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The Case for Mars:

Concept Development for a Mars Research Station

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National Aeronautics and Space Administration

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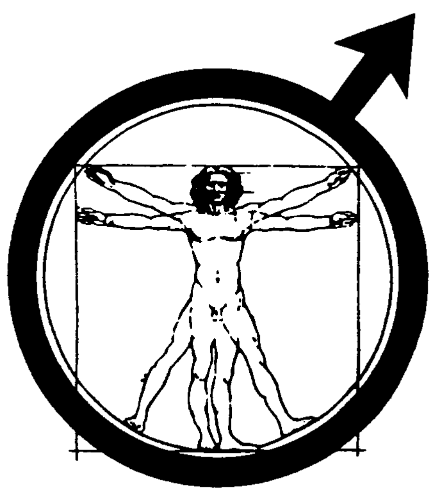

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THE CASE FOR MARS:
CONCEPT DEVELOPMENT FOR A MARS RESEARCH STATION

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ABSTRACT

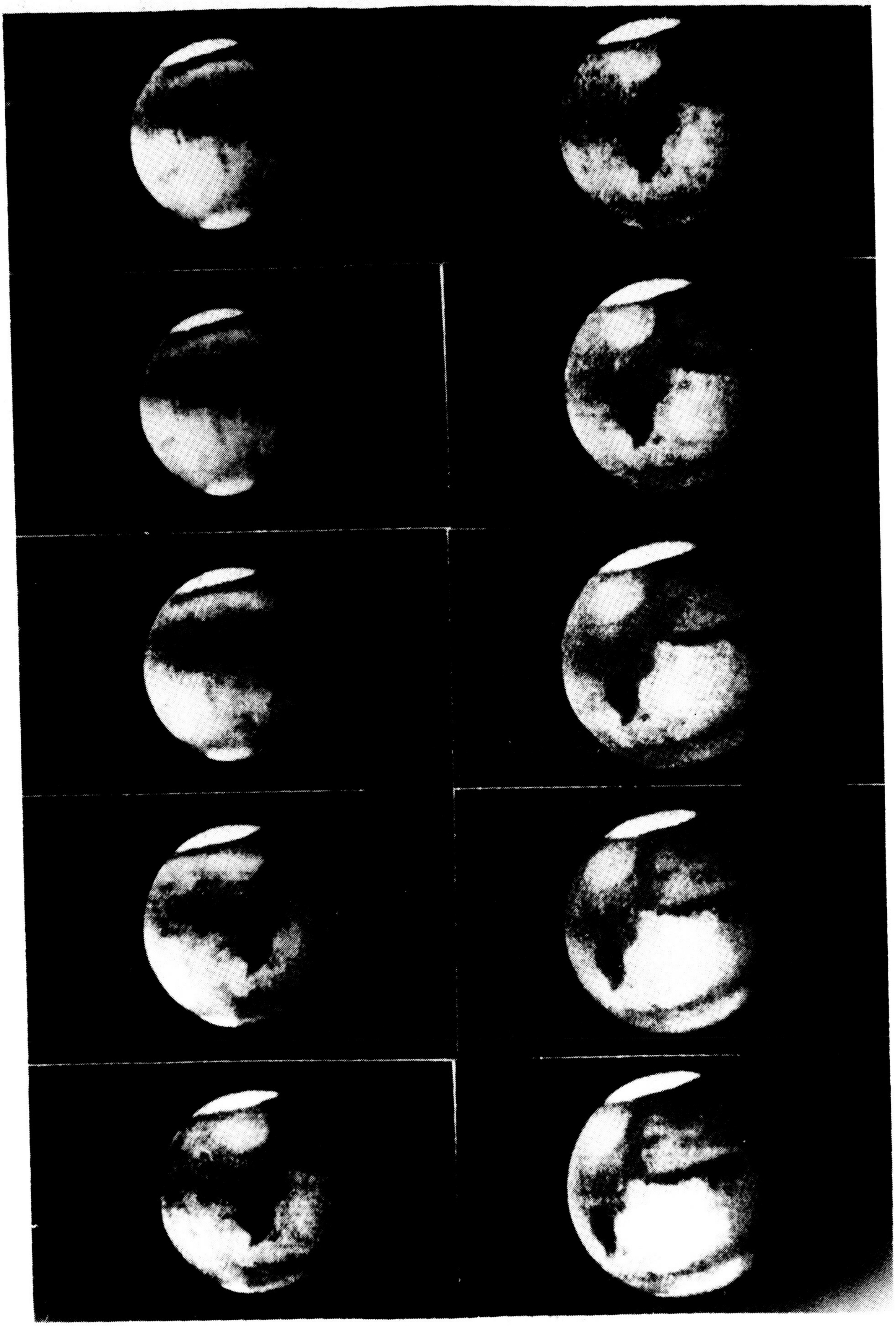
This document describes a program to establish a permanent scientific research base on Mars. We present a Mars base as the much needed long-term focus for the space program. A permanent base was chosen rather than the more conventional concept of a series of individual missions to different sites because the permanent base offers much greater scientific return plus greater crew safety and the potential for eventual growth into a settlement.

The Mars base will strive for self-sufficiency and autonomy from Earth. Martian resources will be used to provide life support materials and consumables. The Martian atmosphere will provide a convenient source of volatiles: CO_2, N_2, and water. Rocket propellant (for returning vehicles), fuels, breathable air, and fertilizers will be manufactured from Mars air. Food will be grown on Mars using Martian materials as plant nutrients.

A permanent human presence will be maintained on Mars beginning with the first manned landing via a strategy of crew overlap. This permanent presence will ensure safety and reliability of systems through continuous tending, maintenance, and expansion of the base's equipment and systems.

A permanent base will allow the development of a substantial facility on Mars for the same cost (in terms of Earth departure mass) as a series of temporary camps. A base equipped with surface rovers, airplanes, and the ability to manufacture consumables and return propellant will allow far more extensive planetary exploration over a given period of years than would an approach that featured a series of short exploration missions such as the Apollo Moon program.

CASE FOR MARS - CONTENTS



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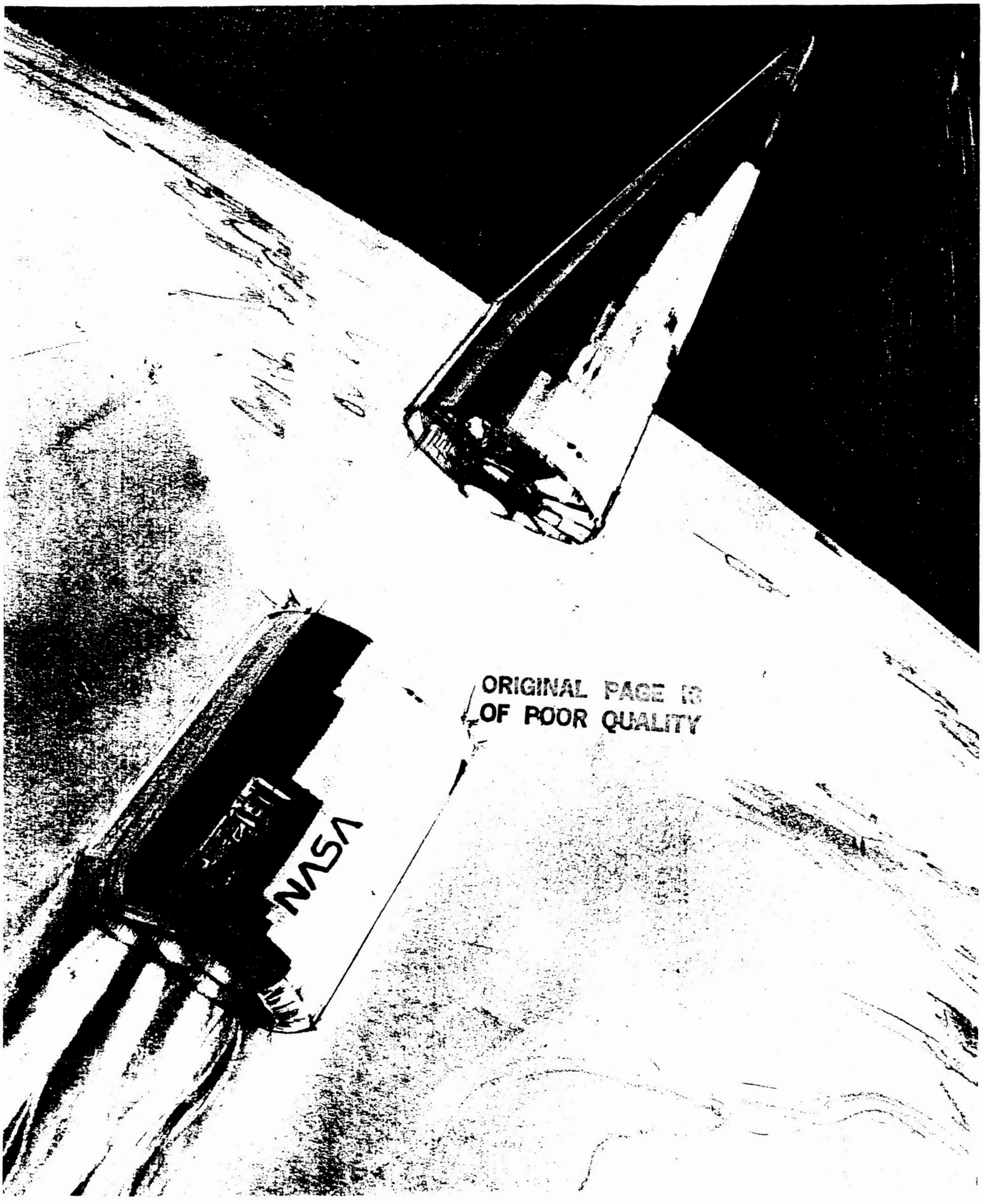
The first mission to establish a Mars Base leaves Earth orbit -- Artist Mike Carroll

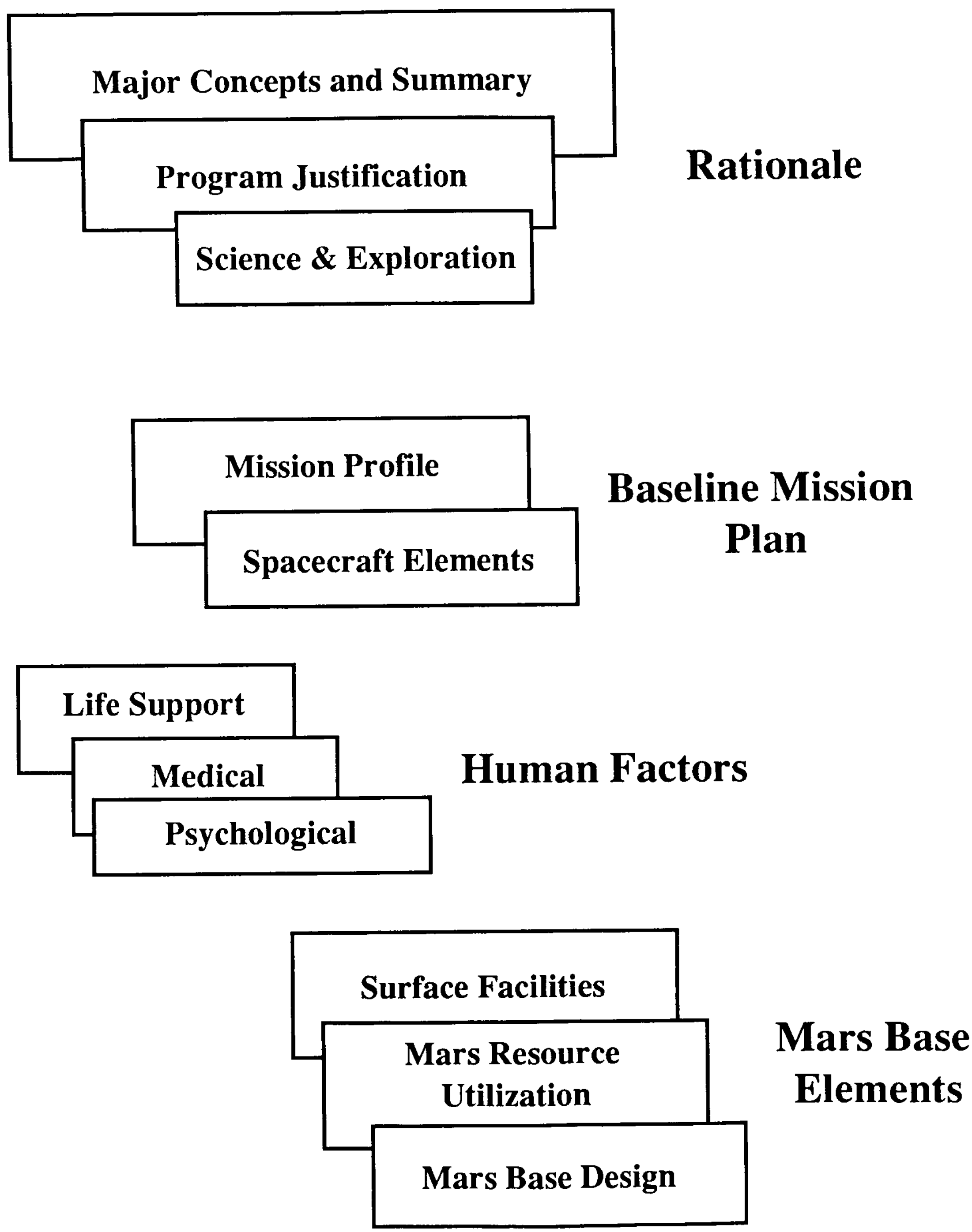


The return vehicle detaches the first stage shortly after lifting off from the Mars base with the crew returning to Earth -- Artist-Carter Emmart

SECTION ONE -- INTRODUCTION AND ASSUMPTIONS: THE CASE FOR MARS

SECTION OUTLINE -- INTRODUCTION AND ASSUMPTIONS

I. REPORT ORGANIZATION



II. OBJECTIVES OF THIS REPORT

Goal: **Definition study for establishing a permanent Mars research base using year 2000 technology.**

Includes:

* Overview and rationale
* Precursor science requirements
* Permanent base science facilities
* Base establishment mission profile
* Transportation element concept development
* Life support and crew factors development
* Mars base facilities definition

Purpose of the Report:

* Concept development for Mars base
* Define technology development requirements
* Determine feasibility of concept

III. MAJOR CONCEPTS AND ASSUMPTIONS

The research base development strategy is based on the following major concepts:

CONTINUED PRESENCE

* **Human crews will maintain a continued presence on Mars beginning with the first manned landing**
* **The initial manned missions establish the base**
* **Information about Mars needed to support the base establishment missions will be obtained by automated precursor missions in advance of the first manned landing**

RESOURCE UTILIZATION / SELF-SUFFICIENCY

* **Martian resources will be utilized to supply consumables**
* **Martian resources will provide propellant for the returning vehicles**
* **The base will strive to achieve self-sufficiency from Earth's resources**

SCIENTIFIC PURPOSE

* **The principal purpose of the base is scientific research**

DISCLAIMERS:

* **This is a preliminary baseline study**
* **Examines only a narrow range of options**
* **Suggests one approach -- not the only one**
* **The options studied in each section is <u>relatively independent</u> of other sections**

SECTION TWO -- EXECUTIVE SUMMARY

1. OVERVIEW

This document describes a program to establish a permanent scientific research base on Mars. We present a Mars base as the much needed long-term focus for the space program. A permanent base was chosen rather than the more conventional concept of a series of individual missions to different sites because the permanent base offers much greater scientific return plus greater crew safety and the potential for eventual growth into a settlement.

The Mars base will strive for self-sufficiency and autonomy from Earth. Martian resources will be used to provide life support materials and consumables. The Martian atmosphere will provide a convenient source of volatiles: CO_2, N_2, and water. Rocket propellant (for returning vehicles), fuels, breathable air, and fertilizers will be manufactured from Mars air. Food will be grown on Mars using Martian materials as plant nutrients.

A permanent human presence will be maintained on Mars beginning with the first manned landing via a strategy of crew overlap. This permanent presence will ensure safety and reliability of systems through continuous tending, maintenance, and expansion of the base's equipment and systems.

A permanent base will allow the development of a substantial facility on Mars for the same cost (in terms of Earth departure mass) as a series of temporary camps. A base equipped with surface rovers, airplanes, and the ability to manufacture consumables and return propellant will allow far more extensive planetary exploration over a given period of years than would an approach that featured a series of short exploration missions such as the Apollo Moon program.

2. SCIENCE AND EXPLORATION

The primary purpose of the Mars Program is scientific exploration. A human presence on Mars will accelerate and enhance scientific exploration of the planet, as humans have unique capabilities which are difficult or impossible to automate. The capability for immediate decisions and plans, the ability to repair and improvise equipment, inherent mobility and flexibility, experience, intuition and intelligence are all unique human traits that make people on Mars the best technique for studying the planet.

Prior to establishing a Mars base, precursor missions are required to investigate the Mars environment and select the best location for a permanent base. The base must be located in an accessible area suitable for a landing field, and must be near to areas of scientific interest. Martian resources will be used for base operations. Thus, the chemistry, mineralogy, and the state and distribution of volatiles on the Martian surface -- particularly water -- must be assessed globally and locally. The meteorological environment of Mars must be studied to forecast the likelihood of dust storms in the base location, and characterize the local, regional, and global weather.

A precursor program to accomplish these objectives includes the planned Mars Observer Mission (MOM). An orbiter mission to provide high resolution images of candidate base site areas is also needed. A network of surface weather stations supported by low resolution orbital imaging of cloud features is desirable for several Mars years in advance of manned missions. Finally, a sample return mission is needed to collect samples of Mars materials from prospective base sites and bring them to Earth for analysis.

The initial human landing at the base site will certify the safety and habitability of the base location, provide ground truth about the presence of water and other raw materials for base operations, set up resource extraction equipment, and establish meteorological stations in support of future manned landings. Permanent scientific research facilities will be the next priority after the survival technologies have been deployed. Facilities for research in atmospheric science will provide for short-term weather forecasting as well as study climate, atmospheric dynamics, and atmospheric chemistry. Geoscience research capabilities will include surface exploration, seismic and drilling equipment, manned and teleoperated rover vehicles, and laboratory equipment for geochemical and petrological study of samples. Life science research on Mars will search for present or past life, supported by appropriate laboratory capabilities.

3. MISSION STRATEGY

The mission strategy is directed toward support of a permanently inhabited Mars base with crew rotation and resupply at each Earth-to-Mars launch opportunity. In this baseline study, a powered-flyby mission profile in which the interplanetary spacecraft does not orbit Mars, was chosen in order to minimize the total mass departing Earth. A Mars powered-flyby and return to Earth is performed by the *Interplanetary Assembly* vehicle, which also serves as the crew's interplanetary habitat. Arriving crew members separate from this habitat in *Mars Shuttle* vehicles while on the approach leg. The shuttles proceed to Mars and land at the base using a combination of aerodynamic braking and rocket thrust. To get into an Earth-return trajectory, the *Interplanetary Assembly* performs (unmanned) a propulsive maneuver as it flies by the planet. Crewmembers returning to Earth depart Mars in *Mars Shuttles* that rendezvous with the *Interplanetary Assembly* (habitat) on the outbound leg departing Mars. In preparation for the next habitat flyby (two years later), the *Mars Shuttles* at the base are refueled using $CO\text{-}O_2$ propellant manufactured from Mars CO_2.

While the newly arrived crew takes up its duties at the base, the returning crew rides back to Earth in the *Interplanetary Assembly*. Arriving at Earth, the crew enter the *Mars Shuttles* and aerobrake down to the Space Station, and the habitat splits into components which aerobrake into Earth orbit. (Later, it is recovered and refurbished for reuse.)

Each mission of the *Interplanetary Assembly* delivers fifteen crewmembers to Mars. To build up the base population in the early stages of the program, a lesser number (e.g. nine or ten) of the base crew will return to Earth. This will not only provide population growth, but also a highly desirable continuity in base operation.

4. VEHICLES

Three new vehicles are involved in execution of the mission strategy developed here. These are: the *Mars Shuttle*, the *Interplanetary Assembly*, and the *Earth Departure Stage*.

The *Mars Shuttle* vehicles, as the name implies, are used to transport arriving crew members to the Martian surface from the *Interplanetary Assembly* or habitat and to bring homeward-bound crew members from Mars to the *Interplanetary Assembly* . At the end of the return journey, they are also used to bring the crew to the Space Station. For the descent to Mars, the Shuttles depend upon aerodynamic braking to slow them from an entry velocity of 5 to 6 km/sec down to a velocity suitable for parachutes. To provide the required accuracy and control, a relatively high lift-to-drag ratio is needed. A biconic airframe (shaped like a slightly crooked cone) provides this capability. Two versions of the *Mars Shuttle* are needed, one is a one-way unmanned cargo vehicle, the other a manned version which can be reloaded with propellant on Mars for the return. The manned version will be a two-stage vehicle, since the $CO\text{-}O_2$ propellant manufactured on Mars is of low performance. (Later in the program, higher I_{sp} propellants may allow a single stage vehicle.) Protection from aerodynamic heating will be provided by a reusable heat shield similar to that used for the Space Shuttle.

The *Interplanetary Assembly* is composed of three identical sections, each an interplanetary spacecraft capable of independent operation. Each section is assembled at the space station, and consists of two habitat modules (based on Space Station designs), a life support system, consumable storage, and a propulsion system using space-storable propellants. All this is attached to a boom and tunnel assembly terminating in a docking adapter which allows the three sections to dock into a pinwheel configuration that is rotated to provide artificial gravity. A crew-type *Mars Shuttle* is docked along each boom. Each section (with its *Mars Shuttle*) is boosted separately on a Mars-bound trajectory from low Earth orbit. The three sections rendezvous and dock on the way to Mars, remaining linked for the remainder of the mission.

The *Trans-Mars Injection Stage* is used to boost the interplanetary spacecraft segment and *Mars Shuttle* assemblies out of Earth orbit and into the Mars transfer trajectory. It uses adapted Space Shuttle Main Engines for thrust.

Cargo versions of the shuttle are boosted to Mars without being attached to a habitat. To provide power and other services to the vehicle during interplanetary flight, a jettisonable service module will be attached. Four loaded *Cargo Shuttles* can be injected into a Mars-bound trajectory by one *Trans-Mars Injection Stage*, and the cargo needed by the initial base establishment mission is approximately what can be carried in these four vehicles.

5. HUMAN FACTORS

Human Factors encompass those facets of mission planning and design which affect the physiology, psychology, and performance of the Mars Base crewmembers (i.e., almost everything!).

Life support facilities must be provided for long-duration spaceflight with primary considerations being mass, volume and reliability. Recycling water and breathable gases is essential. Food is primarily transported with possibly some supplementary food production in flight. Organic waste will be stored for later use as an agricultural commodity at the Mars Base. Development of long-duration life support is seriously lagging behind other technologies relevant to human missions to Mars.

Life support at the Mars Base involves a program of gradually expanding food production and gas recycling capability. Martian water, gases and possibly regolith will provide most of the raw consumable materials. Greenhouses will be used to provide the basic foodstuffs for the Mars Base food chain. Organic wastes will be recycled, and microbial processing will be used to produce a variety of biological products and to enhance the nutritional value of foods. The overall facility is envisioned as a managed ecological system relying on biological cycling of materials when possible. This will be augmented with chemical and mechanical subsystems to provide buffering capability against system oscillations. Emergency food supplies must be cached in case of system failure and possibly periodic maintenance shutdowns.

Medical care must provide for the normal needs of crewmembers over a 5 year mission duration and be able to address a variety of foreseeable problems in unknown and hazardous environments of space and the Martian surface. Since accidents are likely, the capability to perform at least limited surgical procedures is necessary. A carefully selected pharmacopoeia must be included to cover a reasonable range of disease and accident treatments. All crewmembers must be trained in basic rescue and emergency medicine. ***At least*** one physician must be included in the crew. Research on key medical problems to be pursued prior to a Mars mission includes: understanding the effects of zero and fractional gravity over long periods of time and development of ameliorating drugs or techniques, and developing medical devices and techniques appropriate to the space and extraterrestrial environments.

Psychological considerations are involved at all stages of mission planning including crew selection and training, selecting command protocols, scheduling work loads, providing recreational facilities, ergonomics of the Mars Base design, rotating crews from mission to mission, mission continuity with changing personnel, and interpersonal relationships.

6. MARS BASE INFRASTRUCTURE

The Mars base infrastructure supports continued human presence on Mars' surface and exploits Martian resources to supply the crew needs. The base infrastructure provides facilities from which to conduct scientific exploration.

We have outlined the major components and requirements for the Mars base facilities to support an initial crew of 15 people. Major components include: Habitats built out of cargo vessels; Air shells/Greenhouses that are lightweight erectable structures which can be pressurized with Mars air; Power supply to provide power to the base and to the resource extraction equipment (the largest power user); Rovers, trucks, and other mobility units for construction and field experiments; Habitat life support systems, which can inherit considerable technology from space station systems and benefit from the resources available on the Martian surface; and an atmospheric gas extractor which would obtain breathable air and water from the Mars atmosphere.

Breathable air could include an Ar/N_2 buffer gas mixture. These elements together comprise over 5% of the Martian atmosphere and can be obtained by condensing and removing the CO_2 from Mars air. Oxygen can be obtained by reducing atmospheric CO_2. The Mars atmosphere contains water (nearly at saturation) which can be extracted as a useful byproduct with compression and cooling equipment. Rocket fuel can be made from the CO_2 itself (CO and O_2) or in combination with water (CH_4 and O_2). An active research program must be established to look at the use of volatiles and minerals available on Mars in support of the exploration effort. The initial focus of activities at the Mars base must be deploying and "tuning" life-support systems and resource utilization technologies.

Necessary technologies for the Mars base include: Power supply suitable to provide the approximately 200-400 kWatts needed; Mars suit design; Small engines to run on fuel made on Mars; Life support and resource utilization technologies.

7. POLITICAL AND ECONOMIC FACTORS

Engineers and scientists can tell us about rocket power but ultimately it is political and economic power that will extend human presence to Mars. Two major factors influence the design of a Mars program: (1) The potential for conflict resolution through international cooperation; (2) The potential for healthy competition between nations and amongst private enterprise. A strategy for international cooperation is suggested which unifies these disparate interests.

Three teams of nations could participate in a Mars program. The team environment would be somewhat competitive but cooperation would be essential to the success of the program. A cooperative international Mars program would be the largest peaceful joint venture in history and great potential benefits would result. Social and political scientists should study options for international cooperation in a Mars program and potential effect on international relations.

Economic benefits will result from a Mars program. In the near-term, society will benefit from "spin-offs"--that is, technology developed for the Mars program will have applications on Earth. Also, the space infrastructure developed to support the Mars program will open up the economic potential of space. In the far term, the resources of Mars will become a key element in supplying the needs of a space-based economy.

The cost requirements of a Mars program can be factored at rates that add health and not trauma to the U.S. economy. With proper phasing of Mars missions, and with a space infrastructure in place, the management and engineering costs can be shared and optimized. Detailed cost estimates and cost-benefits analyses are needed to quantify the economic implications of a Mars program.

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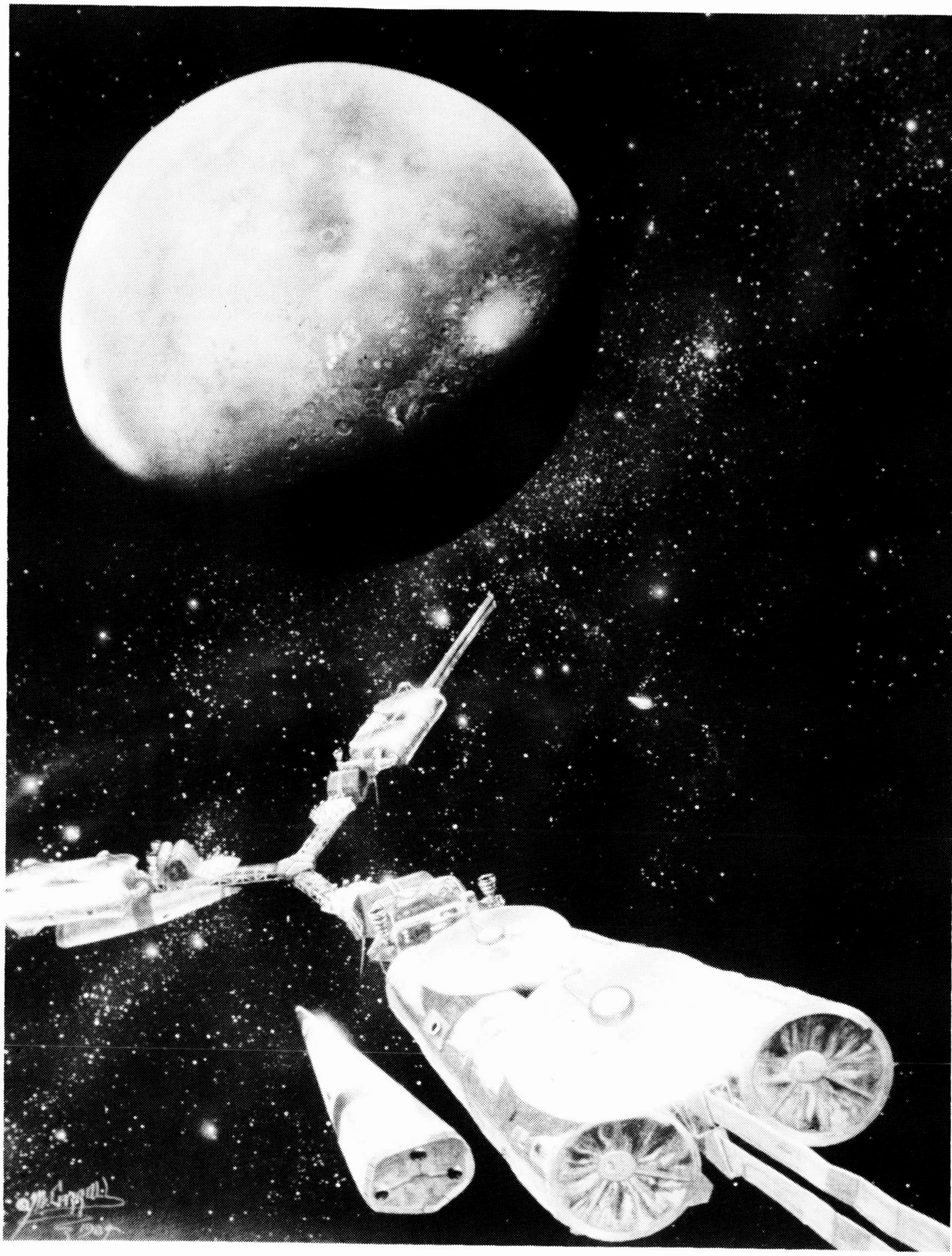

Interplanetary Assembly approaches Mars as Crew Shuttles detach -- Artist-Mike Carroll

SECTION THREE -- MARS BASE PROGRAM OVERVIEW AND RATIONALE

SECTION OUTLINE -- MARS BASE PROGRAM OVERVIEW AND RATIONALE

I. INTRODUCTION: CHARACTER OF THE PROGRAM

II. MARS: A LONG TERM FOCUS FOR THE SPACE PROGRAM

A. REQUIREMENTS OF A LONG RANGE FOCUS
B. WHY MARS AS A FOCUS?

III. WHY MARS? SCIENTIFIC, SOCIAL, AND ECONOMIC REASONS

A. SCIENTIFIC REASONS
B. SOCIAL REASONS
C. ECONOMIC REASONS

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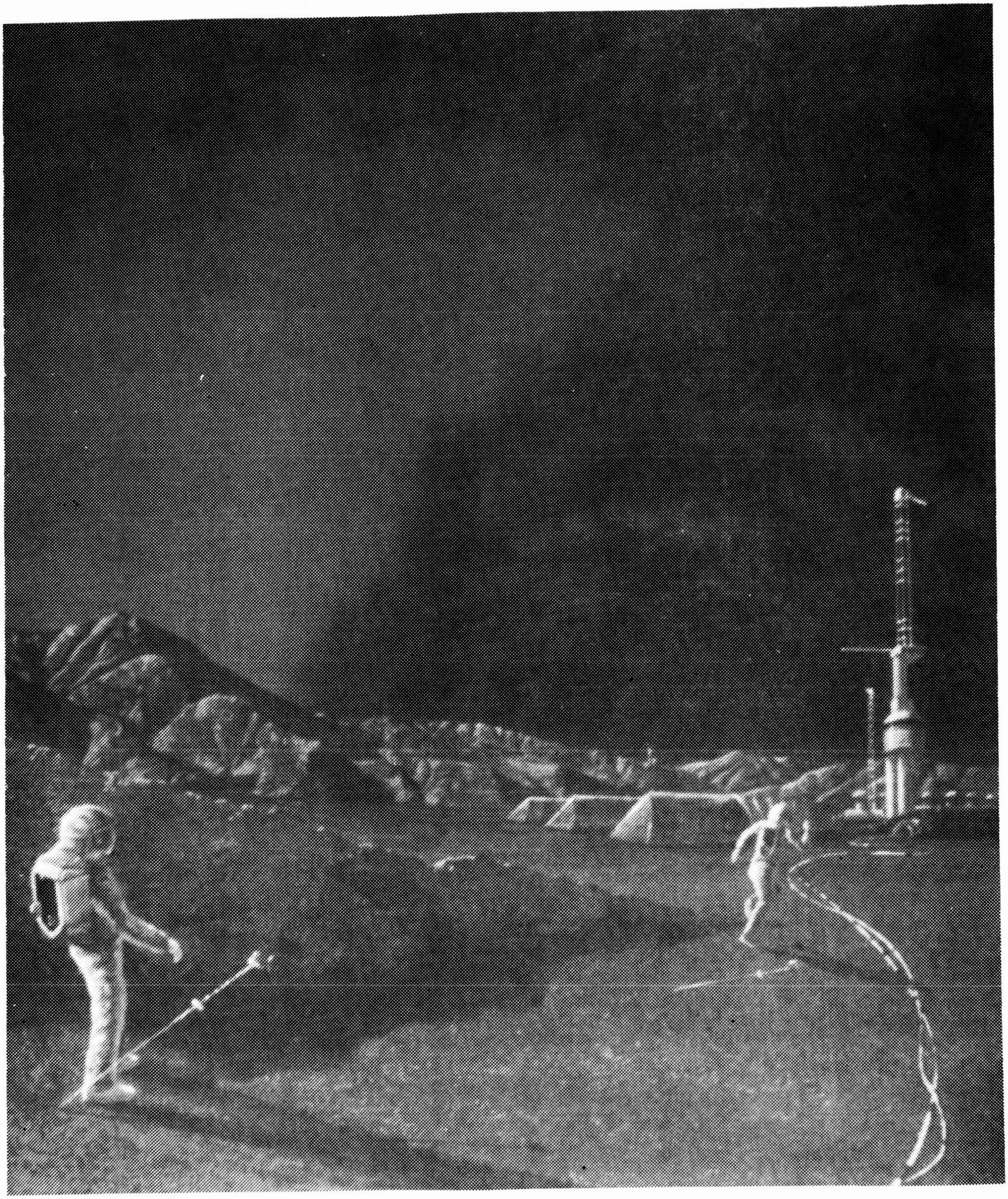

Duststorm approaches Mars base -- Artist Mike Carroll

I. INTRODUCTION: CHARACTER OF THE MARS PROGRAM

The purpose of the Mars program is to establish a permanent scientific research base on Mars as a precursor to eventual colonization. The overall focus of the program is to BE ON MARS not just to GO TO MARS. A program of this nature will require a long-term national commitment and will serve as a scientific and technological driver for the space program for many decades. The proposed Mars program will encourage funding and public support by offering interim milestones while building toward the ultimate goal, a base on Mars.

The Mars base will strive for self-sufficiency and autonomy from Earth. Mars is the most clement planet in the solar system other than Earth. Mars offers the potential for convenient *in-situ* production of life support materials, thereby eliminating the cost of transporting consumables from Earth. It clearly has the potential to support a permanent colony and with anticipated technological developments, self-sufficiency will be achievable.

Beginning with the first mission, Martian resources will be used to the fullest possible extent. The atmosphere of Mars will probably be the most easily accessible source of materials for initial missions. Martian air will be processed to produce fuel for launch from the Mars surface. Additionally, Martian air can be processed and compressed to produce breathable air for humans, greenhouse air for growing plants, and water.

A primary feature of the program will be to maintain a continued presence on Mars from the first mission onward. There are several motivations for this. Equipment can be maintained and kept continuously operable to ensure reliability of systems for subsequent missions. Crew overlap will promote safety and efficiency as anecdotal information can be transmitted where appropriate. Continuous tending of greenhouse "farms" will assure a food supply on Mars. This will lower weight requirements for subsequent missions. In short, self-sufficiency can best be achieved by a continued human presence on Mars.

II. MARS: A LONG-TERM FOCUS FOR THE SPACE PROGRAM

The Mars Research Base Program will provide the much needed focus for the United States Space Effort. For any program to be effective in this role, there must be a long-term commitment. A permanently manned research base on Mars obviously requires such a commitment. Any program must have several attributes to qualify as a long-term focus:

A. REQUIREMENTS OF A LONG RANGE FOCUS

The program must have a good trade-off between the ambitious and the achievable. A permanent Mars research base meets this criteria very well, as our base establishment program demonstrates. The program we have outlined requires some new technological developments, but they are all reasonably anticipated within the next twenty years.

The overall program must be long-term, and offer clearly identifiable near-term milestones. A Manned Mars Research Base meets these criteria very well. The conceptual program outlined here has a 10 year (or more) precursor phase, 10 year development phase for the initial base establishment, and an indefinite continuation phase which has a two year natural cycle. These interim milestones will help to maintain program momentum.

The program goal should incorporate current and planned elements of the space infrastructure. The Mars base program will make use of the shuttle and space station as transportation and assembly points and will use life support and transportation technology developed for Space Station and Lunar Base providing needed long-term objectives for them.

The program goal should have broad scientific objectives and enhance the goals of solar system exploration. A Mars exploration program as a major NASA goal retains the importance of science objectives and maintains a strong science-oriented planetary program in the spirit of the Apollo and Viking programs.

The program must be exciting enough to catch and hold the attention of the public and must be historically significant. Mars has long been an object of interest and speculation for humanity. A Mars base program appeals to the pioneering spirit and imagination. Furthermore, man in space appeals to the human quest for knowledge in a personal way which encourages emotional participation by the individual citizen. Finally, it is obvious that establishing a permanent colony on another planet is of profound historical significance.

B. WHY MARS AS A FOCUS?

Mars is the most clement nonterrestrial planet. Of all the planets, Mars is the most hospitable and comparable to Earth. It is the only planet where a permanent settlement can be established with foreseeable technology.

Mars is abundantly endowed with all the resources necessary to sustain life. Compared to the moon, Mars is a veritable resource garden of Eden. Using Mars resources will allow the colony to become independent of Earth, virtually a requirement due to the long transit times and expense of transporting consumables.

Mars offers the potential for rapid achievement of self-sufficiency. The Mars atmosphere is an accessible source of materials that allows a relatively low-technology approach to manufacturing. Water, breathable air, and rocket propellants can be obtained reliably from the Mars atmosphere beginning with the first manned mission.

A Mars base will have high scientific payoff. All aspects of Mars science will be well served by a Mars base program. In the near term, automated scientific precursor missions will set the stage for landing a human crew. The current NASA plans for unmanned Mars missions can provide the required information to effect a manned landing.

A Mars program encompasses a wide spectrum of activities. These activities range from short-term individual missions which are presently under development (for example, the Mars Observer Mission, MOM) through the effort of base establishment and self-sufficiency of the Mars base and can extend to colonization and even planetary engineering.

A Mars program will require contributions from all branches of NASA, Universities, and the private sector. Science and applications, manned and unmanned facets, logistics and support personnel all have a role to play in a Mars program.

Mars has the potential for long-term economic payoff. Mars and its satellites are likely to be the major source of commercial resources for transportation systems of the future. Mars may become the gateway to the asteriod belt and the outer solar system. Mars will become economically and strategically important when human interests extend to the outer Solar System.

III. WHY MARS?: SCIENTIFIC, SOCIAL, AND ECONOMIC REASONS

A. SCIENTIFIC REASONS

* Mars surface science: Geology, Geochemistry, Geophysics
* Atmospheric science: Understanding of the Mars Atmosphere
* Mars has the greatest potential for useful comparisons with Earth (comparative planetology), especially Climate Studies
* Phobos/Deimos studies
* Is there life on Mars? Was there life on Mars?
* Origins of the solar system

B. SOCIAL REASONS

* Potential for international cooperation / conflict resolution
* Mars is the next frontier: captures imagination and pioneering spirit
* Potential for elevation of the human spirit & national pride
* Eventual strategic importance: gateway to outer solar system
* Secure repository for life, knowledge, and technology
* Mars is the next step in expanding the human race beyond Earth

C. ECONOMIC REASONS

* Mars could provide an impetus for long-range development of science and technology
* Mars can help to orchestrate the transition to a space-based economy
* Mars base will expand the deep space infrastructure
* Technology developed for Mars base will prove useful on Earth
* Mars has Phobos and Deimos in orbit (convenient asteroids with economic potential)
* Mars is the gateway to the Asteroid Belt -- a potential supply depot and transportation node to the outer solar system
* Mars program will have many components in common with the Space Station and the proposed Lunar Base
* Existing technology development programs may be applicable -- e.g. artificial intelligence and robotics will help make the program more affordable and safer

SECTION FOUR --
SCIENCE AND EXPLORATION

SECTION OUTLINE -- SCIENCE AND EXPLORATION

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Exploration party in the polar region investigating the layered terrain -- Artist Mike Carroll

I. INTRODUCTION

A structured program of Scientific Research on Mars is presented. The program proceeds in two phases. First, a precursor phase will provide enough information about Mars to support establishing the base. The second phase encompasses human exploration of Mars staged from the permanent base.

The scientific research program is based on **two major assumptions** about the character of the base: ***(1) The base will strive to achieve self-sufficiency by using Martian resources to supply human needs; (2) Once humans land on Mars, they will maintain a continued presence.***

Since Martian resources will be used from the first mission onwards, an extensive reconnaissance program must precede the base establishment missions. We present a program of unmanned reconnaissance which incorporates the Mars exploration program proposed by the Solar System Exploration Committee (SSEC). The required reconnaissance program could be accomplished by some other means but we don't consider other options here.

Once the base is established, human crews will use fully equipped research facilities to accomplish long-range and in-depth studies of Mars. The capability to explore remote sites and return samples to the permanent base will aid this phase of exploration. We present examples of the exploration strategy and how it proceeds from unmanned exploration missions to the permanent base.

A. WHY HUMAN EXPLORATION OF MARS ?

Human presence can accelerate and enhance scientific exploration of Mars. Much better science can be accomplished with people on Mars than by unmanned exploration because humans have unique capabilities that are difficult or impossible to automate. These capabilities are outlined below:

* **Instantaneous decision making; this includes the ability to change emphasis based on changing environmental or instrument conditions.**
* **Instantaneous analysis, data compaction and synthesis**
* **Experience, intuition and insight**
* **Flexibility and adaptability of human movement; the range of motion that humans are capable of is extremely difficult to automate.**
* **Repairs; ability to repair instruments and equipment.**
* **Tools for a manned mission may be simple. Humans can alter the tools, alter the use and the sequence of use to apply to a given situation.**
* **Visual imagery in three dimensions (vs. 2-D for cameras).**
* **"Seeing", that is, near instantaneous switching of the field of view based on intuition and experience.**
* **Sensory input other than sight (touch, sound, smell) can be immediately integrated.**
* **Succinct environmental descriptions, and intelligent scientific decisions in field examinations and sample collection.**

II. PRECURSOR PROGRAM

A. PRECURSOR MISSION SCIENTIFIC OBJECTIVES

Precursor missions will be required prior to establishing the Mars base. These missions will provide information about Mars to guarantee the safety of the crews, facilitate utilization of Martian resources, and to select an optimal location for the base.

The broad objectives of precursor missions are:

* **Assess Mars environment to assure reasonable safety for crew landings.**
* **Test Martian materials for potential toxic or pathogenic effects.**
* **Locate water sources**
* **Assess chemistry, mineralogy, and biology of the Martian surface**
* **Catalogue useful resources for life support and manufacturing**
* **Facilitate resource use**
* **Document meteorological environment**
* **Locate a safe and accessible base site**

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Evidence that liquid water once flowed on Mars -- Viking Mosaic

B. BASE SITE SELECTION CRITERIA

The precursor program must answer two basic questions: ***1) Where should the base be located? 2) How can human crews be supported?*** Four general criteria must be met by any candidate base location. ***The base must be safe and accessible, it must have a ready supply of useful resources, and it must be in a scientifically interesting area.***

1. SAFETY AND ACCESSIBILITY

The base will be designed for continuous habitation and growth. Repeated landings of crew and cargo dictate that the base must be located in an area which is accessible from orbit. The area should have a stable, relatively benign climate. It must be in frequent contact with Earth via a satellite communications network.

Site selection criteria for safety and accessibility include:

* **A locally flat surface (for several km in all directions)**
* **Mechanically stable surface and subsurface capable of supporting large loads**
* **Relatively benign and predictable local and regional weather (avoid regions of major local dust storms or frequent cloud cover)**
* **Located at a middle to low latitude (to take advantage of planetary spin during surface shuttle ascent and minimize plane change energy requirements)**
* **No local geologic or volcanic hazards**
* **Positioned at a relatively low altitude (high surface pressure for parachute assisted descent requirements)**

2. RESOURCE ASSESSMENT FOR SELF-SUFFICIENCY

We envision the Mars base as achieving self-sufficiency as soon as possible. The base must be located near resources that will make this possible.

The following resources are important to base location:

* **Subsurface water source: Hydrogen will be an important and scarce resource on Mars. If large sources of water can be readily tapped, the capabilities of the base will be enhanced.**

* **Energy Supply**

* **Geothermally active areas (if present)**

* **Suitable insulating and building materials (e.g. unconsolidated sand-size to gravel-size particles)**

* **An accessible source of ores bearing useful amounts of K, C, Ca, N, Na, P, Si, Al, Fe, Mg, Ti for local structural components and bulk materials fabrication**

* **An accessible location for a waste dump**

* **Desirable topographic features**

3. SCIENTIFIC INTEREST

The primary purpose of the established Mars base will be scientific research. Therefore, the base should be located in an area of intrinsic scientific interest. Surface mobility units (rovers, etc.) capable of sustaining a crew for field trips over an area 50 to 1000 km from the base are highly desirable. Also, automated teleoperated rover vehicles or airplanes with a 5000 km range capable of sample return to the base will endow the manned base with global access to the surface of Mars.

Scientific requirements for the base location include:

* **Close to as many different material types, terrain types, and morphological features as possible**

* **Ground access to areas of scientific interest near the base**

* **Close to as many presently active geological processes as possible**

* **Close to an area which may harbor present life or traces of past life (e.g., a region with evidence of past liquid water such as a channel or lake bed)**

C. AUTOMATED PRECURSOR MISSIONS TO MEET SCIENTIFIC GOALS

The scientific goals of the precursor program can be met by automated missions. Much of the scientific information required for establishing a Mars base can be met by missions proposed by the Solar System Exploration Committee (SSEC) of the NASA advisory council as part of the core program for Mars Science*.

Scientific goals for the precursor missions are listed below according to the type of platform required for the mission. The spatial scale of required data sets is shown. Global scale indicates planetwide coverage, regional scale refers to an area of typical radius 1000 - 2000km, and local scale refers to an area of 100 km radius. The right column shows that most of the scientific objectives are accomplished by the SSEC core program missions.

1. ORBITER CLASS MISSIONS

The table on the facing page shows the science objectives required for orbiter class missions. The Mars Observer Mission (MOM) is the first mission of the SSEC Core program. The precursor mission objectives that will be met by MOM are noted. Scientific goals which are not addressed by the SSEC core program missions are indicated as "not covered".

* Planetary Exploration Through Year 2000. 1983. Office of the Superintendent of Government Documents, Washington, D.C.

SCIENTIFIC OBJECTIVES
ORBITER CLASS MISSIONS

ORBITERS	SSEC CORE PROGRAM
GLOBAL SCALE (Planetwide Coverage)	
* Elemental and mineralogical characterization of the surface	MOM
* Surface volatile inventory and distribution	MOM
* Improved Topographic and gravity mapping	MOM
* Atmospheric water vapor: presence and transport	MOM
* Profiles of temperature, dust, and water vapor	MOM
* Wide-angle imaging for global meteorology	MOM, Proposed
* Wind profiles (low vertical resolution)	MOM
* Satellite remote-sensed subsurface ice/permafrost	Not Covered, Technology Required
REGIONAL SCALE (1,000 - 2,000 km radius)	
* High resolution mapping of candidate base areas for site selection (imaging of surface features and topography)	Not Covered

2. PENETRATOR AND NETWORK MISSIONS

Surface penetrators can be used to obtain information about the Martian surface over a widely spaced area. Scientific goals pertinent to establishing a Mars base which can be accomplished using penetrators are shown on the facing page. Surface weather stations with orbital imaging support for cloud motions are necessary to understand the meteorological environment on Mars. The long timescales associated with weather variability suggest that weather data should be obtained for several Mars years before landing a crew. Penetrators will also help to establish the seismic and mechanical stability of the surface and the chemical composition of the surface at the sampled areas. All of these objectives are covered by the Network Science mission plan from the SSEC Core program.

3. ROVER AND SAMPLE RETURN

An unmanned Rover and Sample return mission to Mars is very important prior to landing humans on the surface. Samples of Mars' material must be tested to assure that they pose no chemical or biological hazards to the crews. Returned samples will also allow comprehensive analysis of Martian soil for traces of indigenous life. An automated sample return mission probably will not return actual Martian organisms unless life is widely distributed. The complete understanding of Martian materials made possible by laboratory analysis of actual samples will help to facilitate development of manufacturing processes for use on Mars. This will enhance the capabilities of the initial human crew. For this purpose, it would be best to obtain samples from the proposed base site (or several sites).

A sample return mission could also deploy meteorological equipment around the proposed base sites. A suggested climate station for the base includes sensors to measure temperature, pressure, wind and turbidity at 3 locations surrounding the base.

The Sample Return mission could be refueled for Mars surface departure using fuel manufactured from Mars air. Small automated propellant manufacturing plants have been proposed for this purpose. Implementation of this technology on sample return missions would represent an important engineering test of propellant manufacturing. This technology will then be further developed and implemented for the manned missions.

SCIENTIFIC OBJECTIVES
PENETRATOR AND ROVER/SAMPLE RETURN MISSIONS

PENETRATORS	SSEC CORE PROGRAM
REGIONAL SCALE (1,000 - 2,000 km radius)	
* Surface weather stations (T, P, wind, turbidity- 3+ Mars years operation w/orbital imaging support)	Network Science
* Seismic stability, mechanical stability	Network Science
* Surface chemical composition at several sites	Network Science
ROVER AND SAMPLE RETURN	
LOCAL/REGIONAL SCALE (100 to 1000 km radius)	
* Presence of adsorbed and possibly subsurface water	Rover/Sample Return
* Toxicology analysis	Rover/Sample Return
* Improved understanding of state and distribution of volatiles	Rover/Sample Return
* Chemistry/mineralogy of selected returned samples	Rover/Sample Return
* Ground observations of landforms and surfaces	Rover/Sample Return
LOCAL SCALE (100 km radius)	
* Detection of present life - if widely distributed	Rover/Sample Return
* Deploy final base climate stations (triangular array for T, P, wind, and turbidity)	Not Covered

D. MANNED PRECURSOR: PHOBOS/DEIMOS MISSION

Some of the precursor scientific objectives could be met by one or more manned exploratory missions prior to establishing a base. One option for a manned precursor mission to the Martian satellites has been proposed by Singer*.

The Phobos-Deimos mission concept calls for a base to be established on the satellite Deimos. Astronauts at this base teleoperate a suite of 10 to 20 rover vehicles on the surface of Mars which can return samples to the Deimos base. The large number of surface vehicles makes them expendable and the flexibility of real-time teleoperation means "dangerous" but interesting sites can be explored. In addition, this mission type provides for immediate analysis of samples by humans at the Deimos facility. An example of a Phobos/Deimos mission profile is outlined in Appendix B.

This type of mission could replace the sample return and penetrator phases of an automated precursor program. The mission would provide global-scale scientific reconnaissance and sampling without the complexity of a manned landing. ***The mission is desirable for base site selection because it would allow fairly rigorous assessment of present life on Mars without the danger of contaminating Mars.*** It also allows assessment of the resource potential of the Martian satellites, and also can be developed as a remote staging base for future interplanetary missions.

The scientific objectives of the Phobos-Deimos mission that pertain to establishing a permanent Mars base are shown on the facing page.

*S. Fred Singer, 1984. "The Ph-D Proposal: a Manned Mission to Phobos and Deimos". The Case For Mars, P.J. Boston, ed. American Astronomical Society, Univelt Inc., San Diego.

SCIENTIFIC OBJECTIVES
PHOBOS/DEIMOS MISSION

WIDELY SPACED SAMPLING OF MARS
GLOBAL/REGIONAL SCALE

* **Test toxicology of Mars materials**
* **Search for present or past life without danger of forward or backward contamination**
* **Determine chemistry and mineralogy of a variety of materials**
* **Determine state and distribution of volatiles in surface and subsurface materials**
* **Search for reservoirs of subsurface water**
* **Determine seismic and mechanical properties of surface**
* **Obtain ground observations of landforms and surfaces**
* **Deploy surface weather stations in several locations**

INFORMATION ABOUT MARTIAN SATELLITES

* **Determine chemistry and mineralogy of surface and subsurface materials**
* **Determine state and distribution of volatiles**
* **Assess resource potential for Mars surface or space operations**
* **Asteroid mining feasibility studies and technology development**

III. PERMANENT BASE

Once base establishment begins, human crews will maintain a permanent presence on the surface of Mars. Initial missions will establish the base and set up operational facilities. After the base is operational, scientific research will become the main activity. The objectives of initial missions and the long-term research programs are considered here.

A. SCIENTIFIC OBJECTIVES OF INITIAL MISSIONS

Scientific goals of the initial manned missions are shown on the facing page. These missions will be primarily concerned with certifying the presence of key resources and providing ground-truth for critical information obtained by precursor missions. Scientific information not critical to survival will also be obtained as the crew has time. Deploying a meteorological network in the base area will be important because the prevailing wind direction and base microclimate will influence base operations. Local observations along with weather data from satellites, regional surface meteorology network, and the base area network will be combined to produce forecasts for crew landings and warnings to survey teams.

B. PERMANENT MARS BASE RESEARCH

Information gained by the automated precursor program contributes to the operation of the Mars base and the research program at the base. In the following section, we consider the broad objectives of research on Mars for the fields of Atmospheric Science, Geoscience and Life Science.

SCIENTIFIC OBJECTIVES
FIRST TWO MANNED MARS MISSIONS

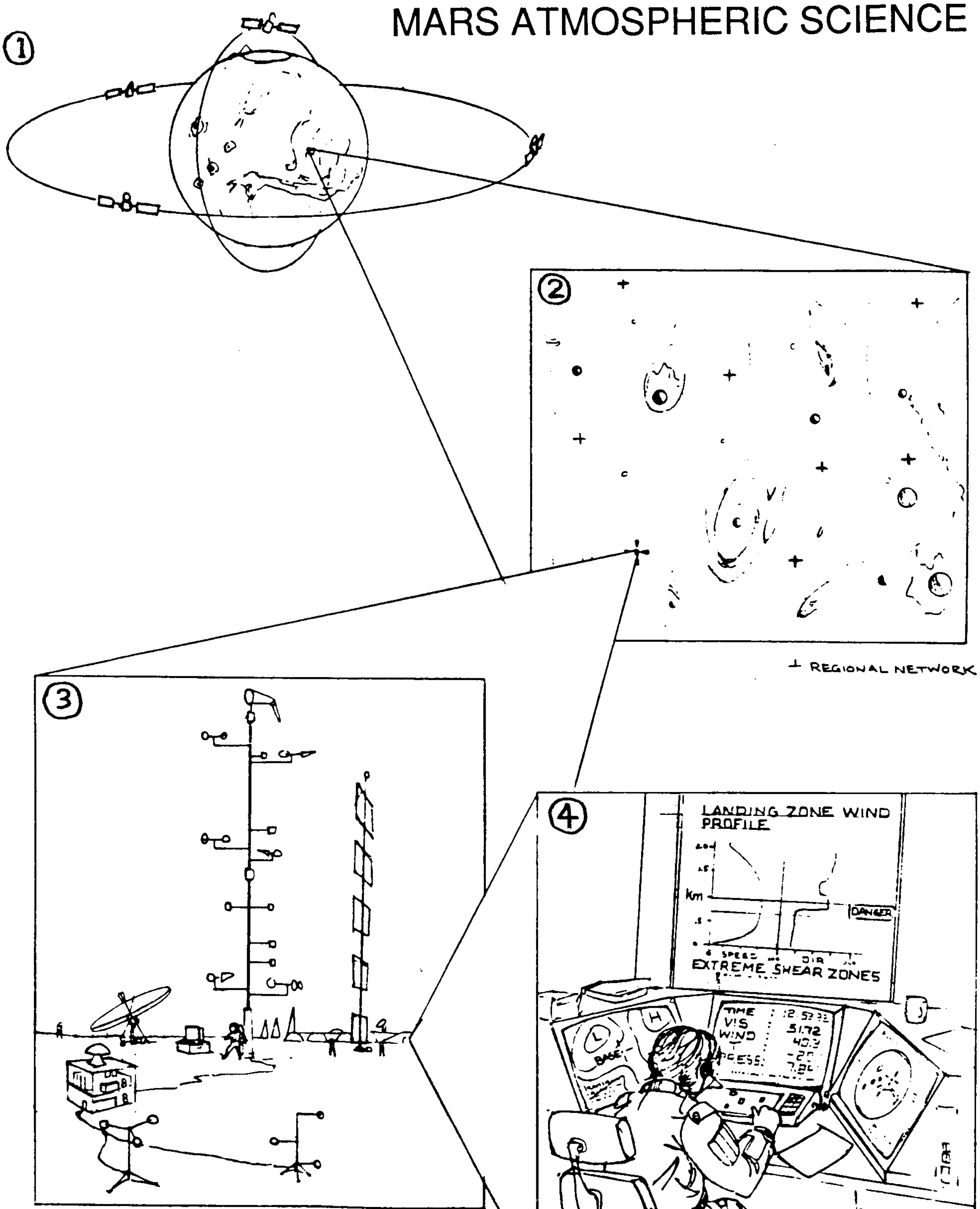
LOCAL SCALE (WITHIN 100 km OF BASE AREA)

* Verify that Martian materials are not toxic.
* Survey base area for presence of necessary resources.
* Obtain high vertical resolution profiles of T, P, wind, water vapor, dust, and radiation.
* Deploy final base weather stations, and observation and forecasting center using satellite, regional and base networks.
* Search for present and past life.

LOCAL/REGIONAL SCALE (100 to 1000 km AREA)

* Investigate state and distribution of volatiles.
* Determine presence of subsurface ice and permafrost.
* Determine surface mineralogy and chemistry.
* Investigate surface and subsurface geology.

MARS ATMOSPHERIC SCIENCE



⊥ REGIONAL NETWORK

BASE METEOROLOGY SITE

FORECASTING CENTER

CARTER EMMART © 1984

1. RESEARCH BASE ATMOSPHERIC SCIENCE

Martian meteorology is important in the manned exploration of Mars for operational and scientific reasons. Phenomena such as global dust storms and winds impact mission design and operation. For example, it would be unwise to land during the season in which global dust storms are most frequently observed or in areas where local storms are common. Scientific goals of atmospheric science research include understanding the current state and circulation of the Martian atmosphere and its past history and evolution. Information gained in the scientific program will also aid day-to-day operations.

The picture on the facing page shows how information from global, regional, and local-scale measurement systems is used for weather prediction and study of the Mars atmosphere.

FRAME 1: This illustrates an Orbiting Satellite System (OSS) which we envision is in place for several years preceding the first human landing providing global imagery as well as wind and temperature profiles. The OSS also provides global remote sensing for geoscience and life science objectives.

FRAME 2: A regional surface meteorological network will provide data on temperature, pressure, wind velocity, turbidity, and moisture. A meteorological station will also be placed at each candidate base site. When used with the OSS, these observations will enable an understanding of global and regional weather processes on Mars and aid prediction.

FRAME 3: The permanent base (10 years after initial landing) has a weather station, a micro-meteorological tower, and remote lidar sensors of local wind, temperature, and dust profiles for use in boundary layer physics and diffusion studies. Also shown is a communications antenna to the OSS which will transmit data directly to the base and serve as a Mars communication satellite. In addition, an advanced base climate station will measure near surface fluxes of momentum, heat, moisture, surface radiation budget, distribution of sand and dust in the lower few meters, and concentrations of chemicals which may be important to long term climate change.

FRAME 4: Shows the base site operational weather center, which would support crew landings and field expeditions. The center will use current data from global, regional and local measurement systems to make short-range forecasts. For example, during a crew landing, base personnel would have global information about clouds, wind, temperature and dust from the OSS. Region-wide pressure patterns, obtained by the regional surface network, would be available for analysis along with local measurements from base instruments.

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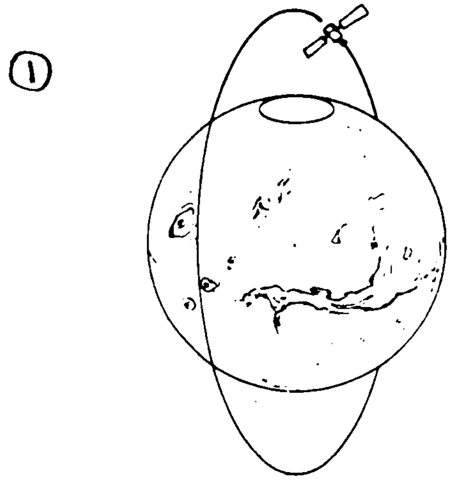
Clouds (probably H_2O) surround Olympus Mons -- Viking Mosaic

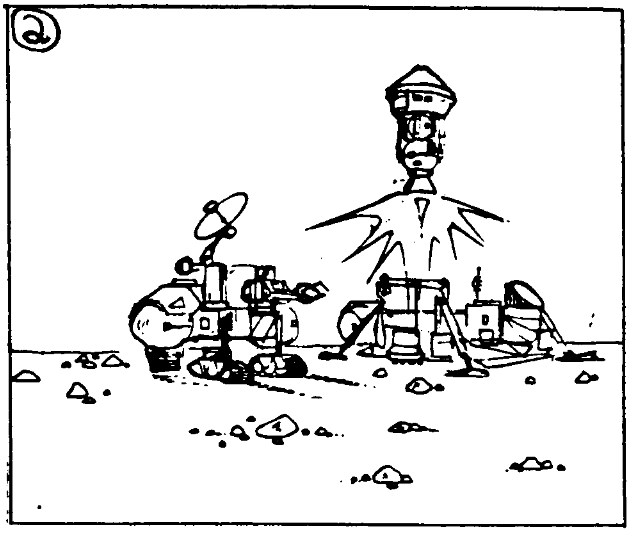
ATMOSPHERIC SCIENCE
LONG RANGE GOALS

* **Describe the mean state of the atmosphere.**
* **Describe the atmospheric seasonal variation and the global transport of water vapor.**
* **Identify important recurring but non-seasonal variations.**
* **Study the past and continuing evolution of atmospheric composition, especially the concentration of radiatively and biologically important gases, and human-induced changes and pollutants.**
* **Identify regions which have low and high variability of meteorological parameters.**
* **Determine the basic components of the general circulation of the atmosphere.**
* **Determine the atmospheric interaction with topography and the polar regions.**
* **Explain the origin and evolution of global and regional dust storms.**
* **Determine the global energy balance and its variability.**
* **Study the past history of Martian climate and its relationship to orbital and rotational perturbations and atmospheric evolution.**
* **Study the interaction of the atmosphere with the solar wind and possible magnetic fields.**
* **Explain the conditions leading to the formation of clouds and fog.**

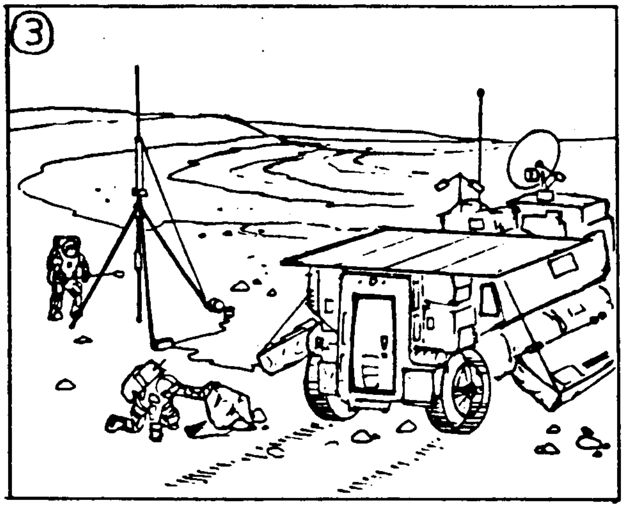
MARS GEOSCIENCE



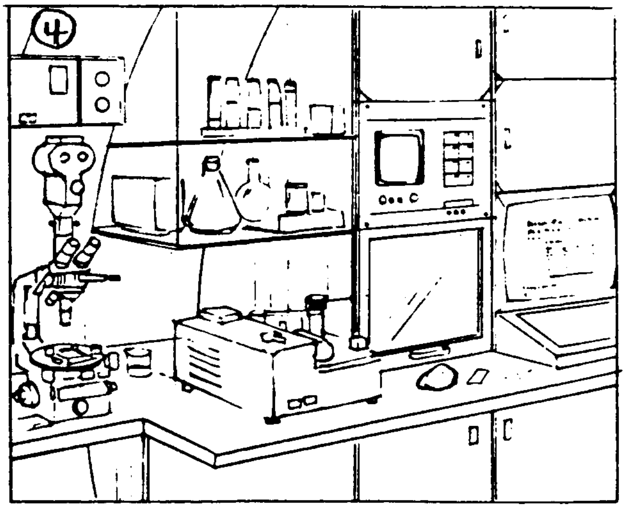
GEOSCIENCE POLAR ORBITER



AUTOMATED SAMPLE RETURN



SURFACE EXPLORATION PARTY



BASE GEOSCIENCE LAB

2. RESEARCH BASE GEOSCIENCE

Mars is an ideal place for geoscientists to explore how variations in comparatively minor factors can influence the evolution and present state of one planet in comparison to another. Mars is the most Earth-like of the planets. As such, it holds the greatest promise for meaningful comparative planetology. Operationally, the success of a self-sustaining human presence on Mars depends on how effectively various natural resources can be located and exploited.

The figure on the facing page shows the evolution of geoscience research from precursor missions to the Mars base.

FRAME 1: A Geosciense orbiter will help locate useful raw materials and provide information leading to optimal base location. It will characterize the global distribution and abundance of volatiles and the elemental and mineralogical composition of the surface. High resolution imaging and topographic mapping from orbit will support the human landing by locating a safe, optimal base location.

FRAME 2: A sample return from candidate base sites is highly desirable prior to the human landing. Analysis of Mars samples from a Sample Return mission will assist technology development for manufacturing processes on Mars.

FRAME 3: Once the base is established, geoscientists could explore remote sites using portable habitats and teleoperate long-range rover vehicles for global exploration. Human exploration will make use of traditional field geology techniques, drilling and seismic profiling, sample collection, and stratigraphic analysis.

FRAME 4: One of the first research facilities on Mars will be a laboratory for geochemical and petrological studies. Possible facilities for the laboratory include:

* **Thin section laboratory and petrographic microscope**
* **Scanning electron microscope/x-ray diffractive spectrometer**
* **X-ray fluorescence spectrometer**
* **Chemistry laboratory**

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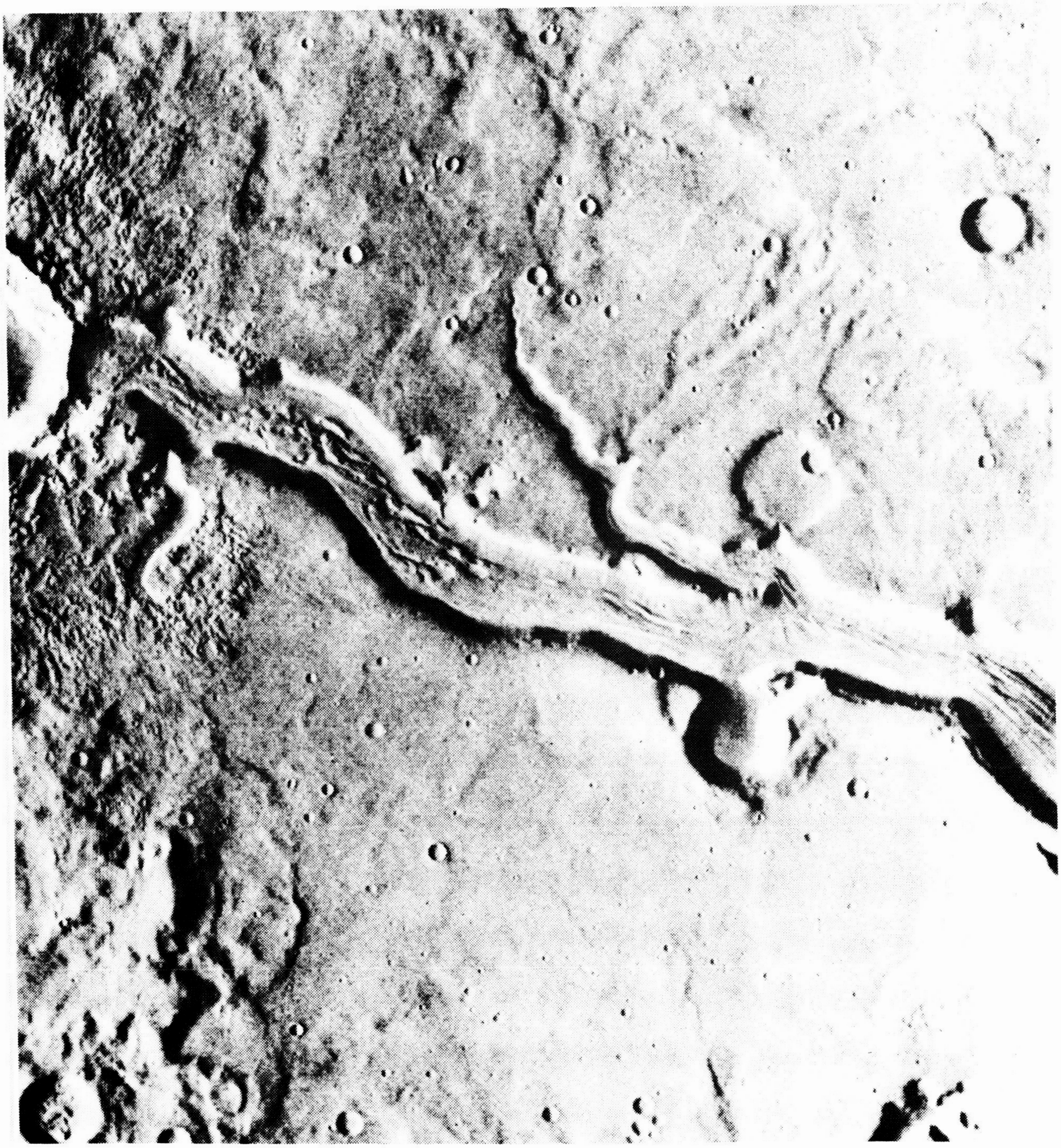

Channel system cut after cratering episode -- Viking Photo

GEOSCIENCE
LONG RANGE GOALS

* **Determine the absolute geochronological ages for a large and geographically disperse assortment of Martian materials.**

* **Sample an unaltered assortment of volatile-containing materials.**

* **Intensively analyze a large and geographically dispersed assortment of Martian rock types and surface materials.**

* **Determine the origin and significance of layered polar deposits.**

* **Determine the Martian surface and subsurface water state, distribution and history.**

* **Determine volatile and outgassing history.**

* **Determine the nature of early crustal genesis and the origin and history of the difference between northern and southern hemisphere crust.**

* **Map the structure, lithology, and stratigraphy of the Martian crust.**

* **Determine the history and present state of organic chemicals.**

* **Determine the distribution, abundance, sources and sinks of volatile materials.**

* **Explore the structure and dynamics of Mars' interior and seismicity.**

* **Measure Mars' global and regional heat flow.**

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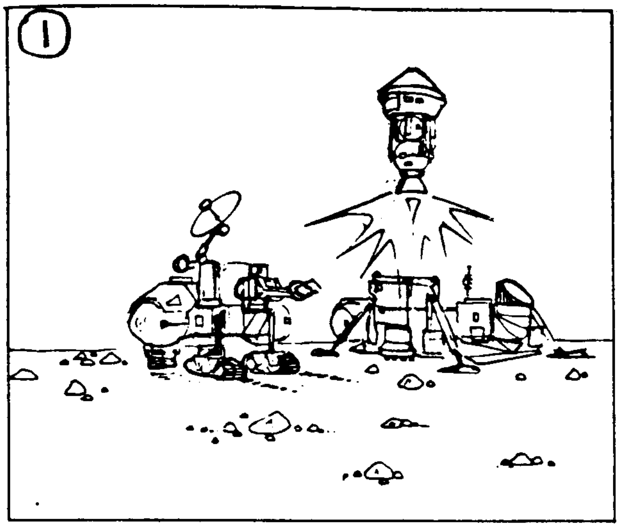
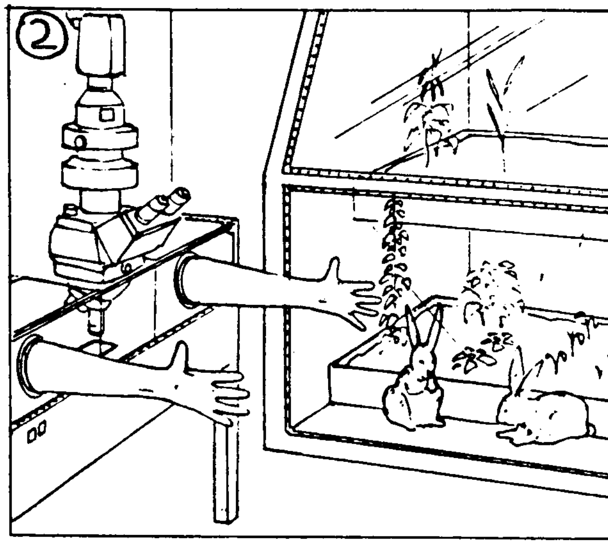
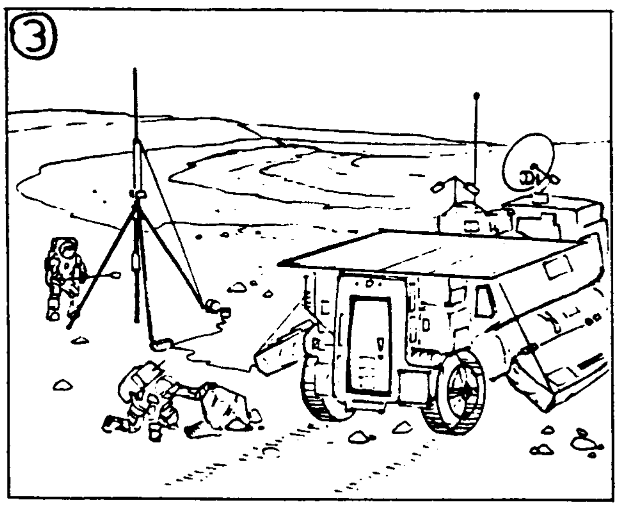
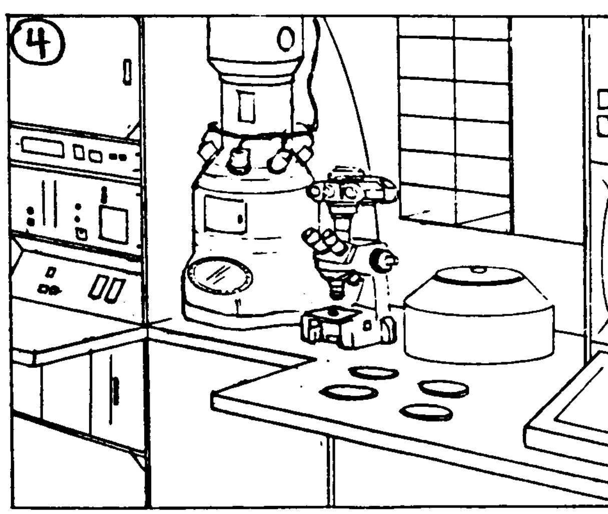
MARS BIOLOGY









3. RESEARCH BASE LIFE SCIENCE

Major questions for the Mars biology analysis program center around the status of life on Mars and include:

* **Is there any form of life presently on the planet?**
* **Would a manned mission jeopardize such indigenous life?**
* **Has there been life in the past?**
* **Are any of the features of the Martian environment toxic or pathological to Earth organisms?**
* **If there is no indigenous life on Mars, what is the potential for introducing Earth life to the planet in the future?**

The picture on the facing page shows how life science research evolves from precursor missions to the Mars base.

FRAMES 1 AND 2: The Mars sample return mission illustrated here will provide material from Mars for investigation. Returned samples are essential prior to a human landing to insure that Martian materials pose no hazards to Earth organisms. Samples will be used for toxicological and biological impact studies on test Earth organisms. Regolith will be analyzed for organic content, organisms or traces, and rocks will be analyzed for endolithic organisms and fossils.

Other precursor missions will provide biologically relevant information on the chemical and physical environment including location and extent of water sources, climatic and hydrological history, the pH, salinity, and oxidation state of regolith. Identification of subsurface permafrost or other volatiles might indicate likely places to search for biological activity.

FRAME 3: Surface sampling by base scientists will operate on a continuing basis. A wider area can be sampled for endolithic organisms and fossils in sediments and rocks. It will be easy for human investigators to simply look under rocks and in crevices for protected micro-environments. They can sample various levels of subsurface regolith as potential habitats and search for possible biological oases (e.g. valleys). Forays may be made to the edge of polar caps to sample moist environments and layered terrain for possible aeolian transported organisms or organic materials.

FRAME 4: Base laboratory facilities will provide complete capabilities for thorough *fundamental* studies in biology and paleontology. Consultation with Earth-based specialists can be sought and samples can be returned to Earth with departing crews for analysis requiring particularly sophisticated equipment.

LIFE SCIENCE
LONG RANGE GOALS

* **Analyze rocks for organic compounds, living endolithic organisms, fossils, and microfossils.**
* **Sample regolith at depth in moister areas for organic compounds and organisms.**
* **Search for protected habitats which could offer protection to cryptic Martian organisms.**
* **Search for fossils and microfossils in erosion features from a variety of different epochs.**
* **Sample the layered polar terrain for signs of biological activity, ice entrapped microfossils, or organic compounds.**
* **Earth-based research: Investigate Mars-tolerant lifeforms.**
* **Earth-based research: Select and genetically modify candidate Martian lifeforms.**
* **Experimentally expose candidate Martian lifeforms to actual Mars environment (partially protected and unprotected).**

IV. TECHNOLOGY DEVELOPMENTS REQUIRED TO COMPLETE SCIENTIFIC OBJECTIVES

PRECURSOR MISSIONS

* Satellite remote sensing of subsurface water (ice & liquid)
* Satellite remote sensing of wind and water vapor profiles

INITIAL MANNED MISSIONS

* Single unit, small biochemical and chemical analysis device
* Single unit small mineralogical analysis device

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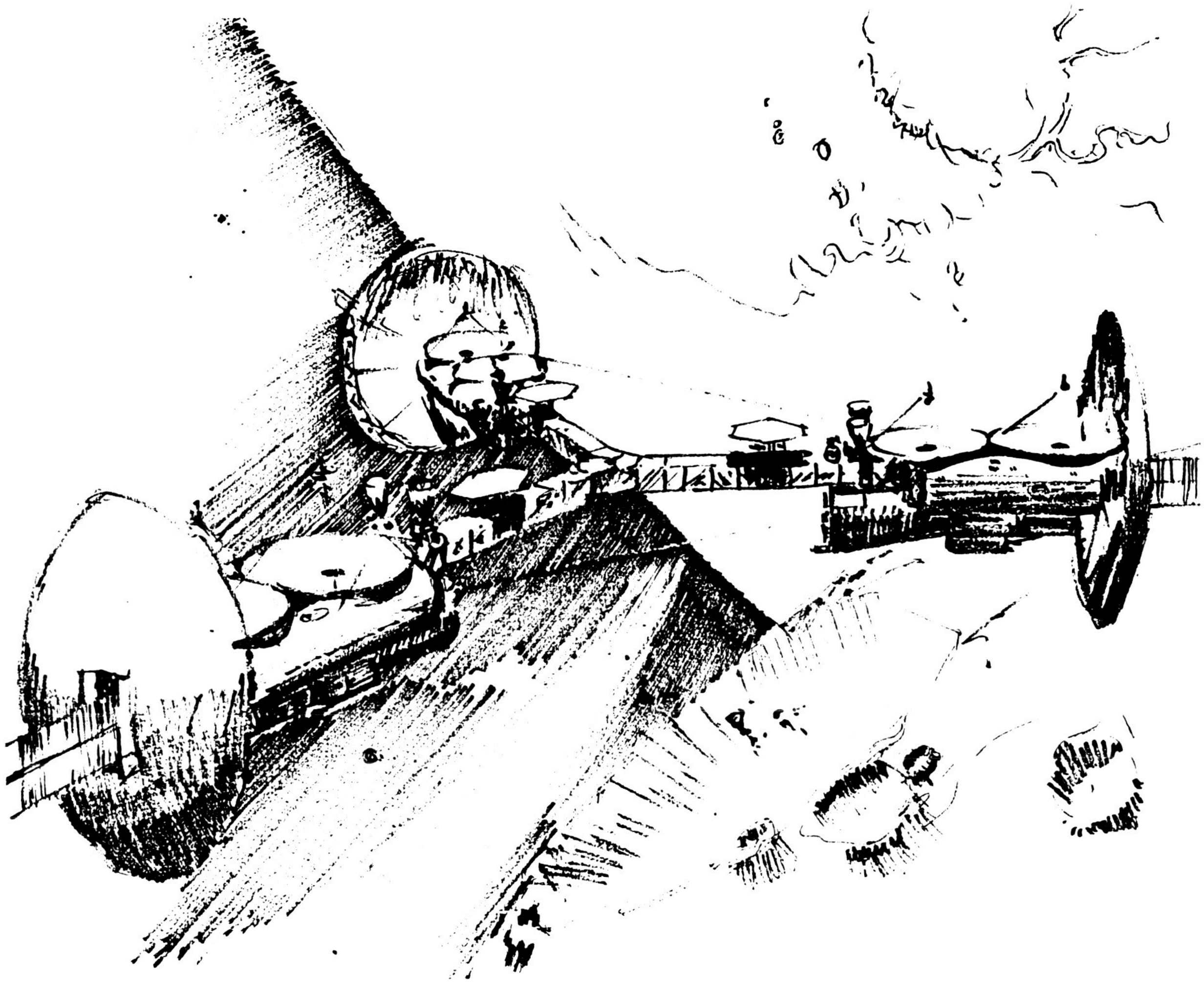
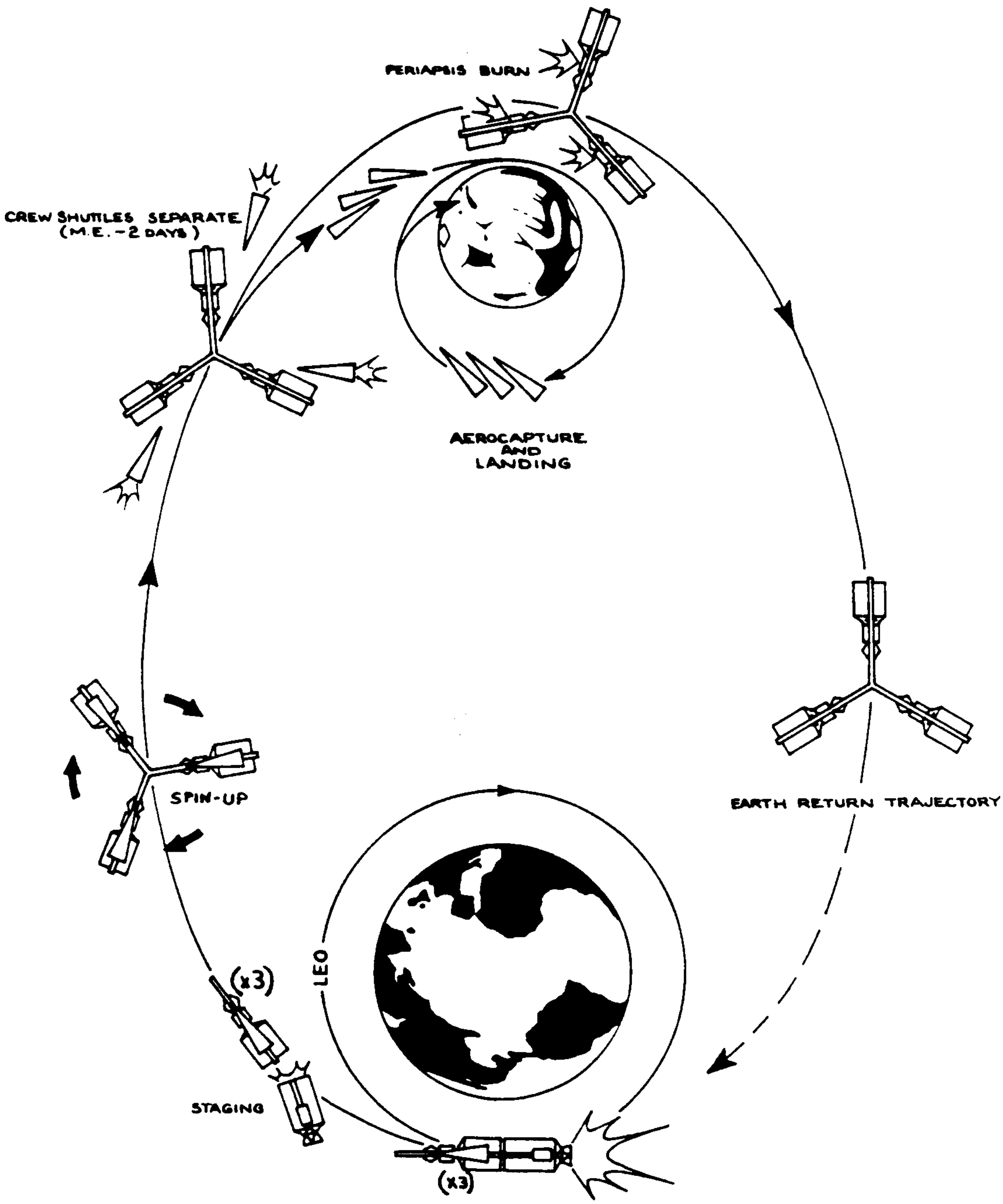


Interplanetary Assembly near Deimos -- Artist-Carter Emmart

SECTION FIVE -- MARS BASE ESTABLISHMENT: BASELINE MISSION PLAN



Primary Mission Scenario -- Artist-Carter Emmart

LEO = low Earth orbit

I. MISSION STRATEGY

A. INTRODUCTION: PRIMARY MISSION SCENARIO

CONCEPTUAL MISSION DESIGN

* 15 person permanent initial base which expands every two years.
* First manned mission to surface sets up base.
* Fuel production & resource utilization on Mars is critical.
* The initial base establishment mission departs from a staging base at the Space Station in LEO.
* Most components return to LEO for refurbishment.
* Transportation to Mars via three redundant spacecraft linked together and spun to provide gravity.
* Mission uses powered-flyby mission profile (Interplanetary Habitat Assembly does not orbit Mars).
* Crew lands on Mars in an aerocapture vehicle (Crew Shuttle).
* Cargo sent in similar aerocapture vehicles (Cargo Lander).
* Shuttles depart Interplanetary Assembly a few days before Mars encounter, and aerocapture to surface.
* Each Crew stays on Mars for at least two years (to wait for the next Habitat flyby - launch windows every two years).
* On missions after the first (ones that include crew rotation), the returning crew takes off from the Mars surface to rendezvous with the Interplanetary Assembly which they ride back to Earth. A few days before Earth encounter, the returning crew boards the crew shuttles which aerocapture into LEO to the Space Station.
* When the Interplanetary Assembly returns to Earth, it uses propulsive braking for return to a 48 hour loose Earth orbit, from which it is slowly aerobraked down to the Space Station in LEO and refurbished.

B. ASSUMPTIONS

We have chosen one possible mission scenario. This baseline mission is not necessarily the way the program will proceed, but it is one achievable option for the phase of the program that establishes the base on Mars.

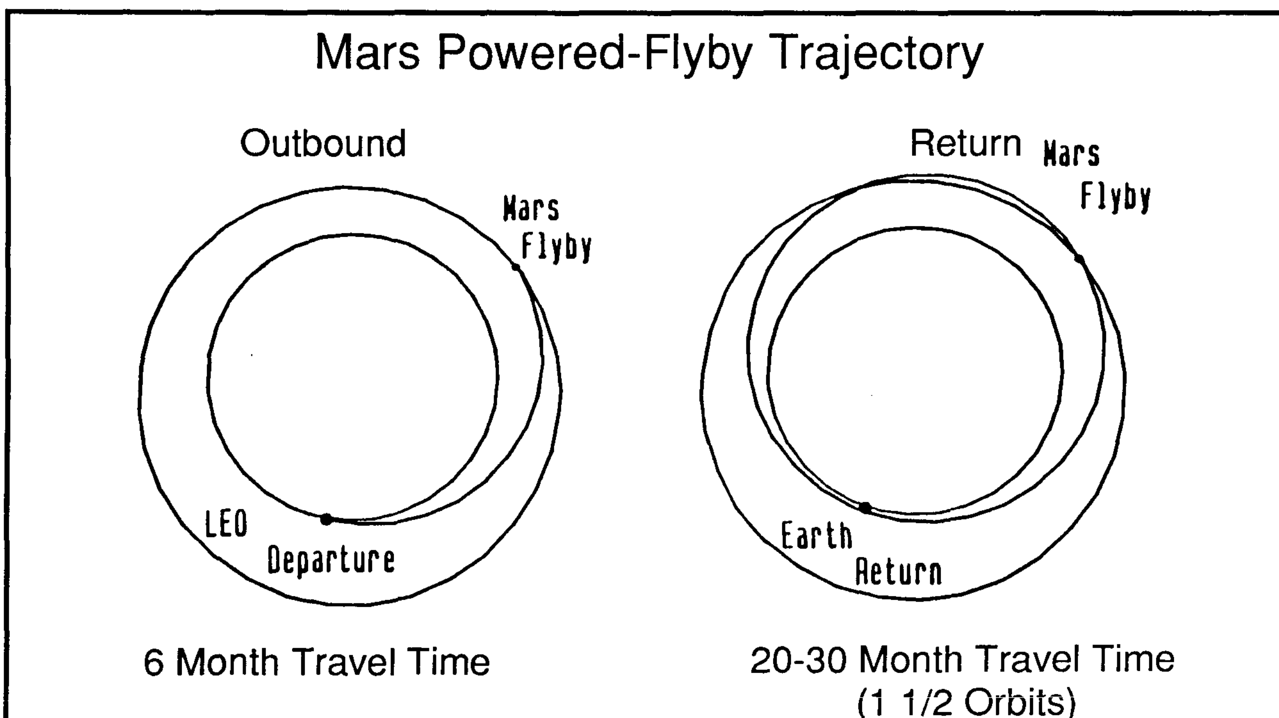
MISSION STRATEGY ASSUMPTIONS:

- **Assume orbital assembly procedures are sufficiently proven to enable construction of complex Mars vehicles at a Space Station.**
- **Use Moon-Base-developed technology if available.**
- **Space Station (SS) technology will be available, including:**
  - **SS derived interplanetary habitats**
  - **SS derived Life support recycling technology**
  - **Earth orbital transfer vehicle (OTV) aerocapture proven concept**
- **A Heavy Lift Launch Vehicle (HLLV) will be developed (payload to low Earth orbit about 75,000 kg).**
- **Mission profile makes use of as much currently available technology and hardware as possible.**
- **Technologies selected to reduce program costs.**
- **Technologies selected to accomplish goals as soon as possible.**

C. MARS POWERED-FLYBY TRAJECTORY*

The powered-flyby mission profile was chosen for our point design for several reasons. The primary reason is the very low propellant requirements of this mission compared to the more traditional Mars orbiting profiles. In the Mars orbiting scenario, the entire Interplanetary Assembly / Habitat must be propelled out of Mars orbit for the journey back to Earth, compared to the flyby scenario where the habitat makes a very small propulsive maneuver at Mars periapsis. Only the small Crew Shuttle must escape Mars, where propellant manufacture is possible, further reducing the mission mass requirements. This mission profile is outlined below:

* **Type I trajectory outbound (6 months)**
* **Small Mars Periapsis burn (about 100 m/sec) - Interplanetary Assembly flies by Mars (doesn't orbit) - Crew Shuttles detach before burn, aerocapture, and land at the Mars base.**
* **Type IV return trajectory (20-30 months)**
* **Launch windows occur about every 2 years.**
* **Personnel go to and return from Mars on alternate missions.**



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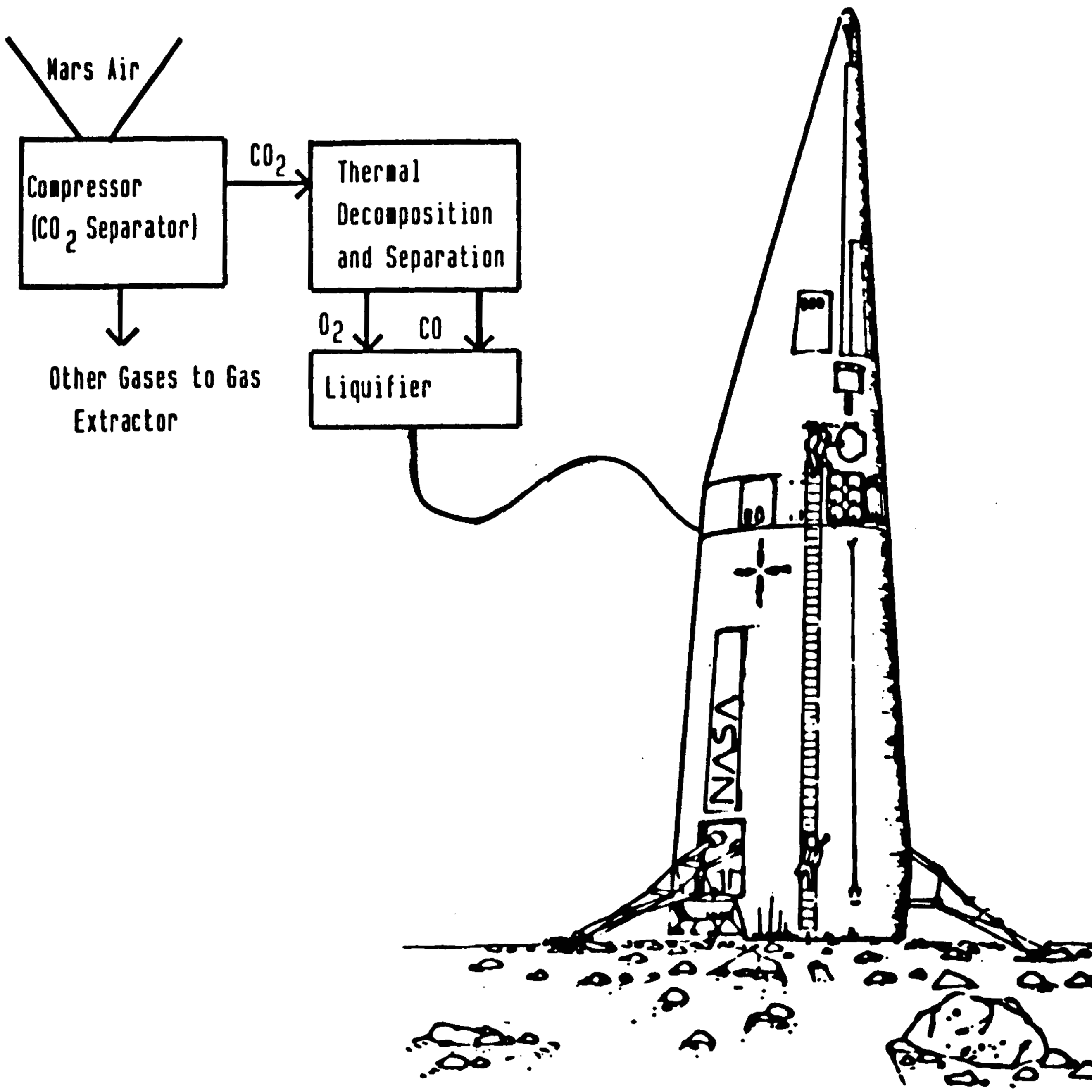
* From S.J. Hoffman and J.K. Soldner, "Concepts for the Early Realization of Manned Missions to Mars". Presented at The Case for Mars II Conference, Boulder, CO, July 10-14, 1984.

Mars Propellant Production



D. MARS PROPELLANT PRODUCTION

* Propellant production on the surface of Mars is used to fuel Crew Shuttle for return launch to rendezvous with Interplanetary Spacecraft.

* Propellant production on the surface of Mars is critical to reducing the cost of the program. It reduces the Earth launch weight by almost an order of magnitude (compared to an equivalent Mars orbiting rendezvous program without it).

* Must be tested on precursor mission.

* CO-O_2 picked as lowest risk/lowest development cost technology.

* About 150 tonnes* of propellant per Crew Shuttle must be produced and liquified from the atmosphere during the two year stay.

* Although this propellant has a low specific impulse+ (I_{sp}=275), it is easy to test on Earth and/or during a precursor mission, and the atmosphere is currently the best known aspect of Mars.

* If a plentiful, easy to use hydrogen source is discovered (or a breakthrough in permafrost mining is made), then methane-Oxygen (I_{sp}=340) is a better choice. However, until the base is set up, we view the risks of this propellant source to be too great to plan a mission around it.

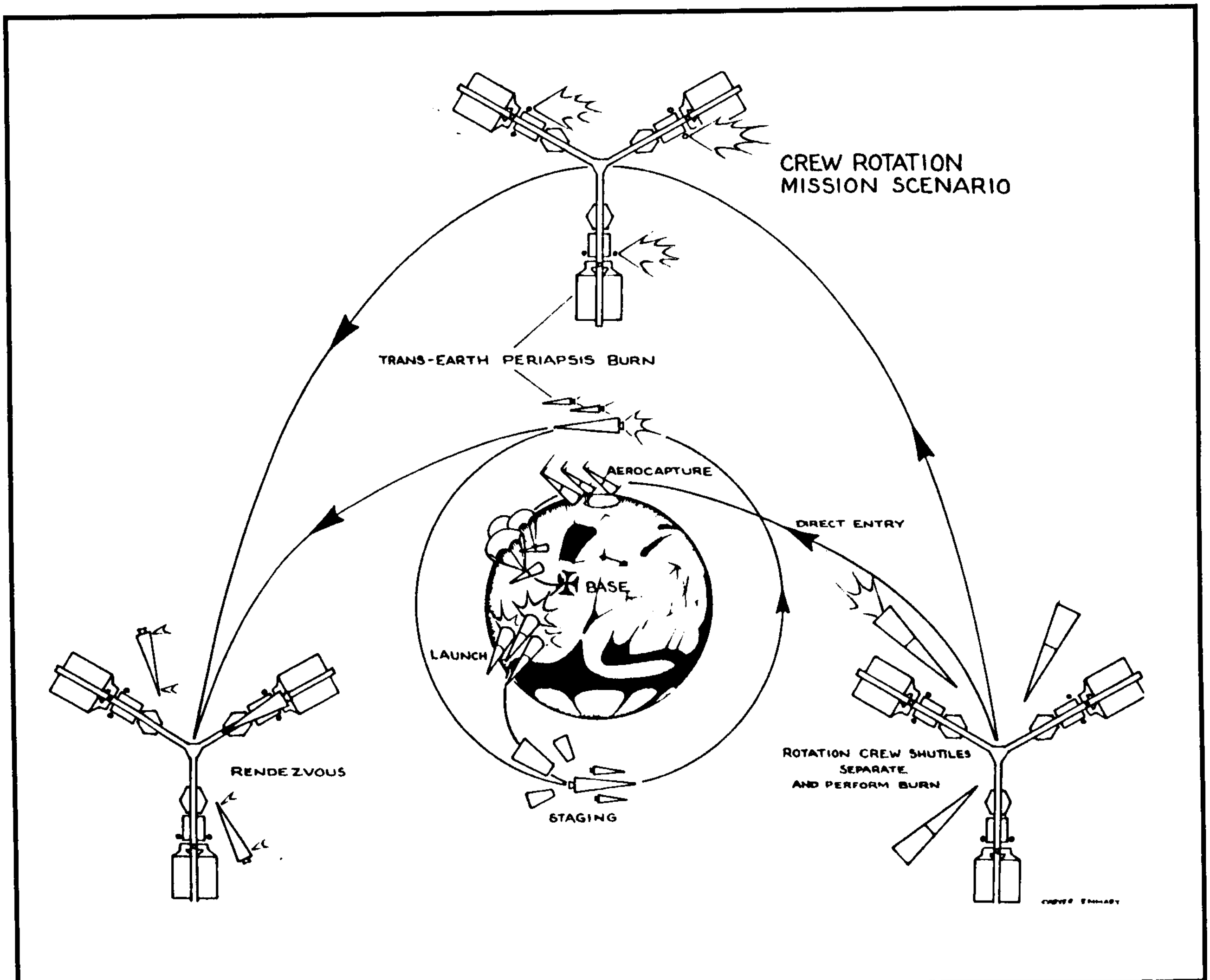
*A tonne is a metric ton, or 1,000 kilograms (about 2,200 pounds).

+Specific impulse is a measure of the "energy content" of rocket propellant. The higher the specific impulse, the more energy a kilogram of propellant can give to a spacecraft. For comparison, the specific impulse of the hydrogen-oxygen propellant burned in the Space Shuttle main engines is about 450 sec.

E. CREW ROTATION

As a result of picking the powered-flyby mission profile, there is a natural crew rotation interval of two years because of the 2 year spacing of launch windows. Crew rotation operates in the following way:

The first crew leaves Earth and arrives at the Mars Base six months later. This crew's empty Interplanetary Spacecraft swings by Mars and returns to Earth. Two years after the first crew left Earth the next launch window occurs -- the second crew leaves Earth and arrives at Mars six months later. When the second crew arrives, the first crew (who will have been at the Mars base for two years) takes off, accomplishes rendezvous with the second crew's Interplanetary Spacecraft as it swings by. The first crew conducts solar and interplanetary studies on the 20-30 month return journey. Each crew arrives back at Earth 4-5 years after leaving.



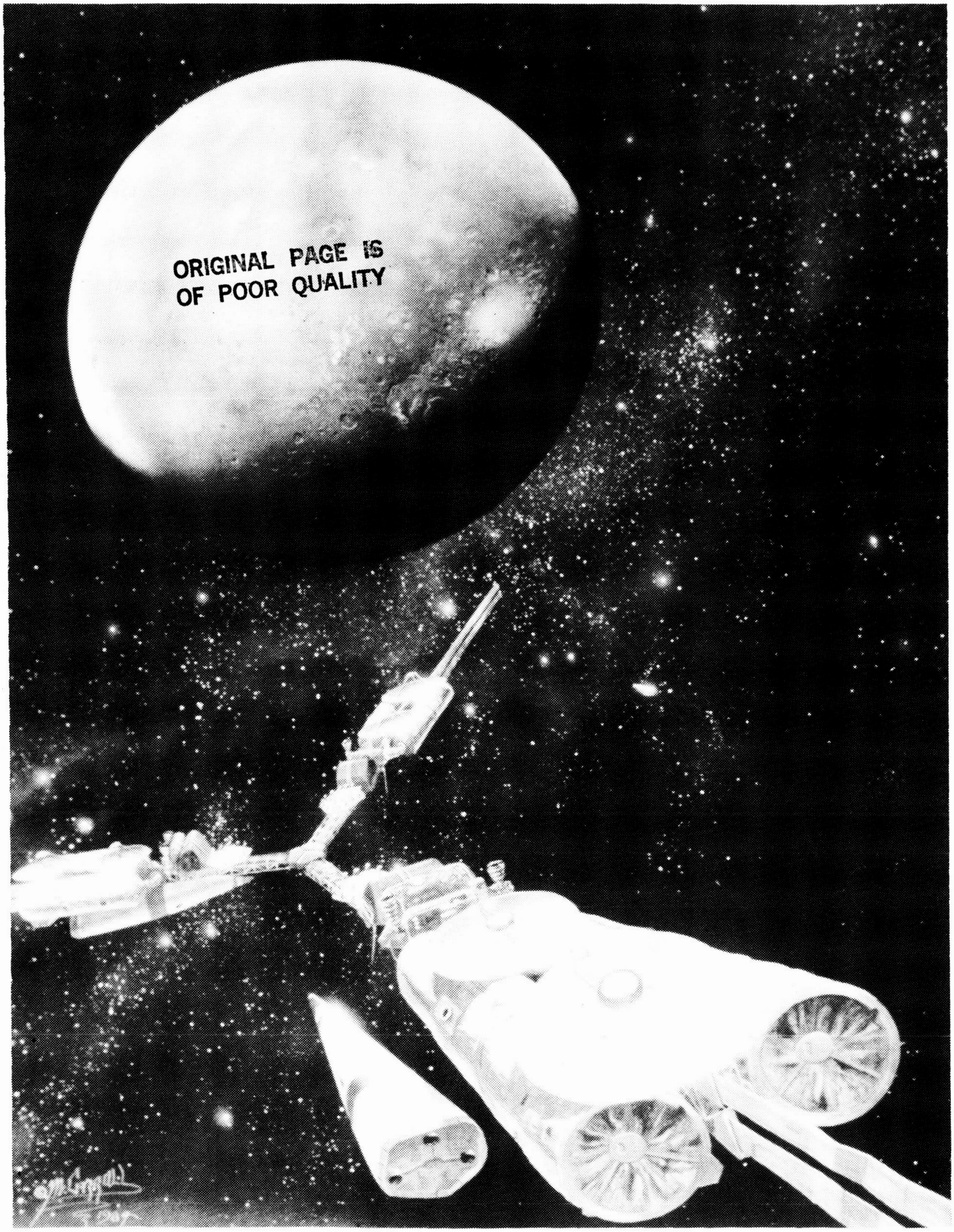
E. TECHNOLOGY DEVELOPMENTS REQUIRED FOR MISSION STRATEGY

* Development of an automated factory for gas extraction and fuel production from the Mars atmosphere.

* Refine Space Station and possibly Moon-Base-developed life support technologies for Interplanetary Vehicles.

* Examine launch windows for powered-flyby trajectories through the year 2050.

* Search for better (shorter) return trajectories and propellant/ flighttime trade-offs.



Interplanetary Assembly approaches Mars -- Artist-Mike Carroll

II. SPACECRAFT DESIGN

A. INTRODUCTION: VEHICLE REQUIREMENTS

Given that we have selected the Mars powered-flyby mission profile, and that we have assumed aerocapture will be a mature technology, the spacecraft requirements of this phase of the program fall into several categories. Starting at the beginning of the Base Establishment Mission, these vehicle requirements are:

* **All components into Earth orbit for assembly at Space Station**
* **Crew and habitat into Mars-bound trajectory**
* **Cargo into Mars-bound trajectory**
* **Habitat for crew during Earth-Mars and Mars-Earth cruise phase**
* **Crew onto Mars surface**
* **Cargo onto Mars surface**
* **Crew off Mars into Earth return trajectory**
* **Crew back into Earth orbit (Space Station)**
* **Interplanetary Spacecraft into Earth orbit for refurbishment**

B. VEHICLE TYPES

To satisfy the above requirements, four new vehicles are needed, all based on existing technology. These are:

- * **Heavy Lift Launch Vehicle* (HLLV, not discussed here)**

- * **Aerocapture Vehicle - There are two variants: *Mars Crew Shuttle* and *Cargo Lander*. The *Crew Shuttle* lands 5-10 crewmembers on Mars and lifts 5-10 crewmembers off Mars into an Earth return trajectory to rendezvous with *Interplanetary Spacecraft* assembly. The *Cargo Lander* uses the same airframe.**

- * ***Interplanetary Spacecraft* - Use Space Station modules and is assembled in LEO at Space Station. Two or three *Interplanetary Spacecraft* will be joined at a central hub to form the *Interplanetary Spacecraft Assembly* and spun for artificial gravity during interplanetary cruise.**

- * ***Trans-Mars Injection Stage* - Uses two Space Shuttle Main Engines (SSME) to propel mission components out of LEO to Mars.**

*The Heavy Lift Launch Vehicle has been discussed as a necessary next component for the Space Transportation System. This vehicle is usually depicted as being constructed of Space Shuttle derived components, and we have assumed the HLLV in use at the start of the Mars base program is capable of launching at least 75,000 kg to low Earth orbit.

C. AEROCAPTURE VEHICLE

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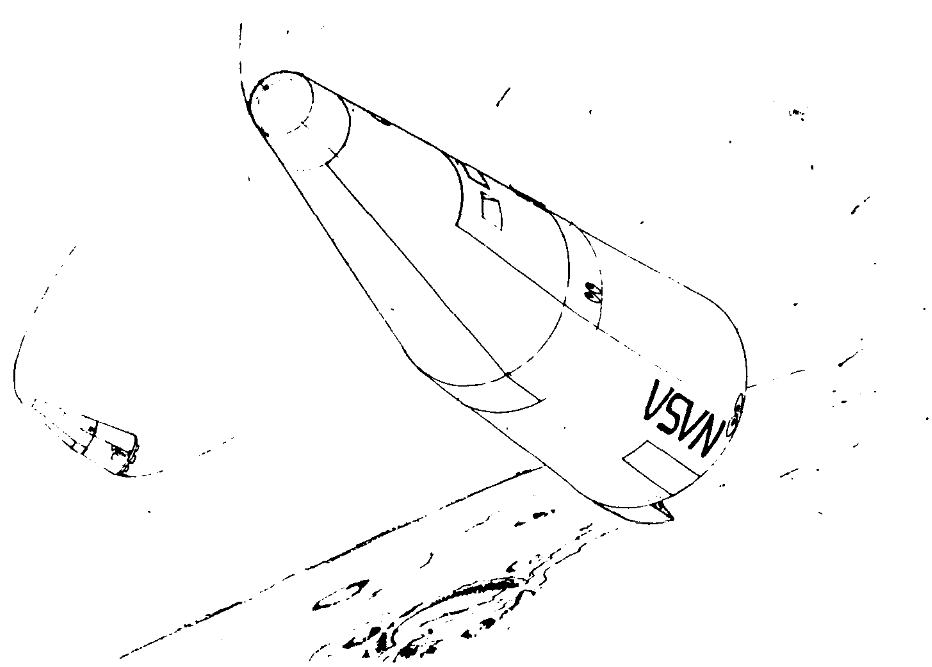
AEROCAPTURE VEHICLE REQUIREMENTS:

* **Must have capability for direct entry from Type I trajectory.**
* **Must be able to maneuver almost anywhere on the planet and land within 1 km of base.**
* **Must reuse the Mars entry vehicle for liftoff from the Mars surface (after refueling). Must put 5-10 Crew in Earth-return trajectory (about 6.6 km/sec delta V), to rendezvous with next flyby.**
* **To keep program costs down, uses same vehicle for aerocapture to LEO on return journey.**
* **Uses same airframe for cargo lander.**



Aerocapture vehicles enter Mars' atmosphere -- Artist-Carter Emmart

C. AEROCAPTURE VEHICLE (continued)

VEHICLE CONCEPT

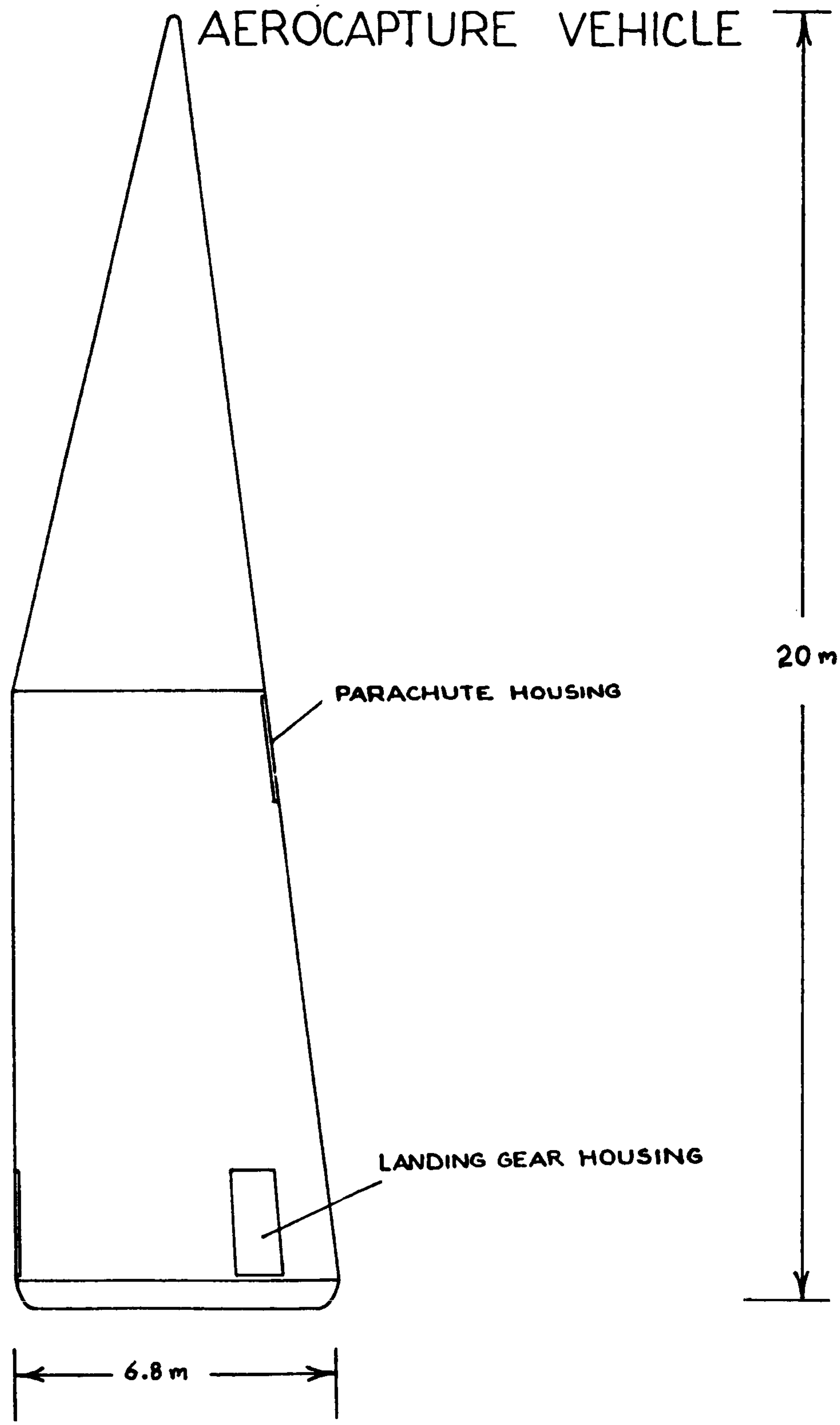
Both the Mars Crew Shuttle and the Cargo Landers will use aerocapture to save on propellant weight. These vehicles will be capable of direct entry from a Type I trajectory and will use aeromaneuvering controlled by body flaps to maneuver almost anywhere on the planet and land within one km of the base. The technology to do this is understood today, although it has not been tested on manned vehicles.

Landing will be in three stages: aerocapture, parachute deceleration, and rockets for final touchdown. Aerocapture and maneuvering will require reusable entry heat shielding and a biconic vehicle shape with a maximum lift/drag of about 1.5. Intermediate deceleration to less than 300 m/s will be accomplished by a drogue chute and a main chute. The descent rocket engines will burn a Carbon Monoxide -- Oxygen propellant which will later be extracted from the atmosphere of Mars and used to refuel the vehicle for takeoff.

Aerocapture technology will require further development to be used as described here, and $CO\text{-}O_2$ engines must be developed and tested.

The aerocapture vehicle concept is illustrated on the facing page.

- **If $CO\text{-}O_2$ propellant is used, then the size of this vehicle is set by the required ascent capabilities (delta V about 6.6 km/sec) and the payload (about 8,000 kg landed, 4,000 kg departure). These numbers imply a Mars lift-off mass of about 174,000 kg with a two stage vehicle.**
- **Biconic airframe is about 20 m long and 6.8 m across at the base.**
- **Vehicle is launched off Earth with HLLV (will not fit in shuttle).**
- **Mass at Mars touchdown is about 28 tonnes (28,000 kg).**
- **Mass at LEO departure (including descent propellant) is 46 tonnes.**


AEROCAPTURE VEHICLE
20 m
PARACHUTE HOUSING
LANDING GEAR HOUSING
6.8 m

3. AEROCAPTURE VEHICLE (continued)

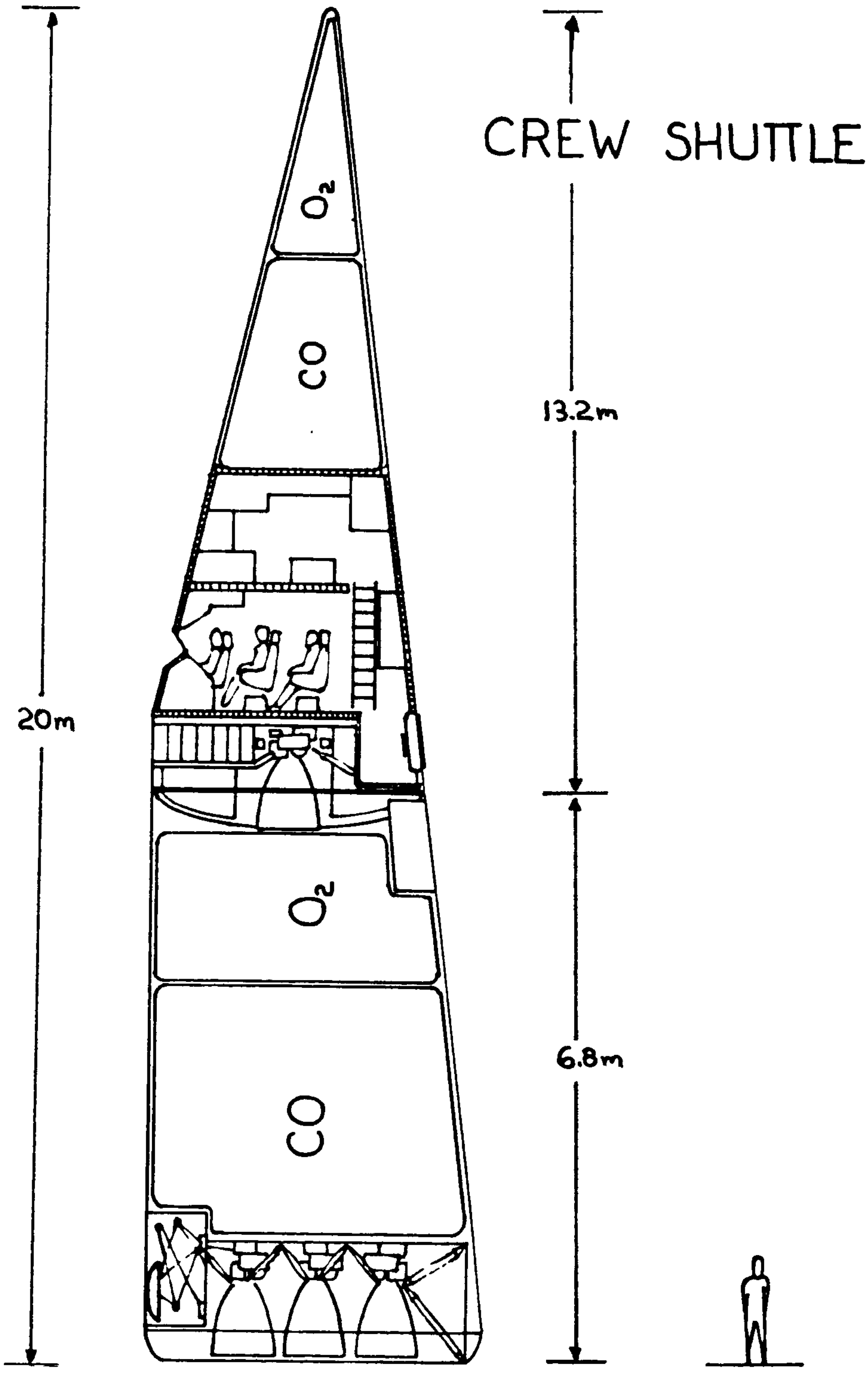
FIRST VARIANT: MARS CREW SHUTTLE

The Crew Shuttle will normally carry 5 crewmembers (10 in contingency mode), plus some cargo: a total payload of around 5 tonnes to Mars. Use of $CO\text{-}O_2$ engines would require a payload mass fraction of 0.03 for a single stage vehicle (somewhat beyond current technology for this type of vehicle), so we have planned a two stage vehicle. Further investigation of strap-on fuel tanks attached at Mars base is needed. This could eliminate the need for staging the shuttle.

The mass of the Crew Shuttle will be about 28 tonnes at Mars touchdown (46 tonnes fueled at LEO departure). Heavy Lift Launch Vehicles (HLLV) will be needed to place these vehicles into LEO for assembly into the Interplanetary Spacecraft. The Crew Shuttle will carry 5 tonnes of cargo, the crew, and a one month open loop life support system. Between planets it will be used as a solar storm shelter for the crew and as extra living space if needed. The crew will also use it as a simulator to practice landing maneuvers. At Mars, the shuttle will ferry crew and cargo to the surface and return crew and cargo from Mars to orbit and thence, to the Earth-bound Interplanetary Assembly. On Mars, the Crew Shuttle is fueled with $CO\text{-}O_2$ propellant extracted from the Mars atmosphere. The lift-off mass of the shuttle is about 174 tonnes, which delivers 5 crewmembers and about 1 tonne of scientific payload to the departing Interplanetary Assembly (in an emergency 10 crew could be accommodated). At Earth, the Crew Shuttle will aerocapture and carry crew and cargo to the Space Station after separation from the Interplanetary Assembly.

The Mars Crew Shuttle is illustrated on the facing page.

- **Two stage vehicle - On descent, the first stage is partially fueled and used for final descent maneuvering.**
- **Mass at lift-off from Mars is about 174,000 kg (determined by ability to put Upper Stage with crew into return trajectory with Interplanetary Spacecraft using $CO\text{-}O_2$ propellant)**
- **Upper stage mass at rendezvous with habitat is 8,000 to 10,000 kg.**


CREW SHUTTLE
20m
13.2m
6.8m
O2
CO
O2
CO

C. AEROCAPTURE VEHICLE (continued)

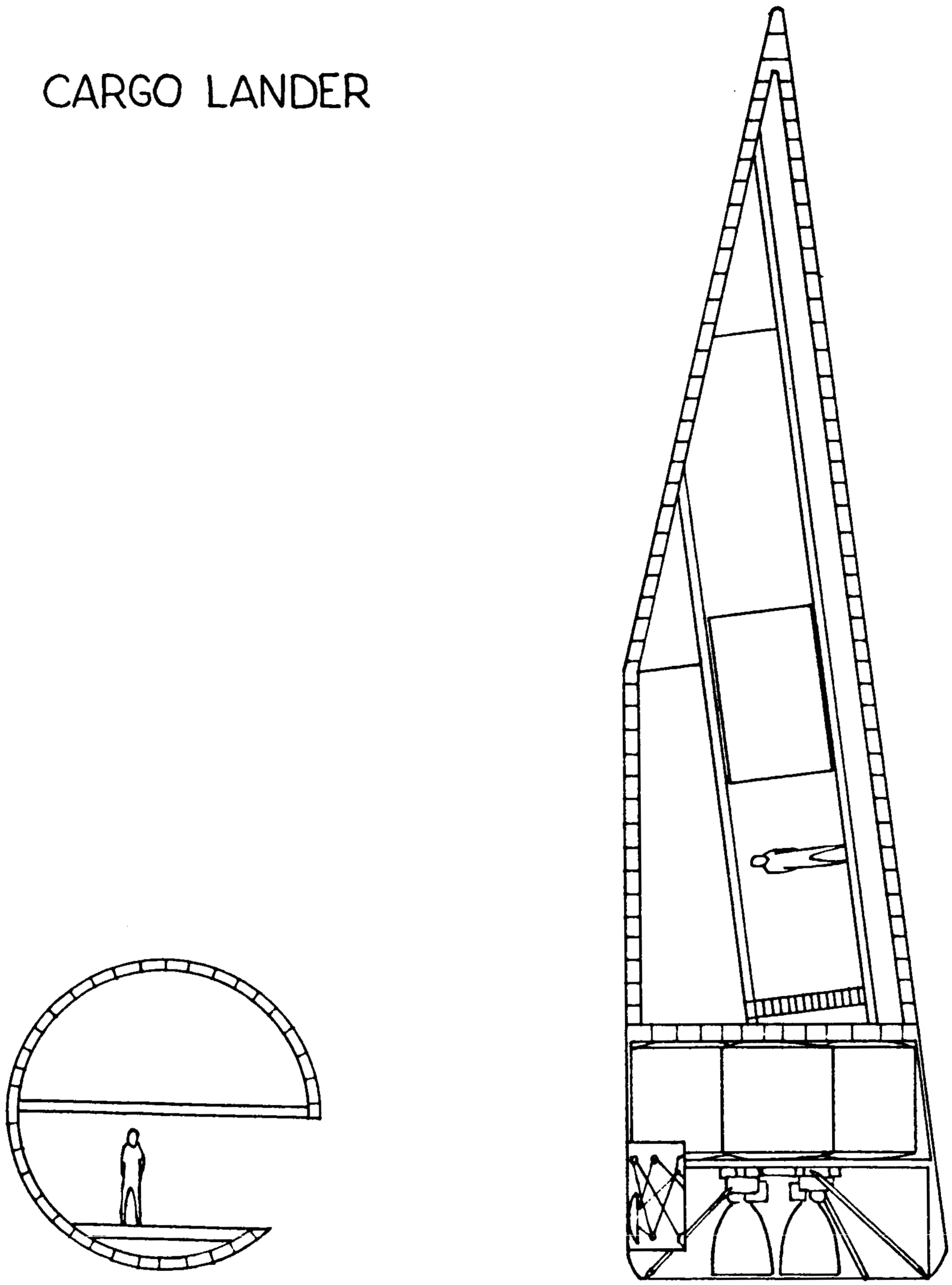
SECOND VARIANT: CARGO LANDER

The Mars Cargo Landers will have many of the same basic components as the Crew Shuttle: a biconic shell for aerocapture and maneuvering, parachutes for intermediate deceleration, and engines for touchdown. The same airframe will serve both vehicles. The Cargo Landers will be one-way vehicles with a payload capacity at Mars of about 18 tonnes. Once on the surface they will be fitted for use as Mars base habitats and workshops. Internal to the airframe will be a pressurizable module (the Base Habitat Module) which will be loaded with the cargo and refitted for living after the cargo is unloaded.

The Cargo Lander is illustrated on the facing page.

- **Vehicle is unmanned and one-way.**
- **Landed cargo is about 18,000 kg**
- **Uses same descent engines as manned vehicle with smaller tanks. Note: OMS-derived, MMH/NTO fueled descent engines could give better payload capability.**
- **Fitted to be used as Mars Base Habitat (a la Skylab) after cargo is unloaded. One of the cargo items is an installed closed loop life support system.**
- **Final descent is controlled (teleoperated) by Mars base crew (due to proximity of landing area to base).**

CARGO LANDER



D. INTERPLANETARY SPACECRAFT

VEHICLE REQUIREMENTS:

* Must provide living area for 5 to 10 crew on 6 month outbound and 20-30 month return missions. Need about 50 m^3 per crewmember.

* Life support system for each of the segments is independent. Sized for 2 year missions (6 months out - 20-30 months return). Closed loop on water and air, open loop for food.

* Must be designed to provide artificial gravity. This doesn't cost much extra, and medical uncertainty is too great today not to plan for it.

* Propulsive capability is about 1.4 km/sec for Mars flyby burn and Earth orbit insertion (EOI) upon return. Only 0.4 km/sec needed if EOI is entirely done with aerocapture.

D. INTERPLANETARY SPACECRAFT - DESIGN

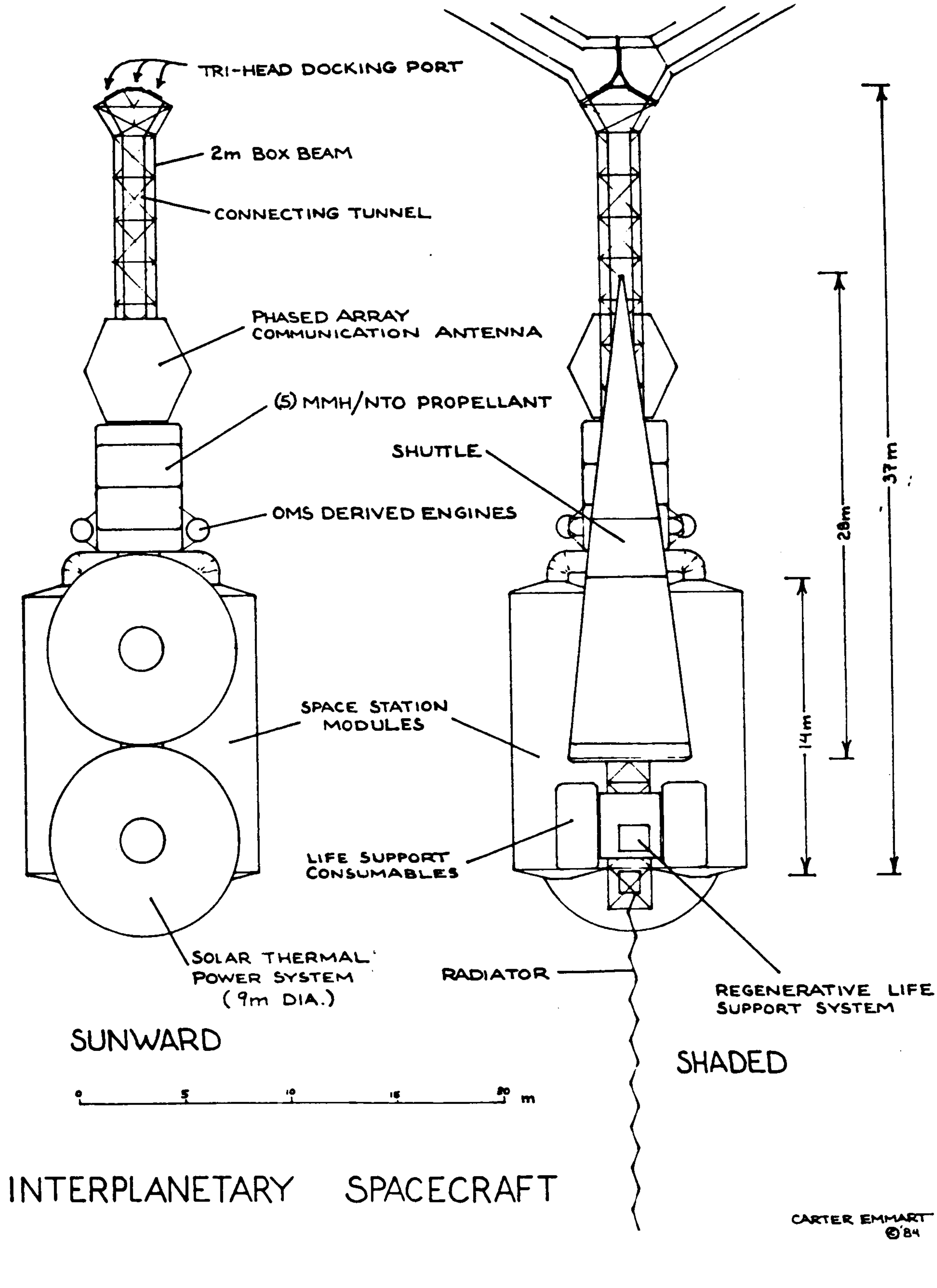
Each arm of the Interplanetary Spacecraft Assembly is an independent vehicle capable of housing 5-10 crew for the two year mission. The arms are connected together in a pinwheel configuration and the vehicle is spun to produce artificial "g". Life support will be closed loop for air and water, open loop for food. Processed human organic waste will be a valuable commodity at Mars base and may be taken down to the surface as cargo. Two Space-Station-derived living modules will provide about 50 m^3 of living space per crewmember for the crew size of 5 per arm. Additional space will be available in the Mars crew shuttle. The living area of the shuttle is located in a tunnel formed by the fuel storage tanks. This area will double as a solar storm shelter with the propellant tanks providing shielding from high-energy radiation.

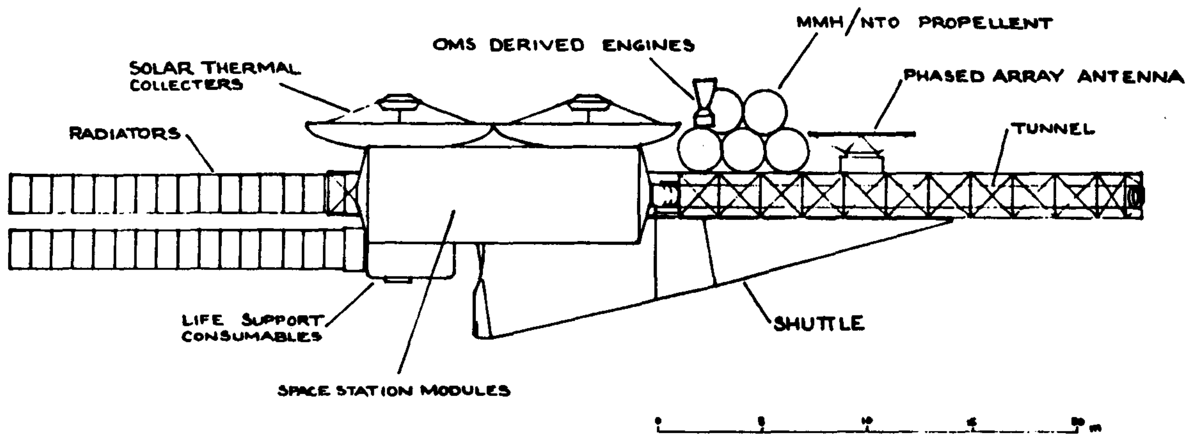
Power for subsystems will be provided by solar thermal collectors on the sunward side. Thermal control is provided by the extendable radiators at the end of the arm. The components are all attached to the strongback truss. The truss also houses a tunnel leading from the living modules to the docking assembly at the hub and could provide shirt-sleeve access between the arms of the Interplanetary Assembly.

Much development of long-term closed life support systems should be done for the Space Station modules which will be the living quarters for the crew during the cruise. Research must be done on the long-term effects of reduced gravity and ways to counteract these effects. Shielding for solar storms and cosmic rays must be provided for long duration space flights.

The Interplanetary Spacecraft is illustrated on the following two pages.

- **OMS-derivative engines for Earth-orbit insertion on return**
- **MMH/NTO propellant tanks**
- **Most components based on Space Station components**
- **Partially regenerative life support system**
- **Phased array communications antenna (electronically steerable)**
- **Solar thermal power system (primarily used for life support)**
- **Tunnel in 2 m box beam (strongback truss) connects living modules to Docking Port -- 3 sections joined after Mars injection burn.**


TRI-HEAD DOCKING PORT
2m BOX BEAM
CONNECTING TUNNEL
PHASED ARRAY COMMUNICATION ANTENNA
(5) MMH/NTO PROPELLANT
SHUTTLE
OMS DERIVED ENGINES
SPACE STATION MODULES
LIFE SUPPORT CONSUMABLES
SOLAR THERMAL POWER SYSTEM (9m DIA.)
RADIATOR
REGENERATIVE LIFE SUPPORT SYSTEM
37 m
28m
14m
SUNWARD
SHADED
0
5
10
15
20
m
INTERPLANETARY SPACECRAFT
CARTER EMMART
©'84



SIDE VIEW

INTERPLANETARY SPACECRAFT

Note: These drawings do not show the aerocapture shield, and the solar "storm shelter" is not shown correctly. See the pencil sketch on page 73 for a more accurate rendition of the Interplanetary Spacecraft Assembly.

E. TRANS-MARS INJECTION STAGE

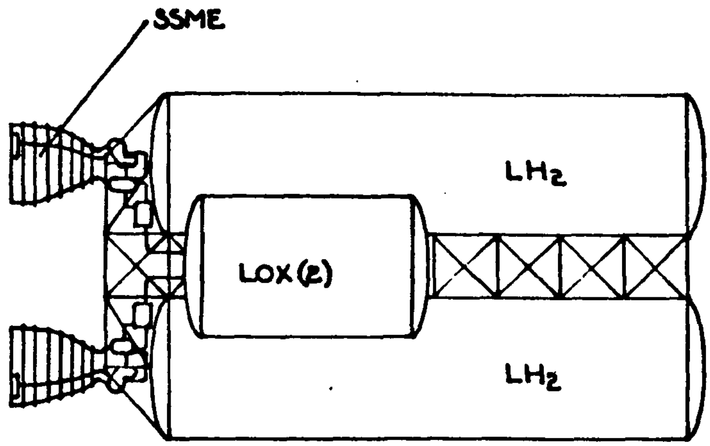
VEHICLE REQUIREMENTS:

- **Vehicle is needed to propel all Mars-bound Interplanetary Spacecraft into hyperbolic trajectories from Space Station orbit.**
- **Mass of vehicle to be put into Mars-bound trajectory is ~220 Tonnes.**
- **Puts payload into Type I trajectory (about 4 km/s delta V).**
- **It is highly desirable to build this stage from existing components.**
- **Because of its size, it must be assembled and fueled at the Space Station.**

VEHICLE DESIGN

The Space Shuttle cargo bay and HLLV will be used to boost the components and propellants for the Trans-Mars Injection Stage (TMIS) into orbit for assembly at the Space Station. This stage uses LH_2/LOX propellant for two Space Shuttle Main Engines (SSME's) which will insert the 220 tonne Interplanetary Spacecraft into a Mars-bound trajectory (delta-V about 4 km/sec). The requirements imply a loaded mass of the TMIS of about 375,000 kg. This is about one-half of the Space Shuttle's External Tank (ET). To reduce development costs, it may be worth using an essentially unmodified ET with added insulation even though there would need to be extra fuel carried because of its larger mass.

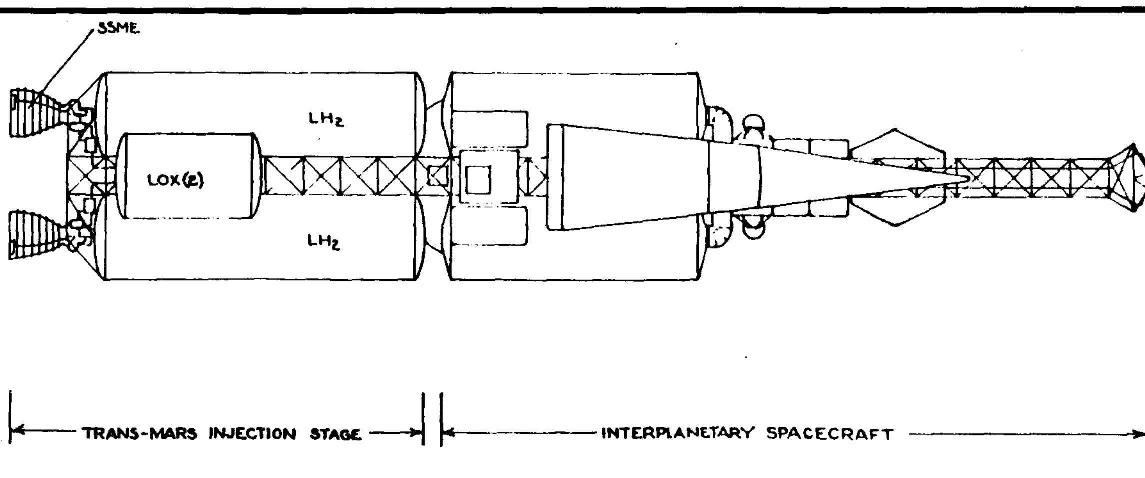
Once an Interplanetary Spacecraft is Mars-bound, the TMIS will be detached. It might be feasible to provide an aerocapture shell and retain some fuel to return the TMIS to low earth orbit for reuse. Three Trans-Mars Injection Stages will be required to boost the three Interplanetary Spacecraft segments towards Mars. A fourth TMIS will be needed on the first mission to boost four Cargo Landers with the cargo needed to set up the base.



TRANS-MARS INJECTION STAGE

F. LEO DEPARTURE CONFIGURATION

- **Three Interplanetary Spacecraft segments are built in Earth orbit.**
- **Fitted with Trans-Mars Injection Stage and fueled.**
- **Mars Crew Shuttles are attached.**
- **A few days out, the three spacecraft rendezvous and link up with tunnels so the assembly can be rotated for artificial gravity.**



LEO DEPARTURE CONFIGURATION

G. INTERPLANETARY SPACECRAFT ASSEMBLY

The rotating Interplanetary Assembly will be positioned with its axis of rotation pointing towards the sun. The sunward side of the assembly will have solar thermal collectors to provide electrical power during the cruise phase. Phased array antennas for Earth communication are located sunward, as are the propellant storage tanks. Behind (anti-sunward) the solar collectors are the two Space-Station-derived living modules, and behind these are the Mars Crew Shuttles, one on each arm.

It is not known today how much artificial gravity will be needed during prolonged stays in space or even if it will be needed at all. Due to this uncertainty we have designed the Interplanetary Spacecraft to provide artificial gravity. Research on the need for artificial gravity and on the dynamics and control of large rotating structures must be done before settling on a vehicle design.

An optional configuration of the assembly uses only two of the arms connected together. This can be used for emergencies or for crew rotation missions where 15 crew are not required on the outbound leg.

An artist's conception of the complete Interplanetary Assembly approaching Mars is shown on the facing page.

- **Reaction Control System rockets are used to spin-up the assembly to produce .38 Earth gravity (Mars normal).**
- **Three living areas are interconnected via pressurized tunnels.**
- **Before returning to Earth, the craft splits up, fires its rockets and/or aerobrakes to put it into a 48 hour orbit, and then aerobrakes slowly to the Space Station for refurbishment and reuse.**

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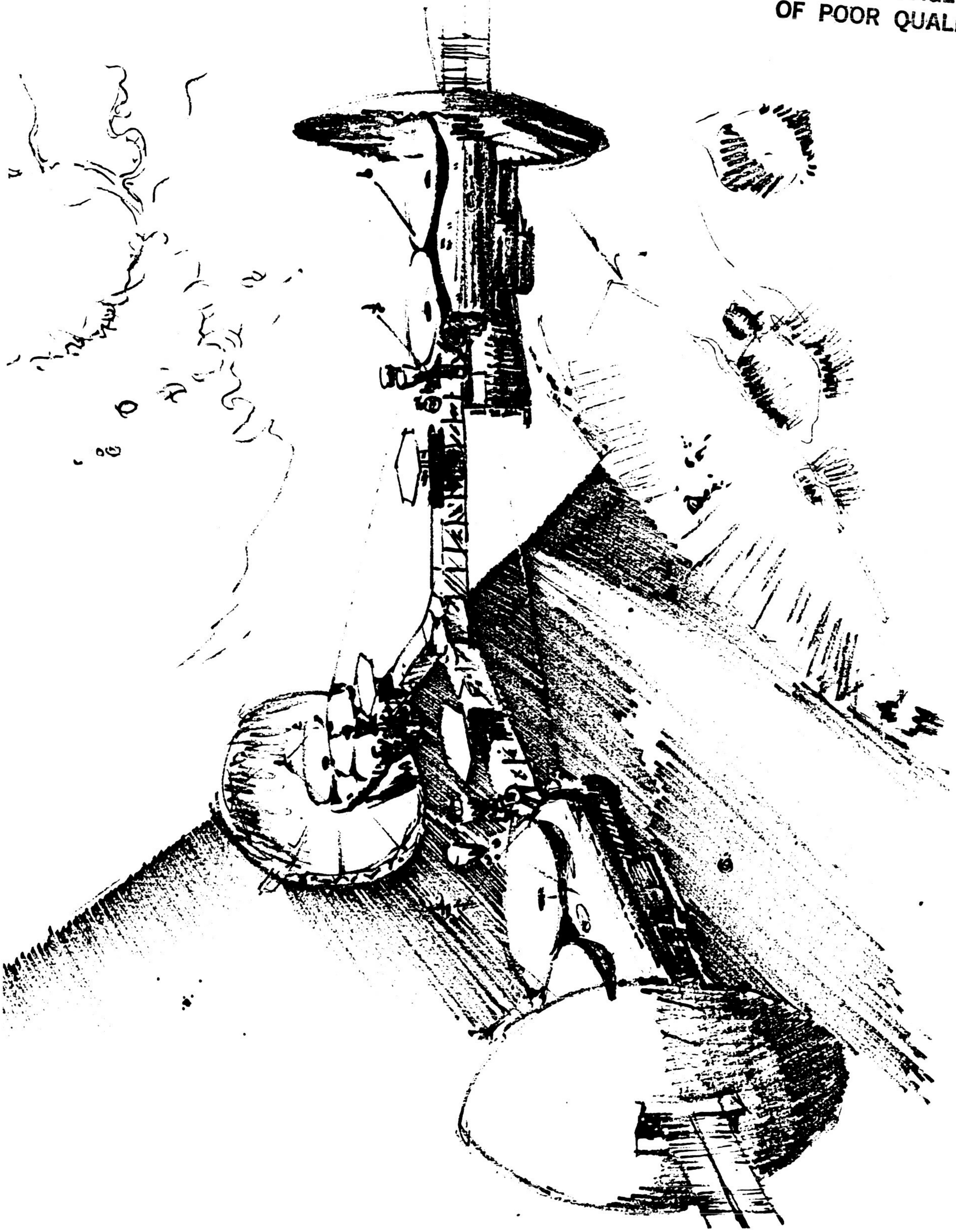

Interplanetary Assembly approaching Mars -- Artist Carter Emmart
Note aerocapture shields attached to each arm.

H. GETTING IT ALL OFF EARTH

EARTH LAUNCH ESTIMATES
(very approximate)

*** Heavy Lift Launch Vehicle (HLLV) used to lift aerocapture vehicles.**
- 2 HLLV PER MISSION (2 aerocapture vehicles per HLLV)

*** Shuttle and HLLV are used to boost Trans-Mars Injection Stage components and propellant off Earth.**
- 5 HLLV plus 1 SHUTTLE per stage (3 stages needed per mission)

*** Space Shuttle cargo bay is used for Interplanetary Spacecraft habitat modules and other components.**
- 20 SHUTTLES PER MISSION

*** First mission requires launch of four unmanned Cargo Landers, service module, and TMIS.**
- 7 HLLV's and 1 SHUTTLE (includes TMIS)

*** *First mission total -- 24 HLLV's***
20 SHUTTLE PAYLOADS

NOTES: 1) Number of HLLV launches needed for TMIS propellant could be reduced by scavenging propellant from Space Shuttle External Tanks.

2) HLLV assumed to deliver 75,000 kg to low Earth orbit.

I. REQUIRED TECHNOLOGY DEVELOPMENTS FOR SPACECRAFT DESIGN

- **Long-term closed life support systems - Mars Base program will use same technologies as Space Station and Moon Base (assuming that they are developed for either of these).**
- **Develop & test CO-O_2 propulsion system.**
- **Develop & test advanced aerocapture technology.**
- **Refine intermediate deceleration technology (parachutes, ballutes).**
- **Heavy Lift Shuttle-Derived Launch Vehicle concepts must be implemented.**

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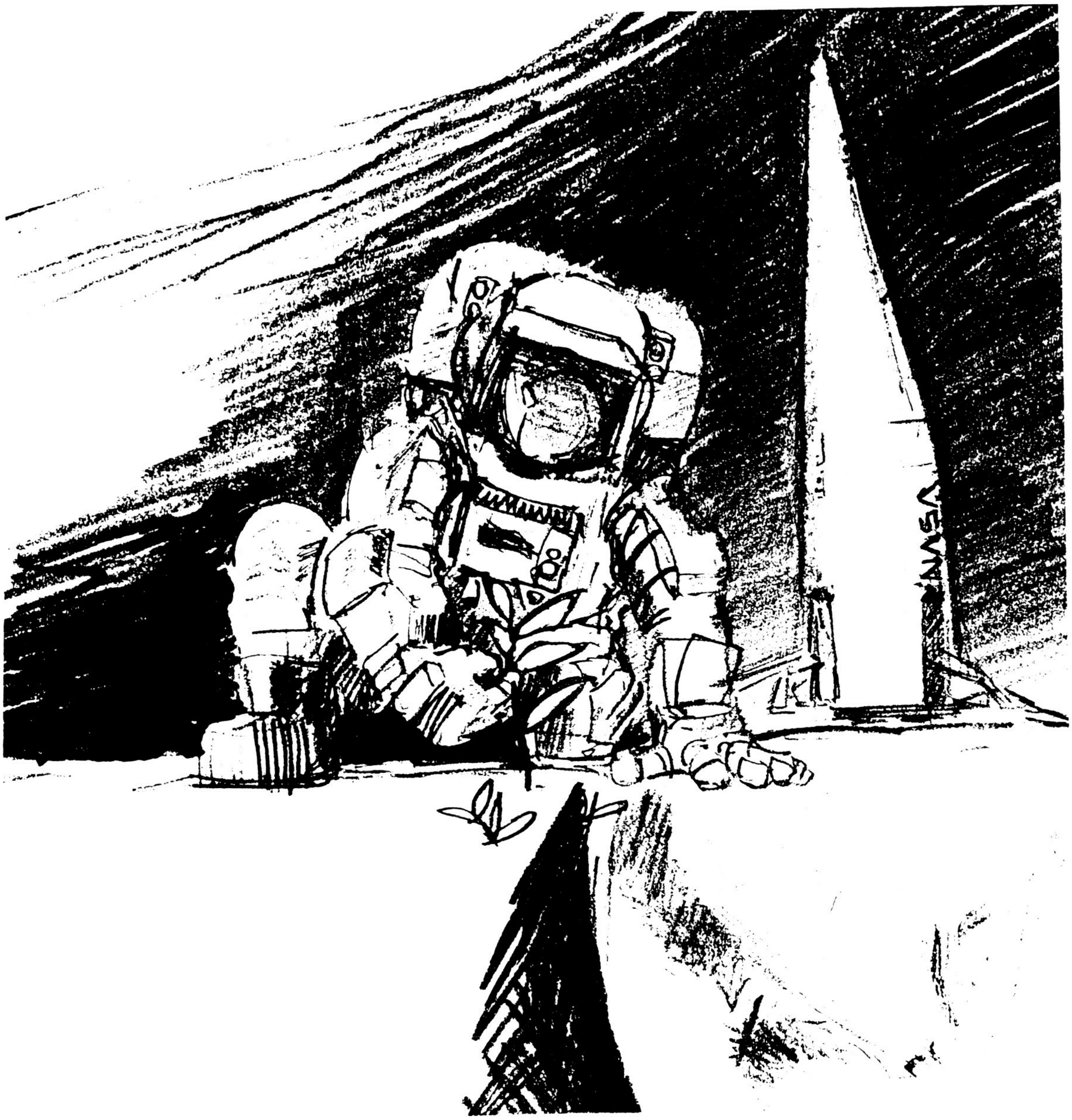

Artist-Carter Emmart

SECTION SIX -- HUMAN FACTORS

SECTION OUTLINE -- HUMAN FACTORS

I. LIFE SUPPORT ASPECTS OF A MARS MISSION

A. INTRODUCTION AND MAJOR CONCEPTS
B. FOOD PRODUCTION FOR MARS BASE - INITIAL CONFIGURATION
C. FOOD PRODUCTION FOR MARS BASE - EXPANSION FOR PERMANENT BASE FACILITY
D. PRECURSOR MISSION RECOMMENDATIONS
E. SPACE STATION RESEARCH RECOMMENDATIONS

II. MEDICAL ASPECTS OF A MARS MISSION

A. FACILITIES AND CREW TRAINING
B. RESEARCH AND DEVELOPMENT AREAS
C. RESEARCH RECOMMENDATIONS

III. PSYCHOLOGICAL ASPECTS OF A MARS MISSION

A. INTRODUCTION AND JUSTIFICATION
B. CREW SELECTION AND TRAINING
C. FACILITIES FOR GOOD MENTAL HEALTH
D. MENTAL HEALTH MAINTENANCE
E. CREW EFFICIENCY
F. RESEARCH RECOMMENDATIONS

I. LIFE SUPPORT ASPECTS OF A MARS MISSION

A. INTRODUCTION AND MAJOR CONCEPTS

Life support systems fall into two major categories:

1. **Interplanetary spacecraft life support systems**
2. **Surface life support systems**

Interplanetary spacecraft and Mars surface life support systems are qualitatively different in terms of required useful lifetimes of system equipment and necessary degree of closure. Spacecraft systems can be refurbished at each return to Earth but surface systems must have much longer service lifetimes to be practical for the base. The Mars environment will provide input of materials into the life support cycle, whereas spacecraft systems must be totally autonomous. The food strategy of the spacecraft is dominated by weight and volume considerations. This restricts or prohibits food production. However, growing crops on Mars will be less expensive than transporting edibles from Earth.

Interplanetary spacecraft life support criteria

* Compact and low mass
* Complete closure of water and breathable gas systems
* Food requirements provided, not produced
* Waste storage or ejection
* Easily serviceable by crew
* Subsystems convertible for use on Mars surface

Surface life support criteria

* Low mass, can be less compact when deployed
* Water and gas systems augmentable by Martian materials
* Some food production on surface even initially
* Stored supplies in case of food production failure
* Waste recycling as a matter of routine
* Constructable and serviceable by crew
* Expandable capability

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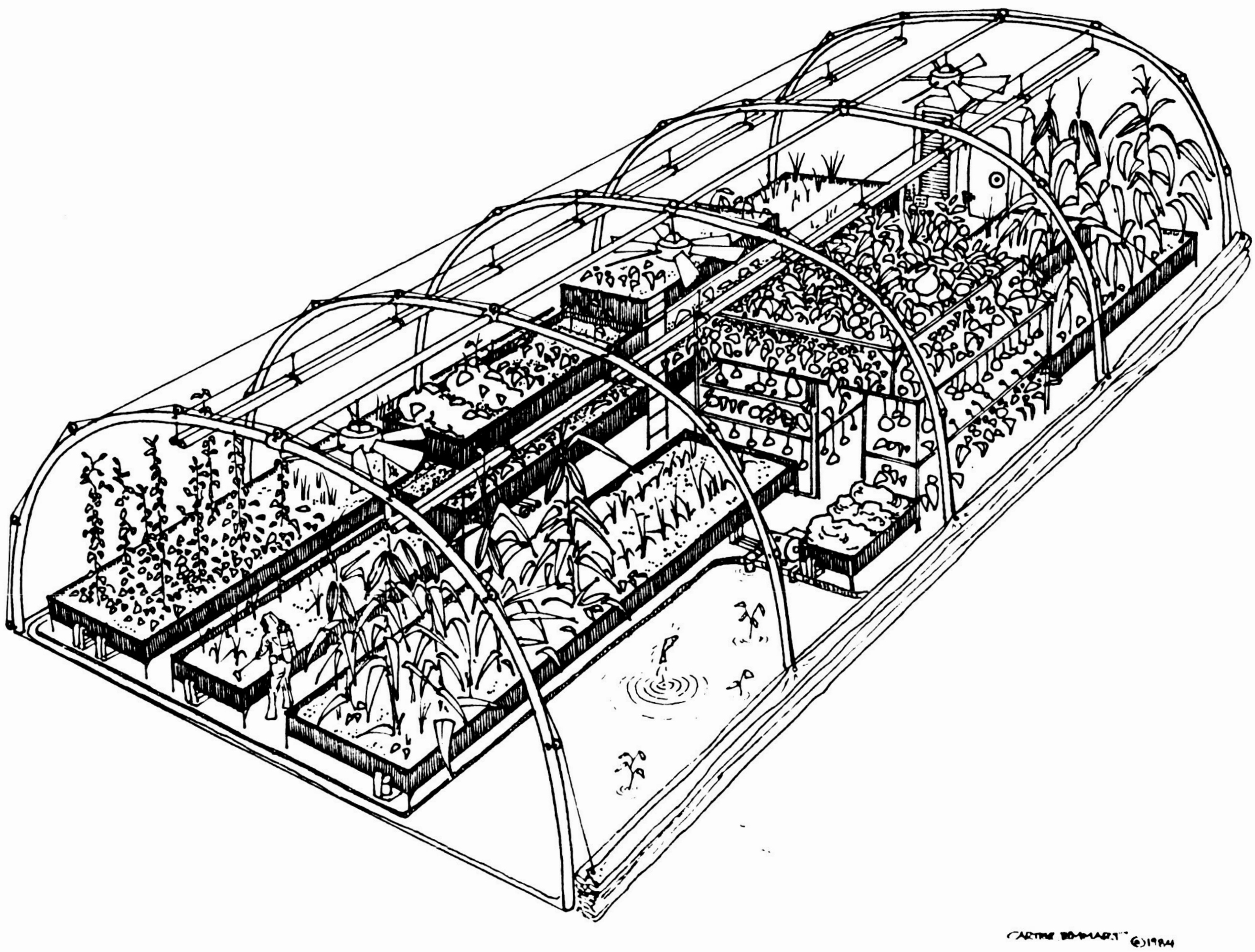


Artist's conception of suitable components
for initial Martian greenhouses
Artist-Carter Emmart

B. FOOD PRODUCTION FOR A MARS BASE - INITIAL CONFIGURATION

Initial base has above-ground lightweight plastic greenhouses with less than 1 bar internal pressure. With this strategy, initial food production facilities can be easily deployed. The low internal pressure reduces the need for heavy, complicated internal support structure for such greenhouses. The exact pressures involved may vary depending upon the requirements and tolerances of the plants (or algal cultures) involved, however we envision the internal pressure values to fall between 100 and 500 millibars. The ionizing radiation at the Martian surface will be less damaging to plant tissues than to animal or human tissues. However, plant performance under such conditions must be tested. The illustration on the previous page is an artist's conception of some of the important features of low-pressure Mars greenhouses.

Greenhouses have gas environments tailored for optimal food production. Plants prefer different atmospheric gas compositions than humans need. Also, different plant varieties prefer different gas compositions. Modular greenhouses will allow plants to be grown in the gas environment most suited to maximum production of food for each variety.

Greenhouses can use natural light augmented by solar spectrum artificial lighting for optimal lighting and minimization of power requirements. Controlling the day/night cycle of plants allows control of maximum growth, flowering and fruiting. During long Martian dust storms, greenhouses could be supported entirely by the artificial lighting.

Hydroponics, aeroponics or conventional agricultural growing methods can be chosen to maximize food yield of particular items. Hydroponics involves the use of an inert substrate (usually vermiculite on Earth) to hold plant roots down. Plant nutrients are supplied at the optimal rate in liquid form. Aeroponics relies on liquid nutrients sprayed directly onto the exposed rootballs of plants which are suspended on wire shelves. Yields from both of these new growth techniques are high. One drawback seems to be possible genetic degeneration of the stock. Ways may be found to prevent this. An alternative scheme produces seed stock via conventional growth methods and then uses this stock in the more artificial, high yield food production phase.

Martian regolith (probably requiring treatment) can serve as a growth substrate for plant roots. Depending on toxicity testing from Mars sample return, Martian surface material could be used as the basis of soil or as the inert substrate for hydroponic gardening. Possibly washing or chemical processing would be needed to prepare it for use.

Labor intensive activities can be largely automated. Spraying of roots, light control and many other functions can be performed by computer command. This would free the astronaut /gardeners for monitoring the status of the greenhouse plants, performing growth experiments and other activities.

Greenhouses can exchange photosynthetically generated O_2 for respiration generated CO_2 with human habitat areas minimizing resupply requirements from Mars air. The mass balance figure on the following page demonstrates schematically the flow of food, oxygen, carbon dioxide and water between the greenhouse and crew compartment areas for a 15 crewmember habitat area.

Gas exchange balance can be regulated and buffered by gas reservoirs. These reservoirs can take up the slack caused by differences in respiration and photosynthetic rate, differential water demands, and periodicity of life cycles of greenhouse plants. They can be filled and maintained by the Mars gas extractor which is an integral part of the overall habitation/greenhouse system.

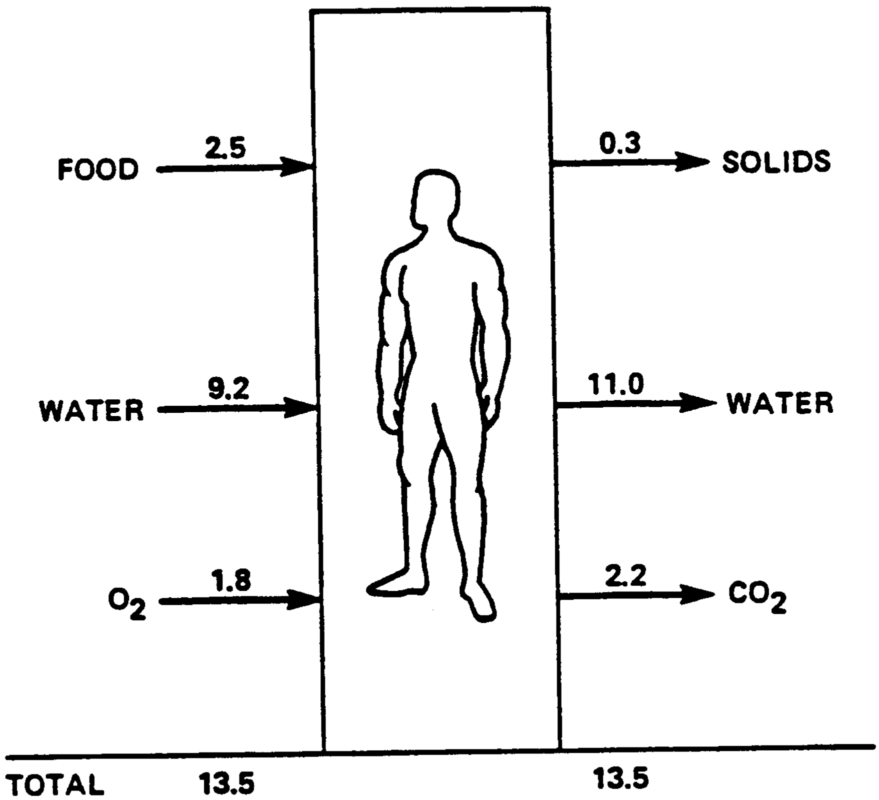
Secondary microbial processing will lead to higher nutrient value of many plant derived foodstuffs. Microbial processing of plant material into foods such as tofu and tempeh increases their digestibility, and vitamin content, as well as adding amino acids to the diet that plants tend to lack.

Single cell protein (SCP) can be produced from microbial cultures. This term refers to the extraction of edible protein from cultures of algae, bacteria, or yeasts. This can be supported in part by feeding organisms waste materials or even exotic substrates like alcohol, organic acids, and industrial waste materials.

Waste recycling functions can be performed via microbes. Production of organic fertilizer from plant and human wastes for return to the greenhouse growth medium can be accomplished by microbial processing.

Enzymes and antibiotics can be produced using the same facilities as single cell protein production. Enzymes for nutritional, medical and industrial applications and antibiotics for the treatment of diseases can be produced by culturing microbes on a variety of substrates including those mentioned above. This is a mature technology requiring only adaptation to the Mars environment.

Gardening activities may serve a psychologically therapeutic function. On Earth, gardening is an emotional and creative outlet for millions of people. It could serve a similar purpose at the Mars base even during the initial, relatively austere phase of its establishment.



Human requirements - Mass throughput of food, water and oxygen in pounds per person per day.

C. FOOD PRODUCTION FOR A MARS BASE - EXPANSION FOR PERMANENT BASE FACILITY

* **Expansion of greenhouse system can be accomplished by gradually deploying additional modules.**

* **Fish, crustaceans, and light-requiring single-celled-protein production can be accomplished in greenhouse constructions.**

* **Transition from simple plastic bag greenhouses to more rigid structures or partially buried greenhouse facilities will occur over a period of 5 to 10 years after initial landing.**

* **Plants best suited to Martian greenhouse conditions can be developed on Mars.**

* **Seed stocks and cultures of life support organisms will be maintained at Mars base, reducing the need for resupply from Earth.**

* **Growth experiments in semi-protected environments can be conducted on the Martian surface.**

* **Base personnel will expand food storage facilities and build up surplus food supply for emergency use.**

D. GROUND-BASED AND PRECURSOR MISSION RESEARCH RECOMMENDATIONS

- *Research on closed ecological systems is essential!*

- **Develop reliable long-duration chemical and physical recycling systems.**

- **Gather more information on the chemical composition and structure of the Martian regolith.**

- **Develop technology for extracting desired materials from the Martian atmosphere and regolith.**

- **Select and test appropriate greenhouse construction materials.**

- **Develop plant varieties suited to postulated Mars greenhouse conditions.**

- **Estimate energy requirements to produce a unit mass of crops and net consumable food (i.e. calories and mass after processing).**

- **Assess likely human nutritional needs for a Mars base scenario.**

E. SPACE STATION RESEARCH RECOMMENDATIONS

* ***Research on closed ecological systems is essential!***

* **Study a wide variety of organisms for pre-adaptation to space environment and fractional or zero gravity.**

* **Test long-duration chemical and physical recycling systems.**

* **Conduct thorough long-duration physiological studies on humans in the space station environment.**

* **Study psychological response of humans to the space station over long periods of time.**

* **Assess human nutritional needs in the "working" space environment.**

* **Develop medical procedures applicable in fractional or zero gravity.**

* **Develop a corps of career space workers.**

II. MEDICAL ASPECTS OF A MARS MISSION

A. FACILITIES AND CREW TRAINING

Health and happiness of the crew is paramount to the success of any manned Mars mission. The liveability of the spacecraft and the Mars base must be optimized within weight and mission strategy considerations. We suggest an absolute minimum of 30 m^3 total inflight volume and 6-9 m^3 initial Mars shelter volume per human (not including expansion). This is well within the approximately 50 m^3 allotted to each individual in the design of the Interplanetary Spacecraft habitat. Aerobic exercise facilities to combat cardiovascular degeneration and resistance exercises to maintain skeletal muscle tone (and possibly reduce bone loss) must be provided. Carefully planned hygiene facilities are important to physical health and to perception of self-worth and morale, as is appetizing, wholesome, and familiar food.

Extensive medical monitoring of crew will be highly desirable. Medical monitoring of the crew will be valuable for understanding the impacts of space and planetary environments on humans. Such monitoring must be accomplished with a minimum of interference to the crew by physician crewmembers and possibly by non-intrusive automated systems.

A period of acclimatization and screening for infectious diseases in the space environment prior to leaving for Mars is recommended.

All the crew should be trained in basic medical, rescue, and life support procedures. Medical emergencies and injuries can be reduced by workload planning, emphasis on teamwork, and continuous communications particularly during hazardous operations. However, a mission involving a large number of crewmembers over a 3 to 4 year period is likely to have incidents of trauma or acute disease at some point. All crewmembers must be trained in basic life support procedures, firefighting, and extravehicular activity rescue. At least one crewmember should be a physician of the "general practitioner" variety.

Capability for X-ray examination, physical examination, limited surgery, accident injury treatment, and medications for a variety of illnesses is necessary. Medical facilities should include a sick bay, diagnostic tools (x-ray, lab analysis of blood, urine, and tissues, general physical exam materials), respiratory support, cardiovascular support and monitoring, a relatively complete pharmacopoeia, limited dental and surgical equipment, decompression chamber (airlocks could serve this purpose), a computer-based or microfiche medical library, and capability for medical communication with consultation teams on Earth. An approximate cargo estimate for sick bay and medical equipment and supplies is 500 kg/vehicle occupying 4 m^3.

B. RESEARCH AND DEVELOPMENT

There are many potentially dangerous physiological effects from long interplanetary voyages. Hazards of space and Mars environments include radiation, zero or fractional gravity, calcium loss and muscle atrophy in zero gravity, non-pathogenic disease risks similar to those of a healthy adult on Earth, injury from hazardous activities in a new and dangerous environment, and space suit activity decompression problems.

Medical effects of the space environment on humans must be studied over relatively long periods of time to determine: 1) How much radiation protection is required for 3-4 year missions and, 2) Is artificial gravity necessary? If so, is 1/3 g or 1 g better?

Acceptable radiation exposure levels must be determined. This information directly affects the amount of radiation shielding required both on the spacecraft and at the Mars base. An unprotected human, in space for 4 years, could be exposed to 4-6000 rem. A worst-case solar flare could cause 1600 rem exposure. We recommend providing shielding adequate to reduce the probability of exposure to more than 300 rem to less than 5% over a five year mission. The probability of exposure to more than 100 rem in a single flare should be less than 5% over the mission duration.

A program of long duration exposure research must be carried out on the Space Station to address the numerous unanswered questions about human physiology in space. We have insufficient knowledge of long term health effects of low or zero gravity; however loss of bone calcium, skeletal muscle atrophy, and cardiovascular deconditioning do occur. At present there are no adequate techniques for preventing or alleviating the loss of calcium during zero gravity. No information is available on the effects of 1/3 g (Mars gravity) on this physiological response.

While we do not currently know enough about long duration human response to space, we do have an upcoming opportunity to study this board the Space Station. We must use this opportunity to the fullest extent since this is an important area which could present problems long after the engineering details of the mission are well in hand.

We recommend that artificial gravity be provided on the interplanetary spacecraft in spite of greater engineering and propellant demands. Much of modern medical technique relies implicitly on the presence of gravity, e.g. drip intravenous administration of saline and glucose, or even surgical procedures (how will we strap intestines and other organs down if an abdominal incision is necessary?). Even a minor wound could fill the cabin with droplets of blood.

It may prove less technologically demanding and less massive to provide artificial gravity than to develop means of combating zero gravity degeneration of the crew. Artificial gravity also allows use of the same medical devices for both the spacecraft and base phases of the mission.

C. RESEARCH RECOMMENDATIONS

* **Test physiological effects of long-duration exposure to zero gravity. The Space Station provides this opportunity.**

* **Develop techniques and pharmacology for combating deleterious effects of the space environment.**

* **Define radiation shielding requirements.**

* **Develop and test medical procedures and equipment for use in space and on Mars.**

III. PSYCHOLOGICAL ASPECTS OF A MARS MISSION

A. INTRODUCTION AND JUSTIFICATION

The isolation and confinement of small spacecraft can cause a wide array of psychological symptoms including psychosomatic illnesses, lowered performance, and social tensions. Several suggested prevention strategies are listed below. Psychological and social needs of crewmembers must be considered. Planning to meet these needs must avoid three common fallacies:

1) ***Fallacy 1:*** Psychological and social variables are unimportant and adverse reactions can be suppressed by adequate crew willpower. - No groups sent into space so far have been subjected to the same stresses as the long time-frame of a Mars mission is likely to elicit. Potential difficulties must be taken into careful consideration in the design of a Mars mission.

2) ***Fallacy 2:*** Social and psychological difficulties will be "solved" by the time a Mars mission is undertaken. - Our understanding of psychological variables lags far behind our technological expertise, consequently we cannot assume that our knowledge of human behavior (or human behavior itself) will be fundamentally different or "better" than its present state.

3) ***Fallacy 3:*** Social and psychological factors are so overwhelming as to block expansion of the human species into space. - The catastrophic impact of social and psychological factors is exaggerated with respect to mission success. To date, no space mission has been ruined by adverse crew behavior and with adequate attention to incorporating psychological considerations it can be dealt with effectively in the future.

B. CREW SELECTION AND TRAINING

Crew selection factors: Mars explorers will be selected on the basis of both technical skills and personality traits. Desirable personality traits that make people suitable for confined and isolated settings include a high level of competence and motivation, a strong need to achieve, 'cooperativity', emotional stability, maturity, and interpersonal sensitivity. It will be necessary to consider how the personal traits of the entire crew intermesh to determine the suitability of a given individual.

Choose people who can be happy in space, i.e. people with hobbies and interests which can be pursued in space or at a Mars Base, and possibly people with prior experience in space. Boredom could become a significant problem on long term missions. One important implication of this is that action-oriented individuals who do well on short duration missions may be replaced by more introspective, reflective individuals.

Considerations for crew number and gender: Democratic decision making and prevention of command deadlocks suggest that an odd number of crewmembers is preferable. Long mission times argue for a nearly equal number of men and women in the crew to promote social normality. At present, it is very difficult to draw any conclusions about the behavior of mixed-gender or ethnically mixed crews since there have been so few of them to date. Behavioral research along these lines is recommended.

Select and train crews as units not as individuals. Mission success depends on the performance of the entire crew. Crew compatability and efficiency is more important than the abilities of the individual crewmembers.

Two phase approach to crew selection. Phase one consists of selection of 3-5 crews based on initial testing and interviews. Phase two consists of careful monitoring of each crew as it is subjected to exhaustive training. The most trouble free and effective crew is chosen for the actual mission.

Exhaustive training in authentic environments is essential, e.g. antarctic stations, Space Station, ships, and submarines. Spacelike environments differ from space itself in many significant ways. The most useful behavioral data for Mars mission use will be from the space shuttle, the Space Station, and possibly a lunar base. These studies should be carefully planned and conducted as unobtrusively as possible on personnel. Studies should be designed not to interfere with normal activities and anonymity of the individuals under study should be guaranteed.

C. FACILITIES

Provide adequate recreational facilities. Long duration missions will require a balance between work and relaxation activities. Good food is also very important to morale.

Provide good communication ties with Earth for contact with families and friends and access to Earth news and events. Martian crews must make a mid-mission transition to the succeeding crew and a post-mission transition back into Earth society. In addition, it is important for society to understand and share the Martian experience. Attention to developing the crew's relationships to other crews, to mission control people, and the home community is vital.

Everyone must have some private and inviolable space. Spacecraft and habitat designers must provide three types of areas: highly limited access areas assigned to one individual, partially limited access available to different individuals or small groups of people at a time, and public access areas available to all crewmembers at any time. Internal space should be as user-definable as possible. Movable partitions and furniture and changeable decorations could be useful in this connection.

D. MENTAL HEALTH MAINTENANCE

Everyone must have in-flight and on-surface assignments. The need to provide everyone with in-flight and on-surface work roles and the necessity of skill redundancy in case of incapacitation of the primary responsible individual may require that many crewmembers possess unusual combinations of skills. Additionally, choosing people who can be constructive and content during the long periods of interplanetary flight will require a great deal of planning.

A crewmember knowledgeable in psychiatric medicine is necessary. While spaceflight will not necessarily induce psychological difficulties, neither will it grant immunity from such difficulties. Between 10%-25% of the general populace will experience some psychiatric problem at some point in their lives. As more and more people are sent into space, the odds increase that there will be some episodes of mental illness. Psychiatry should simply be one of the areas of medical competence represented in the crew. Psychopharmacology and biological psychology (i.e. management of the biological bases of behavior) offer the promise of other effective ways of dealing with various manifestations of mental distress.

E. CREW EFFICIENCY

Chain of command is critical: A democratic form of command is recommended for normal operations. However, the crew must be able to instantly revert to a military-type chain of command for emergencies and hazardous situations, e.g. current operation of scientific research vessels. Traditionally, manned spaceflight has used military or quasi-military command structures. We suggest a mixture of autocratic, consultative, and democratic strategies. The commander would make autocratic decisions for mission-related issues requiring speedy resolution. Consultation with other crewmembers would be employed in matters not involving strong time pressure. Democratic procedures would be used for daily issues involving life on board or in the base. Procedural transitions across these decision-making boundaries require much further study and careful implementation.

Smooth transition of base operations with successive crew rotations is aided by overlap in the duty cycles of personnel. This allows for direct communication of anecdotal and accumulated information to new crewmembers. Means for easing the transition of newcomers into the established base include *a priori* familiarity of the new and old crews. This could be accomplished if the crewmembers had trained together previously. Secondly, a sponsorship system in which each "old timer" has the responsibility for helping several newcomers adapt to the base can be used. Thirdly, frequent communication between the incoming spacecraft and people at the base camp may help establish good foundations for building working relationships upon arrival.

Suggested crew rotation plan for a crew of 15: Retention of 1/3 of the crew, five crewmembers stay for the duration of the second mission. Ten new crewmembers come to replace the homeward bound crew contingent. In expansion phase, 15 crewmembers come to replace the 10 homeward bound crew contingent. We use a 1/3 crew rotation simply as an illustration and the precise strategy for accomplishing it is necessarily dependent upon the actual mission scenario chosen.

F. RESEARCH RECOMMENDATIONS

* Psychological studies of individual behavior in the confined environment of research bases like those in the Antarctic.

* Study of human psychological response in space via the Space Station.

* Develop problem solving and daily conflict management techniques for application in spacecraft and Mars Base environments.

* Develop ways to implement chain-of-command decisions in emergency situations.

* Carry out extensive research on human interpersonal relations which relate to the success of long-duration missions in space.

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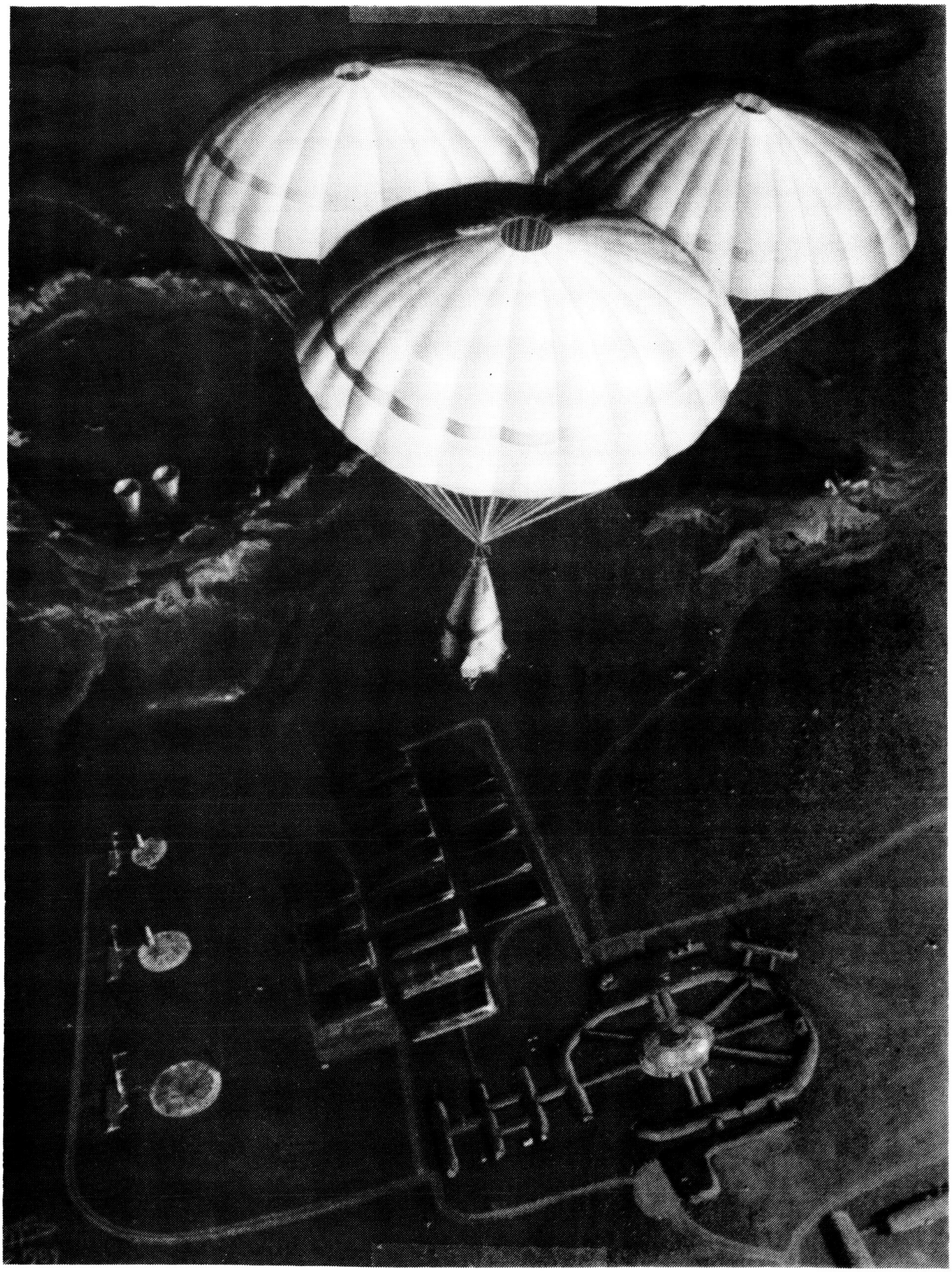
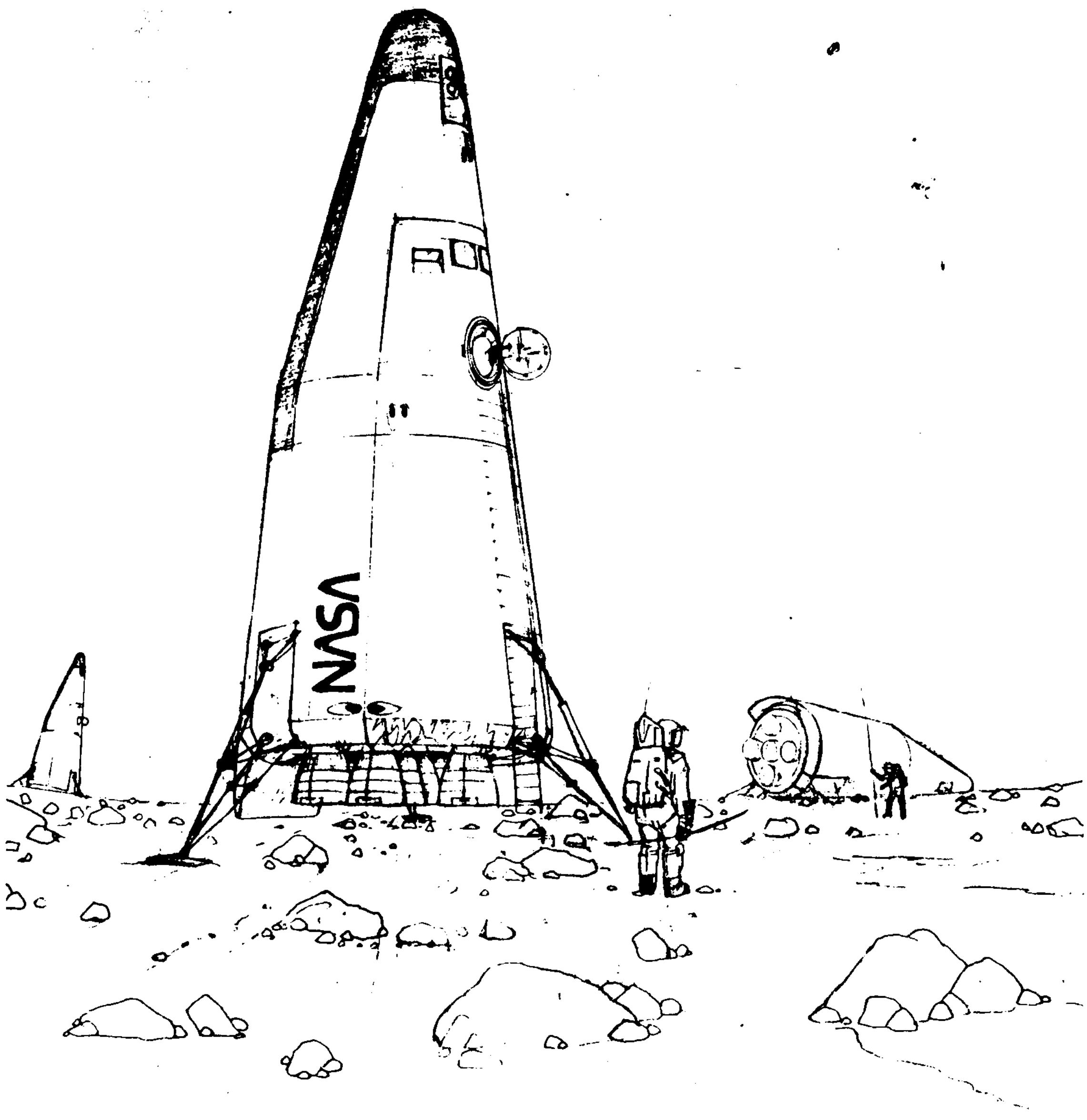


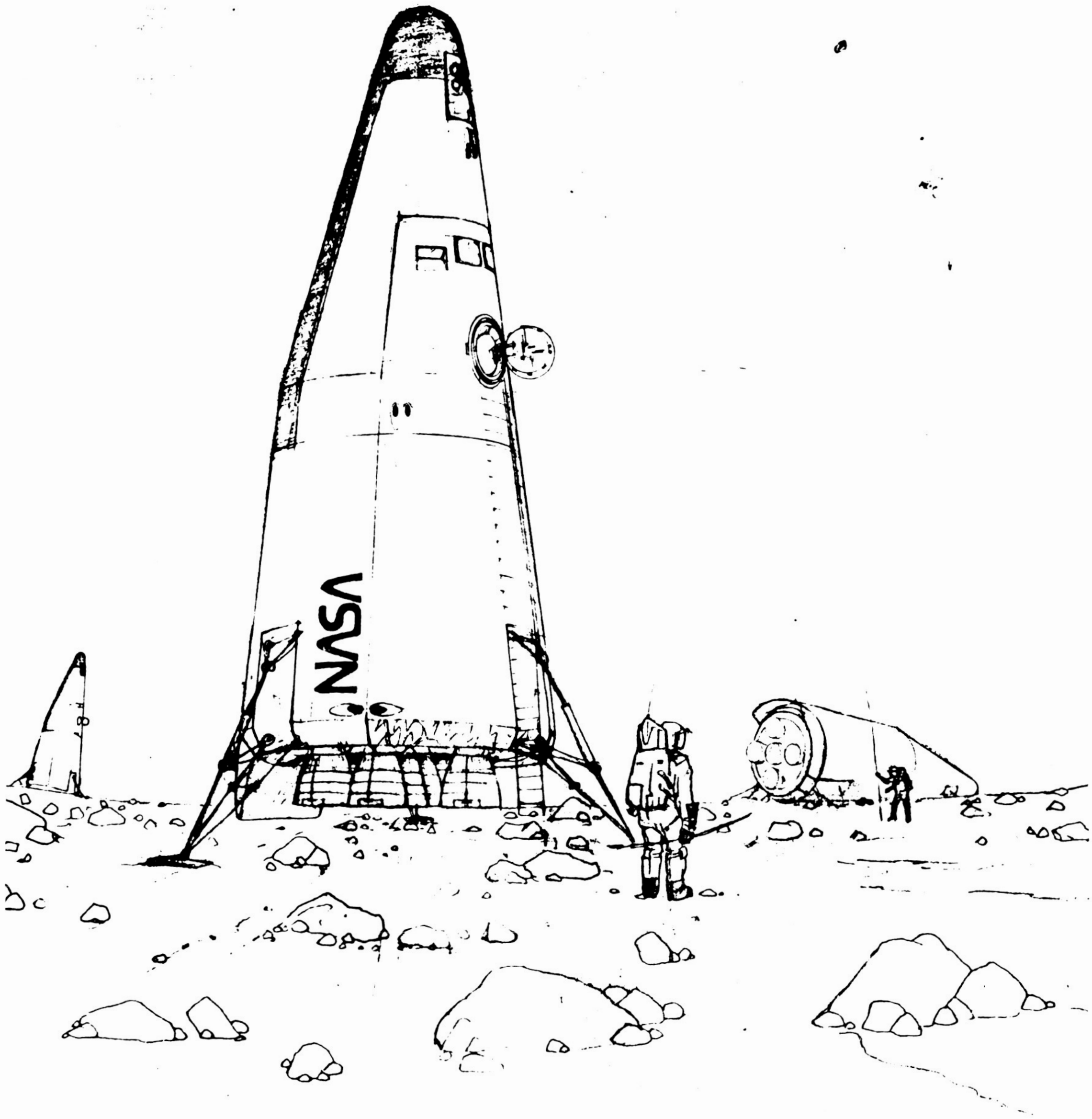
Crew Shuttle approaching Mars Base, just before parachutes are jettisoned -- Artist Mike Carroll

SECTION SEVEN -- MARS RESEARCH BASE INFRASTRUCTURE

SECTION OUTLINE -- MARS RESEARCH BASE INFRASTRUCTURE



The first Crew Shuttles at the Mars Base -- Artist Carter Emmart



The first Crew Shuttles at the Mars Base -- Artist Carter Emmart

I. MARS BASE MAJOR CONCEPTS

The base is designed to support a continued human presence primarily for the purpose of scientific exploration of Mars. Eventual self-sufficiency of the base is the goal. This will result in lower operational and maintenance costs, higher degree of safety for personnel and make eventual expansion more feasible. Self-sufficiency of the base will be aided by making full use of Martian resources. Local production of bulk consumables will result in lower cost and higher reliability of supply than transporting them from Earth.

- **Continued Human Presence**
- **Scientific Exploration**
- **Self-sufficiency/Local Resource Use**

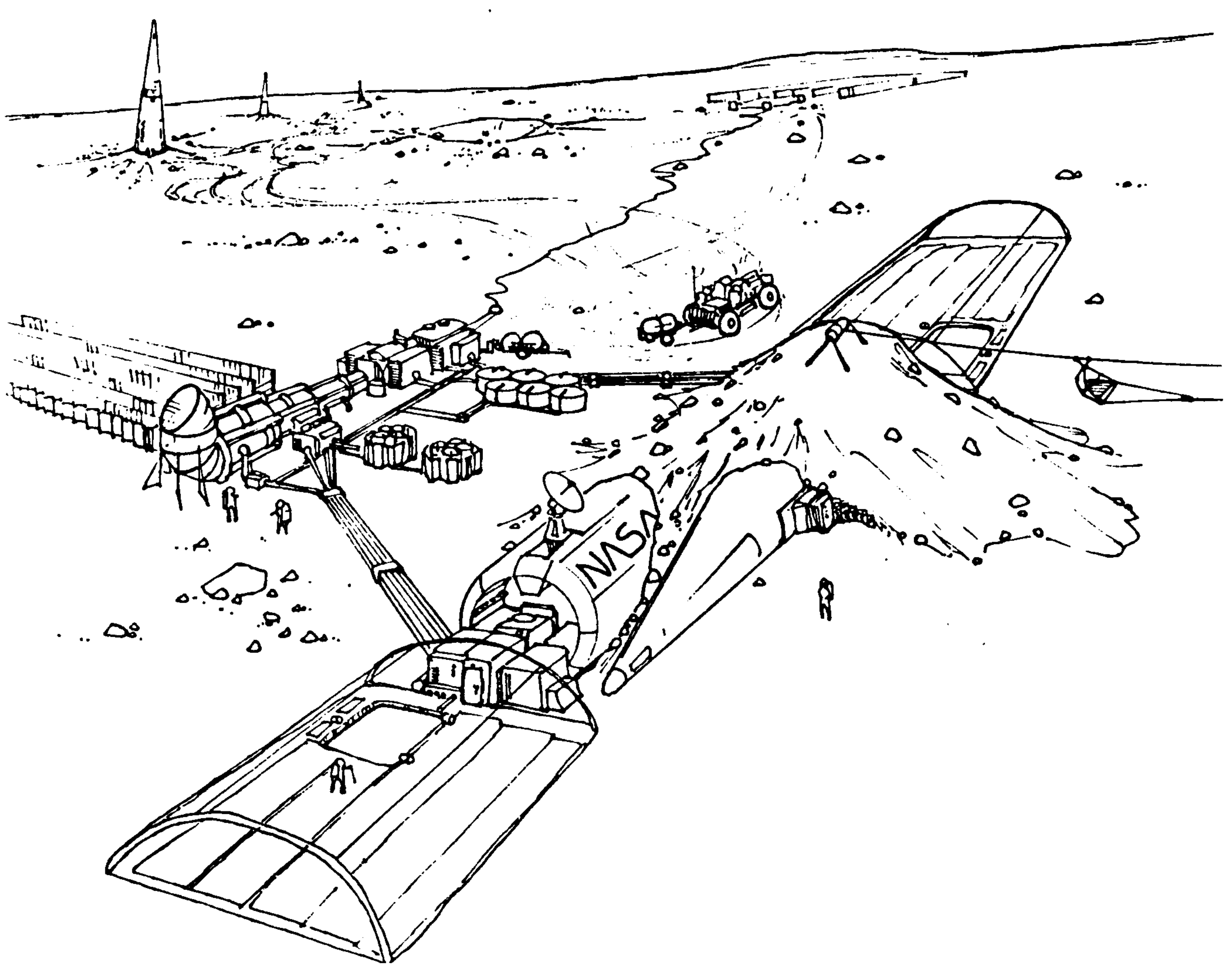
II. ASSUMPTIONS

The base is designed to accommodate an initial population of 15 crewmembers. It is planned to provide a reasonable living environment for two year surface times. It includes completely redundant food supplies to support the initial mission in its efforts to build and operate the base. The first mission crew is responsible for solving problems in base design, making the base operational, and establishing routine maintenance and inspection protocols.

- **15 person crew**
- **2 year surface tours of duty**
- **First mission brings necessary food and supplies for survival**
- **First mission builds base and brings it to operational status**

III. STRATEGY FOR BASE ESTABLISHMENT

There are several distinct phases involved in the establishment of a Mars base. Precursor missions will locate useful resources and identify opportunities and dangers presented by the environment of Mars. The second phase will include the initial landing, deployment, and implementation of the facilities needed to make the base operational. In the third phase, adapting the base to the Mars environment will require some exploration of the surroundings and selected research activities. In the fourth phase, the dominant activities will be full scale scientific studies and exploration of Mars. Base expansion, the fifth phase, will occur when it becomes both desireable and feasible after primary operational status is achieved.



IV. MARS BASE FACILITIES

The Mars base pictured on the facing page illustrates all of the major physical components of the initial configuration. Although initially austere, the base can be expanded further to accommodate expanding scientific research needs and more ambitious exploration.

MAJOR PHYSICAL COMPONENTS OF THE MARS BASE

* MATERIALS PROCESSING

Atmospheric gas processing/extraction, water extraction, storage tanks
Fuel production, storage tanks
Soil preparation equipment

* HABITATS AND AIRSHELLS

Cargo vehicle shells with furnishings for habitats
Air locks and tunnels
Air-shell superstructures
Greenhouse hardware: H_2O tank, pumps, lights, radiators, plant growth apparatus

* LIFE SUPPORT AND FOOD PRODUCTION

Air and water recycling technology, gas and water reservoirs
Environmental control, leakage make-up control
Backup systems in case of failure

* MOBILITY

Rovers, tractors, Science van

* POWER SUPPLY

Main, auxiliary and special purpose supplies
Power storage and distribution technology

* EQUIPMENT

Earth moving system (dragline, bucket, cable, winch, etc.)
Communication systems
Scientific equipment

* SUPPLIES

Food, imported consumables
Fuel, Water, Nitrogen, Oxygen
Imported materials for support of science and exploration

A. MATERIALS PROCESSING

The Mars atmosphere contains all of the essential components needed to prepare breathable air, water and fuel for a Mars base or for resupplying spacecraft. Because the atmosphere is present everywhere on the planet, using it to provide consumables removes one constraint on base location. Other advantages of this approach are that no heavy mining equipment is required and automated processing technology can be employed. Automated gas processing facilities could be landed and operated ahead of the crew arrival to assure adequate initial reserves of air, water and fuel upon arrival. Continuous operation of such processing facilities, even if they are relatively slow, can be used to maintain reservoirs of life support consumables for emergency situations. The figure on the facing page illustrates the conceptual relationship between Mars air and its various products.

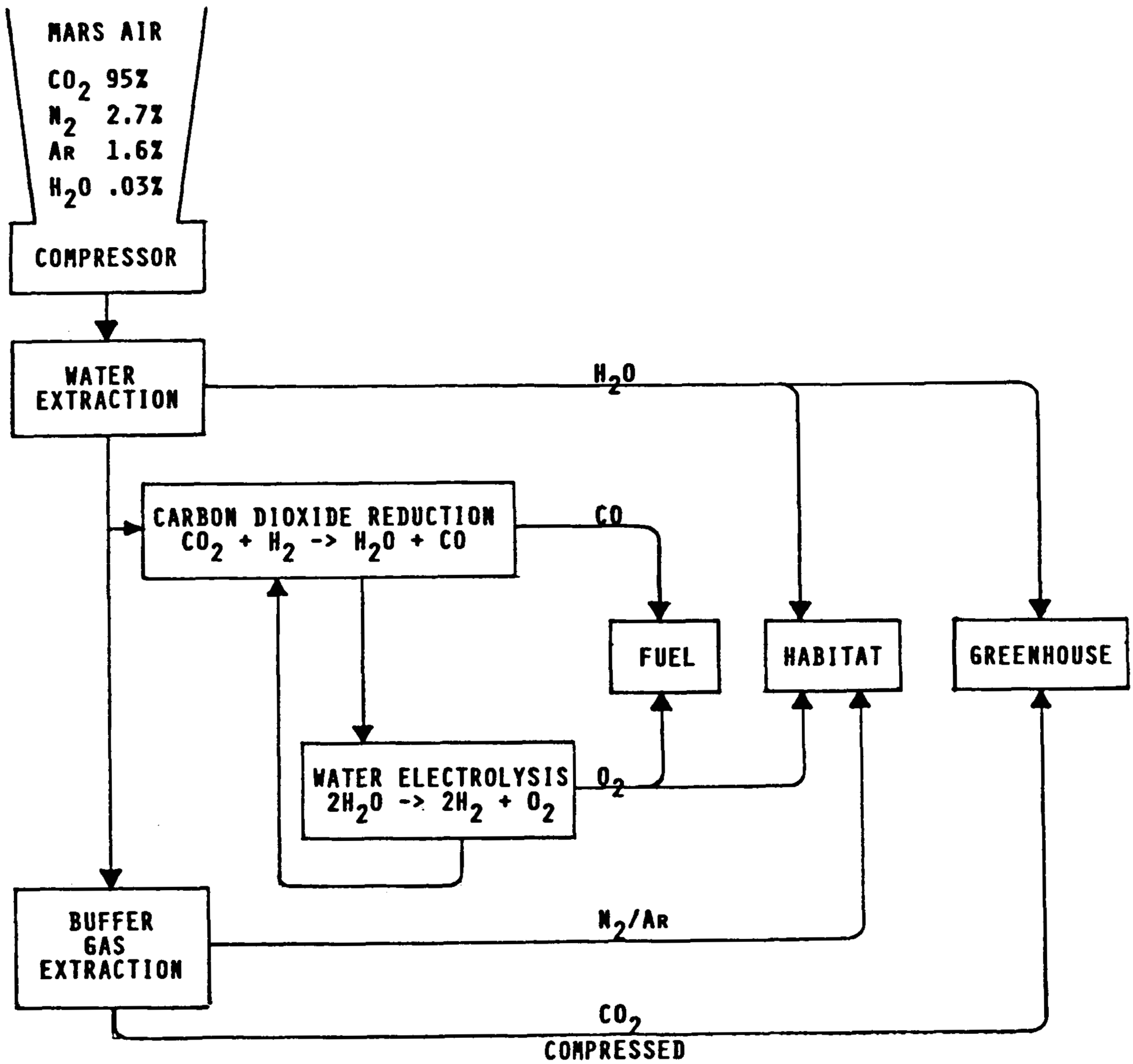
Breathable Air: The atmosphere of Mars consists of 95% carbon dioxide, 2.7% nitrogen, 1.6% argon, trace amounts of other gasses, plus 0.03% water (variable). Breathable air can be prepared from the Mars atmosphere by reduction of the atmospheric carbon dioxide to obtain oxygen. Nitrogen can be extracted from the atmosphere directly. Argon may be usable as another inert component, although medical testing of argon is advisable for long duration use.

Water: Water can be obtained by dehumidifying Martian air. Since large volumes of Mars air must be processed to obtain needed supplies of water, there is a high energy cost of extracting it (~30 kilowatt-hour per kilogram of water). Water will be the most valuable commodity on Mars and must be conserved and recycled in the habitats and greenhouses. While atmospheric supplies may be adequate for the initial base, its scarcity and energy expense may eventually limit agricultural expansion, hydrocarbon manufacture, hydrogen based fuel production, or other manufacturing processes. More convenient and abundant sources of water (e.g. the polar caps or a possible subsurface permafrost layer) will be an important exploration priority.

Propellants: Propellants suitable for rovers and rockets may be derived by reducing atmospheric carbon dioxide to produce carbon monoxide/oxygen propellant which can be used in rovers and for refueling Crew Shuttles for return to Earth. Although this choice requires the development of new engines, it is attractive over propellants using liquid hydrogen, methane, or hydrazine because it does not expend valuable supplies of hydrogen which would be difficult to reclaim from engine or rocket exhaust, and the liquefied components are easier to store than hydrogen. If sufficient quantities of water can be found, then electrolysis can be used to produce hydrogen/oxygen or methane/oxygen, superior propellants for rockets and surface mobility.

The processes needed to produce breathable air, water, and fuel from the atmosphere will require compressors to bring the gasses to working pressures. These compressors will also provide the capability to pressurize the habitats, greenhouses and storage reservoirs. In this base design, the gas extractor compressor and other noisy equipment is placed at a distance from the habitats with heat radiators and storage tanks for air, water and fuel placed conveniently nearby.

PROCESSING OF MARS AIR TO EXTRACT BREATHABLE AIR, WATER AND FUEL



B. HABITATS

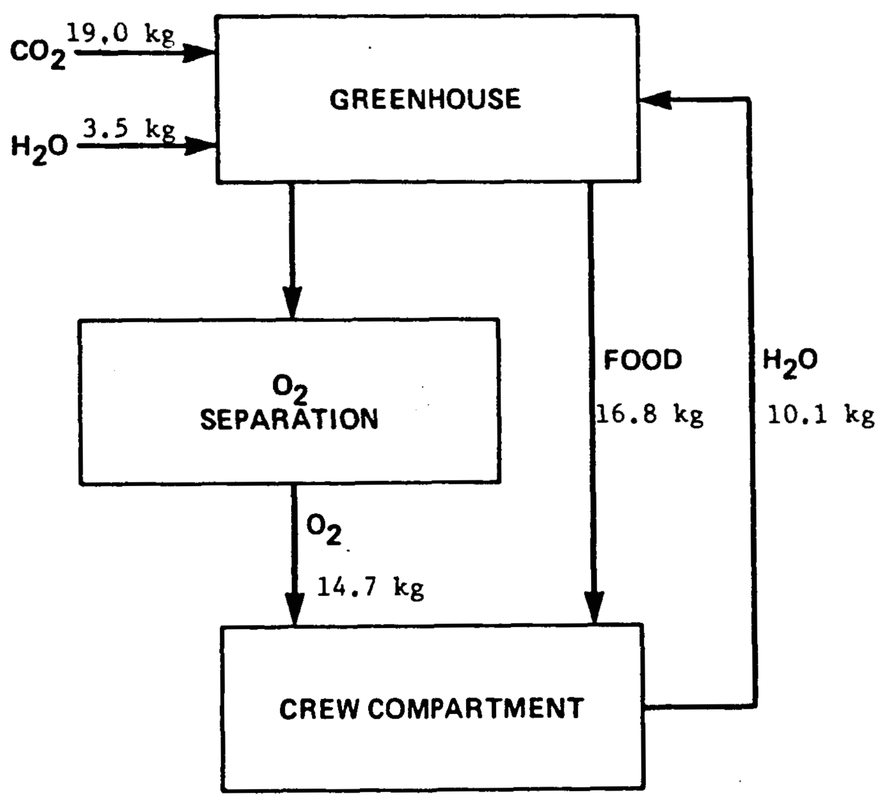
Initial habitats will be constructed from cargo vessels shipped from Earth. Each shell can house about 5 crewmembers and contains private quarters, common areas, food preparation and hygiene areas. Laboratory and utility facilities will be constructed in other cargo shells. Each habitat will be fitted with air locks which are used for entry/exit and medical emergency decompression chambers. The habitats will be interconnected by tunnels and covered with several meters of Martian surface material for radiation protection. Facilities for waste processing, life support and storage will be located outside the habitats. Habitats can be heated by waste heat from the gas extractor or artificial lighting for greenhouses, nuclear thermal power sources, or heated electrically. Pressurization of the habitats will be maintained by the gas processing plants and pressurized reservoirs of buffer gas and oxygen. Later in the program, habitats may be constructed from materials manufactured on Mars.

C. AIR SHELLS

Air shells are erectable structures which are held rigid by moderately pressurized Mars air or a breathable mixture. Only a very light frame is needed to support them. They may be anchored to the surface and partially filled with regolith or other floor material and insulating material. Attachment to the habitats will allow easy access by personnel using only minimal life support equipment. Air shells can be used as greenhouses, as large partially protected workspaces for certain scientific purposes, and as minimum protection service facilities for rovers and other heavy equipment maintenance. The advantages of air shells are their extreme light weight, foldability, and expendability. Research is required to identify the optimum materials (trade-offs between weight, radiation filtering, thermal protection, and durability against UV and wind).

D. LIFE SUPPORT

Food production: Initial greenhouses will be inflated structures which can support a modest pressure (25-75 mb) and can provide some shielding against the strong surface ultra-violet radiation. They can be attached to habitats to allow convenient access for gardening and gas exchange between humans, plants, gas extractor and control systems. They may have the option of using natural sunlight, filtered (to remove non-photosynthetic wavelengths) and concentrated sunlight, or artificial light. Waste heat from lighting sources, additional waste heat from materials processing systems or from nuclear power sources can be used to maintain warmth. Containment and recycling of greenhouse water will be an important design consideration. Greenhouses will contain pools or reservoirs to accept partially reprocessed wastewater. Some wastewater can be recycled directly as water for plants. Greenhouses and habitats can be pressurized using waste carbon dioxide from the gas processing facilities or by direct compression of the Mars air. Oxygen produced by greenhouse plants or photosynthetic algae may eventually be used to supply the habitat as plant production becomes reliable. Eventually greenhouses may be built partially or wholly underground to improve thermal efficiency and radiation protection.



Mass flow of oxygen, water, food and carbon dioxide between greenhouse and crew compartment. Values are for a 15 person crew.

Waste processing: Waste processing of plant, food, human and animal waste products will be designed to conserve water and to optimize the production of fertilizer for greenhouses. Holding, septic and processing tanks and equipment can be located within the greenhouses to provide easy access and maintenance. Waste treatment can include microbial processing of wastes to serve as fertilizer or to produce useful compounds on a miniature industrial scale, e.g. solvents.

E. MOBILITY

Vehicles will be able to use fuel manufactured from the Mars atmosphere (e.g., carbon monoxide/oxygen). Maintenance facilities must be present at the base. Mobility requirements on Mars must be met by matching the range and capability of rover vehicles with the specific mission tasks to be performed and the anticipated terrain types to be encountered. Mobility will be required for travel around the base, to launch and landing sites, for retrieval of cargo vessels, for travel to scientific sites, and for long distance expeditions.

Individual space suits must be available for use around the base site. Full-protection suits for outside use with minimal or no pressure differences between habitat and suit are desirable to minimize pre-breathing time before exposure to pressure differentials. Possibly partial protection suits for use in pressurized greenhouse and workspace air shells may be desirable.

F. POWER SUPPLY

Energy requirements must be met on a continuous basis and energy storage and backup energy production facilities are necessities. Energy considerations will probably be the limiting factor for base expansion, and work needs to be done to find optimal energy sources and energy conserving processes and systems.

The power available will influence base operations, choice of resource processing techniques, and expansion. Power is required to operate life support systems, fuel production plants, other materials processing, for habitat needs, and for scientific and maintenance requirements.

Immediate needs can be met with nuclear thermoelectric generators and solar cell arrays. Both of these have lifetimes on the order of ten years. Solar cell arrays have the disadvantage of losing effectiveness during Martian dust storms which may last for months. The self-sufficiency and continuous presence requirements for the base suggest that long term expandable power generation options should be developed. Nuclear reactors or solar power satellites would allow major base expansion. Nuclear power devices must be placed at a safe distance from the base.

Energy storage will be required both for safety reasons and as a means of load leveling. Energy storage should be integrated with the need to build up reservoirs of energy intensive consumables, e.g. life support compounds and fuel.

V. BASE DEVELOPMENT ACTIVITIES

The initial mission must carry out a sequence of critical activities to successfully establish the base. Subsequent missions must make the operation and safety of the base high priority tasks. Some exploration and research must be done to support these priorities. Beyond these activities, there is other important research and exploration to be done. However, these latter mission tasks can be performed at the discretion of the crew when they can be safely incorporated into the running of the base. Below is the envisioned sequence of critical items and the list of additional important tasks to be carried out by base personnel.

A. CHRONOLOGY OF CRITICAL INITIAL TASKS

* **Manned vehicles land within kilometer of chosen base site.**
* **Cargo vehicles land at chosen base site.**
* **Crew verifies critical information based on precursor missions.**
* **Cargo vehicles unloaded and materials trucked to chosen area.**
* **Empty cargo vehicles skidded to habitat area for use as habitats.**
* **Habitats are put in place, fitted with air locks and interconnected with tunnels.**
* **Power sources setup and activated; energy storage initiated.**
* **Mars resource extractors assembled: air, water, propellant.**
* **Life support systems and furnishings are installed in habitats.**
* **Habitats buried (by dragline) for radiation protection.**
* **Life support systems deployed: air revitalization, food supply, waste processing.**
* **Secure launch and landing capability.**
* **General survey of base area.**

B. SURVIVAL RESEARCH AND EXPLORATION

* Atmospheric forecasting
* Medicine - Detailed monitoring of human responses to the base environment and to the planet
* Water assessment (look for permafrost, etc.)
* Regolith assessment for agriculture
* Mineral assessment

C. DISCRETIONARY SCIENTIFIC ACTIVITIES

* Requires complete scientific facilities on base.
* Conduct sample collection and detailed investigation of scientifically interesting areas.
* Network science (heat flow, seismology, weather stations, etc.)
* Biology - search for present and past life.
* Experimental agriculture conducted in Mars greenhouses.
* Establish environmental baselines and study human impact on planet.
* Study dynamics of Martian environment & response to perturbations.

D. BASE EXPANSION

* Expand number of personnel.
* Increase habitat and laboratory facilities.
* Acquire additional scientific equipment as needed.

VI. TECHNOLOGY DEVELOPMENTS REQUIRED FOR MARS BASE

* Power sources
* Long term life support and recycling technology
* Atmospheric gas processing to make life support consumables and fuel
* Air shell/greenhouse design and material research
* Carbon monoxide/oxygen engines
* Mars suits for work outside and in low pressure air shell/greenhouses
* Methods for adequate radiation protection for humans and other organisms
* Design for a fully habitable 500 km range manned rover vehicle

VII. LUNAR BASE AND MARS BASE COMPARISON

A quick inspection of the list below illustrates the many similarities between a Mars base and a lunar base. Much of the technology is complementary. Development for either contingency could assist in the establishment of the other.

LUNAR BASE REQUIRES SIMILAR TECHNOLOGY

* **Landing sites for resupply and return**
* **Habitats**
* **Closed Ecological Life Support Systems (CELSS)/air revitalization, food production, waste processing**
* **Radiation shielding and shelter**
* **Power production**
* **Energy storage technology**
* **Construction material manufacture**
* **Rover/tractor design**
* **General survey**
* **Soil and mineral assessment**

LUNAR BASE REQUIRES DIFFERENT TECHNOLOGY

* **Air Shells/Greenhouses**
* **Water production**
* **Production of breathable gas**
* **Fuel production**

LUNAR BASE DOES NOT HAVE THIS REQUIREMENT

* **Water assessment**
* **Atmospheric forecasting**

SECTION EIGHT -- POLITICAL AND ECONOMIC FACTORS

SECTION OUTLINE -- POLITICAL AND ECONOMIC FACTORS

I. INTERNATIONAL COOPERATION

A. INTRODUCTION
B. SCENARIO FOR COOPERATIVE PROGRAM
C. INTERNATIONAL AGREEMENTS
D. RECOMMENDATIONS

II. ECONOMIC FACTORS

A. NEAR-TERM ECONOMIC BENEFITS
B. LONG-TERM ECONOMIC BENEFITS
C. DEVELOPMENT OF A SPACE INFRASTRUCTURE

III. MISSION PHASING

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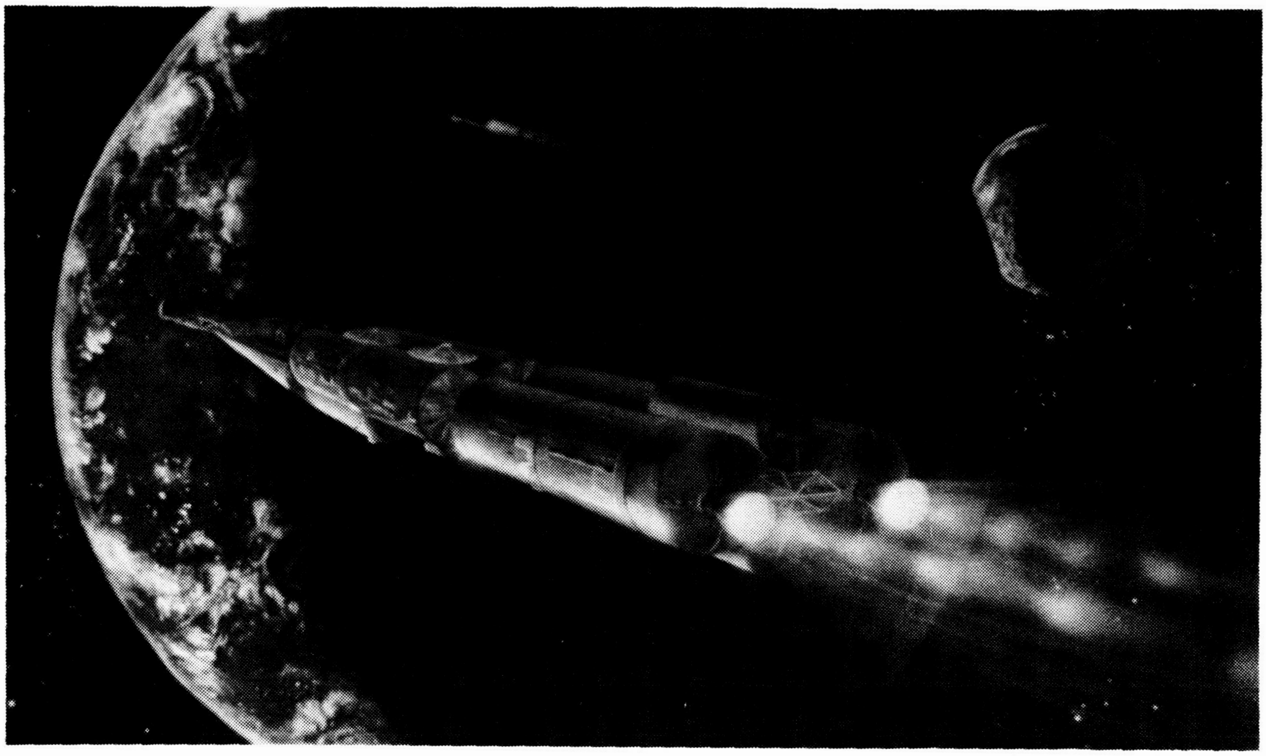


Interplanetary Spacecraft leaving Earth orbit -- Artist Mike Carroll

I. INTERNATIONAL COOPERATION

A. INTRODUCTION

Two major factors will influence both the decision to go to Mars and how the program will be accomplished: ***1) The desire for cooperation, to lessen tensions and unify people behind a common goal, 2) The desire to pursue competitive national interests and the interests of private enterprise.*** These two factors appear at odds, but there are times when both can be served by the same action. Treaties between nations, contracts between individuals and companies are examples where self-interest can be aligned with the interests of a larger group.

The race to the Moon and the U.S. Apollo program is a clear example of a competitive program between the United States and the Soviet Union. Competitive programs are likely to increase international tension because some nation must "lose". However, competition can be useful, as it was in the Apollo program, in maintaining momentum and accomplishing a goal.

The Antarctic research program provides a useful paradigm for a cooperative Mars program. Many nations maintain active research programs in Antarctica, including the United States and the Soviet Union. Scientific programs in Antarctica are mostly independent, but cooperation is maintained through data exchange and cooperation in the field and in emergencies.

An international cooperative Mars program would be the largest peaceful joint venture in history and great benefits could potentially result. However, planners must be careful in designing an international program. We suggest the following requirements:

REQUIREMENTS FOR COOPERATIVE PROGRAM

- **A Mars program should not be vulnerable to adverse changes in international relations.**
- **Both cooperation and competition should be incorporated into planning a Mars program.**
- **A Mars program should be a tool for conflict resolution.**

B. SCENARIO FOR COOPERATIVE PROGRAM

We have examined one possible scenario for a cooperative program. In this scenario three teams of nations participate in the Mars program. This team strategy will be initiated in the development phase of the program and will continue throughout the mission phase.

EXAMPLES OF NATION-TEAMS

Team 1: United States, nations of Latin America, and the Middle East
Team 2: Soviet Union, India, and nations of Africa
Team 3: Nations of Europe, Japan, China, Canada, Australia

DEVELOPMENT PHASE OF PROGRAM

In the development phase of the program, each team will develop some of the hardware for the mission. Tasks could be divided so that each mission component is independently developed by two different teams. This will create hardware redundancy and will protect the program from cancellation if one team withdraws. Also, international pressure will encourage nations to remain involved since national prestige will be at stake.

Development Phase: Program Features

* **Each team develops hardware: Costs are split three ways.**
* **Two teams independently develop each mission component.**
* **Teams compete in meeting design and development schedule.**
* **Teams cooperate in crew training, interfacing spacecraft components, and exchange technology where necessary.**

MISSION PHASE OF PROGRAM

The Mars Base mission profile naturally adapts to the team strategy for international cooperation. A subcrew from each team could inhabit one interplanetary vehicle for the transit phase of the mission. Spacecraft from the three teams would rendezvous and link up on the trans-Mars trajectory. The teams would land on Mars simultaneously. They would cooperate in building the base and implementing facilities for survival. If necessary, teams would cooperate in rescue efforts. Scientific programs could be separate, but data exchange would be cooperative.

Mission Phase: Program Features

* **Each team occupies one Interplanetary Spacecraft**
* **Teams link up for interplanetary cruise**
* **Teams simultaneously land on Mars**
* **Cooperation of teams in rescue efforts and survival on Mars**
* **Cooperation in data exchange**

C. INTERNATIONAL AGREEMENTS

Paradigms exist for the management of large, joint international programs. They include:

* **Antarctic Research program**
* **International Geophysical Year**
* **Global Atmospheric Research Program**

International treaties governing the use of space must be careful not to rule out incentives for private enterprise and not limit access by all interested parties. Current treaties governing the use of space serve as a guide for future agreements. They suggest that:

* **Space is for the benefit of all humanity.**
* **Nations are allowed free access for exploration and the use of outer space.**
* **Military bases are forbidden on the celestial bodies but military personnel may work on peaceful efforts.**

D. RECOMMENDATIONS

* **Qualified organizations should study international cooperation in a Mars program and its effect on international relations.**

* **Historians should review the analogies to permanent Mars bases and Mars colonization. Their recommendations would be helpful in assessing potential ramifications of such a venture on Mars.**

II. ECONOMIC FACTORS

Economic factors include direct and indirect costs and benefits to society both in the near and long term. The costs of a program can be forecast reasonably well once the details of the program are adequately specified. The benefits are difficult to forecast beyond the near term.

A. NEAR-TERM ECONOMIC BENEFITS

New technologies developed for Mars will help solve or better manage problems on Earth. Examples include:

* **Developments in robotics**
* **Food-growing technology for hostile Earth environments**
* **Water conservation and recycling technology**
* **Chemical and mineral processing technology**
* **Atmospheric extraction of water for arid areas**
* **Low maintenance, efficient power systems**
* **Energy efficient technology and energy conservation strategies**
* **Human physiology and medical advances**
* **Unforeseen products**

B. LONG-TERM ECONOMIC FACTORS

Mars is the gateway to the outer solar system and, eventually, will hold the same importance for that frontier as the city of St. Louis had in the development of the American west. When asteroids are mined and the outer solar system is exploited, Mars will become a key element in the transportation and materials systems. Mars and its satellites represent material resources important to operations in space. Possible Martian commodities of the future include:

* **Fuels**
* **Radiation shielding**
* **Metals**
* **Breathable air**
* **Food**
* **High gravity environment for human gestation and birth**

C. DEVELOPMENT OF A SPACE INFRASTRUCTURE

A Mars program provides initiative and a focus for developing a space infrastructure which will give mankind access to the entire solar system. The feasibility of a Mars base relies on the existence of this infrastructure. The elements of the infrastructure include:

LEO INFRASTRUCTURE

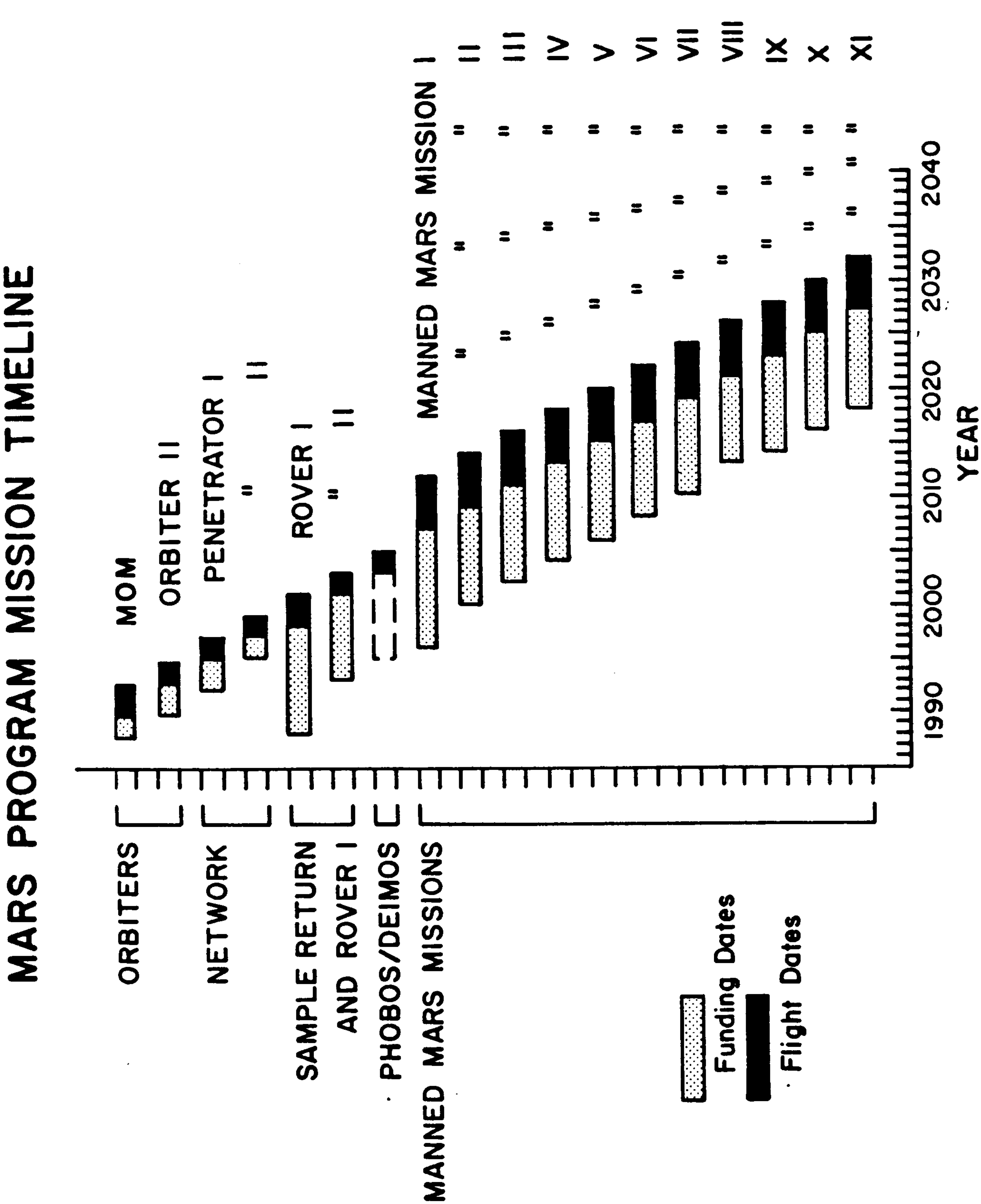
Shuttle operations
Space station configured for deep space support
Space manufacturing
Space construction and propellant handling
Closed-loop long-term life support systems

GEO INFRASTRUCTURE

Space construction
Orbital transfer

OTHER PROGRAMS (HELPFUL BUT NOT ESSENTIAL)

Lunar Base experience
Extraterrestrial manufacturing
Food production in space
Phobos-Deimos manufacturing


MARS PROGRAM MISSION TIMELINE
ORBITERS
NETWORK
SAMPLE RETURN
AND ROVER I
PHOBOS/DEIMOS
MANNED MARS MISSIONS
MOM
ORBITER II
PENETRATOR I
II
ROVER I
II
MANNED MARS MISSION I
II
III
IV
V
VI
VII
VIII
IX
X
XI
1990
2000
2010
2020
2030
2040
YEAR
Funding Dates
Flight Dates

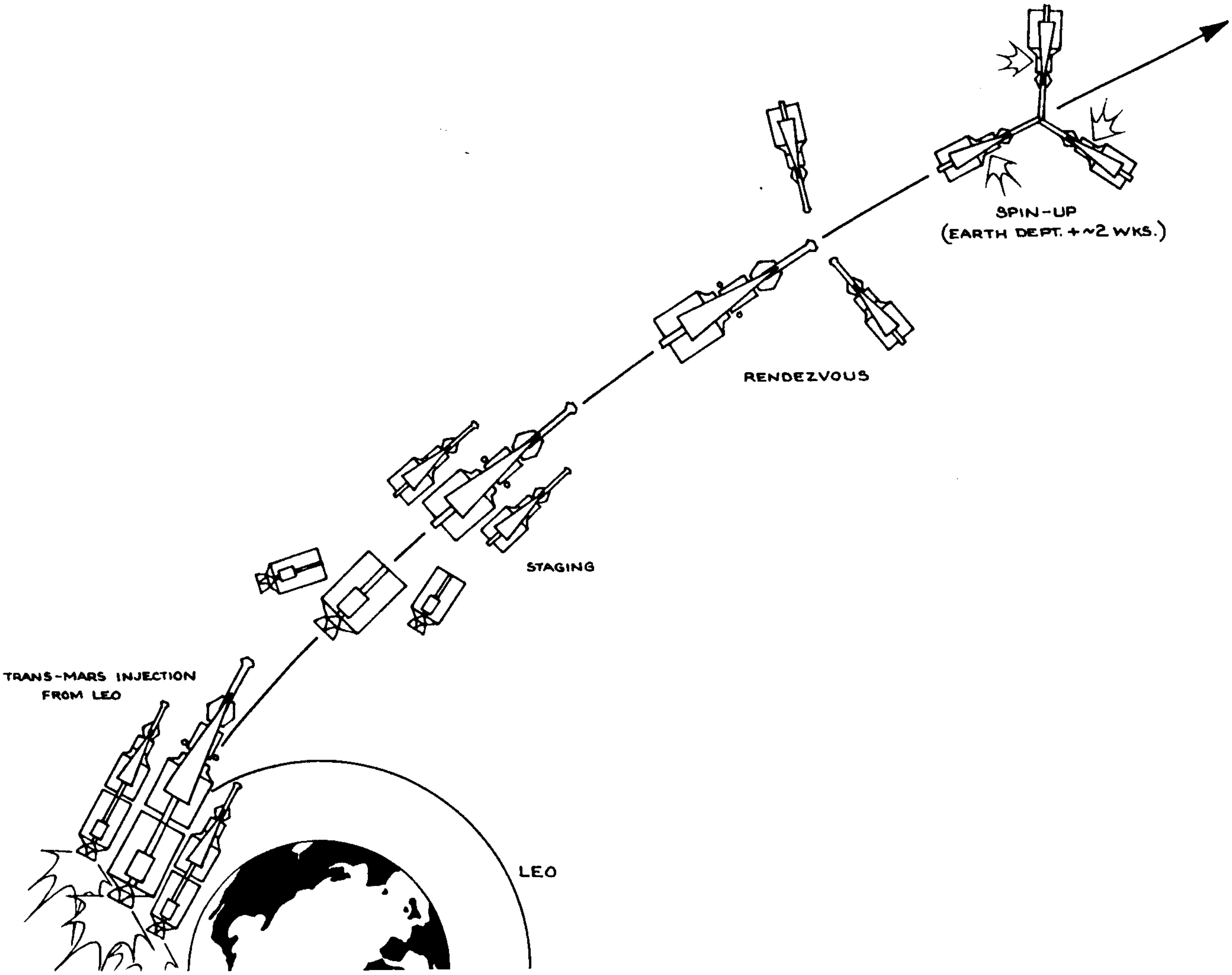
III. MISSION PHASING

With a program of advanced planning, an infrastructure in LEO, and operations at GEO, cost requirements for a Mars program can be factored at rates which add health and not trauma to the U.S. economy. The cost of program initialization could take fifteen years to rise and decline with a maximum amplitude of not more than twice the long-term support requirements.

The figure on the facing page shows the proposed mission phasing for the Mars program missions. The program under consideration is more long-range than anything previously considered. It includes a scientific precursor phase with automated Orbiter, Penetrator, and Rover/Sample return missions. Next there is a base establishment phase which sets up a 15 person permanent research station. Finally, there is a maintenance and ultimately base expansion phase.

A manned mission to the Martian satellites Deimos and Phobos has been proposed as a scientific precursor to a human landing on Mars (see Appendix B). This mission meets the scientific objectives of Penetrator and Rover/Sample return class missions and has many other desirable features. The Phobos-Deimos mission is represented in the figure on the facing page with dotted lines indicating that it is an alternative to Penetrator and Rover Sample return missions or could augment them.

Mission timing is designed to maintain an ongoing program, to share management and engineering, to reduce competition between missions, and to maximize learning between missions to benefit subsequent missions. Phasing for the manned missions is controlled by the desire to maintain a continued human presence on Mars.



EARTH-SPACE DEPARTURE

APPENDIX A --
DETAILED BASELINE MISSION TIMELINE

A. EARTH DEPARTURE PHASE

Mission Start minus one year -- Earth launch of mission components and assembly of three LEO Departure Assemblies

Mission Start (T=0) -- Trans-Mars Injection (TMI). Three Interplanetary Spacecraft Departure Assemblies burn out of Earth orbit into Type I trajectory roughly simultaneously.

T plus 2-4 hours -- Vehicles deploy solar power systems.

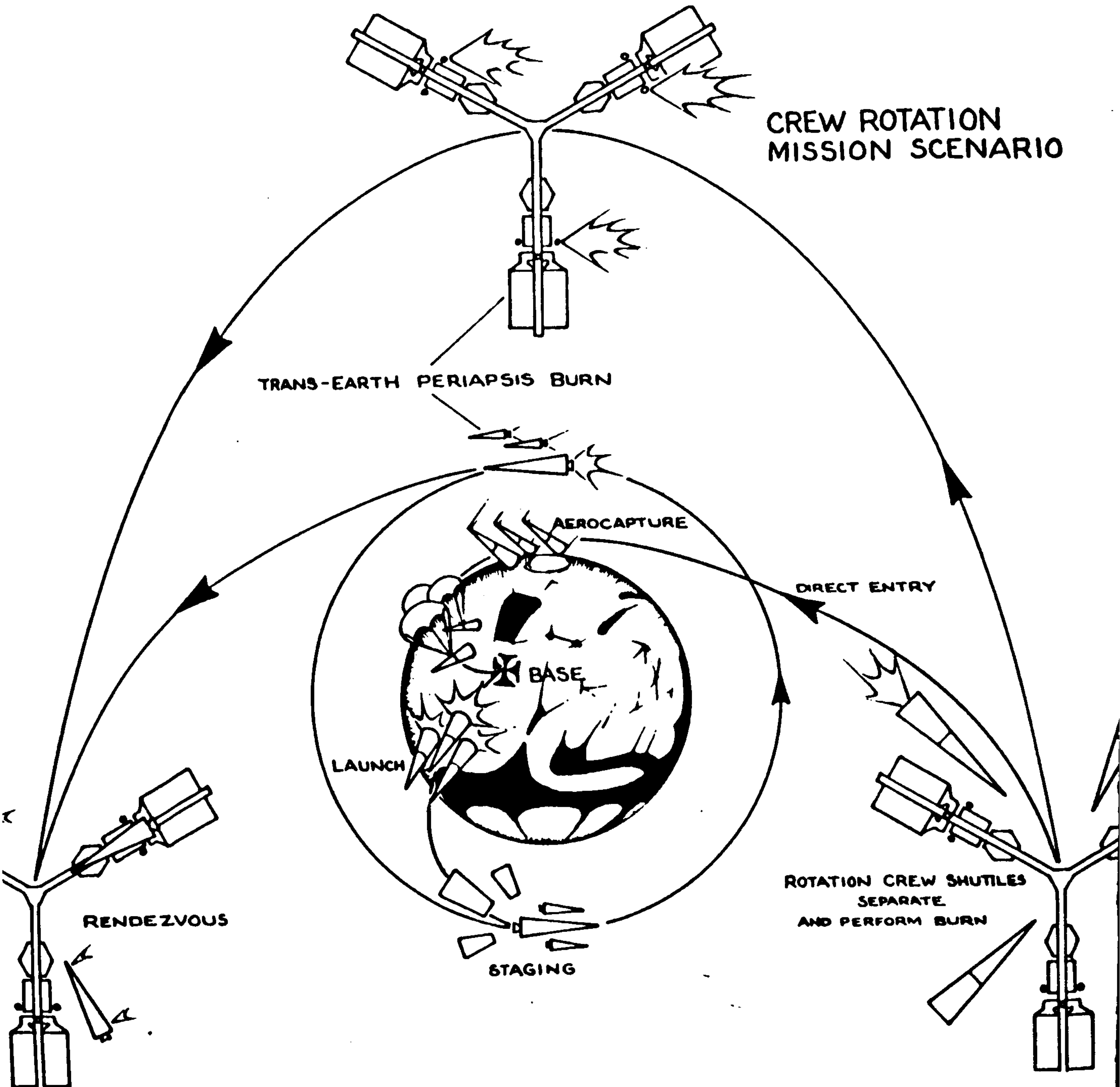
T +2 days -- Rendezvous of three Interplanetary Spacecraft.

T +3 days -- Assembly of Interplanetary Spacecraft into triangular configuration. (Interplanetary Assembly)

T +3 to 8 days -- Check-out and spin-up Interplanetary Assembly.

B. CRUISE PHASE - Outbound

T +8 days to 6 months -- During the cruise phase to Mars, Crew Shuttle is used for solar storm cellar. Also, the volume of the shuttles will be used for secondary living space, and as simulators for landing training. Interplanetary Assembly cruises in 1/3 g spinnning mode for 6 month transit time.


CREW ROTATION
MISSION SCENARIO
TRANS-EARTH PERIAPSIS BURN
AEROCAPTURE
DIRECT ENTRY
BASE
LAUNCH
RENDEZVOUS
STAGING
ROTATION CREW SHUTTLES
SEPARATE
AND PERFORM BURN

C. MARS ENCOUNTER PHASE

Mars Encounter (M.E.) minus 7 days -- Despin Interplanetary Assembly.

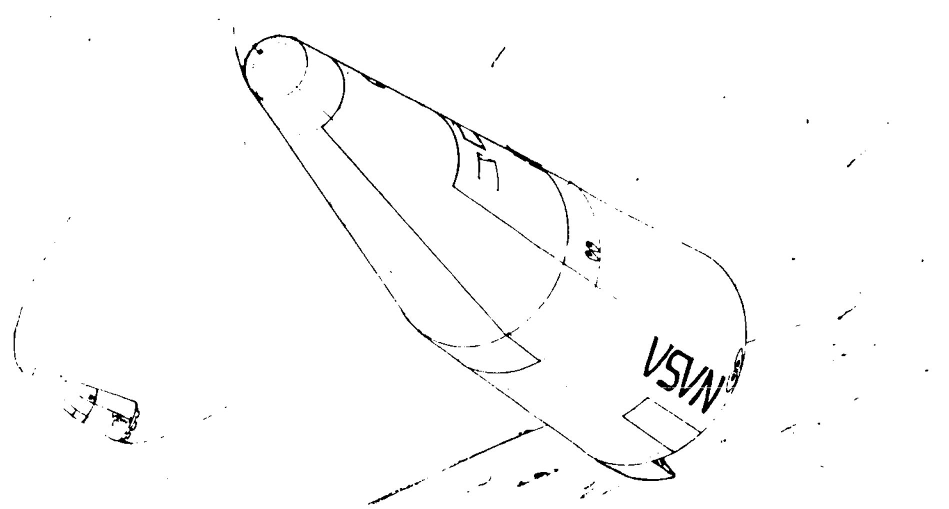
M.E. minus 3 days -- (Resupply Missions) Returning Crew Shuttles (none on first mission):

A. Take off from Mars Base, drop first ascent stage when spent, and go into large elliptical parking orbit.
B. Shuttles do plane changes and final preparation for return injection at M.E. minus 3 days to M.E. minus 1 day.

M.E. minus 2 days -- Incoming Mars Crew Shuttles - final checkout and detachment from Interplanetary Assembly.

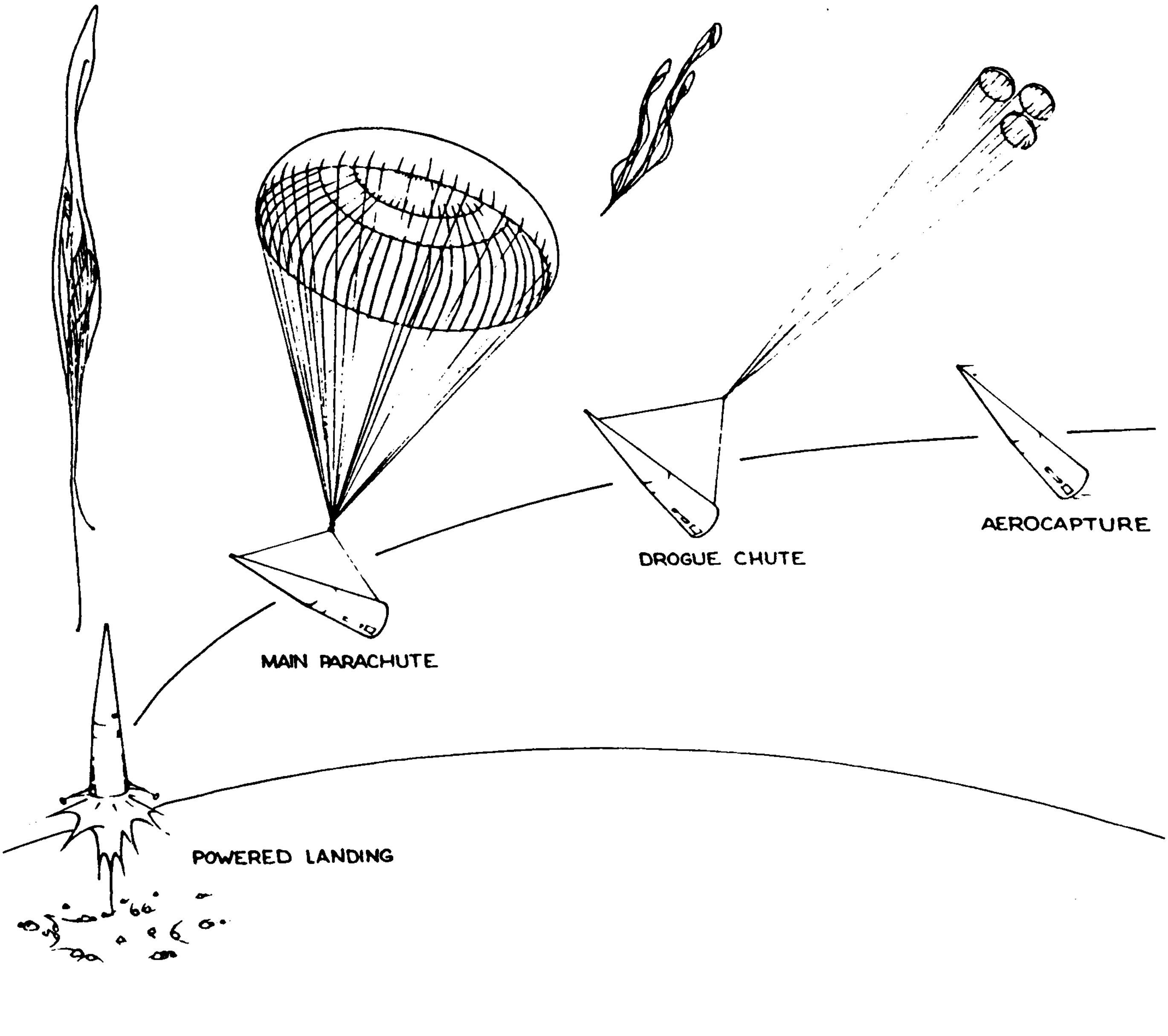
Mars Encounter --

A. Periapsis burn by Interplanetary Assembly engines to put it into Earth return trajectory.
B. (Resupply Missions) Return injection burn by returning Mars Crew Shuttles (after confirmation of successful powered flyby maneuver of Interplanetary Assembly).



Crew Shuttles entering Mars' atmosphere -- Artist-Carter Emmart

CREW SHUTTLE/CARGO LANDER DESCENT SEQUENCE



C. MARS ENCOUNTER PHASE (continued)

M.E. plus 1 hour -- Incoming Mars Crew Shuttles enter and land (for first mission only or bad weather at Base: aerocapture into orbit).

A. Final site selection by orbiting shuttles (first mission only) 1-2 days.
B. Deorbit burn (first mission only or weather contingency).
C. Atmospheric entry deceleration to Mach 2-3.
D. Ballute or drogue chute deployment.
E. Main parachute deployment - slow to 100 m/sec.
F. Parachutes jettisoned (after landing engines fire).
G. Maneuvering to soft landing using landing engines (same engines as the first ascent stage).

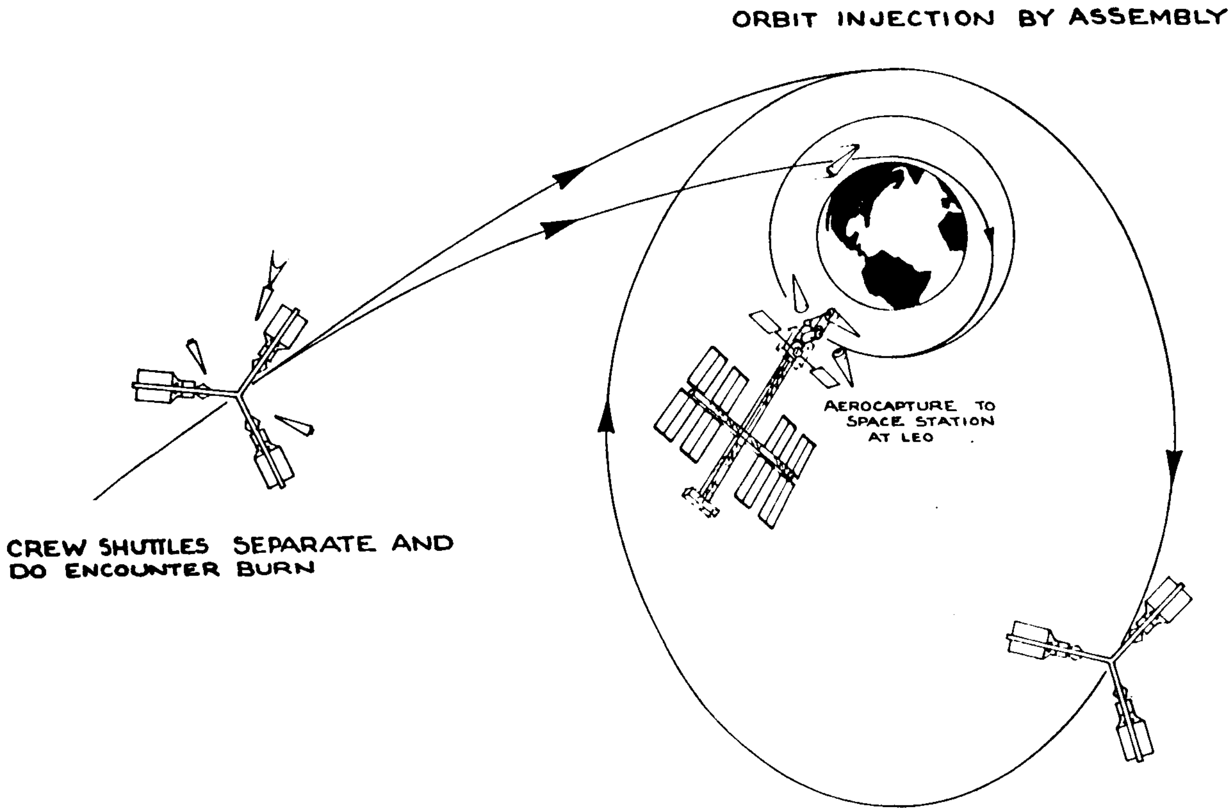
M.E. +1 hour to 2 years -- Crew departs Mars Shuttles and builds base. Mars Crew Shuttles are refueled (CO-O_2 propellant) with Mars resource extractor over the next two years.

M.E. +1 day - For first mission only - Cargo Landers on Type I trajectories arrive and land within 2 km of base shortly after Crew Arrival.
For subsequent missions, cargo vehicles may come on both Type I & Type II trajectories to spread out arrival times.

M.E. +2 days - (For resupply Missions) Rendezvous and docking of returning shuttles with Interplanetary Assembly.

M.E. +2 days to 10 days - (For resupply Missions) Check-out and spin-up Interplanetary Assembly.

RETURN TO EARTH



D. CRUISE PHASE - Return

M.E. +10 days to 20-30 months -- Interplanetary Assembly - cruise for 20-30 month return trajectory (Type IV).

E. EARTH RETURN AND CAPTURE PHASE

Earth Encounter (E.E.) minus 10 days -- Despin Interplanetary Assembly.

E.E. -2 days -- (Resupply Missions) Final checkout and detachment of Crew Shuttles from Interplanetary Assembly. Interplanetary Assembly splits into three Interplanetary Spacecraft components.

Earth Encounter -

A. Orbit injection burn or aerocapture of Interplanetary Spacecraft engines into 48 hour or larger orbit.
B. Crew Shuttles aerocapture to low orbits and rendezvous with Space Station.

E.E. +1 to 8 weeks -- Interplanetary Spacecraft circularize orbits.

E.E., + 8 weeks until next mission starts -- Rendezvous Interplanetary Spacecraft with space station and refurbish for future use.

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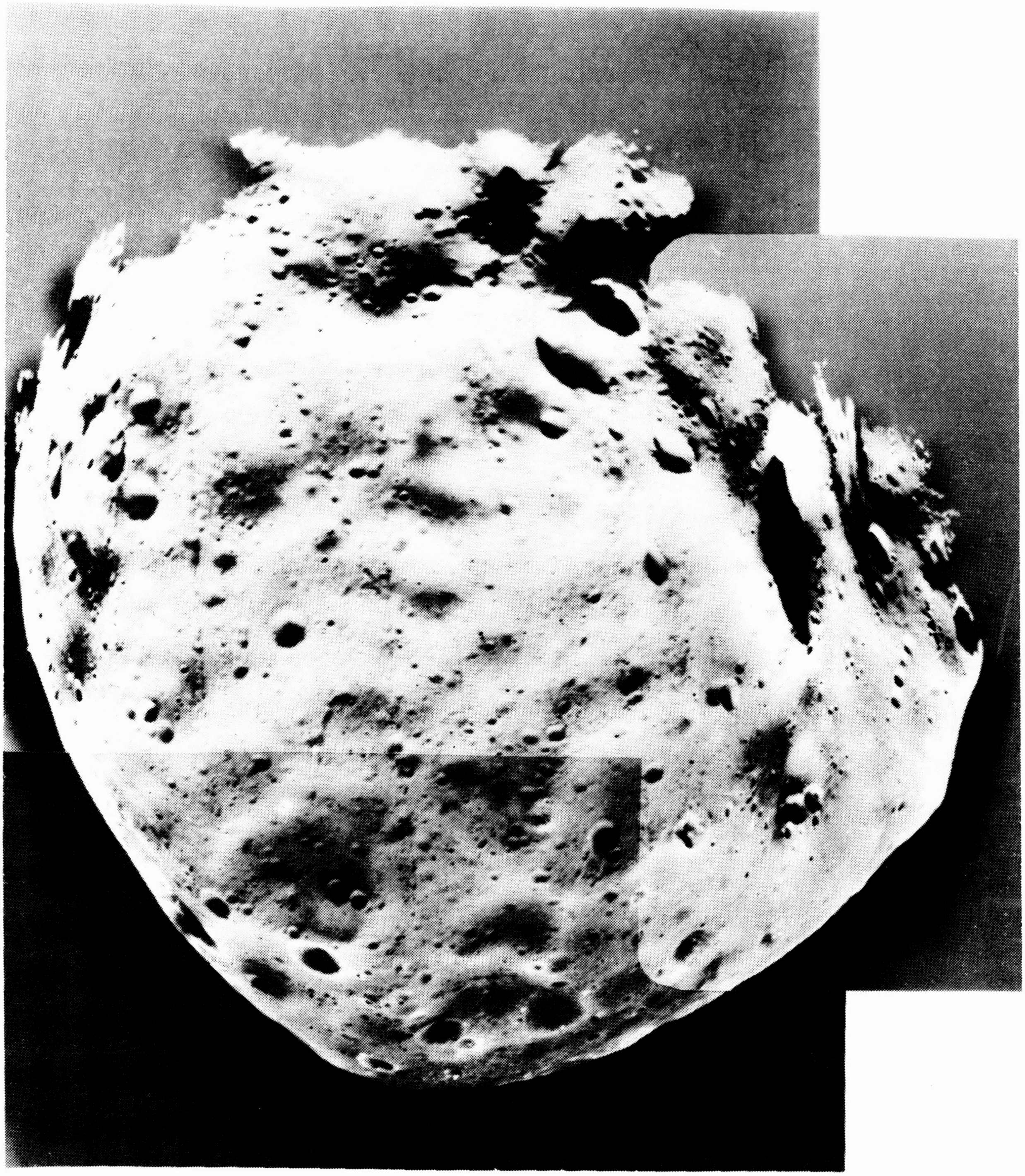
OF POOR QUALITY



Phobos -- Viking Photo

APPENDIX B --
PHOBOS/DEIMOS PRECURSOR MISSION

I. WHY PHOBOS/DEIMOS FIRST?

A. SCIENTIFIC REASONS

* Basic science of asteroidal bodies
* Origin of Solar System
* Use of teleoperated rovers to explore the Martian surface for a thorough reconnaissance of Mars before committing to manned landing on the surface.
* Sample return could be analyzed on Phobos or Deimos Base to determine need for other experiments or to direct other sample collection.
* Protects against forward contamination of Martian surface. Allows testing of Martian materials to assess probability of back contamination of Earth.
* Two missions for the price of one: Mars sample return and asteroidal sample return from satellites.
* Maximizes scientific return better than any other <u>single</u> manned mission.
* Best scientific precursor giving sample return for optimal base site selection.

B. ECONOMIC REASONS

* Takes less fuel to go to Phobos or Deimos than Mars' surface.
* Takes less fuel to go to Phobos than the Lunar surface.
* Much more equipment could be taken for the same cost.
* Can leave equipment in orbit for reuse later.
* Possibility of fuel manufacturing on Phobos or Deimos.
* Good for testing asteroidal mining missions.

II. NEEDED PRECURSOR MISSIONS/DEVELOPMENTS

* Mars Observer Mission (c.1990)
* Phobos/Deimos penetrator mission
* Space Station assembly facilities

III. PHOBOS/DEIMOS MISSION OUTLINE

A. FIVE VEHICLES SENT TO MARS VICINITY

- TWO HABITABILTY MODULES (60 TONS EACH)
- DEIMOS BASE MODULE (40 TON FUEL PROCESSING & LAB MODULE)
- PhD SCIENCE MODULE (40 TONS SCIENTIFIC EQUIPMENT)
- MARS BASE MODULE (40 TONS FOR MARS LANDING)

B. USES ORBITAL TRANSFER VEHICLES (OTV) - OFF-THE-SHELF TECHNOLOGY

C. REFUELING AT DEIMOS AND RETURN IN HABITABILITY MODULES

D. RESOURCES LEFT AT DEIMOS (OR PHOBOS):

- 90 TON/YEAR FUELING STATION
- 2 MARS OTV's
- 1 EXTRA OTV STAGE
- CONTROL STATION AND LIVING QUARTERS
- 100 kW SOLAR POWER ARRAY
- 2000 kW SOLAR FURNACE
- 60 TONS OF N_2O_4/N_2H_4 FUEL

E. RESOURCES LEFT ON MARS:

- AIR SEPARATION PLANT (11 TONS/YEAR)
- WATER COLLECTION (18 TONS/YEAR)
- REUSABLE ROVERS
- 50 kW SOLAR POWER ARRAY
- MISCELLANEOUS OTHER SUPPLIES

IV. TECHNOLOGY DEVELOPMENTS REQUIRED FOR PHOBOS/DEIMOS MISSION

* Aerocapture vehicles
* Improved automated mining and processing equipment
* Mars lander vehicle
* Mature Orbital Transfer Vehicle
* Penetrator probes
* Greatly improved life support systems

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15. Supplementary Notes

16. Abstract

~~This document describes~~ A program to establish a permanent scientific research base on Mars. ~~We present~~ A Mars base as the much needed long-term focus for the space program. A permanent base was chosen rather than the more conventional concept of a series of individual missions to different sites because the permanent base offers much greater scientific return plus greater crew safety and the potential for eventual growth into a settlement.

The Mars base will strive for self-sufficiency and autonomy from Earth. Martian resources will be used to provide life support materials and consumables. The Martian atmosphere will provide a convenience source of volatiles: CO_2, N_2, and water. Rocket propellant (for returning vehicles), fuels, breathable air, ~~and~~ fertilizers will be manufactured from Mars air. Food will be grown on Mars using Martian materials as plant nutrients.

A permanent human presence will be maintained on Mars beginning with the first manned landing via a strategy of crew overlap. This permanent presence will ensure safety and reliability of systems through continuous tending, maintenance, and expansion of the base's equipment and systems.

A permanent base will allow the development of a substantial facility on Mars for the same cost (in terms of Earth departure mass) as a series of temporary camps. A base equipped with surface rovers, airplanes, and the ability to manufacture consumables and return propellant will allow far more extensive planetary exploration over a given period of years than would approaches featuring a series of short exploration missions such as the Apollo Moon program.

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