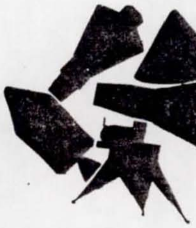


From Mercury to Mars

BY MAXIME A. FAGET
AND PAUL E. PURSER

The cumulative technology of Mercury, Gemini, Apollo, and space-station operations will establish a sound base for manned interplanetary flight

The NASA manned spaceflight program has the basic aim of exploring as much of the universe as practical, using man as a sensor, computer, and decision-maker to improve exploration. In existence since the establishment of NASA in 1958, this program now includes as approved developments the Mercury one-man spacecraft, the Gemini two-man rendezvous spacecraft, and the Apollo lunar-landing mission.

Under study in the various NASA centers are more advanced missions, such as the orbiting space station, a lunar base, and interplanetary manned missions. Although not yet approved programs, these advanced studies undertake to provide the basic technology for extending our efforts when advisable.

How can these various projects provide orderly progress in the goal of solar-system exploration? This is the question we would like to discuss, first, in terms of general comments on the development process.

The over-all planning of a total manned spaceflight program should be based on a logical sequence of steps. The planning of each individual project within such a total program should be similarly based. Individual projects should normally be established only to cover the greatest reasonable advance in capabilities that seems feasible within the state of the art at any given time. Future steps within the total program should be planned to take advantage of foreseen progress in the state of the art and individual projects should be so planned as to allow the insertion or use of unforeseen real advances or breakthroughs. Yet the goals of each phase of the program should be rather firmly established beforehand and care must be exercised to avoid delays resulting from continual changes brought about by the insertion of apparent or less-consequential advances. The proverbial wisdom of the ages would be required to completely avoid this paradoxical situation of planning for advances but yet not letting changes introduced by the advances result in undue delays.

The successful demonstration of man's capabilities in space and the advances made in spacecraft and launch-vehicle technology open a broad vista of possible manned spaceflight programs. Yet the national economy and technical resources cannot conceivably support all the possible programs. For this reason, the attack on the space frontier must be pointed and deep, rather than broad. Each succeeding program must be planned not as an end in itself, but as both a useful mission and as a steppingstone in technology leading to the next program.

Many of us would agree scheduling such far-reaching programs needs improvement over past practice. It has been traditional, in this country at least, for planners to overestimate progress during the immediate future and to underestimate progress for the more distant future. The graph appearing on page 27 illustrates this point. The estimate made at $T_{(0)}$ will likely be optimistic for short times, because of a tendency to set tight schedules, based on the assumption that every system will work as planned. Setting tight schedules keeps each element of the system moving ahead at its maximum pace; and, for those systems which do not exhibit developmental troubles, allows the introduction of advances in the state of the art.

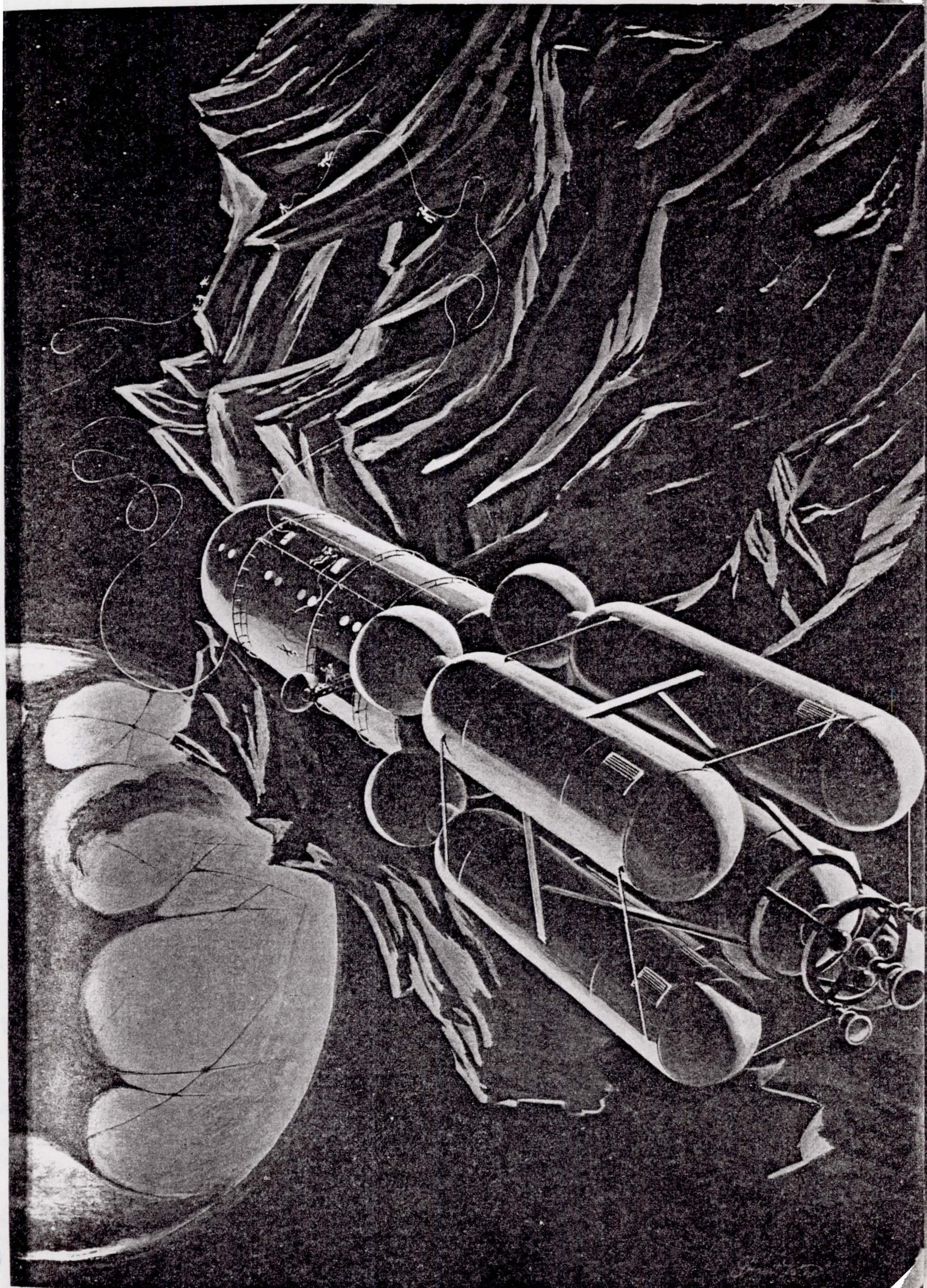
Some systems are prone to developmental troubles. The tight schedule is not met and progress in the near future is less than estimated. The increased progress in the far future results both from the advances introduced as just stated and from the normally cautious approach of planning on step-by-step progress and not purposely counting on breakthroughs occurring.

To get the best progress, we think planners of future programs and projects should:

1. Plan pointed, specific, and orderly programs that provide useful short-term knowledge and lead logically into the next longer term step.

2. Insure that estimates of near-future progress are not lowered.

RENDEZVOUS WITH PHOBOS, illustrated by MSC artist Grant Lathe—a goal for manned spacecraft development.



3. Be prepared to make less progress than estimated in the early phases of a program.

4. Be prepared to encounter otherwise unforeseen advances which will speed progress in later stages of a program.

5. Plan the approach to new programs so that, although the goals are firm and not subject to continual change, the plans are flexible enough to be modified to accept breakthroughs and advances in the state of the art.

The present manned spaceflight program—Mercury, Gemini, and Apollo—each prosecuted to a successful termination, will develop a fairly strong technical base for planning future projects.

The initial experience of manned spaceflight has been obtained in Mercury. This experience is not only applicable to flight and ground-operations crews but is also important in all phases of design engineering and management. Since Mercury is a simple spacecraft system, this experience will be greatly broadened in Gemini and then in Apollo.

Gemini will provide the first attempts at maneuvering in space in which the magnitude and direction of the velocity changes made will be computed during the flight in response to the situation created during the mission. Similarly, the capability will be developed to land at a predetermined point by guiding the spacecraft in re-entry and descent attitudes. Gemini will also allow longer flights and more complex experiments.

Apollo will give the first deep-space navigation experience. In many respects, Apollo will also have the first real mission. Its crew will be transported to the moon, and experiment, explore, and gather samples there. In Mercury and Gemini, except for incidental experiments, the mission objective is to learn about spaceflight. The Apollo crew is expected to guide the craft down to the surface of a hostile world only vaguely understood in detail and extremely difficult to reach. This requirement is challenging our technology and is also stimulating the growth in this technology needed for our future projects. When Project Apollo achieves its initial goal, our technology will have attained greatly increased capability in launch vehicles, high-energy propulsion systems, deep-throttling rocket engines, guidance and navigation equipment of high accuracy and reliability, and great increases in propulsion system reliability, streamlined launch procedures, a greatly improved and expanded deep-space network, and many other such attainments.

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Future projects in the manned spaceflight program must be considered in view of our present efforts. Developments in the progress of both spacecraft and launch vehicles will represent significant increases in capability. As we have said, these improvements will be obtained only through large investments in money and manpower, and for this reason future projects must both complement these efforts and represent in themselves significant improvements in desirable capabilities.

Presently, three advanced projects are receiving serious consideration—the orbital space station, the lunar base, and the interplanetary spaceship. Both the orbital space station and the lunar base are achievable within the capabilities of the advanced Saturn launch vehicle, and in this sense will profit from developments of the present program. The lunar base is not quite as clearly defined as the orbital station (see page 52). A better assessment of this project will result when more is learned about the character of the moon from the Ranger and Surveyor projects as well as from Apollo.

Research has been in progress on multimanned orbiting space stations during the last two years both within NASA and by contractors.

The space station will allow scientific studies of meteoroids (density, velocity, size, and direction of flight); studies of the complete spectrum of space radiation; and astronomical observation at visible, ultraviolet, infrared, and radio frequencies; detailed investigations of weather patterns on earth and of the solar- and earth-radiated heat balance as affected by cloud cover and as it affects cloud cover; and detailed studies of the earth's geography, defining much better the relative location of many geographic features on the earth's surface.

The space station or the lunar base will put investigations of materials, structural systems, electrical power systems, communications, etc., in the real space environment, and so will eliminate the need for simulating or partially simulating these environments on the earth's surface. They will allow engineers to study systems in space over long periods of time under more adequately controlled conditions of both observation and measurement. For instance, a large multimanned orbiting space station will allow long-term research into maintenance-free communications satellites.

The large size and weight and extremely long-duration missions of the manned space station, moreover, will permit investigation in the real space environment of many specific systems—environmental control, electric power, propulsion, communication, navigation and guidance, etc.—required for manned planetary missions.

This cumulative technology should indeed establish a sound basis for manned interplanetary flight and all this foresees.

The first interplanetary spaceship project will probably be designed for an initial exploration of Mars; and the next generation of space hardware will be clearly represented in the exploration of this planet. Virtually every aspect of the system will benefit from and perhaps be dependent on yet-to-be-developed improvements in technology. Some of these might be revolutionary departures from the past, such as nuclear propulsion.

It is obviously premature to attempt to conceive hardware designs of interplanetary spaceships in any significant detail. Yet it is important from time to time to try to visualize future mission requirements so that today's research and development efforts may perhaps be better focused. Let us discuss some considerations which will shape the design of this mission and which should influence research and development efforts in the interim.

Mars has an orbital period of roughly 1.88 terrestrial years. Opposition presents the natural time for missions to be flown, and these occur at intervals of slightly over two years. Time and distance for the next several oppositions are as follows:

DATE	DISTANCE (mi.)
Feb. 3, 1963	61,700,000
Mar. 8, 1965	61,700,000
Apr. 13, 1967	56,200,000
May 29, 1969	45,300,000
Aug. 6, 1971	34,600,000
Oct. 21, 1973	40,600,000
Dec. 13, 1975	53,100,000

Eccentricity of the planetary orbits (primarily Mars) causes opposition distance to vary, and a 2-deg difference in the orbital planes of earth and Mars results in a variation of the energy (velocity) required to make the mission at each opposition. Low-energy transfers require approximately a half year each way, depending on the distance at opposition.

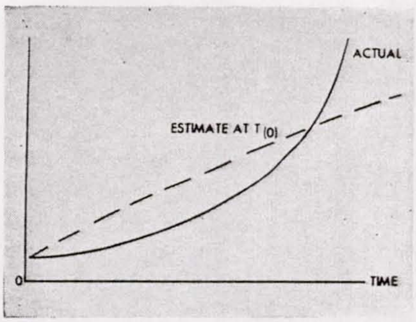
Then the nature of the mission—fly-by, orbital reconnaissance, rendezvous with a Martian moon, or planetary landing—naturally affects total energy requirement.

The fly-by mission will demand the least energy but will also have the least scientific value. It will give the crew an opportunity for a close-up observation of Mars. This mission may be feasible within Saturn launch-vehicle capability, especially if earth rendezvous were to be employed. Assuming only minor velocity adjustments would be made during the mission, the proximity of the fly-by to Mars would depend on the velocity in the vicinity of Mars and the amount the spacecraft path was to be deflected. For this reason, the proximity will be totally dependent on the manner in which the whole mission is planned. The shorter the total mission (higher energy), the closer will be the fly-by path. This is a necessary feature only of those missions in which it is desired that the spacecraft return to earth without a major propulsive thrust in the vicinity of Mars.

In addition to providing the crew with a close-up optical observation of Mars, a fly-by mission could take advantage of other means of probing for scientific information. Detailed surface-temperature measurements could be made with bolometers. Spectrographic analysis of the atmosphere could be obtained by observing the entry wakes of probes. Similarly, bombs might be used to analyze surface constituents. Other probes might be soft-landed on the surface for more sophisticated investigations. All these many measurements, however, would have to be made during a short period when the crew would also be concerned with the most exciting exercises of the spacecraft's navigation. Furthermore, these measurements are in many ways no better than those which might be obtained with a properly operating, rather sophisticated, unmanned probe.

Mars orbital reconnaissance would differ from the fly-by mission by using rocket power in the vicinity of the planet first to enter into and then depart from an orbit about it. The use of propulsion in the vicinity of Mars releases the mission from the proximity restraints which characterize the fly-by mission. Significant savings in the energy requirements could be achieved by using an eccentric orbit entered (and left) at perigee, rather than by using a circular orbit. This eccentric orbit would provide sufficient opportunity for close-up observation of Mars, as well as excursions through its magnetic field and radiation belts. In general, the same types of measurements would be made as those in the fly-by mission, except that there would be a much longer time for observation and an opportunity to approach much closer to the Martian surface.

Mars has two very small, apparently natural, satellites—Phobos and Deimos, conservatively estimated at 10 and 5 mi. in diam, respectively. Lacking significant gravity, these satellites can be landed on simply through orbital-rendezvous techniques. The satellites have orbits essentially in the plane of the Martian equator, and so inclined to the ecliptic by about 25 deg. Making this plane change in approach will require additional energy.



PROGRESS in an engineering development typically takes this form. Judging the future from t_o has historically been a difficult matter, full of pitfalls.

These two moons are in fairly low orbits, Phobos 3300 n. mi. above the surface and Deimos 11,000 n. mi. Besides being interesting in themselves, they should be ideal sites for long-duration research instrumentation set up to observe the planet throughout its seasons (assuming the near certainty that they have reached a fixed relative orientation to Mars through gravity-vector stabilization and magnetic damping).

The mission designed to land men on the surface of Mars will not only require the largest and most complex spacecraft system, but will also provide the greatest return in scientific data. This mission will require much more propulsive energy for velocity changes than those previously described, especially in any short-duration flight attempted. The Mars landing mission may have to await the development of nuclear propulsion to be considered practical.

A number of alternate mission schemes may be considered. The use of a separate landing module as will be used in Project Apollo is certainly an obvious contender. This landing module may be launched from either a close-in circular orbit or a highly eccentric orbit with a low perigee. The circular orbit would require the least performance from the excursion module, but would require more performance from the mother ship. Since the lander can use atmospheric braking for descent, this tradeoff would appear to favor the elliptical orbit from a performance standpoint. Operationally, however, the circular orbit would appear to be somewhat simpler.

In the Apollo mission analysis, clear-cut performance gains were shown for the rendezvous technique. Since Mars has an atmosphere, a new performance tradeoff study would be required for this condition to determine if the advantage would still remain.

Operationally, however, the direct-landing technique may be hard to justify. It would commit an extremely complicated and heavy spaceship to a landing on the far side of the planet without the benefit of updated reconnaissance. This vehicle would also have to make a successful hypervelocity atmospheric maneuver with the very awkward-to-carry propulsive capability necessary for return to earth.

The employment of earth-orbit rendezvous for assembly of the total mission capability will most likely be required. Reliability might be enhanced by use of a fleet of two or three vehicles, rather than a single spacecraft. The fleet approach may also be used to improve capability through resupply or refueling in transit. Perhaps the most significant manner in which in-transit rendezvous could be employed would be a pickup maneuver immediately after trans-earth injection. In this event, the pickup craft would trail the landing party by several weeks during the outbound journey. It would be guided along a fly-by trajectory and hence would require only modest propulsion capabilities. The spacecraft would leave the surface of Mars, on an orbit about Mars, at the proper time to rendezvous with the pickup vehicle on the homeward-bound leg. While this may be considered a high-risk operation, it may be favored as a scheme that would lie within practical chemical-rocket capability.

Many unknown environmental factors contribute to uncertainty in the design approach. It is hoped that more factual information on the environment can be obtained during the same period in which spacecraft technology is improving. Mission and system analysis can then be carried out with a minimum amount of guesswork when the time comes for the final design decisions.

More facts about the Martian weather need to be known. The velocity and direction of surface winds and the nature of any sandstorms are certainly important considerations. Apparently there are seasonal effects and, undoubtedly, there are variations with time of day and latitude. It might be mentioned that a special statistical study of wind and wave conditions in the Atlantic Ocean had to be made as part of the operational analysis that went into the landing system design for Mercury. Not as much will be known about Martian weather as about Atlantic Ocean weather. The result will undoubtedly be the use of design margins as a substitute for knowledge.

At this time, only conjectures can be made about magnetic fields and trapped radiation belts about Mars. However, a mission envisioning an extended period of orbiting the planet must include an estimate of the radiation dose. There is also a need for knowledge of the micrometeorite flux in the regions of space between Mars and earth. Although Mariner gave indications of decreased micrometeorite encounters as it left the vicinity of earth, this can only be considered a favorable sign. Mars is much closer to the asteroid belt and may also share the earth's apparent ability to concentrate micrometeorites.

The surface characteristics of Mars and its atmosphere are not as well defined as might be wished. It does not seem likely that a horizontal landing would be employed on the initial attempt. For this reason, improved knowledge will not strongly affect the design approach. The biological environment, on the other hand, will undoubtedly be an issue of concern from the standpoint of extra-vehicular operations.

From a communication standpoint, the possible existence of ionized layers that would block part of the transmission spectrum may be of interest. It would seem unlikely, however, that this would include part of the spectrum not already blocked by the earth's layers. Thus, this would only be a consideration in choosing a frequency for communicating between the landing vehicle and the mother ship.

More information can undoubtedly be obtained with improved observation of Mars from the earth's surface. It is safe to predict, however, that only modest changes in the total knowledge of the planet can be obtained in this manner during the next decade. The necessary knowledge of the environment of the mission must come from other sources. Primarily, improvements can be obtained by use of manned fly-by and Mars-orbital missions and possibly from unmanned probes sent to the vicinity and the surface of Mars. Because Mars has an atmosphere, the landing of probes, particularly those launched from a manned Mars-orbital spacecraft, should not be too difficult. The simplicity of atmospheric deceleration and aerodynamic stability, as opposed to rocket deceleration and black-box stability, will go far to overcome the difficulties associated with the remoteness of the planet. Such probes would not only be of immediate value to science, but would materially assist the manned mission.

Moreover, the knowledge of Mars might be greatly enhanced by observations from an earth-orbit space station or a lunar base. The almost continuous observation of Mars will be very valuable in assessing the seasonal and daily variations in the surface environment and will, perhaps, provide a means for interpretation and evaluation not otherwise available.

Special attention has been given here to the Mars-exploration mission as the most advanced mission on which conjecture is timely. Again, we direct the reader's attention to the fact that, in order to insure the proper planning of the utilization of the nation's resources that can be committed to the space program, the frontier for exploration must be both pointed and deep. A broad attack on this frontier could absorb the total resources of the nation. It is important that the program goals selected be those giving a very high return per unit effort in the short range while at the same time opening opportunities for similarly high gains during the next program generation. ••