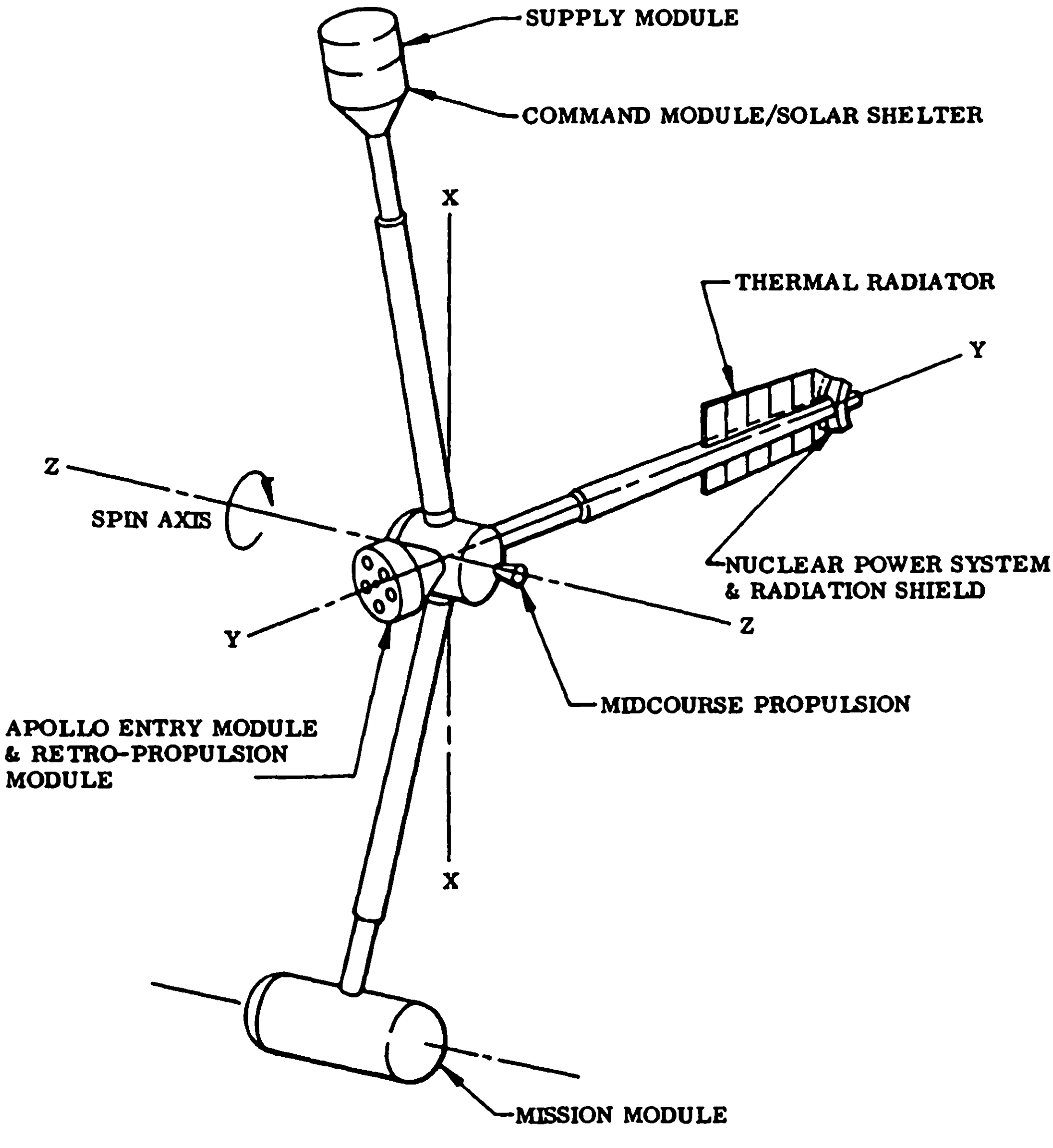


Figure 27 Lockheed manned interplanetary spacecraft nuclear power system combined command module/solar shelter.

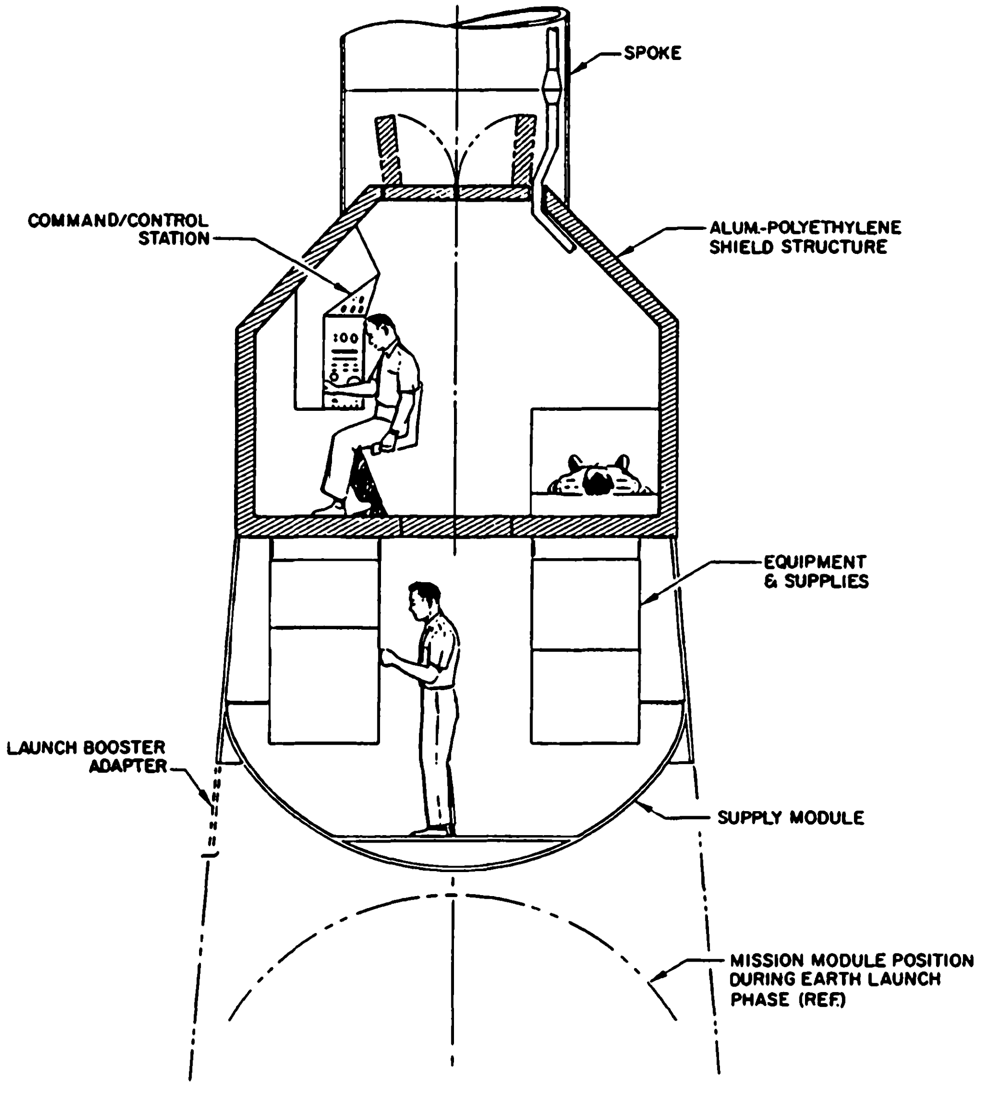


Figure 28 Cutaway of Lockheed solar shelter with command/control center and supply module.

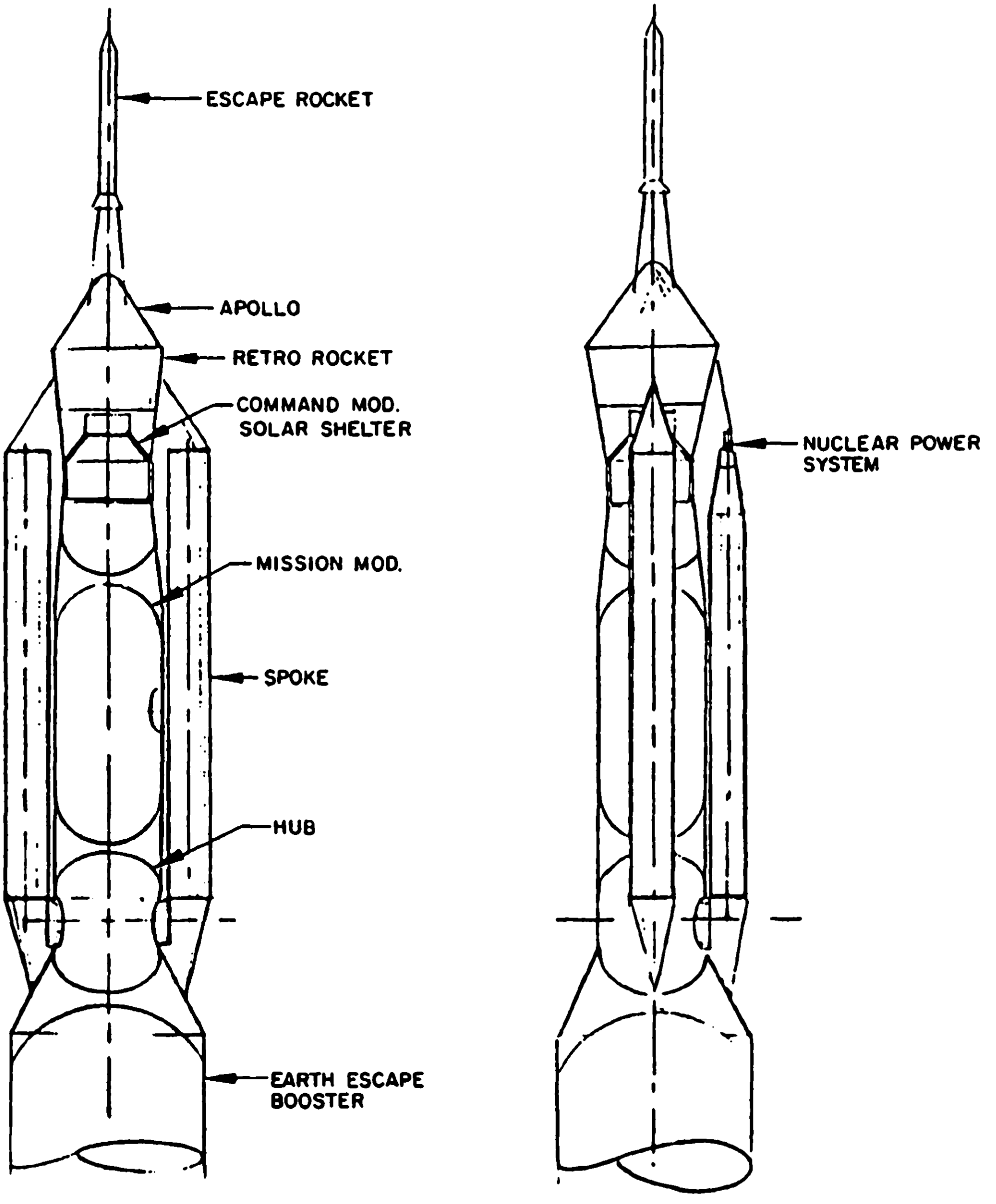
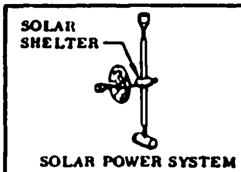
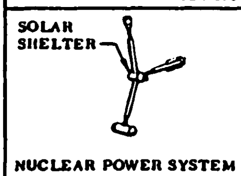
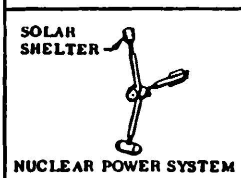
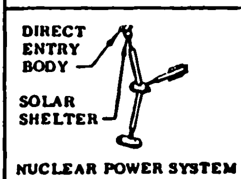


Figure 29 Launch configuration of Lockheed nuclear power system.

At launch the spacecraft would be folded as shown in Figure 29. The crew would accommodate itself in the entry body and the erection sequence on orbit would proceed as follows: (a) the entry body would rotate 180 degrees and two crewmen would transfer into the command module/solar shelter, (b) the entry body would next be maneuvered to the side of the hub and docked, (c) the command module/solar shelter would be rotated, attached to the spoke, and this assembly would then rotate 90 degrees and be secured to the hub, (d) the mission module and spoke would rotate 90 degrees, the spoke secured to the hub and the module to the spoke, and (e) the nuclear power system and spoke would rotate 90 degrees and the spoke would be secured to the hub. The nuclear power system would then be activated to supply power to the spacecraft.

Injection payload weights for the various spacecraft configurations studied are summarized in Table 13. Detailed weight breakdowns for the Venus flyby are given in Table 14, and the same data for the Mars mission appear in Table 15.

Table 13
INJECTION PAYLOAD WEIGHTS

	INJECTION PAYLOAD				
	VENUS		MARS		
	.001†	.01†	.001†	.01†	
	37,838 kg 83,420 lb	35,706 kg 78,720 lb	48,278 kg 106,440 lb	46,055 kg 101,540 lb	MODIFIED APOLLO
	44,770 kg 98,700 lb	42,412 kg 93,500 lb	56,774 kg 125,161 lb	55,407 kg 122,149 lb	REGULAR APOLLO
	41,593 kg 91,700 lb	39,665 kg 87,450 lb	50,691 kg 111,750 lb	48,513 kg 106,950 lb	MODIFIED APOLLO
	48,848 kg 107,690 lb	46,735 kg 103,033 lb	60,789 kg 134,014 lb	58,397 kg 128,740 lb	REGULAR APOLLO
	43,502 kg 95,910 lb	41,370 kg 91,210 lb	53,170 kg 117,220 lb	49,511 kg 109,150 lb	MODIFIED APOLLO
	52,145 kg 114,960 lb	48,582 kg 107,104 lb	63,524 kg 140,043 lb	60,042 kg 132,367 lb	REGULAR APOLLO
	39,510 kg 87,110 lb	37,514 kg 82,710 lb	44,054 kg 97,120 lb	40,789 kg 89,920 lb	

† PROBABILITY OF RECEIVING MORE THAN 200 RADS TO THE BLOOD FORMING ORGANS

Table 14

SPACECRAFT WEIGHT SUMMARY, VENUS FLYBY (KILOGRAMS)

Item	Solar Power System		Nuclear Power Systems: Hub/Solar Shelter		Nuclear Power Systems: CM/Solar Shelter		Nuclear Power Systems: NASA/MSC Entry Body	
	.001*	.01*	.001*	.01*	.001*	.01*	.001*	.01*
Emg. Escape Rocket	3,628	3,628	3,628	3,628	3,628	3,628	3,628	3,628
Crew	231	231	231	231	231	231	231	231
Apollo Module	5,126	5,126	5,126	5,126	5,126	5,126	-	-
Apollo Retro-Prop.	5,080	5,080	5,080	5,080	5,080	5,080	-	-
NASA/MSC Entry Mod.	-	-	-	-	-	-	6,804	6,804
Command Mod/Solar Shelter	-	-	-	-	5,216	3,447	5,216	3,447
Mission Module	3,910	3,910	3,910	3,910	3,910	3,910	3,910	3,910
Env. Control/Life Support	4,627	4,627	4,627	4,627	4,627	4,627	4,627	4,627
Hub	-	-	-	-	1,406	1,406	1,406	1,406
Hub/Solar Shelter	4,763	3,130	5,216	3,628	-	-	-	-
Spokes	2,436	2,436	3,085	3,085	3,293	3,293	3,293	3,293
Probe	2,268	2,268	2,268	2,268	2,268	2,268	2,268	2,268
Inst. Guid. Nav. Comm.	916	916	916	916	916	916	916	916
Adapters, Fairings	1,996	1,814	2,608	2,586	2,495	2,404	2,495	2,404
Power Supply	907	907	2,721	2,721	2,721	2,721	2,721	2,721
Attitude Control System	907	907	907	907	907	907	907	907
Midcourse Propulsion	3,946	3,765	4,264	3,946	4,672	4,400	4,082	3,946
Miscellaneous	1,361	1,134	1,361	1,361	1,361	1,361	1,361	1,361
Launch Weight	42,102	39,879	45,948	44,020	47,857	45,725	43,865	41,869
Earth Escape Weight	37,838	35,706	41,593	39,665	43,502	41,370	39,510	37,514
Interplanetary Orbit Weight	36,845	34,756	40,083	38,185	42,102	40,070	38,060	36,164
(Standard Apollo)								
Launch Weight	49,034	46,585	53,203	51,090	56,500	52,937		
Earth Escape Weight	44,770	42,412	48,848	46,735	52,145	48,582		
Interplanetary Weight	43,776	41,462	46,974	45,255	50,745	47,282		

*Probability of receiving more than 200 rads to the blood-forming organs.

Table 15

SPACECRAFT WEIGHT SUMMARY, MARS FLYBY (KILOGRAMS)

Item	Solar Power System		Nuclear Power Systems: Hub/Solar Shelter		Nuclear Power Systems: CM/Solar Shelter		Nuclear Power Systems: NASA/MSC Entry Body	
	.001*	.01*	.001*	.01*	.001*	.01*	.001*	.01*
Emergency Escape Rocket	4,082	4,082	4,082	4,082	4,082	4,082	3,628	3,628
Crew	231	231	231	231	231	231	231	231
Apollo Module	5,806	5,806	5,806	5,806	5,806	5,806	-	-
Apollo Retro-Prop.	9,027	9,027	9,027	9,027	9,027	9,027	-	-
NASA/MSC Entry Mod.	-	-	-	-	-	-	6,804	6,804
Command Mod/Solar Shelter	-	-	-	-	6,486	3,357	6,486	3,357
Mission Mod	3,910	3,910	3,910	3,910	3,910	3,910	3,910	3,910
Env. Control/Life Support	7,485	7,485	7,485	7,485	7,485	7,485	7,485	7,485
Hub	-	-	-	-	1,497	1,497	1,497	1,497
Hub/Solar Shelter	5,561	3,565	5,988	4,082	-	-	-	-
Spokes	2,436	2,436	3,085	3,085	3,221	3,221	3,221	3,221
Probe	2,268	2,268	2,268	2,268	2,268	2,268	2,268	2,268
Inst. Guid. Nav. Comm.	916	916	916	916	916	916	916	916
Adapters, Fairings	2,114	2,114	2,580	2,649	2,649	2,649	2,649	2,649
Power Supply	2,040	2,040	2,722	2,722	2,722	2,722	2,722	2,722
Attitude Control Sys.	907	907	907	907	907	907	907	907
Midcourse Propulsion	4,944	4,717	5,307	5,035	5,578	5,062	4,491	4,355
Miscellaneous	1,361	1,361	1,361	1,361	1,361	1,361	1,361	1,361
Launch Weight	53,086	50,862	55,681	53,503	58,160	54,501	48,590	45,325
Earth Escape Weight	48,278	46,055	50,691	48,513	53,170	49,511	44,054	40,789
Interplanetary Weight	46,808	44,585	43,331	47,153	51,810	48,151	42,604	39,339
(Standard Apollo)								
Launch Weight	61,582	60,215	65,597	63,205	68,332	64,850		
Earth Escape Weight	56,774	55,407	60,789	58,397	63,524	60,042		
Interplanetary Weight	55,304	53,937	59,429	57,037	62,164	58,682		

*Probability of receiving 200 rads to the blood-forming organs.

Since the 1970-1980 timeframe was specified for the study, all evaluations of launch vehicles had to be predicated on the Saturn V and its various stages, actual and proposed, as shown in Figure 30.

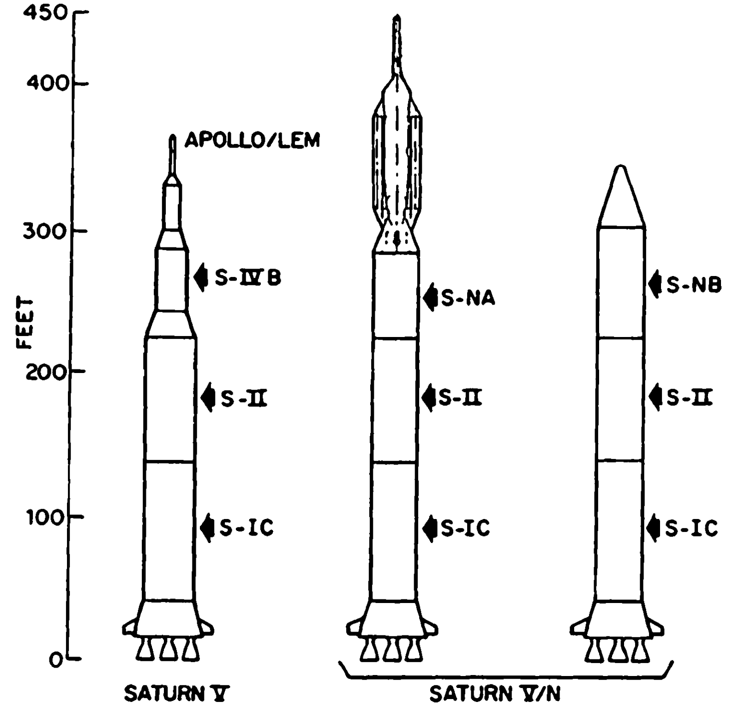


Figure 30 Saturn V configurations studied by the Lockheed team.

Flyby missions were analyzed using both an all-chemical Saturn V launch vehicle and a variation incorporating a nuclear-powered upper stage. One alternative studied for the former configuration consisted of two S-IVB stages while another would be capable of orbiting an S-II stage. Both approaches would require modifications to the stages, orbital rendezvous and on-orbit fueling operations.

Figure 31 shows NERVA nuclear stage configurations considered by the Lockheed Missile and Space Company team. S-NA is the designation given to any nuclear stage powered by a Mod 1 engine. Two sizes were studied: (a) S-NA1 for stages with a propellant capacity of less than 64,000 kilograms, and (b) S-NA2 for stages with propellant capacities in excess of that amount. The name S-NB applies to any stage using Mod 2 engines. Engine characteristics assumed are given in Table 16. Venus and Mars flyby configurations for nuclear stages are shown in Figure 32 while Figure 33 depicts the tank structure for a typical nuclear stage.

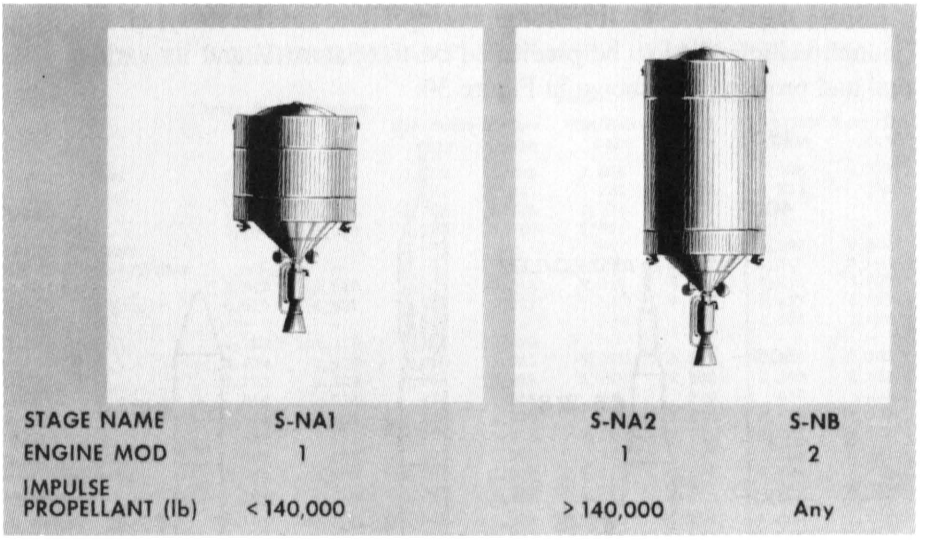


Figure 31 Nuclear stage configurations investigated for Lockheed early interplanetary missions.

Table 16

NERVA ENGINE CHARACTERISTICS

	Model Number		
	1	2	3
Reactor power (Mw)	1,120	1,271	2,020
Thrust (lb)	56,100	62,540	97,200
Specific impulse (sec)	763	790	779
Reactor exit gas temp (°R)	4,090	4,300	4,300
Chamber pressure (psia)	550	600	600
Restarts	0	1	1

Nozzle area ratio = 40 : 1

Source: Aerojet-General Corporation, Nuclear Lunar Logistics Presentation, LMSC B061597, 10 October 1963

Conclusions reached by the LMSC team during the course of the EMPIRE study program include:

1. A manned Venus flyby based on a single Saturn V/N (nuclear upper stage) launch could not be completely ruled out.

2. The Venus flyby definitely appeared to be possible based on two Saturn V launches (single rendezvous). The mission could be initiated from orbit by: (a) staging of either of two S-IVB's, two nuclear stages, or an S-IVB/nuclear combination; or (b) one large nuclear stage.

3. The liquid oxygen/liquid hydrogen propellant required for the Venus flyby mission was beyond the amount that could be orbited in an S-IVB stage by a Saturn V. Therefore, a flyby initiated with one S-IVB would not be possible unless propellant were added through refueling, or providing additional tanks, or developing another suitable propulsion stage.

4. The ability to perform a Mars low-energy flyby with two Saturn V launches to orbit could not be resolved at the time.

5. It was determined that three two-stage booster configurations would yield the highest performance: S-NA1/S-NA1, S-NA1/S-NA2, and S-IVB/S-NA1. Substituting a Mod 2 or superior engine would provide an even greater capability. However, the S-NA1/S-NA1 would require close to a 50-50 split in the payload launched to orbit, greatly complicating rendezvous operations and systems. The S-NA1/S-NA2 would require two different nuclear stage sizes. The S-IVB/S-NA1 would achieve high performance because the thrust-to-weight ratio for each stage would be sufficient to reduce gravity loss to a minimum. However, it presented configuration problems arising from a first stage of smaller diameter than the second stage.

6. The Saturn V appeared incapable of launching a single nuclear stage into orbit with sufficient propellant to accomplish a Mars low-energy flyby. Thus, either the payload mass would have to be reduced or some other configuration or operational change would need to be devised.

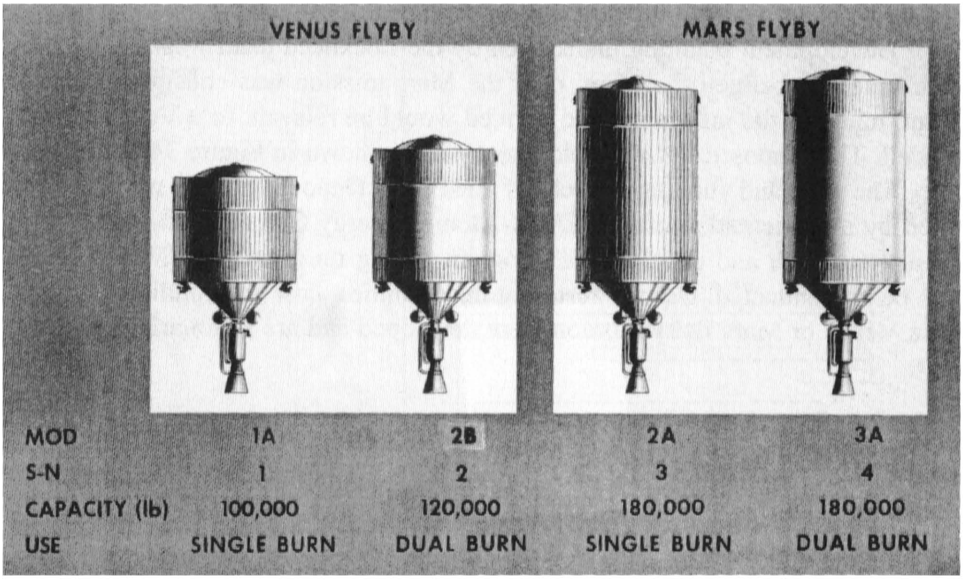


Figure 32 Engine characteristics for Lockheed nuclear stages planned for Venus and Mars flybys.

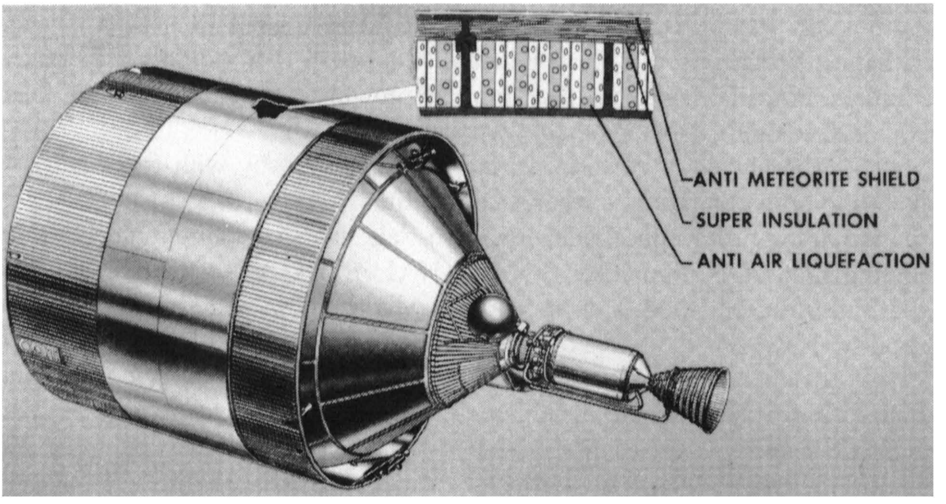


Figure 33 The Lockheed S-N two-stage configuration.

There were, of course, ways to overcome the discrepancy between payload requirement and booster capability. Three Saturn V launches, for example, with two orbiting S-NB nuclear stages and a third orbiting the intact payload, would virtually guarantee Mars flyby capability. This was seen as one of the simplest and least costly methods offering the greatest chance of success.

Development planning undertaken by the Lockheed team was restricted by both time and budget; therefore, only the Mars mission was considered. In any event, much of the information so derived would be relevant to a Venus mission as well. The proposed flyby development plan is shown in Figure 34.

The cost and funding aspects of EMPIRE, tenuous at best, were complicated by a reorientation of the NASA-Atomic Energy Commission nuclear propulsion research and development program during the time the EMPIRE study was being conducted. Despite resulting uncertainties, cost and funding estimates for a Venus or Mars flyby mission were developed and are summarized in Table 17.

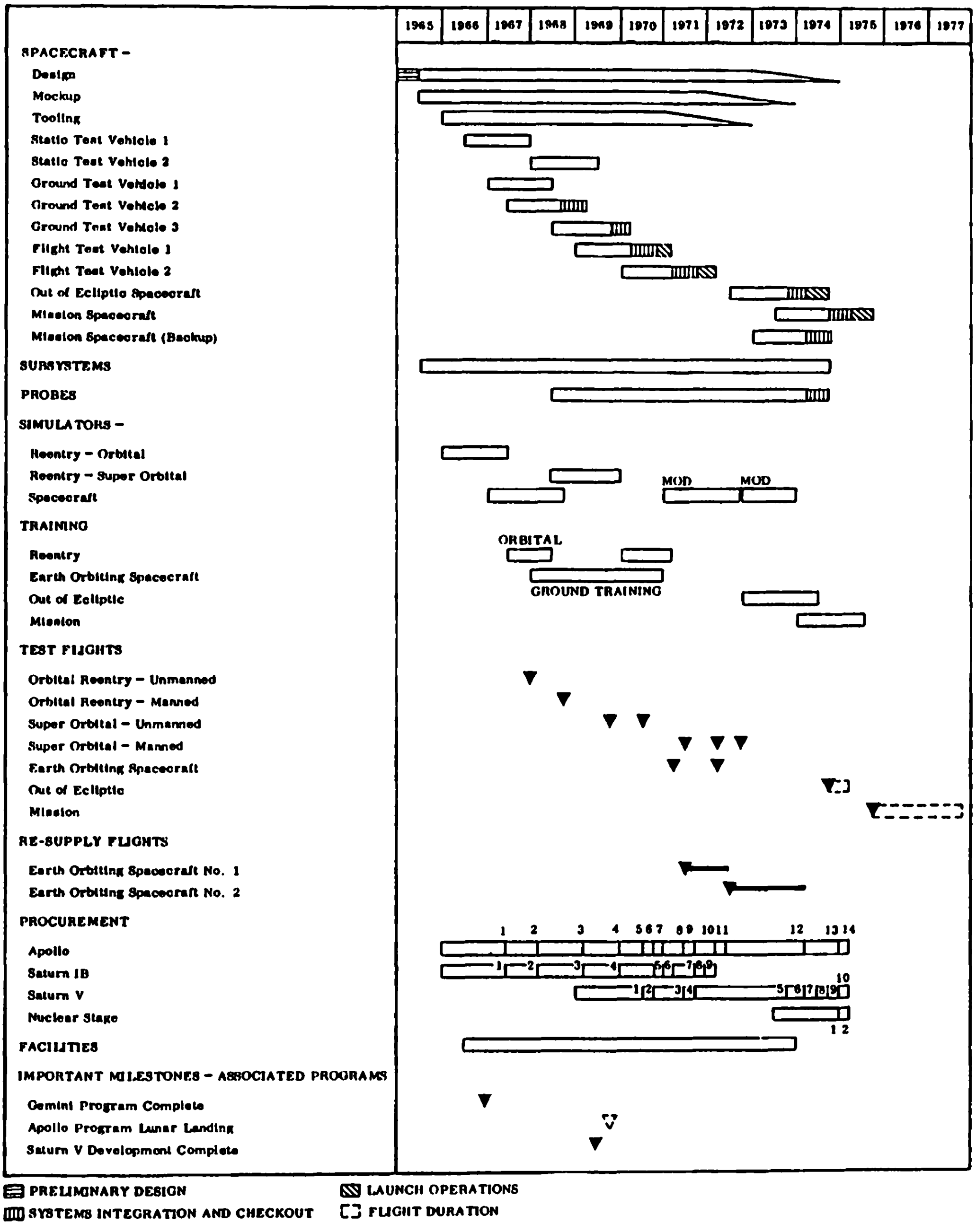


Figure 34 Development plan for Lockheed 1975 flyby mission.

Table 17

COST ESTIMATE SUMMARY (MILLIONS OF DOLLARS)

		System	
		S-NA	S-NB
1.	Engineering and Systems Integration	$ 700.0	$ 700.0
2.	Spacecraft Hardware	788.0	788.0
3.	Launch Vehicles	631.0	642.0
4.	Apollo Procurement	280.0	280.0
5.	Launch Operations	98.1	98.2
6.	Subsystems Development	443.0	443.0
7.	Probes	250.0	250.0
8.	G.S.E. and Facilities	50.0	50.0
9.	Development of S-NB Stage	-	540.0
10.	Man Rating of S-NA Stage	194.2	-
11.	Crew Training	8.0	8.0
12.	Communications During Mission	5.0	5.0
13.	Maintenance	30.0	30.0
14.	Transportation	20.0	20.0
	TOTAL	$3,497.3	$3,854.2

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