Vol. 3, No. 1: Jan.-March 1990
Special Information Topic Issue

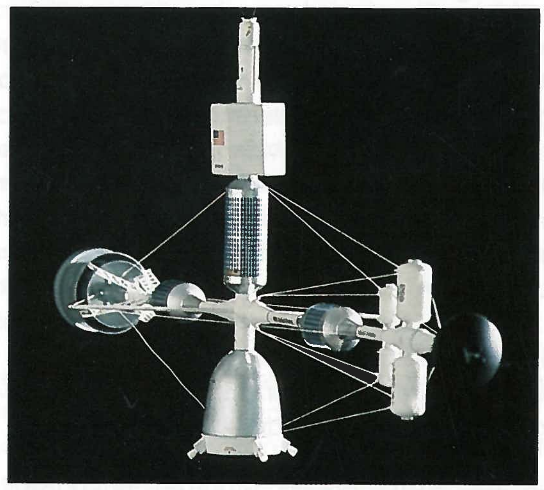
SICSA OUTREACH
Sasakawa International Center for Space Architecture

Manned Missions to Mars: Planned Bold Journeys Into Tomorrow

Human exploration of Mars, long of interest to prominent aerospace leaders and planetary scientists, is currently being accorded great importance as a goal of U.S. space policy for the next century. President George Bush initially expressed his administration's commitment to this goal in his July 20, 1989 speech at the Air and Space Museum in Washington, D.C. on the 20th anniversary of the first Apollo Moon landing. His long range plan proposed: *"First, for the coming decade for the 1990s*—Space Station Freedom-*our critical next step in all our space endeavors. And for the next century, back to the Moon. Back to the future. And this time back to stay. And then, a journey into tomorrow—a journey to another planet; a manned mission to Mars."*

Following the President's speech, Vice President Dan Quayle, head of a newly formed National Space Council, requested that NASA recommend plans to guide a major lunar/Mars initiative. NASA responded 90 days later, presenting five mission plan options that vary according to whether the overriding priorities are low cost, speed, or simplicity.

NASA will soon award contracts to several planning teams headed by qualified aerospace companies to conduct lunar/Mars mission studies in support of President Bush's mandate. SICSA is pleased to participate with members of the General Dynamics Space Exploration Initiative team to advance these challenging and worthwhile space policy goals.



SICSA Manned Mars Vehicle Concept
Design and Model by Sean Nolan

SICSA is undertaking studies to crew support requirements and related system design options for planetary exploration missions. Habitats being addressed include Mars transportation vehicles and surface facilities.

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SICSA is grateful to General Dynamics, Space Systems Division in San Diego and Houston for donating funds to print this issue.

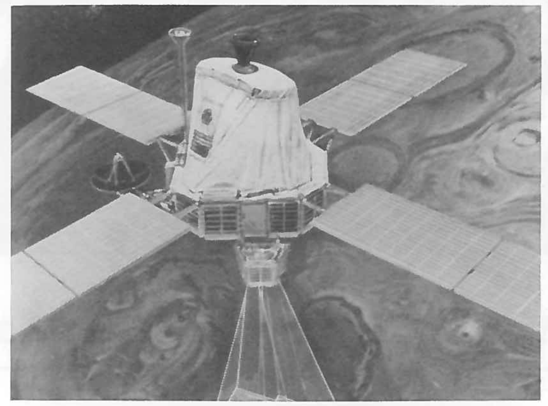
History of Interest

In 1953, 16 years before Apollo astronauts Neil Armstrong and Buzz Aldrin first left human footprints on the Moon, the brilliant rocket engineer Wernher von Braun published a study offering bold concepts for undertaking a manned Mars expedition. Von Braun's proposal envisioned a massive convoy of ten space ships, each with a crew of seven astronauts to accomplish a 1,000 day mission. The plan would necessitate delivery of 80 million pounds of hardware and propellants to low-Earth orbit (LEO), imposing logistic requirements similar in scale to a *"minor military operation extending over a limited theater of war."*[1]

Between 1961 and 1966 NASA awarded nearly 60 contracts to investigate methods and technologies for human excursions to Mars. One study project termed *"Early Manned Planetary Interplanetary Roundtrip Expeditions (EMPIRE)"* examined hardware system requirements for a Mars-Venus swingby proposed for a 1970-1972 time frame. NASA concluded from these studies that a manned Mars mission was feasible and could take advantage of Apollo-class technologies. It was recognized, however, that such an initiative would be very expensive and complex.

The successful Apollo program encouraged President Nixon's Space Task Group, chaired by Vice President Spiro Agnew, to recommend a manned Mars mission in 1969. The U.S. Congress which was preoccupied with national economic problems, the Vietnam war, and charges of political corruption rejected this proposal.[2]

Motivated scientists, engineers and other space enthusiasts continued to actively support manned Mars mission planning and advocacy. Interest and progress was advanced by important conferences sponsored by the University of Colorado in Boulder, NASA and other organizations where research and planning data were exchanged.[3] In 1987, a new Office of Exploration established at NASA Headquarters was authorized to examine lunar/Mars mission requirements and options for consideration by the President.



Viking Orbiter Above Mars
NASA Illustration

1. *Sixteen years later von Braun proposed a scaled-down approach for a manned Mars landing mission to take place in 1982 that was presented to President Nixon's Space Task Group. This plan would provide a convoy consisting of only two redundant Mars space ships with a crew of six each that would utilize systems and experience from the Apollo lunar program and other 1970s space missions. The spaceships were to be powered by advanced nuclear thermal propulsion systems. Estimated total weight in LEO was estimated to be 3.2 million pounds.*

2. *The prevailing anti-Mars attitude in the 1970s was typified by Presidential Science Advisor Dr. Frank Press who believed that a convincing case had not been put forward. He stated in 1978 that "... if the Soviets decide to spend $70 billion to land men on Mars in five years, we say God bless them."*

3. *In 1981, a group of proponents gathered at the first "Case for Mars Conference" held in Boulder, Colorado. This important meeting provided stimuli to Mars mission research by uniting a "Mars underground" and reactivating public interest and debate. The conference, along with two others held in Boulder in 1984 and 1987, produced a number of influential papers that were published by the American Astronomical Society.*

View From Viking Lander on Mars Surface
NASA Photo

4. *The unmanned Viking spacecraft launched in August and September, 1975, returned a wealth of data about conditions on the red planet. These two identical spacecraft, each made up of an orbiter and a lander, were dispatched by Titan III E/Centaur launch vehicles from the same Cape Canaveral pad, arriving in Mars orbit on June 19, 1976 and August 7, 1976 respectively. While the spacecraft elements were designed with the objective of operating for only 90 days, they remained in operation from two to six years.*

The Viking orbiters served as communication relays for the landers, photographed the surface, and mapped the planet's thermal and water vapor characteristics. The polar caps and dust storms were of special interest. Lander 1 arrived on the plains of Chryse Planitia (22.27°N, 47.97°W) on July 20, 1976 and functioned well into 1982. Lander 2 settled onto the plains of Utopia Planitia (47.67°N, 225.74°W) on September 3, 4,014 miles from Lander 1. Both sites are on flat plains in the northern hemisphere below the Mars datum (zero elevation) within large basins. Common missions were to photograph the terrain, measure and monitor the atmosphere and climate, determine the nature and inorganic composition of the soil, and conduct chemical and biological soil tests in search for evidence of rudimentary life forms.

Predicted Program Benefits

Many believe that manned exploration of Mars, the most challenging and exciting adventure of our time, will soon become the catalyst for a new course of human evolution in space. Embodied in such missions are opportunities to gain important scientific knowledge, compelling stimuli for technological advancement, potential economic benefits, incentives for international cooperation, and expansion of human progress and consciousness into the cosmos.

Enormous costs of future lunar/planetary missions will be extremely difficult to justify on the basis of "sprint" expeditions that culminate without follow-on plans that build upon achievements. Most advocates agree that the preferred goal is to establish permanent settlements that truly extend human presence in our Solar System. Mars, the most Earth-like of our neighbor planets, is a logical staging base, material source and testbed to support progress in space over many decades or centuries to come.

It is argued that a manned Mars program will bring much needed long-term focus to current and planned NASA programs while offering a bonanza of benefits in a variety of scientific fields. Included are geosciences, meteorology, and possibly biology. Although two U.S. Viking landers that arrived on the Mars surface in June and August, 1976 did not detect living organisms or complex organic matter, many biologists do not rule out the possibility of life (past or current) at other more likely locations where ultraviolet radiation protection is afforded and where water may be present.[4]

Mars may prove to be a source of valuable resources to help sustain human settlements or even provide materials for export. The relatively Earth-accessible Mars moons Phobos and Deimos are believed to have abundant quantities of water-bound hydrogen, for example. This vital substance which is a major component of chemical rocket propellant and water is not likely to be significantly available on Earth's Moon.

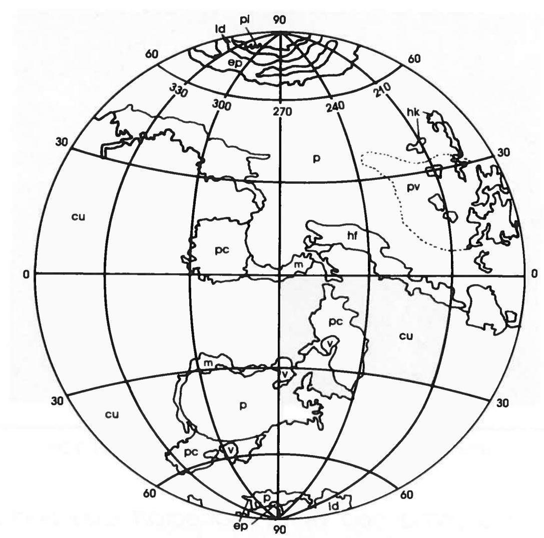
The Martian Climate

Mars, the fourth planet from the Sun after Mercury, Venus, and Earth has an equatorial radius of 3,390 km (2,107 miles) which is slightly more than half that of Earth and about twice that of the Moon. The axis of rotation, which is inclined 25 degrees to the ecliptic, produces seasonal temperature changes. Due to the planet's high orbital eccentricity there is seasonal asymmetry, with shorter and hotter summers in the south than in the north. A thin atmosphere composed mostly of carbon dioxide (95.3 percent) influences a wide range of diurnal and seasonal surface temperatures which vary from 140K (-207.4°F) in winter on the southern polar cap, to as high as 290K (80.6°F) at mid-day during summer in mid-southern latitudes. Other components of the atmosphere are N_2 (2.7 percent), Ar (1.6 percent) and lesser amounts of O_2, H_2O and noble gases other than argon.

The Mars atmosphere is only about one percent as dense as Earth's, and a significant fraction of the CO_2 condenses on the polar caps in winter. Atmospheric pressure varies from 7 mb at zero elevation during southern winter to 9 mb at zero elevation during southern summer. All surface water either evaporates or freezes.

Gigantic dust storms blown by tidal winds sometimes engulf nearly all of the planet. While most of the dust usually settles in about three months, the atmosphere always retains a significant dust component. Local dust storms are common occurrences during midsummer in the south. These storms will severely impair visibility during future Mars surface traverses and will impact spacecraft launches and landings.

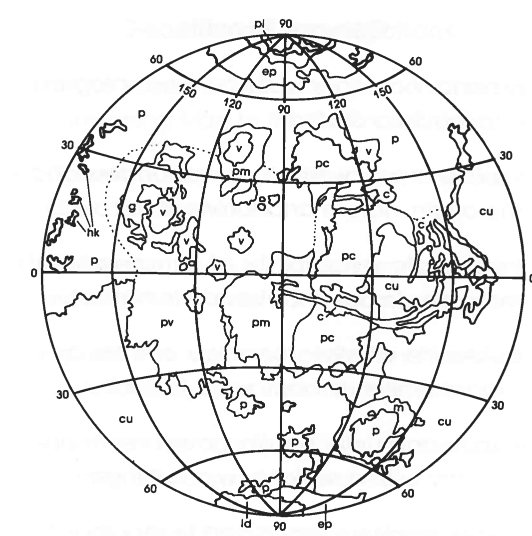
The possible presence of strong wind shears must be considered in planning manned Mars operations. Much can be learned about these conditions and patterns using both manned and unmanned observational methods to study sources of wind generation, movement patterns, and decay of local and global dust storms. Imaging of cloud motions over time can also provide global information about atmospheric temperatures.



Mars Plotted on a Lambert Equal Area Base
Source: From Hutch and Head 1975, copyrighted by American Geophysical Union

Mars Characteristics

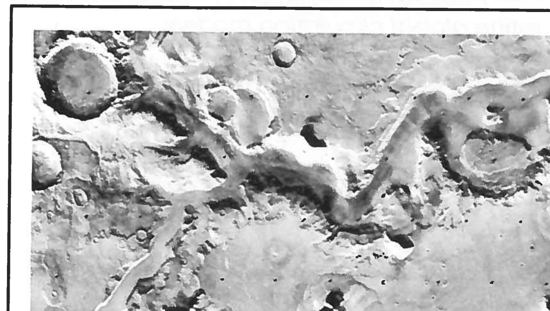
- *Mean distance from Earth: 7.83 × 10^7 km.*
- *Mean distance from Sun: 2.28 × 10^8 km.*
- *Diameter: 6,787 km (approx. 1/2 Earth).*
- *Axial rotation: 1.02 Earth days (24 hrs, 37.4 min).*
- *Average orbit eccentricity: 0.0934.*
- *Orbit inclination: 1°29′.*
- *Mass: 6.418 × 10^{23} kg (approx. 0.108 Earth).*
- *Mean surface gravity: 0.38 Earth gravity.*
- *Escape velocity: 5.0 km/sec (approx. 0.45 Earth).*
- *Surface temperature range: 140 to 290K (-207 to 80.6°F).*
- *Surface pressure: 6 to 15 mb.*
- *Albedo: 0.25 (approx. 0.83 Earth).*
- *Sidereal year: 686.98 days (approx. 1.89 Earth).*
- *Moons: Phobos and Deimos.*



c:	channel deposits	m:	mountains
cu:	cratered, undivided	p:	plains
ep:	etched plains	pc:	cratered plains
g:	grooved	pi:	permanent ice
hf:	hummocky, fretted	pm:	mod. cratered plains
hk:	hummocky, knobby	pv:	volcanic plains
ld:	layered deposits	v:	volcanic constructs

Mars Plotted on a Lambert Equal Area Base
Source: From Hutch and Head 1975, copyrighted by American Geophysical Union

Olympus Mons Volcano Viewed from Viking
NASA Photo



Martian Channels Viewed from Viking
NASA Photo

The Martian Terrain

Mars can be divided into two hemispheres by a plane dipping 50 degrees to the equator and oriented to intersect the 50°N latitude parallel at 330°W. The most ancient and densely cratered surfaces are found on the more southerly hemisphere. The more northern hemisphere contains most of the lightly cratered plains and large volcanoes. Remnants of old craters that underlie many of these plains can be seen protruding through the surface. Polar regions are nearly devoid of craters and are relatively young.

Mars possesses a variety of volcanoes ranging from a few hundred meters to hundreds of kilometers across. The largest, Olympus Mons, towers more than 25 km (15 miles) above the surrounding plains. The volcano is circled by a peripheral plateau 550 km (342 miles) across. Lavas drape over the cliff that defines this plateau, extending the true diameter of Olympus Mons to about 700 km (435 miles), more than five times greater than the largest volcanoes on Earth.

Numerous channels on Mars are of three main types: runoff, fretted and outflow. Runoff channels resembling river valleys on Earth may have been formed by slow erosion of a running fluid such as water (including precipitation). Fretted channels are erosional features that might be accounted for by freeze/thaw processes. Outflow channels bear a striking similarity to large Pleistocene flood features found in eastern Washington.

Mars, like Earth, has been volcanically and tectonically active with a surface affected by actions of wind, water and ice. Unlike Earth, however, weathering currently occurs more slowly due to low temperatures and inefficient removal of weathered products. Ejecta from volcanism has accumulated for billions of years. Mountains, canyons, basins and impact craters offer well preserved records of diverse forces that have shaped the planet and Solar System over the ages. Unlike on the Moon, the craters have been slowly eroded by winds that transport surface materials globally.

Mars Exploration and Science

Exploration of space in general and Mars in particular is held by many to be a matter of manifest destiny, one of those inexorable movements that characterizes our fundamental human quest for knowledge and adventure. Space, the final frontier, offers great mystery and challenge that reveals much about the origin and future of our planet and all life that it supports. Human exploration offers an added dimension of personal experience and achievement that is also fundamental, but sometimes difficult to quantify in terms of economic value-added benefits.

As with the westward expansion of the United States, Scott and Amundsen's race to the South Pole, and Hillary's conquest of Mt. Everest, we value achievements that impose great difficulties and risks to extend enterprise and awareness beyond familiar boundaries. The planets will certainly be explored, and Mars, the planet most like our home, will predictably be the first. This can be accomplished by manned surface landings and/or teleoperated robotic rovers controlled by humans on the Martian moons Phobos and Deimos.

While science will not necessarily be the most important reason for going to Mars, manned Mars missions will serve a number of major scientific objectives. They will yield understanding about how planets are formed; how they change in response to self-generated and external influences; special features and conditions on Mars; and potential for past, present and future life on the planet and elsewhere in the universe. Scientific investigations will also produce information about resources on Mars, Phobos and Deimos that can support future settlements in space, and possibly provide propellants for interplanetary travel. Such research will require and motivate the development of new technologies that can be expected to realize significant applications on Earth. Resulting science and technology initiatives can also be expected to provide incentives and opportunities for international cooperation to share costs and distribute benefits.

General Benefits

- *Expand human presence and progress into the Solar System.*
- *Explore a new world to better understand the origin, nature and future of our own.*
- *Investigate availability of extraterrestrial resources to advance space initiatives.*
- *Determine whether there was or is life on a planet similar in many ways to Earth.*
- *Inspire and unify public, government and industry with a major new challenge.*
- *Stimulate new science and technology for beneficial space and terrestrial uses.*
- *Promote and focus international cooperation to improve understanding and peaceful relations.*

Climatological Investigations

- *Survey volatiles, their offgassing history, and fixation within the crust.*
- *Examine ways volatiles are exchanged with the atmosphere.*
- *Investigate interactions between the atmosphere and surface including mountains and ice caps.*
- *Study the dynamics of the atmosphere to refine global circulation models.*
- *Monitor local pressures, vertical temperatures, and winds at selected sites.*
- *Determine the origin, evolution, and propagation mechanisms of dust storms.*
- *Determine the severity and effects of wind shears upon structures/operations.*

Geoscience Investigations

- *Refine ideas about ways planets form by comparing Mars to the Earth and Moon.*
- *Compare the meteorite impact history of Mars and the Moon.*
- *Determine changes in Sun energy output evident in sedimentary surface materials.*
- *Explore the uplands, plains and polar regions to study reasons for dichotomy.*
- *Analyze the composition of the crust, mantle and core of the planet.*
- *Investigate volcanic and tectonic activity to help reconstruct the geologic history of the planet.*
- *Search for water and other valuable resources on Mars, Phobos and Deimos.*

Biological Investigations

- *Explore UV-protected, water-rich surface and subsurface locations that are potentially conducive to supporting life.*
- *Undertake a variety of tests for extant and former life forms that are not possible to accomplish without human exploration.*
- *Investigate conditions necessary for organic growth and photosynthesis as they have existed or are currently present.*
- *Conduct controlled experiments which test the ability of selected plants to survive and reproduce in the Mars environment.*
- *Undertake agriculture experiments in artificially controlled environments to determine potential benefits to support human settlements.*

Advantages of Human Operations

Involvement of humans in Mars science operations offers a number of important advantages over total reliance upon automated procedures. Key among these are the abilities of people to physically seek out and examine targets of interest; deploy, operate and maintain equipment; and make critical, on-the-spot, real-time judgements in response to unforeseen opportunities and events. Timely, autonomous decisions are particularly critical in planetary exploration missions because of communication delays associated with long distance transmissions and inopportune communication interruptions caused by atmospheric disturbances or inoperative relays. The round trip communication link between the Earth and Mars can be as much as 40 minutes.

To capitalize on these advantages it is important that astronauts be trained for independent science judgements and be prepared for appropriate response interventions. The U.S. Apollo, Skylab and Shuttle Programs have all clearly demonstrated the versatility and value of human presence when these conditions are met. On numerous occasions the crews have conducted significant impromptu experiments, rendered qualitative assessments, and have undertaken critical emergency repairs and maneuvers that were vital to mission success.

Manned operations will greatly expand and facilitate capabilities to survey and analyze surface conditions on Mars. Many of these activities will entail traverses to explore and characterize areas of scientific interest remote from the landing site. Samples will be collected for study on location, at an orbiting space station, or in laboratories on Earth. Seismic, surface drilling, atmospheric monitoring, communications and other equipment will be set up, checked out and periodically attended. Crews will also demonstrate operational procedures in preparation for future missions, potentially anticipating the creation of permanent settlements which will use and export extraterrestrial resources.

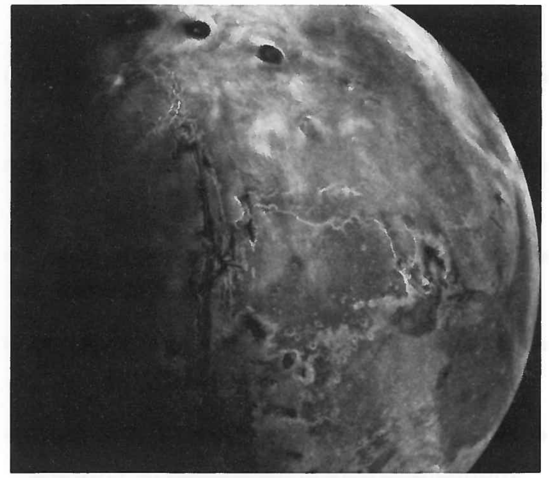
Martian Resources

Use of extraterrestrial resources potentially offers an opportunity to dramatically reduce costs of providing logistical support and propellants associated with interplanetary travel and space settlements. Accordingly, the discovery and development of space resources is a priority that will profoundly influence the nature and pace of all future large scale space endeavors. Mars, and its moons Phobos and Deimos, warrant careful consideration as sources of important volatiles and other substances.

T. R. Meyer and C. P. McKay discuss useful materials that might be obtained form the atmosphere and soils on Mars in a paper titled *"The Resources of Mars for Human Settlement"* which appeared in the Journal of the British Interplanetary Society in 1989 (see chart opposite). One extremely interesting substance is water, a source of hydrogen not likely to be available on our Moon. Meyer and McKay estimate that ground ice may comprise 5-10 percent of Mars' high-latitude solids. If so, this ice could be mined, melted and electrolized to create hydrogen/oxygen propellants to be used for interplanetary vehicles.

Routine orbital and surface operations might also be facilitated by water and other propellants obtained from Mars. J. R. French proposes some possibilities in a paper titled *"Rocket Propellants from Martian Sources"*, Journal of the British Interplanetary Society, 1989. Three fuel options identified by French are CO/O_2, O_2/CH_4 and O_2/H_2. Of these, the CO system which would not require water, would offer the lowest performance.

Despite its low specific impulse, CO/O_2 could be used to power rockets that launch payloads into low-Martian orbit. Similar rockets could also propel surface to surface transportation systems that carry supplies and materials used in connection with exploration activities. Methane would offer systems for intermediate performance relative to CO/O_2 and H_2/O_2 combinations, but would present less difficult fluid and thermal management problems than O_2/H_2.



Mars, the Red Planet
NASA Photo

Materials On Mars

Air-Derived Materials/Processes	
H_2O:	*dehumidification of Mars air.*
O_2:	*reduction of CO_2, Sabatier process.*
N_2/Ar:	*liquefaction, fractional distillation.*
CO:	*reduction of CO_2, Sabatier process.*
H_2O_2:	*auto-oxidation, electrolysis.*
NH_3:	*electrosynthesis.*
N_2H_4:	*Raschig process.*
HNO_3:	*Oswald process.*
N_2O_4:	*produced from HNO_3.*
HCOOH:	*electrochemical reduction of CO_2.*
CH_4:	*catalytic hydrogenation of CO.*
Soil-Derived Materials/Processes	
H_2O:	*evaporation of ice and permafrost.*
H_2O_2:	*electrolysis of H_2SO_4 vac, evap.*
O_2:	*electrolysis of water.*
S:	*from sulfides, sulfates.*
Fe:	*from amorphous Fe-oxides, magnetic minerals.*
Ti:	*from titanomagnetite, ilmenite ($FeTiO_3$).*
Al:	*molten electrolysis of oxides.*
Mg:	*molten electrolysis of epsomite.*
Ceramic:	*from clay, SiO_2, Al_2O_3, H_2O.*
Glass:	*from SiO_2, Al_2O_3, MgO, CaO, K_2O.*
Duricrete:	*from silicates, salts, iron minerals, CO_2*
Cement:	*from silicates, water.*
Plaster:	*from gypsum/calcium sulfate.*

Source: T.R. Meyer and C.P. McKay
Journal of the British Interplanetary Society, 1989

The Mars Moon Phobos
NASA Photo

Phobos Characteristics

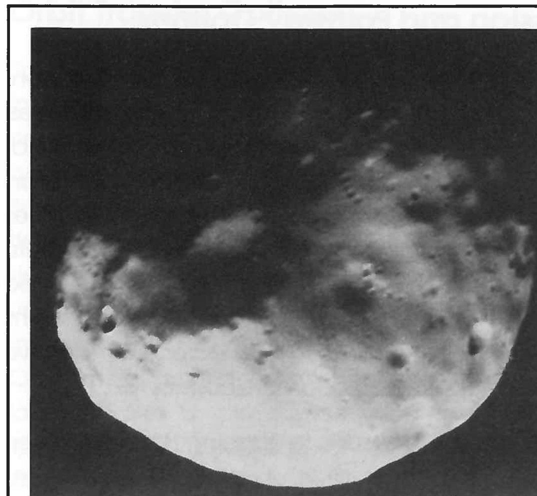
- *Semi-major orbit axis 9,378 km (5,827 mi).*
- *Average orbit eccentricity: 0.015.*
- *Orbit inclination: 1.02°.*
- *Orbit period: 7 hrs, 39 min., 14 sec.*
- *Diameters: 20 km × 21 km × 18 km.*
- *Rotation: synchronous.*
- *Density: approx. 2 gm/cm³.*
- *Mass: 9.8 × 10^{18} gm.*
- *Mean surface gravity: approx 6 × 10^{-3} g.*
- *Escape velocity: approx. 15 m/sec.*
- *Albedo: 0.05.*

Source: NASA Viking Program

Deimos Characteristics

- *Semi-major orbit axis: 23,459 km (14,577 mi).*
- *Average orbit eccentricity: 0.00052.*
- *Orbit inclination: 1.82°.*
- *Orbit period: 30 hrs, 17 min, 55 sec.*
- *Diameters: 7.5 km × 6.0 km × 5.5 km.*
- *Rotation: synchronous.*
- *Density: approx. 2 gm/cm³.*
- *Mass: 2.0 × 10^{18} gm.*
- *Mean surface gravity: approx 10^{-3}g.*
- *Escape velocity: approx. 10 m/sec.*
- *Albedo: 0.06.*

Source: NASA Viking Program



The Mars Moon Deimos
NASA Photo

Phobos and Deimos Resources

An intriguing possibility exists that propellants and other valuable resources might be obtained from Mars' moons Phobos and Deimos. Due to the unfortunate failure of recent Soviet Phobos probes, firm information about the composition of these bodies is inconclusive. However, Phobos and Deimos are known to have low albedos, low densities, ancient surfaces, nonspherical forms and reflection spectra that suggest that they are volatile-rich carbonaceous chondrite objects which may be comprised of as much as 10-20 percent water. Some scientific models suggest that ice may be present at depths below a few tens of meters at high latitudes on Phobos if free water was initially present. (See the technical paper by F. P. Fanale and J. R. Salvail, "Loss of Water from Phobos", *Geophysics Research Letter 16*, pp. 287-290, 1989.)

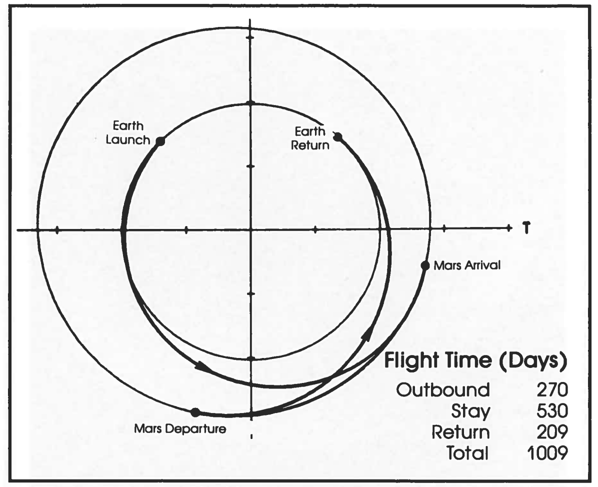
Surprisingly, every two years, less propellant is required to travel to Phobos and Deimos from Earth than to reach our Moon. In addition, the low gravity on Phobos and Deimos avoids the need for high-impulse rocket propulsion systems otherwise required for soft landings and high energy take offs. A disadvantage relative to the Moon is that round-trip travel times are much longer, involving two to three years rather than days.

Mission and Pathway Options

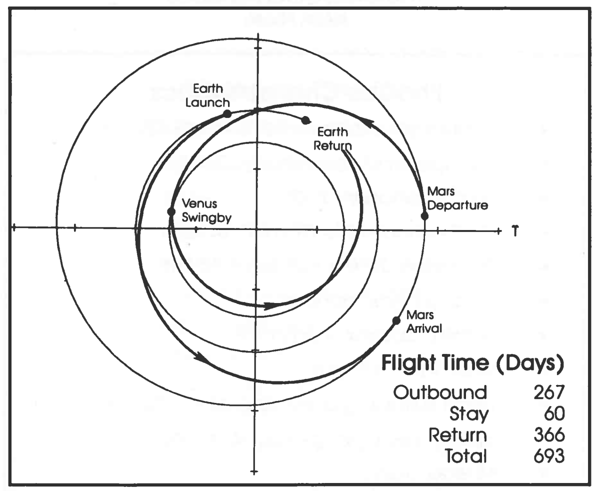
Manned Mars mission concepts fall into four general types: Mars swingbys, Mars orbital captures, Mars surface landings, and Phobos/Deimos landings (rendezvous). The value of manned Mars swingbys is essentially limited to science activities enroute to Mars and to Mars vehicle checkouts. Manned Mars orbital missions also offer limited benefits because unmanned orbital missions have already proven to be extremely effective without imposing comparable costs or risks.

A manned Mars surface landing for exploration leading to the establishment of a permanent base would most likely be preceded by unmanned reconnaissance missions to locate a site with appropriate conditions and resources. Since it probably would not be possible to make a final site selection until humans were in Mars orbit, it might be prudent for an unmanned supply ship to leave needed materials and equipment in Mars orbit prior to the departure of the initial landing crew from Earth. This is commonly referred to as a "split" mission scenario. Upon arrival in Mars orbit the crew would select a base site, considering such factors as accessibility, resources, Earth communications, and science priorities. They would then land, offload and deploy equipment; survey and sample soil conditions and composition; and make necessary site preparations for the next crew.

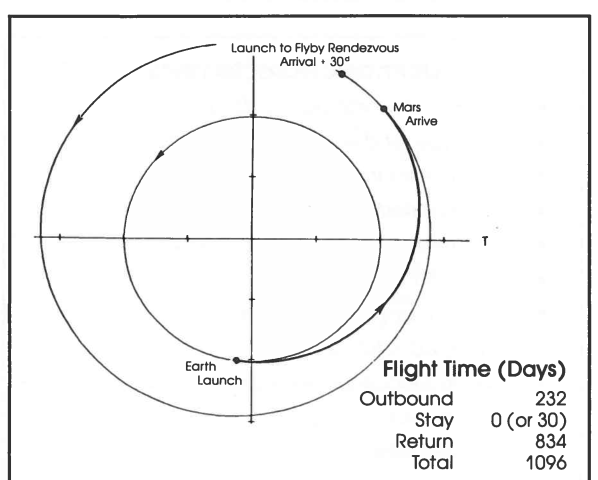
The Phobos/Deimos landing approach is favored by those who argue that large-scale scientific reconnaissance of Mars can be accomplished most efficiently and in the least environmentally disruptive manner by astronauts operating a robotic rover fleet from laboratories on Martian moons. A "Phobos/Deimos first, then on to Mars" option appears to offer attractive advantages because the Martian moons are highly accessible and would only require about half the chemical propellant and hardware weight in low-Earth orbit relative to Mars landing missions. Water-derived propellants obtained from Phobos/Deimos might then be used to access Mars and to support surface operations.



Conjunction Class Mission
Source: J.C. Niehoff*



Opposition Class Mission - Venus Swingby
Source: J.C. Niehoff*



Ballistic Transfer Mission - Rendezvous
Source: J.C. Niehoff*

Conjunction Class Missions

This orbit transfer approach represents the lowest energy, most traditional concept. The departing spacecraft follows a trajectory transfer path spanning about 180 degrees, arriving at Mars when Earth is moving into conjunction with the planet. Astronauts would be required to remain on the surface typically 1-1.5 years until phasing with Earth allows low-energy return. (This would probably be feasible only after substantial habitation capabilities are established following earlier missions.) A return time of 209 days would result in a total trip time of about 2.8 years, enabling highly energy-efficient missions.

Opposition Class Missions

In this high-energy approach for delivering people to Mars, the arrival at Mars of the spacecraft coincides with the approach of Earth to opposition with the planet. Astronauts have about 30 to 60 days near or on Mars before launching into a return trajectory to Earth. Total flight time is 1.6 years. Mission energy required for return can be reduced if the spacecraft swings past Venus to reshape the orbit and adjust the velocity. This extends crew time on the surface to approximately two months and increases total trip time to about 1.9 years.

Ballistic Transfer Missions

These missions make use of a "free return" swingby spacecraft which follows a short arc trajectory to Mars. The spacecraft then continues on to complete 1.5 revolutions about the Sun before returning to Earth (due to Earth-Mars phasing). This spacecraft is preceded to Mars by another spacecraft arriving 30 days earlier containing a lander with an ascent/rendezvous vehicle and crew. After a month on the surface, the crew rendezvous with the swingby spacecraft as it passes by Mars for the return trip. Total crew trip time for this relatively energy-efficient mission approach is three years.

Orbit Transfer Options

Spacecraft can deliver people to and from Mars following different orbit transfer strategies. Each option presents distinctly different and important advantages and disadvantages. Factors influenced include total trip time required, surface time afforded, mission launch windows, propulsion energy required, and the number/types of vehicles needed. Basic transfer orbit possibilities include Conjunction Class missions, Opposition Class missions, and Ballistic Transfer missions. The latter involves a split mission using two separate spacecraft launches, one for Mars crew transport and the other for the return leg.

Advanced manned missions to Mars may also take advantage of benefits afforded by two other types of transfer orbit options that use low-thrust or cycling trajectories. On low-thrust transfer missions, the spacecraft would be launched into an outwardly spiraling orbit for a considerable amount of time until it finally escapes the Earth's gravity well. After continuously thrusting while enroute to Mars, the spacecraft eventually spirals inward prior to its arrival in orbit about Mars. Crew surface stay times could range from 100-200 days with total missions lasting about 2.5 years. For return, the process is reversed.

Cycler orbits would repeatedly re-encounter both the Earth and Mars, possibly offering an efficient and safe way to continuously transport people and cargo to and from a permanent Mars settlement. As the cycling spacecraft passes each planet, a shuttlecraft "taxi" vehicle would be launched to rendezvous with it and transfer payloads. Applying one scenario, a cycler's multiple orbits would encounter Earth every five years and Mars every 3.75 years. An innovative "up/down escalator" orbit proposed by Apollo XI astronaut Dr. Buzz Aldrin would use the Earth's "slingshot" effect to enable regular encounters at the Earth and Mars approximately every two years.*

* For additional information see J.C. Niehoff. 1988. Pathways to Mars: New Trajectory Opportunities. In the *NASA Mars Conference*, Vol. 71, 381-401. American Astronautical Society. Copyright granted by Univelt Inc., P.O. Box 28130, San Diego, California 94128.

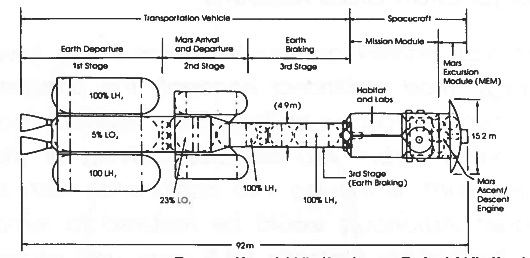
Spacecraft Planning Considerations

A variety of spacecraft concepts have been proposed to carry people to the surface of Mars and back. Important factors influencing the best approach include launch time frame options, the desired stopover time, and the special nature of mission activities to be accomplished.

The mission time frame will affect the maturity of available technology options and their impacts upon support requirements. Development schedules must allow adequate time for the design, fabrication and testing of highly autonomous and reliable systems that can operate for long periods in harsh environments. All prudent measures must be taken to minimize the weight of all elements to optimize propulsion energy economy without compromising safety.

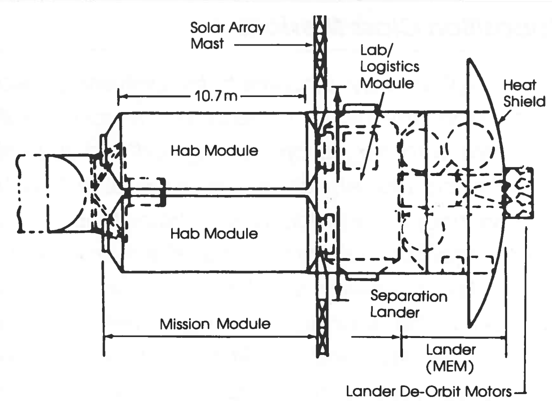
Allowable stopover time is directly influenced by the selected spacecraft trajectory and launch window. Practical opportunities will be limited to times when the heliocentric positions of the Earth, Mars, and potentially, Venus are in optimum alignments.[5] Longer missions and stopovers will impose a need for greater system operating lifetimes and reliability. They will also require more propellant and food expendables, and will expand equipment accommodation needs to support more varied and intensive activities.

Mission activities influencing spacecraft development include element assembly, fueling, and checkout in low-Earth orbit; living/working-related activities during Mars transfer; and landing/ascent and surface operations. LEO operations will require a fleet of Earth-to-orbit launch vehicles to transport the spacecraft components, propellant and crew, composed of Space Shuttle-derived and/or Heavy Lift Launch Vehicles (HLLVs). The interplanetary spacecraft must be sized to accommodate a Mission Module (MM) with crew support equipment and consumables, and a Mars Excursion Module (MEM) containing surface landing/ascent vehicles, habitats, surface traverse and sample retrieval equipment, and science provisions.



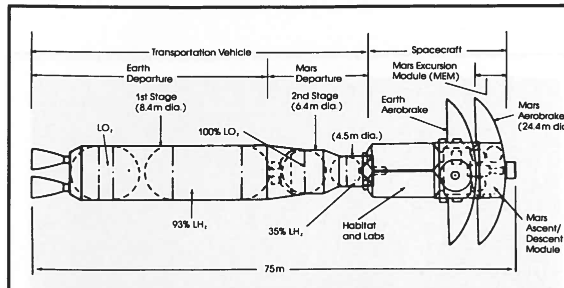
	Propellant Wt (kg)	Total Wt (kg)
1st stage	1,027,602	1,083,127
2nd stage	305,313	328,409
3rd stage	72,995	79,674
Spacecraft	32,661	132,088
Total	1,438,571	1,623,298

All Chemical Propulsion Vehicle
1999 Opposition Class Concept, NASA-MSFC



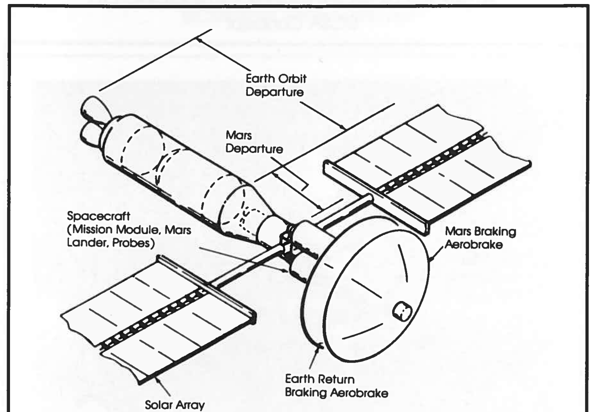
Habitat/MEM Accommodations
Concept, NASA-MSFC

5. *Several good opportunities for a Venus flyby with a 40-60 day stopover (Opposition Class mission) will occur in the 1997-2031 time period. A 1999 launch using this trajectory will offer a 60 day stay time with a 30 day window, representing a substantial improvement in propulsion efficiency over the same trajectory mission launched in 1997 (a 40-day stay time with a 10-day window). Good opportunities for Conjunction Class missions will occur in 1997, 1999, 2001, and in the 2030 to 2045 time frame. For additional information see "Mars Mission Concepts and Opportunities", A.C. Young, Marshall Space Flight Center, in proceedings of* Manned Mars Missions Working Group Papers, *Vol. I of II, 103-113, NASA-MSFC (1985).*



	Propellant Wt (kg)	Total Wt (kg)
1st stage	445,359	484,691
2nd stage	72,474	78,951
Spacecraft	32,661	149,729
Total	550,494	713,371

Chemical Propulsion/Aerobraking Vehicle
2001 Opposition Class Concept, NASA-MSFC



All-Aerobraking Mars Vehicle
Concept, NASA-MSFC

6. *The entry corridor for aerocapture is defined by a trajectory with flight path angles steep enough to avoid skipping out of the atmosphere, yet shallow enough to achieve a desired apoasis while maintaining acceptable g-load and aerodynamic heating levels. At Earth, Conjunction Class missions are expected to reach a maximum velocity of 38,000 ft/sec. Opposition Class missions might significantly exceed this unless the spacecraft made multiple aerobraking passes. For additional information see "Manned Mars Mission Vehicle Design Requirements for Aerocapture", O. Hill and R. O. Wallace, Marshall Spaceflight Center.* Manned Mars Missions Working Group Papers, *Vol. I of II, 114-128, NASA-MSFC (1985).*

Propulsion and Braking Concepts

Mars interplanetary spacecraft proposals include single and multiple vehicle concepts using a variety of propulsion and braking approaches. Single vehicle approaches can be expected to represent the simplest, cheapest and most reliable option for early missions. Multiple spacecraft using either similar or different propulsion systems offer potential advantages for later missions involving permanent settlements with extensive and sustained levels of operations.

The most frequently considered Mars transportation vehicle concepts would apply chemical propulsion systems using cryogenic liquid storable or solid storable fuels. One propulsion stage would be provided to effect escape from the Earth's gravity; a second would brake the spacecraft into a Mars elliptical orbit and effect an escape maneuver from that orbit; and a third would brake the vehicle into a 24 hour elliptical orbit upon return to Earth. Braking of the spacecraft in the vicinity of Mars and Earth might be assisted or accomplished by an aerobraking device that takes advantage of controlled atmospheric drag to slow the vehicle. This idea presents large fuel saving benefits for Conjunction Class missions that afford the most favorable entry corridor during approaches.[6]

Applying aerocapture at Mars and Earth can potentially reduce initial spacecraft weight and assembly time in LEO dramatically. B. Barisa and G. Solmon at the NASA Marshall Space Flight Center estimate that an all-aerobraking strategy can save about 2 million pounds over an all-propulsive option, saving years to deliver and assemble the much smaller vehicles in LEO depending upon the capacity of launch vehicles.

Very low-thrust ion-drive (solar electric and nuclear electric), nuclear-thermal, solar sail and hybrid propulsion technologies are being investigated for cargo missions which are not time-critical. A possible disadvantage of this approach is long periods spent in the Earth's trapped radiation belts that can damage sensitive equipment.

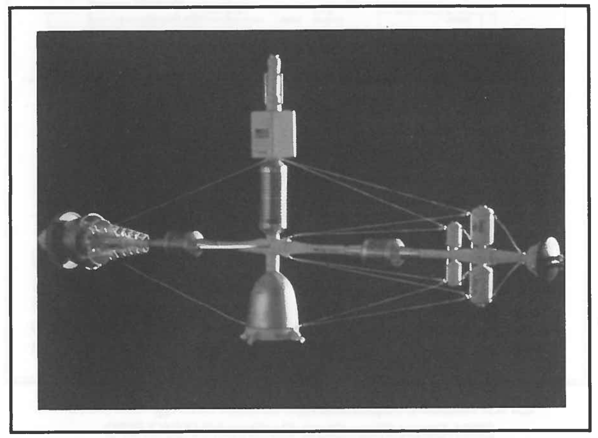
Artificial Gravity Spacecraft

It may be necessary to rotate the spacecraft to produce artificial gravity that will prevent crew deconditioning during long voyages to and from Mars. Without such a provision the astronauts may not be in adequate shape to perform vital activities when they arrive on the Mars surface, or to even survive rapid deceleration g-loads upon reentering the Earth's atmosphere.

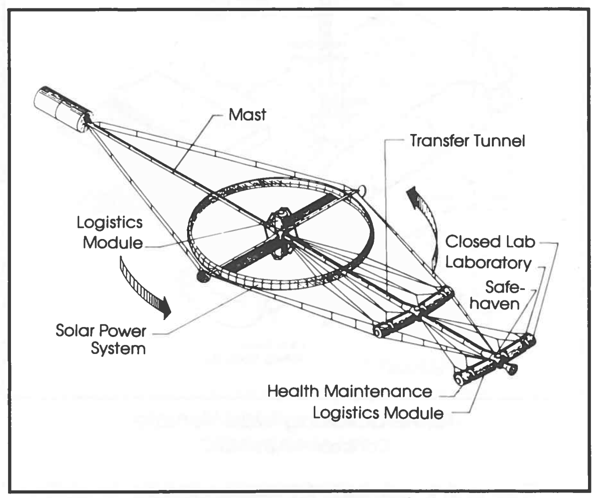
Much remains to be learned about the effects of prolonged weightlessness and reduced gravity upon human health. We do know from U.S. *Skylab* and Soviet space station experiences that lengthy missions under microgravity conditions can cause detrimental body changes. Included are reductions in bone calcium, muscle and blood cell mass, cardiopulmonary strength and immune system effectiveness. What we do not know are the gravity levels required, either constantly or intermittently, to maintain health. Concrete answers are needed before sending people on Conjunction Class missions to Mars lasting 2.8 years (1.5 years on the surface), or Opposition Class Venus Swingby missions lasting 1.9 years (about 2 months on the surface). Important data can be obtained from future manned lunar surface missions and outposts which may precede voyages to Mars. Variable gravity life science facilities in low-Earth orbit could also provide instructive lessons.*

A number of proposed rotating Mars spacecraft concepts would apply either rigid structures or flexible tethers to swing crew living areas around the axis of flight trajectory in a large enough arc to avoid dizziness. The tethered approach, while interesting, imposes a significant amount of mechanical complexity and is yet unproven. All spinning vehicle concepts present design challenges with regard to preferential orientations of solar arrays, radiators and antennas. An alternative to rotating the spacecraft might be to provide rotating sleeping chambers within the habitat modules. Crewmembers would be positioned with heads near the center, a method that has been demonstrated to avoid dizziness.

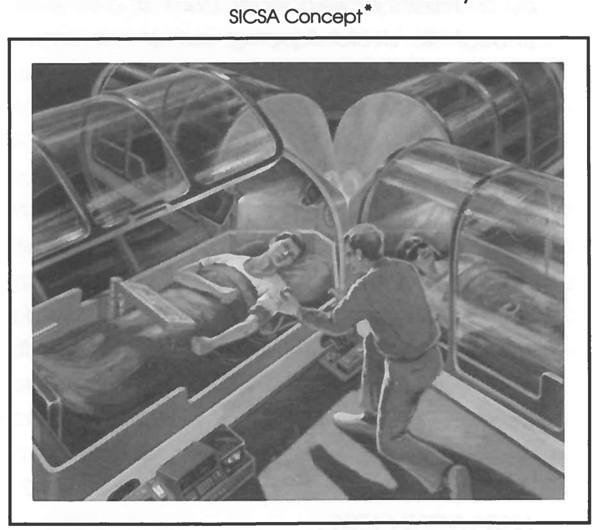
* See *SICSA Outreach*, Vol. 1, No. 5, Variable G Life Science Facility (Jan.-Feb. 1988).



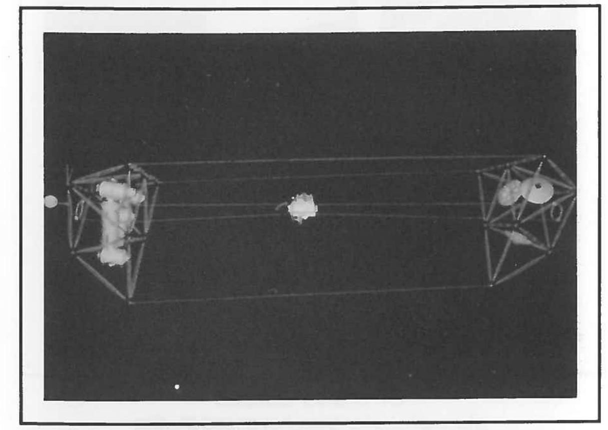
Artificial G Manned Mars Spacecraft
SICSA Concept



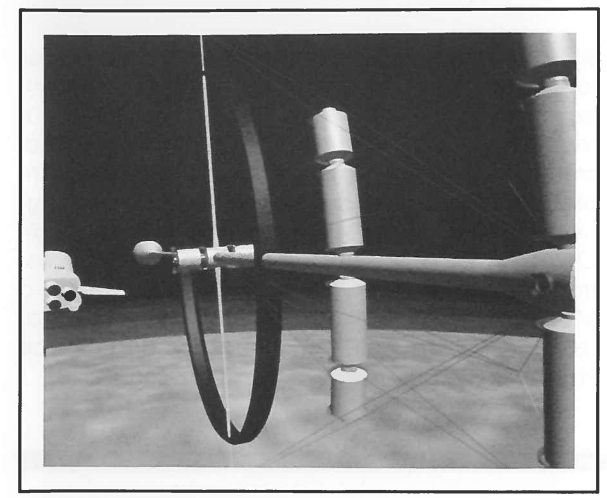
Variable G Life Science Facility
SICSA Concept*



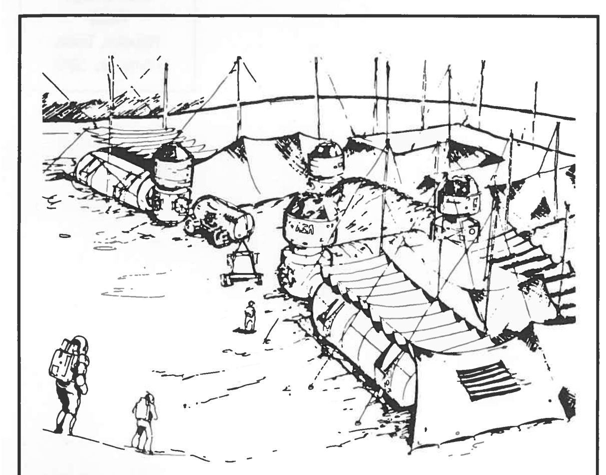
Variable G Sleeper
Concept: P. Diamandis, Design: Bell and Trotti, Inc.



Tethered Artificial G Spacecraft
SICSA/Buzz Aldrin Concept



Variable G Life Science Facility
SICSA Concept



Lunar Base Serving as a Reduced G Laboratory
SICSA Concept

Space Radiation Concerns

Space radiation dangers pose health risks that are more difficult to solve than problems associated with extended periods of reduced gravity. Spacecraft on long missions to Mars will be exposed to constant bombardment by galactic cosmic ray (GCR) radiation levels at least two orders of magnitude greater than have been experienced on previous space flights. Astronauts on the two to three year-long voyages will also risk exposure to one or more large, potentially lethal, solar proton storms. The probability of experiencing major solar storms will be influenced by mission timing with respect to the Sun's 11 year cycles of activity. Shielding to limit crew radiation hazards represents perplexing problems. To be effective, the barrier must be thick enough to avoid dangerous secondary emissions as the shielding material itself becomes ionized. Thick, massive shielding will greatly impact spacecraft weight and propellant requirements. Still, onboard solar "storm shelters" will quite certainly be needed.**

The Human Challenge

Mars exploration and settlement presents the ultimate human challenge of our age, not only for the people who will develop the advanced technologies and hardware systems, but for those who will use them as well. Missions to Mars and its moons will test the emotional stability of small crews that must endure years of isolated confinement, cut off from the security and comforts afforded by fellow beings and services on their home planet. They will experience dangers on surface traverses to explore diverse Martian landscapes with vast rocky fields and sand dunes, ancient volcanoes and craters, and majestic mountains rising from smooth plains. Resourcefulness and judgement will be essential to respond to unexpected equipment failures using very limited tools, often under hostile environmental conditions. Over time, these pioneers will create permanent man-made environments for colonists who will follow to expand human presence into the Solar System...into tomorrow.

** See *SICSA Outreach*, Vol. 2, No. 3 Space Radiation Hazards (July-Sept. 1989).

SICSA Background

SICSA is a nonprofit research, design and education entity of the University of Houston College of Architecture. The organization's purpose is to undertake programs which promote international responses to space exploration and development opportunities. Important goals are to advance peaceful and beneficial uses of space and space technology and to prepare professional designers for challenges posed by these developments. SICSA also works to explore ways to transfer space technology for Earth applications.

SICSA provides teaching, technical and financial support to the **Experimental Architecture** graduate program within the College of Architecture. The program emphasizes research and design studies directed to habitats where severe environmental conditions and/or critical limitations upon labor, materials and capital resources pose special problems. Graduate students pursue studies which lead to a Master of Architecture degree.

SICSA Outreach highlights key space developments and programs involving our organization, our nation, our planet and our Solar System. The publication is provided free of charge as a public service to readers throughout the world. Inquiries about SICSA and Experimental Architecture programs, or articles in this or other issues of *SICSA Outreach*, should be sent to Professor Larry Bell, Director.

Dr. Bruce Cordell
Manager, Lunar-Mars Advanced Studies
General Dynamics Space Systems Division

SICSA is indebted to many people too numerous to list who are information sources for this report; experts who are working to transfer dreams of human planetary exploration into reality. Special credit is owed to Dr. Bruce Cordell whose comprehensive and very substantive inputs have significantly influenced the contents of this *SICSA Outreach* edition. Dr. Cordell earned a B.S. Astrophysics degree at Michigan State University; a M.S. Planetary and Space Physics degree at U.C.L.A.; and a Ph.D. in Planetary and Space Physics at the University of Arizona, Tucson.

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