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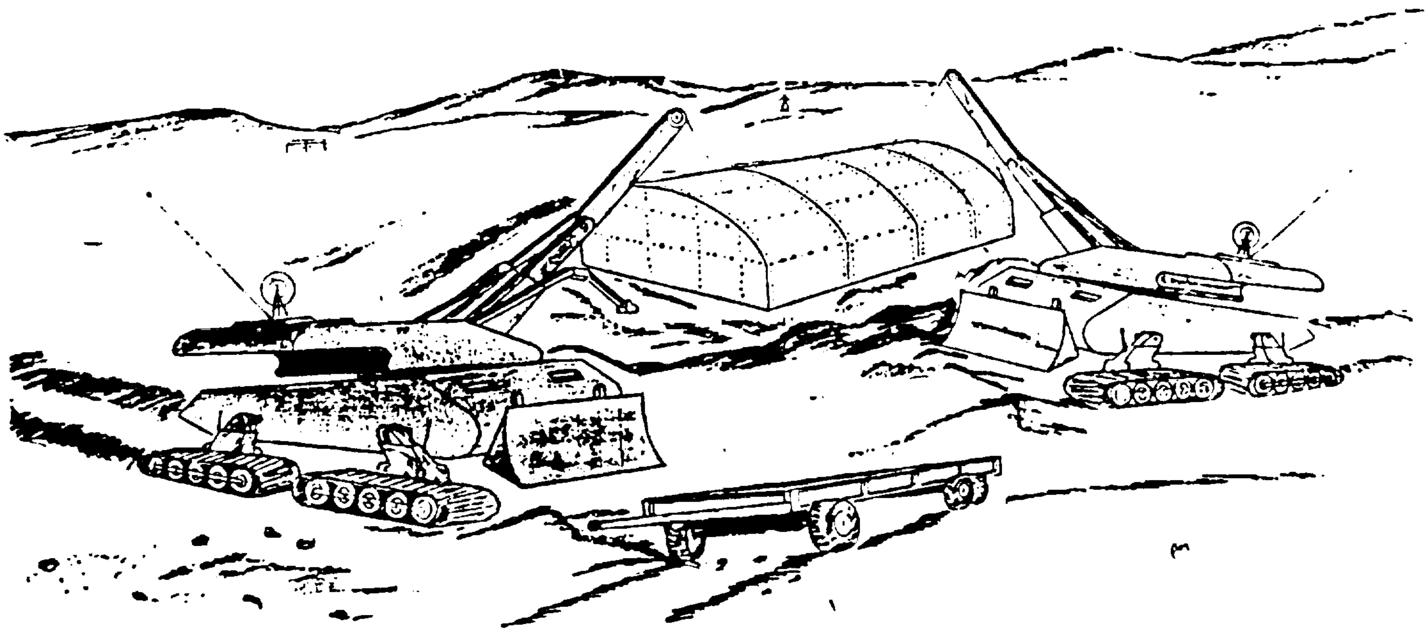
M.I.N.G.

MARS INVESTMENT FOR A NEW GENERATION



ROBOTIC CONSTRUCTION OF A PERMANENTLY MANNED MARS BASE

FINAL REPORT

MAY 1, 1989

FINAL REPORT FOR THE ROBOTIC CONSTRUCTION OF A PERMANENTLY MANNED MARS BASE

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ABSTRACT

This is the final report on the research sponsored by NASA/USRA (University Space Research Association) in conjunction with the University of Texas at Austin Senior Design Program. M.I.N.G., the Mars Investment for a New Generation, has outlined in this report the basic procedure in which to robotically construct a manned Mars base. The reseach procedure was divided into three areas: Environment, Robotics, and Habitat. The results are as follows.

The base as designed will consist of these components: two power plants, communication facilities, a habitat complex, and a hanger, a garage, recreation and manufacturing facilities. The power plants will be self-contained nuclear fission reactors placed approximately 1 km from the base for safety considerations. The base communication system will use a combination of orbiting satellites and surface relay stations. This system is necessary for robotic contact with Phobos and any future communication requirements.

The habitat complex will consist of six self-contained modules: core, bioshpere, science, living quarters, galley/storage, and a sick bay which has been brought from Phobos. The complex will be set into an excavated hole and covered with approximately 0.5 m of "sandbags" to provide radiation protection for the astronauts. The recreation, hangar, garage, and manufacturing facilities will each be transformed from the four one-way landers.

The complete complex will be built by autonomous, artificially intellegent robots. Robots incorporated into our design are as follows: Large Modular Construction Robots with detachable arms capable of large scale construction activities; Small Maneuverable Robotic Servicers capable of performing delicate tasks normally requiring a suited astronaut; and a trailer vehicle with modular type attachments to complete specific tasks; and finally, Mobile Autonomous Rechargeable Transporters capable of transferring air and water from the manufacturing facility to the habitat complex.

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1.0 INTRODUCTION

This document is the final report summarizing the research efforts completed by the M.I.N.G. Coorporation (Mar's Investment for a New Generation) on the design of a robotically constructed Mars base. Outlined in this section are the project background, design objectives, and design groundrules and assumptions. Subsequent report sections cover construction plan considerations which have been divided into three technical groups: environment, robotics, and habitation. Recommendations and a summary section are included which present design results. A management overview is presented which details company structure and reviews the plan of attack in fulfilling the RFP (Request for Proposal) requirements. Finally, a cost analysis section briefly shows the cost material of the design effort.

1.1 PROJECT BACKGROUND

The reasons for establishing a permanently manned Mars Base are numerous. Primarily, human presence on Mars will allow utilization of new resources for the improvement of the quality of life on Earth, allowing for new discoveries in technologies, the solar system, and human physiology. Such a mission would also encourage interaction between different countries increasing international cooperation leading to a stronger unification of mankind. Surface studies of Mars, scientific experiments in multiple fields, the search for new minerals and natural resource production are more immediate goals of the Mars mission. Finally, in the future, colonization of Mars will insure man's perpetual presence in the universe.

Establishing a base on Mars as opposed to another planet is due to its proximity to Earth as well as being the most habitable planet other than Earth. Mars has most of the elements necessary for human survival, including carbon dioxide as well as water. Temperature variations also are similar enough to Earth to allow for a permanent manned Mars establishment.

Robotic construction is a feasible alternative to human construction of the Martian base. The Martian atmosphere does not provide adequate radiation protection, and the harsh environment makes it extremely difficult for humans to work efficiently and safely. Bulky space suits are not suitable for construction tasks. Robots can easily operate under these Martian conditions and would also be more efficient at large scale construction activities. Robots don't require the life support and are capable of repairing each other.

1.2 DESIGN OBJECTIVES

The objective of the M.I.N.G. Corporation in this design effort was to present a feasible, cost effective plan for the construction of a permanently manned Mars base which would be completed entirely with robotics. Design developments incorporating new and envisioned technologies were an important aspect of our design effort. Identification of driving technologies was another important aspect of our project and has been included in its own section under recommendations.

1.3 PROJECT GROUNDRULES AND ASSUMPTIONS

A set of groundrules have been established to narrow the scope of the design effort. These initial assumptions specify the course of our design work in detailing available and existing resources within the base construction time frame.

* A fully operational lunar base will be a major assumption of this design effort. A lunar base is necessary to study the variety of technological problems of man in space.

* Long term living in space will be assumed to have been studied over the course of Space Station, Moon Base, and Phobos missions, thereby answering most questions on human habitation in space. These known solutions can then be easily applied within the framework of the Mars Base.

* Precursor accomplishments assumed by that design, such as the existence of a Heavy Lift Launch Vehicle, a Space-Docking facility in

Low Earth Orbit, and efficient Orbit Transfer Vehicles are likewise presumed. Additionally, following the evolutionary expansion into space, the design will assume that a man-tenable facility is in existence at Phobos.

* Manned missions to the Martian System have starting dates ranging from an optimistic year of 2020 through a pessimistic date of 2045. This time frame, posed 30 to 50 years into the future, allows for huge gains in technological development which may facilitate the design effort.

* Construction of the manned facility will be completed almost exclusively through the use of advanced robotics. If unforeseen problems do arise, human supervision will be available from the Earth, moon or Phobos for reprogramming or teleoperation.

* The facility will accommodate an initial crew size of six to eight members. Small crew sizes minimize mass requirements. However, a larger crew results in fewer interpersonal difficulties and a better distribution of the work load.

* The Mars base will utilize components of the Phobos base, such as the sick bay and exercise equipment. The base will also be designed to allow for unlimited expansion due to the permanently manned base objective.

* Necessary teleoperations will be undertaken from the operational Phobos Base. Communications satellites positioned by the Phobos installation will be used for Phobos-Mars and Earth-Mars communications.

* All Martian equipment should be thoroughly tested in a simulated Martian environment on Earth.

2.0 LANDINGS AND ORDER OF OPERATIONS

The objective of Mars Investment for a New Generation (M.I.N.G.) was to design a permanently manned robotically constructed base on Mars. Research completed during the contract period led to the development of what M.I.N.G. considers the optimum design for this task. This section presents a comprehensive overview of the order of operations required to construct a Martian base as laid out by M.I.N.G. Also included is a schedule of landings on Mars with details of work to be achieved during the intervals between landings.

As stated previously, Mars base construction will begin only after the base established on the Martian moon Phobos has become operational. A team of specialists will be present on Phobos during the entire construction period monitoring progress and providing teleoperation assistance as necessary. However, unless serious problems arise, men will not be going to the surface of Mars until the base is entirely completed.

The automated construction process will be completed within a maximum time period of 60 days, which is a design safety limit of human stay-time on Phobos. Due to the modularity of the design, each step can be extensively tested and improved in multiple test scenarios by the construction team, the robots, at locations on Earth. This will insure that each robot is capable of completing its required task. To correct problems encountered by the robots or faults in the design, a period of up to two years may be required for simulated test cases on Earth before actual mission engagement.

2.1 INITIAL LANDING

The first landing on the Martian surface assumes that all the necessary unmanned probe work has been completed; and, significant mapping has been provided to the robots. This mapping will provide the robots with working knowledge of the terrain before disembarking from the lander. The first landing will serve as an initialization phase of the Base construction. The one-way lander, which is described in more detail in the report from Startruck, will carry as its cargo: the robots along with their attachments, a trailer with its attachments, the base power sources, and the communications equipment. Plans call for three Large Modular Construction Units (LMCUs) and two Small Maneuverable Robotic Servicers (SMRS) with a variety of multi-purpose attachments (see Section 4.0 for more details on the robots).

From the preliminary mapping, the overall scope of the base area will be known. Figure 2.1 shows the projected layout the completed base. The first heavy lander will set-down at the edge of the projected landing area where it will remain permanently serving its new purpose as the unpressurized garage. This structure will house the robots, their attachments, their recharging power connections, and a robotic servicing area.

Once on the ground, the robots will be able to disembark from the lander via a ramp. Their immediate tasks after system checks and local mapping will be to clear the areas for the communication system and two power plants. They will also install necessary lighting equipment to be used to supplement future work. Once accomplished, one large unit and one small unit will use the trailer to transport a power system to its permanent location. Another set of robots will be available to move the communications set up to its location. Upon arrival to the site, the unit will be positioned properly, and the small dexterous robot will complete any necessary checks and tests. Direct link cables will be run from the communications and power set-ups to the lighting fixtures and the lander, which will be used as the service garage from that point on. One power unit and the communications link which will maintain communications with Earth and the Phobos base will be activated. Until the point of permanent communication's receiver set up, Phobos communications will be conducted via the onboard communications equipment of the lander itself. The robots, capable of communicating to one another, will also be able to communicate to Phobos through the satellite link which will transmit signals to the orbiting satellites, installed during the Phobos base construction. Meanwhile, the remaining power unit set-up can be achieved by the third robot. This station will remain un-activated until the base module units have arrived.

At this point, one LMCU (Large Modular Construction Unit) will systematically begin clearing a landing area and then proceed to clear the area required for the manufacturing facility. The remaining two LMCUs will begin the necessary controlled explosive work needed to clear the area required for

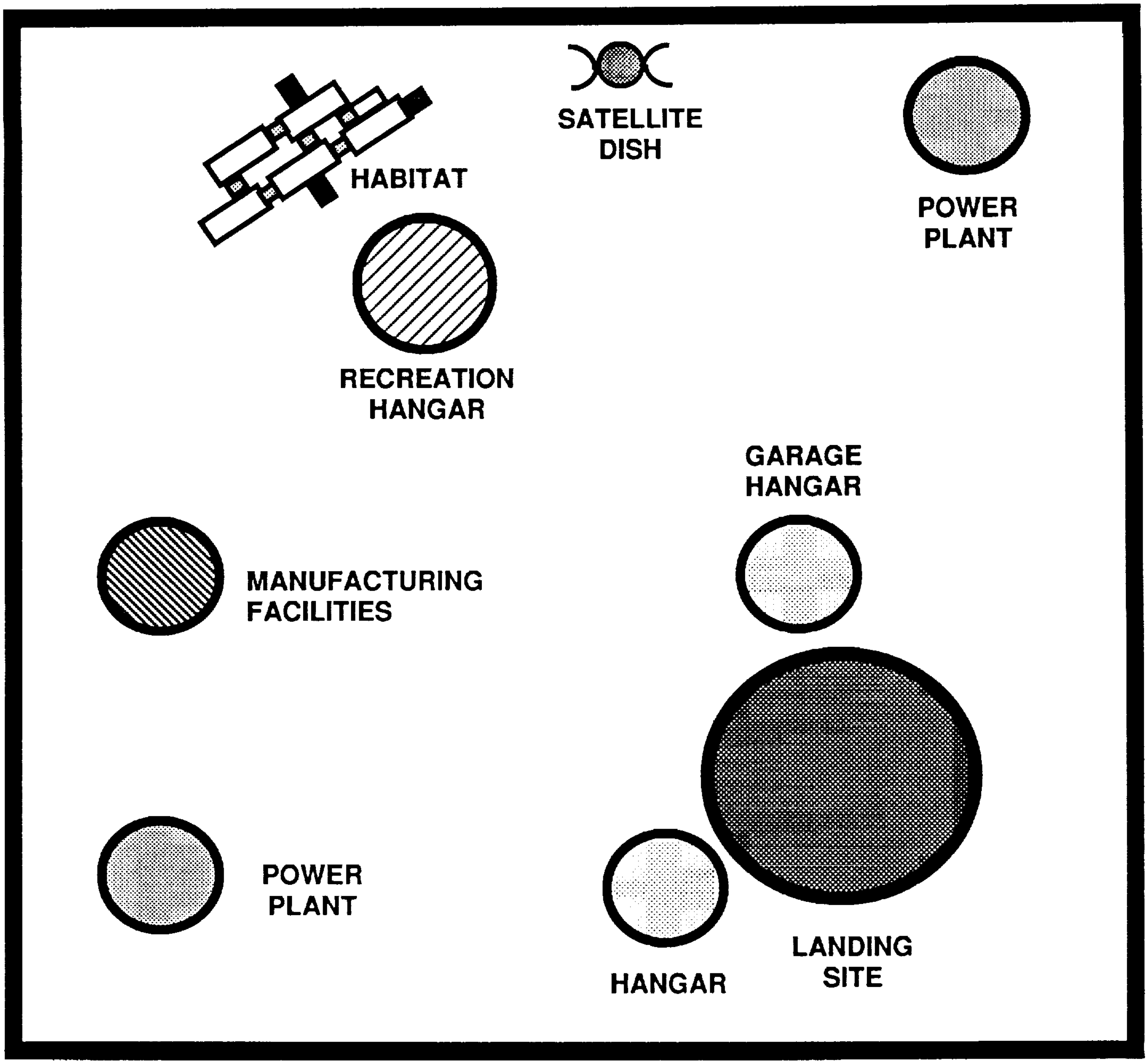


FIGURE 2.1 - BASE LAYOUT

partial burial of the modules. The explosives will be set with exact soil composition taken into consideration. The area will have sloping edges and will measure approximately 42 m X 14 m X 1 m. After detonation of the explosives from a safe distance, the robots will begin clearing the area and leveling the newly formed excavation with a laser ground-leveling type system similar to conventional equipment in use on many farms today. One larger unit will then set-up the trailer sand bagging attachment, while the smaller units load and initialize the apparatus and begin its operation. The sandbags will be used to cover the module to protect the inhabitants from harmful radiation. When the module area leveling and clearing is completed, the next landing is ready to begin.

2.2 LANDINGS II AND III

The landings in this section will be for the purpose of bringing prefabricated self-contained modules to the surface. Landings II and III will consist of one-way landers and will house three modules at a time. The landings will need to be separated only by the time required to unload the modules. Each will again take place at some perimeter area of the landing site as the one-way landers will remain permanently at the base. An empty lander will later serve as a long-term service area for future landers. The second lander will carry two modules, with additional space filled with emergency fuel and empty fuel tanks to be used on future missions. The lander will be unpressurized; however, an inflatable pressurized structure will be on the inside of the lander to make it usable as a recreation facility for the base.

The modules will be removed one at a time by at least two LMCUs due to their size and weight. Placed in the trailer and hauled to the site, the two LMCUs will locate the module in its position as shown in the conceptual drawing, located on the cover. This will begin an iterative process described as follows: a module will be located (following layout pattern shown in Figure 5.2), the adjoining node will be placed in its proper position, aligned exactly by the smaller robotic units, and locked into place by a type of lever locking system.

As this process is developing, the third LMCU will be running the cables from the communications system and power stations. The cable can be buried with a robotic attachment with connections made by the SMRS once the modules are in location. As soon as the two robots finish module set-up, they must go to receive the manufacturing facility.

2.3 LANDING IV

In the space which has been cleared for the manufacturing facility, the last of the one-way landers will land carrying its cargo, equivalent in mass and size to about three of the modules. This facility will be modularized for future expansion and will immediately be able to begin air and water production upon connection to the power units.

The MART (Moble Autonomous Rechargeable Tanks) will be a type of robot, less sophisticated than the other robots, but capable of carrying within itself the compressed air and water required for an entire base complex. This unit will be first programmed by the SMRS with the best path to the modules and then will be able to travel independently of the modules whenever required. Its first duties will be to transport the air for the five modules to the base location and inject the compressed air into the complex.

The robots will now begin the final phase of the module installment. One of the SMRS will now enter the modules and lock the second lock of the nodes from the inside. Each module will then be injected with colored air from the MART and pressurization will be conducted on one module at a time. Any air leakage can be detected by the outside robots. The necessary repairs can be initiated, and the process repeated until each module is pressurized. The biosphere module will be pre-pressurized as the organic materials inside will be growing and developing unattended on the long journey from the Earth system.

At this point, an extensive check of all base systems can be made to insure items were undamaged during transport. If damaged, steps must be taken to repair or seal off the afflicted area until the arrival of man to enact repairs.

By this time, the trailer-sandbagging attachment will have filled enough sandbags to cover each module. The available robots can then begin covering the modules with prepared sandbags in a predetermined fashion previously practiced on Earth. The Sick Bay from Phobos should be placed before the base is entirely covered.

2.4 LANDING V

The design of the Phobos base by Phobia calls for the inclusion of a Sick Bay, which after its use on Phobos, will later be used permanently on Mars. At this point in the Mars Base construction, the Sick Bay should be removed from Phobos. The base will be nearly completed and could already house men if an emergency arose on Phobos.

The Sick bay will be transported by the first of the reusable Mars to Phobos transportation ships. This spaceship will be capable of carrying at least one module at a time for future base expansion. The ship will land in the cleared landing area, and one of the robots will immediately transport the Sick Bay to the module area on the trailer vehicle. It will be placed like the other modules, and the nodes will lock it into its permanent location.

The robots will finish covering the module and additional system checks will be completed. The robots will attend to other tasks such as additional clearing and may begin some scientific exploratory scouting.

Throughout the construction process, the robots should be undergoing extensive automated periodic self-tests to check for mechanical problems, and making repairs and replacements where necessary. The robotic operations are designed such that the total loss of up to three robots does not eliminate the base construction, however, it would delay the planned sequence to some extent.

At this point, construction of the Mars Base is complete. Astronauts from Phobos can immediately transport to Mars for some on-site expansion, or the base can have all essential elements shut down until such time as when the first permanent manned expedition is launched from Earth.

This essentially completes the design description of the base construction. In the following sections, extensive detail is taken to discuss all the various components of the base itself, as well as reasons for considerations implemented in the design.

3.0 ENVIRONMENTAL GROUP

In this section, the design decisions concerning base location, manufacturing facilities, and the power for the complex will be presented. The basic criteria that influenced the design decisions will be stated. In addition, the recommendations for the geographic location, types of manufacturing and power requirements are discussed.

3.1 ATMOSPHERE AND CLIMATE

Table 3.1 shows the composition of the Martian atmosphere near the surface. As can be seen from the table, the main component is carbon dioxide (CO_2). Because of the abundance of CO_2, a cost effective approach to the production of breathable air, which is 21 percent oxygen, should involve the disassociation of oxygen from this CO_2. The oxygen could then be combined with other essential elements to produce the atmosphere for the habitat modules. However, due to the low concentration of nitrogen in the Martian atmosphere, it may be more cost effective to initially supply the base with nitrogen rather than extract it from the atmosphere.

TABLE 3.1
COMPOSITION OF THE ATMOSPHERE AT THE SURFACE

GAS	PROPORTION
Carbon Dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon Monoxide	0.07%
Water Vapor	0.03%
Neon	2.5 parts per million (ppm)
Krypton	0.3 ppm
Xenon	0.08 ppm
Ozone	0.03 ppm

The surface temperature of Mars is much lower than that of Earth. Temperatures at the surface of Mars depend on factors such as latitude, season, time of day, and surface properties. The temperatures are lowest just before dawn, rising rapidly in the morning to a maximum just after noon. The Northern and Southern hemispheres of Mars have different temperature variations due to the precessional effects, with milder temperatures in the North (Guest, et al.). The lowest temperatures occur at the South Pole during the winter, reaching as low as 148 K. The highest temperatures, at mid-latitudes in the Southern hemisphere, can reach 295 K. Because of the low temperatures, the robots which will construct the base should have sufficient insulation for any temperature sensitive equipment. Also, to a lesser extent, the base will require some insulation to retain heat.

One phenomenon of Martian weather that effects design decisions is the global dust storm. Originating in the southern hemisphere, dust storms on Mars can expand to cover much of the planet, and can last four or five months. The winds during these storms can reach 17 meters per second (m/s) with gusts of 26 m/s (Carr). Due to the low atmospheric density, the dynamic pressure due to these winds will be relatively low. Dust particles in the air, however, might have an adverse effect on radio wave transmission, thereby disrupting communication to and from the Martian surface. Also, with these storms, there is some shifting and buildup of particles similar to sand on Earth. Any surface structure must take into account this type of buildup around exposed structures. The amount of sand buildup will vary according to geographic location. Any openings, therefore, must have efficient seals to prevent sand from entering. This sand may lead to corrosion of any machinery or buildings which are exposed for long periods of time to the surface environment.

3.2 GEOGRAPHIC LOCATION

The location of the base should meet several requirements. These include:

* "Flat" area for landing facilities

* Traversable terrain from landing site to base construction site

* Stable ground (i.e.,low probability of landslides, lava flow, etc.)

* Relatively mild weather conditions (i.e., safe from extreme temperature variations, dust storms)

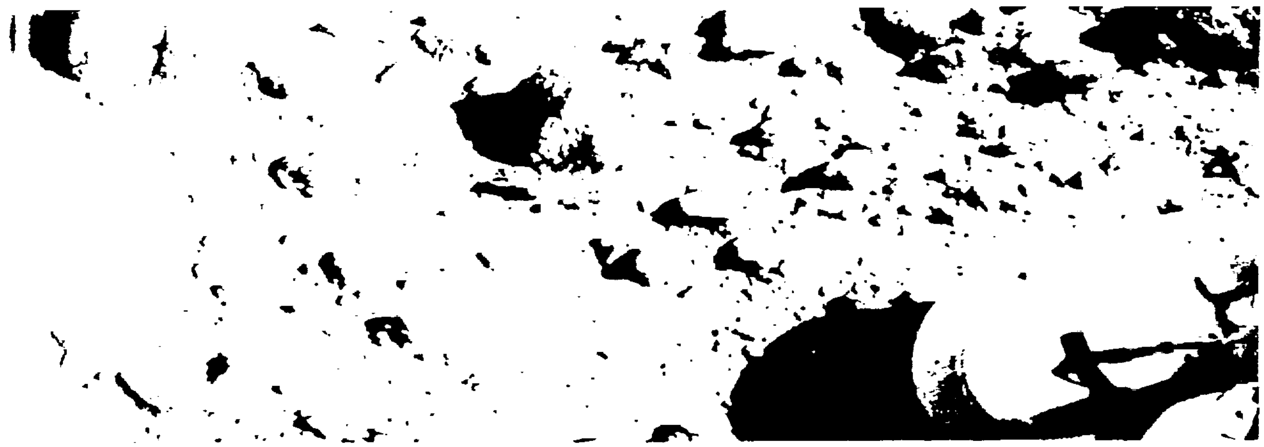
* Potential mineral and liquid oxygen (LOX) mining sites nearby

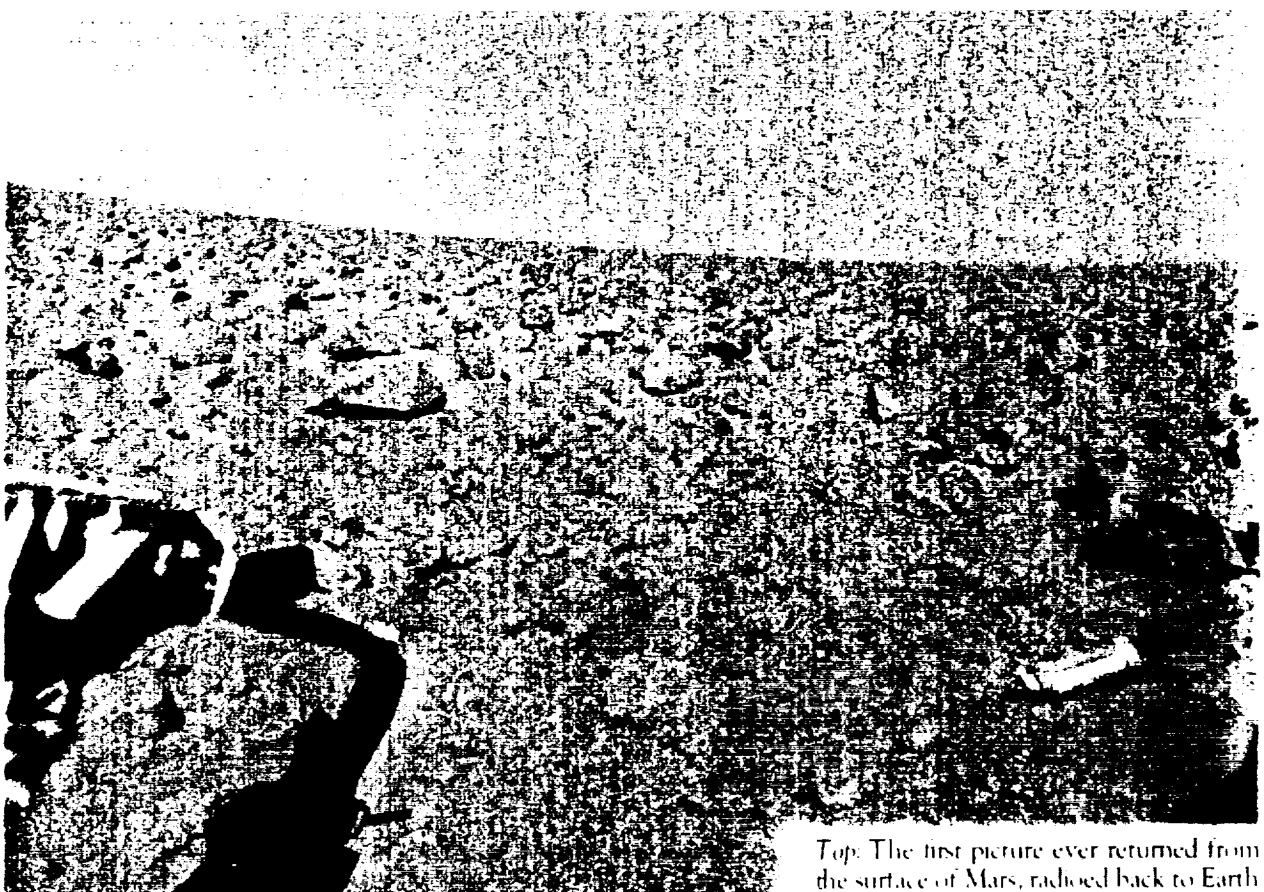
* Proximity to Tharsis Bulge

The Tharsis Bulge is a region of Mars where the average density is greater than that of the rest of the planet. Advantages of the Tharsis Bulge region are that gravity is slightly higher due to the greater density, and evidence suggests the possibility of large concentrations of water under the surface. The Tharsis Bulge lies between -20° and 50° latitude and from 70° to 150° W longitude.

Research indicates that the Northern hemisphere fulfills more of the basic requirements listed above than does the Southern hemisphere. Note also that a "flat" area is not necessarily smooth; the Martian terrain is cluttered with many sizes of boulders and smaller rocks. An example of this terrain can be seen in Figure 3.1, which shows a photograph of the landscape taken by Viking 2.

Due to the choice of habitat configuration, the options for the location of the base have been restricted. The choice of location must be a flat area large enough for landing, base construction, and future expansion. Several locations on Mars which meet the criteria were considered. These regions, determined from examining maps obtained from the U. S. Department of the Interior, in order of preference, are





Top: The first picture ever returned from the surface of Mars, radioed back to Earth on July 20, 1976. At right is a portion of landing pod 2, resting safely on the surface. Another landing pod was later found to be buried in sand. The vesicular rock at center is some ten centimeters across. *Bottom:* The landscape of Utopia, as viewed by Viking 2. The surface sampler arm is extending at left. Its metal shroud is the ejected cannister on the ground at right. Nothing resembling a living organism or an artifact of intelligence was found at either Viking landing site.

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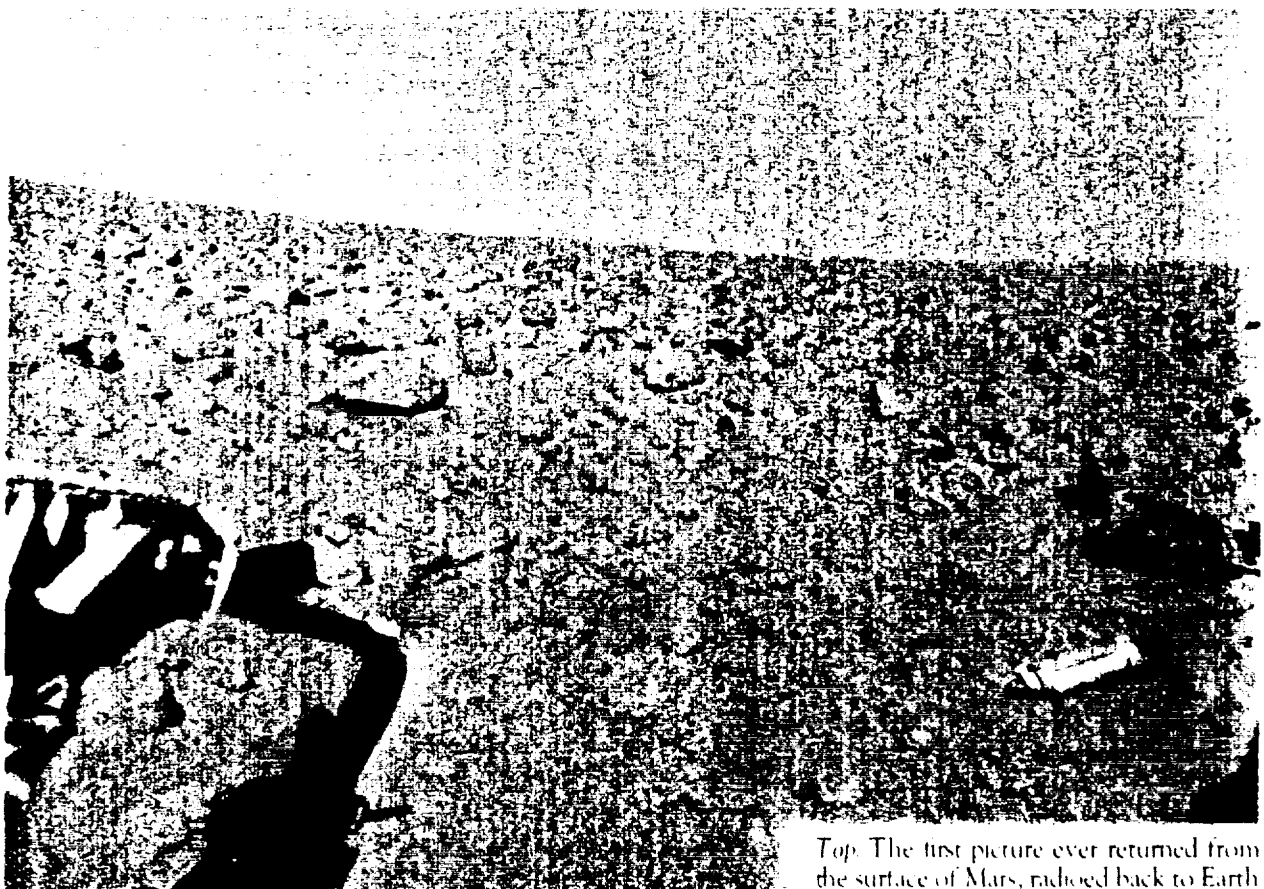
FIGURE 3.1 - PHOTOGRAPH FROM VIKING 2



Top. The first picture ever returned from the surface of Mars, radioed back to Earth on July 20, 1976. At right is a portion of landing pod 2, resting safely on the surface. Another landing pod was later found to be buried in sand. The vesicular rock at center is some ten centimeters across. *Bottom.* The landscape of Utopia, as viewed by Viking 2. The surface sampler arm is extending at left. Its metal shroud is the ejected cannister on the ground at right. Nothing resembling a living organism or an artifact of intelligence was found at either Viking landing site

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FIGURE 3.1 - PHOTOGRAPH FROM VIKING 2

(1) -5° to 5° Lat., 65° to 75° W Long.

(2) 10° to 40° Lat., 240° to 280° W Long.

(3) 20° to 50° Lat., 140° to 170° W Long.

The main advantage of the first location, shown in Figure 3.2, is its proximity to the equator, making access from a low-Martian orbit and communication with Phobos easier. This area, on the east edge of the Tharsis Bulge, is close to interesting geography such as the Lunae Planum and Valles Marineris. The Valles Marineris near this site along the equator extend 4,000 km with depths of 4 km at places. Significant information on the history of Mars could possibly be obtained by exploring these valleys. The main disadvantage of this site is that the valleys make landings more difficult and restrict long distance travel by land (Murray).

The next location being considered is shown in Figure 3.3. the main advantage of this location is that it is the largest of the regions being considered. Landing in the vicinity of the base and long distance travel by land would be easier in this large region. However, it is likely that this region is more subject to severe wind and dust storms, which result in constantly changing surface conditions, such as sand dunes or drifts. Furthermore, this location is not near the Tharsis Bulge.

The third location being considered is shown in Figure 3.4. This region is much larger than the primary location, but access to it may be complicated by the proximity of Olympus Mons, the largest mountain on Mars. This location is on the west edge of the Tharsis Bulge.

3.3 MANUFACTURING FACILITIES

To sustain life and maintain base operations with minimal support from Earth, Martian resources, shown in Table 3.2, must be utilized.

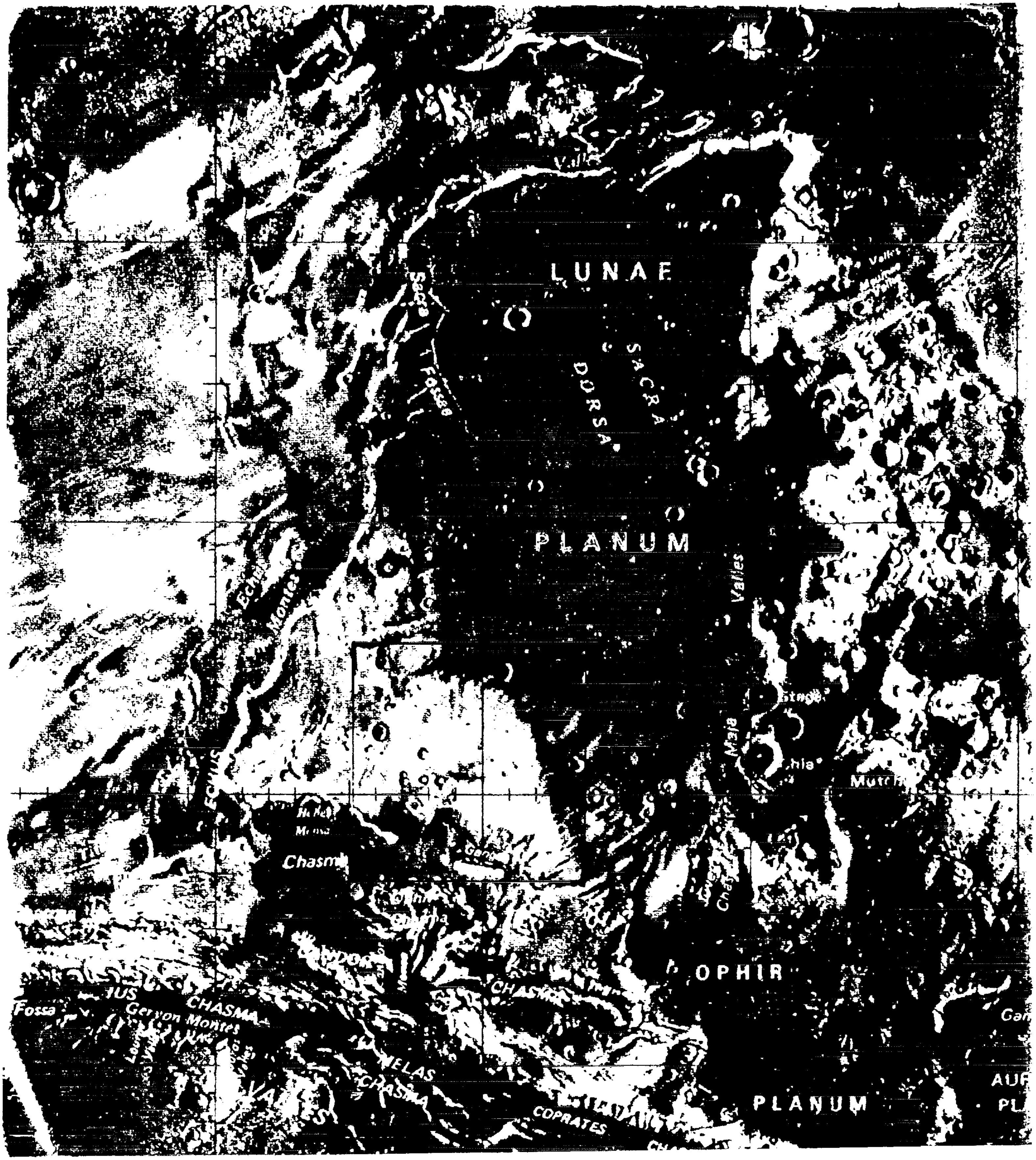

FIGURE 3.2 - PHOTOGRAPH OF FIRST CHOICE

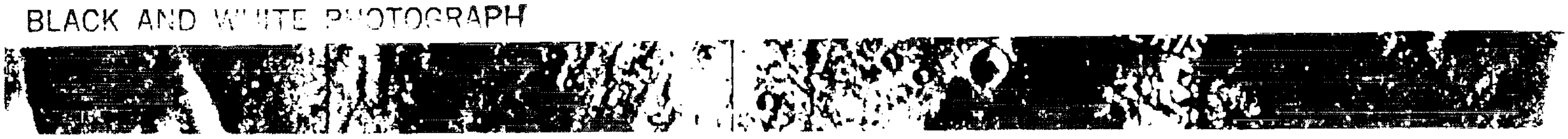

FIGURE 3.3 - PHOTOGRAPH OF SECOND CHOICE

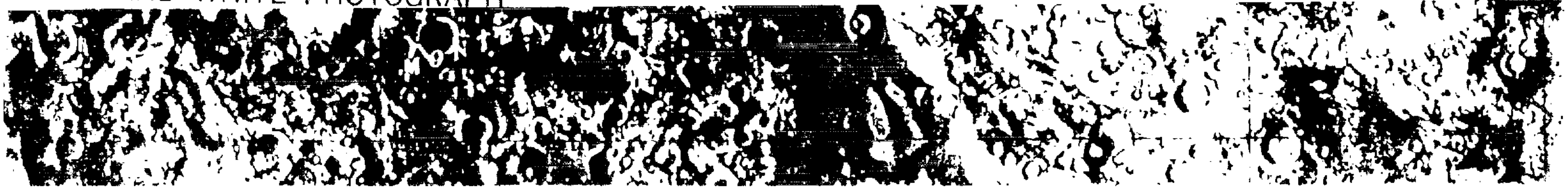

FIGURE 3.4 - PHOTOGRAPH OF ALTERNATE CHOICE

TABLE 3.2
COMPOSITION OF SURFACE SOIL SAMPLE

Oxygen	42%
Silicon	20%
Iron	13%
Ferrous oxide (rust)	19%
Traces of Mg, Ca, S, Al, Cl, and K	

Air and water are the principal needs of the base. The manufacturing facility (MF) should be placed above ground and approximately 0.5 kilometers (km) away from the habitat complex. The MF should be constructed in two phases. The first phase should consist of the initial manufacturing system which includes:

* Air and water production (AW)
* Recycling plant
* Experimentation facility
* Storage / expansion space.

A proposed configuration for this facility is shown in Figure 3.5. The systems within the facility should be built so that they can operate automatically, and any breakdowns can be repaired by the robots. A monitoring system with a malfunction indicator should be included as well as a system to let the robots know when or what types of raw materials (e.g. soil, rocks, ice or water) are needed. When humans land on Mars, the monitoring system should be transferred to the core module in the habitat complex. Since robots will be used

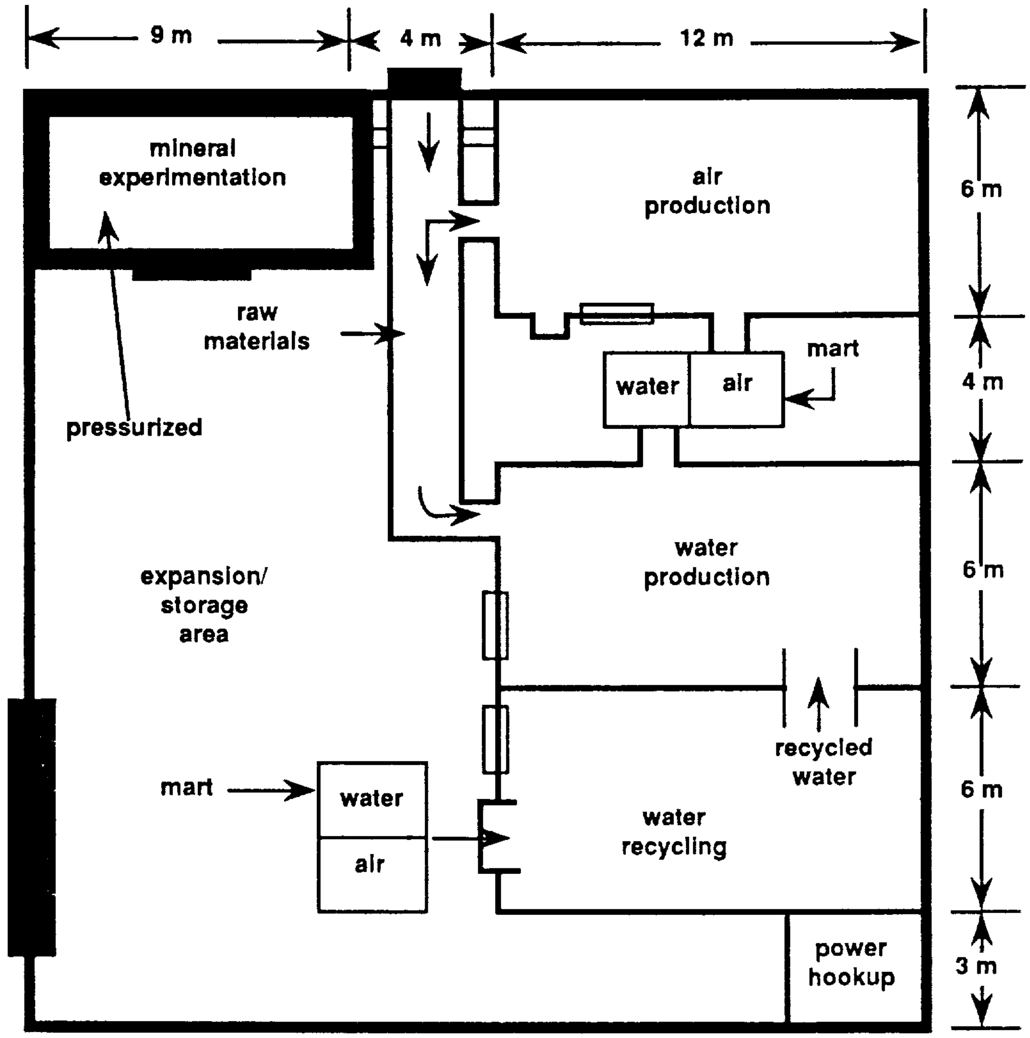

FIGURE 3.5 - MANUFACTURING FACILITY LAYOUT

in the building of the systems and any subsequent repairs, the machinery of each system must be spaced far enough apart to allow the robots room to maneuver.

If total power loss occurs, the AW and recycling system should be designed to operate at reduced power by rechargeable batteries. A periodic maintenance schedule to recharge and maintain the battery's power will have to be incorporated into the duties of the robots.

The raw materials (soil, water, or atmosphere) will enter the facility near the AW system. This door should be able to direct the raw materials to the AW production area. The material entering the AW system will be converted to both air and water for the astronauts. It is assumed that the technology required to construct and operate such a system will have been developed by the time of base construction. An example of a preliminary design of such a system can be found in "Design of a Surface-Based Factory for the Production of Life-Support And Technology-Support Products," (Prarie View A&M). The characteristics of the air to be produced for human use are shown in Table 3.3.

TABLE 3.3
AIR COMPOSITION

Element	**Partial Pressure**
O_2	22.7± 9 kPa
N_2	26.7 to 78.9 kPa
CO_2	less than .4 kPa
H_2O	1.00± .33 kPa (40% rel. humidity)

Once produced, the air and water should be stored in large pressurized tanks. One option to transport the air and water from the MF to its destination is to design the storage tanks as mobile, autonomous, rechargeable tanks (MARTs), shown in Figure 3.6. The mechanism for mobility of the MART would be similar to that of other robots designed to travel around the base. The

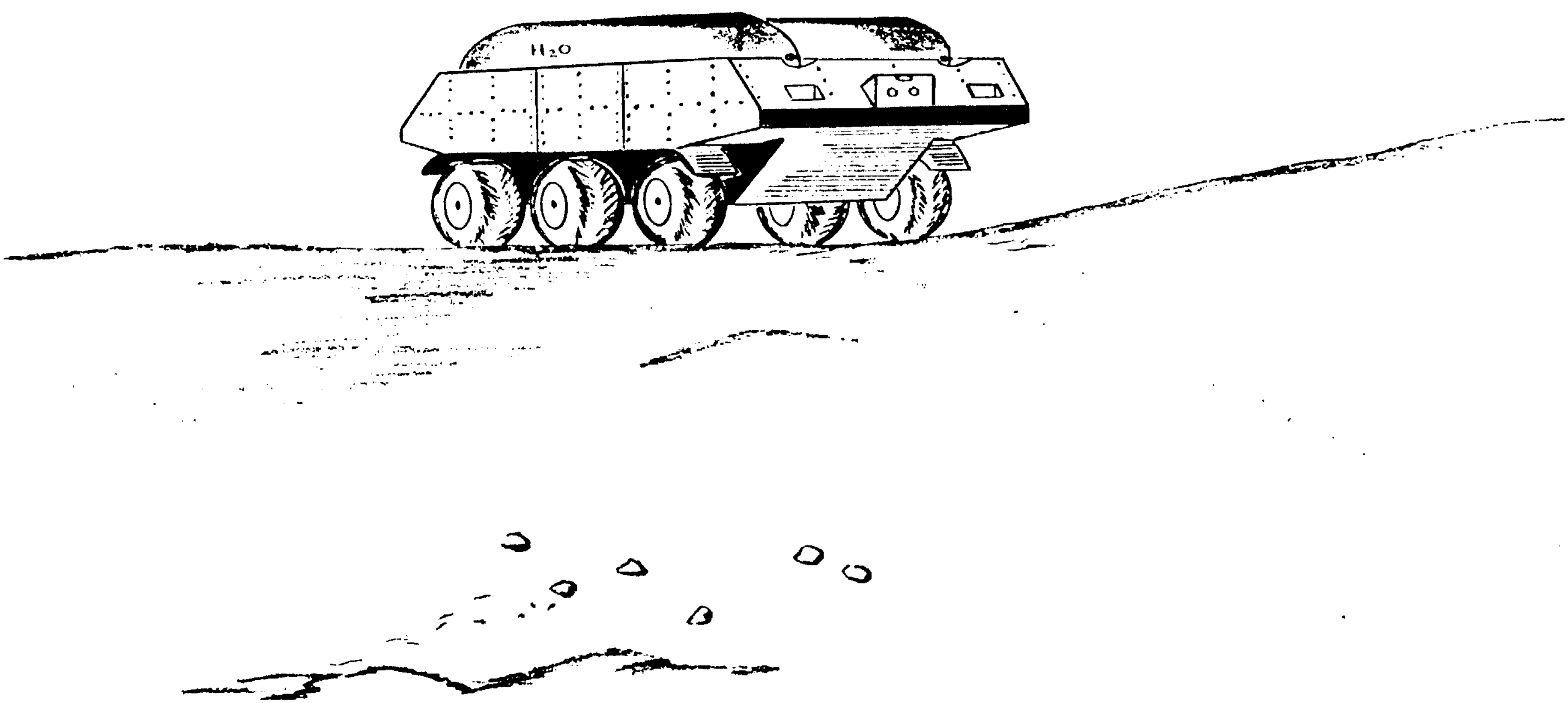

FIGURE 3.6 - MOBILE AUTONOMOUS RECHARGEABLE TANK

MART would have a microprocessor to allow for communications with the monitoring system of the MF to dispatch the MART without human intervention when base supplies run low. Each MART would contain both air and water tanks which would be pressurized. The minimum number of MARTs for an interim base would be four--one to supply air and water to the base, one to collect waste from the base, while another is refilled and recharged at the MF, and one to deposit collected waste into the recycling system. The air and water MARTs are not interchangealbe with the other MARTs and have different connecting interfaces. Additional MARTs would become necessary as the base expands and new facilities are added. The rate of rotation of these tanks will depend on life support requirements, which are shown in Table 3.4 (Davis, et al., 1988).

TABLE 3.4
LIFE SUPPORT REQUIREMENTS

Needs		**Effluents**	
Oxygen	1.84 lb.	CO_2	2.20 lb.
Food	1.36 lb.	Urine	3.44 lb.
H20 in food	1.1 lb.	Respiration and perspiration	4.02 lb.
Food prep. H2O	1.58 lb.	Clothing	2.5 lb.
Clothing	2.5 lb.	Sweat solids	0.04 lb.
Drink	4.09 lb.	Hygiene H2O	12.00 lb.
Hand/Face wash H2O	4.0lb.	Feces	0.27 lb.
Shower	8.00 lb.	Clothes wash H2O	27.5 lb.
Clothes wash H2O	27.5 lb.	Total	51.97 lb.
Total	51.97 lb.		

The other option for transporting water and air from the MF to the base entails the construction of a system of pressurized and insulated pipes. This option would involve extensive construction costs since pipes would have to run from the MF to all locations requiring air and water. Due to the long distances, thermal control problems would arise in transporting the air and/or water to and from the MF.

Initially, all base air will be provided by the MF. However, over time much of the air and water will be purified through efficient use of biosphere type modules. The MF will then be devoted to utilization of Martian resources.

Another system of the MF will be the mineral or experimentation section. This system should be set up to receive, process, and analyze samples of the Martian soil. These samples, taken by robots after completion of the base, would help determine which minerals or ores could be mined to produce Martian products. This section of the MF should be pressurized to allow human participation in the analysis loop.

The second phase of the MF will involve expanding the facility. After determining which materials can be extracted and produced, a supply ship can bring to Mars the proper mining attachments for the robots, and refining or processing equipment. These new systems could be placed and operated in the MF expansion/storage area.

It is assumed that the fuel production for transportation needs will take place on Phobos, although some fuel for local and emergency needs should be manufactured on Mars. Fuel produced on Phobos will be stored on Mars in pressurized vessels underground. These vessels will be old lander fuel tanks buried near the landing/launch area. Some fuel for local and emergency needs should be manufactured on Mars. If liquid oxygen (LOX) is the primary propellant of spacecraft at the time of base operation, a facility for LOX production can be designed from similar technology applied at the Lunar Base. Another possibility for fuel is methane, which could be used for Mars operations (rovers, MARTs, manufacturing processes, heating, etc.). The essential elements for producing methane, which are water and carbon dioxide, are believed to be easily accessible on Mars.

3.4 POWER

A permanent power source will be essential for the successful operation of the Mars Base. The base requires a power source which meets the following conditions:

* Prefabricated
* Long life
* Low maintenance
* Redundancy (for contingencies)
* High specific power
* Low weight.

Power sources that have been investigated and the factors that affected the design decisions are as follows:

Radioisotope Thermoelectric Generators (RTG) - RTG's have low specific power, approximately 4 W/kg, limits their use to low power applications. Technological advances greatly increasing this specific power are not foreseen (Johnson, p.929).

Photovoltaic (PV) - PV systems have also been used in space. This type of system produces 50-60 W/kg in continuous sunlight but requires energy storage for periods of darkness (Johnson, p.929). Another disadvantage is that the large deployment area of the solar collectors increases potential chances for damage from micrometeorites.

Wind - Although high winds are common on Mars, the low atmospheric density rules out this alternative. Another disadvantage of this option is that an efficient energy storage method must be used in conjunction with wind turbines for periods of low wind activity.

Geothermal - Since one of the Viking landers recorded a "Marsquake," geothermal power was included as a power source alternative. However, more data on the internal activity of Mars must be gathered to decide if this is a viable option for power generation.

Solar Dynamic - This type of system uses a focusing mirror to concentrate solar energy into a receiver which heats a working fluid. This system has the same disadvantages as the PV in that a very large area is required for solar energy collection.

Nuclear Fission - This type of power system has also been successfully utilized in a non-terrestrial environment. We will assume this type of power system will be developed and perfected during its use at the Moon Base. Current NASA research into space power systems is focusing on nuclear fission.

Nuclear Fusion - This type of power system has also been investigated in our study. Fusion is an excellent future source of power on Earth since it utilizes the oceans' vast resources of hydrogen. However, even considering technological advances such as superconducting magnetic containers for the energy plasma, the lack of hydrogen on Mars and the total mass of such a system would be prohibitively large for use at the Mars base (Davis, et al., 1988).

Having considered all of these options, only nuclear fission and advanced solar power appear capable of meeting the power criteria required to operate the Mars complex. A comparison between the two systems reveals the nuclear fission to be the most viable option. As shown in Figure 3.7, an estimated 25 Heavy Lift Launches from Earth would be saved using fission reactors instead of solar power. This corresponds to nearly 2 million kilograms saved (Johnson, p. 933). Furthermore, advanced solar power requires either constant exposure to sunlight or an energy storage system for periods of darkness in order to provide continuous power. On the other hand, a nuclear fission reactor can continuously provide power regardless of lighting and weather conditions.

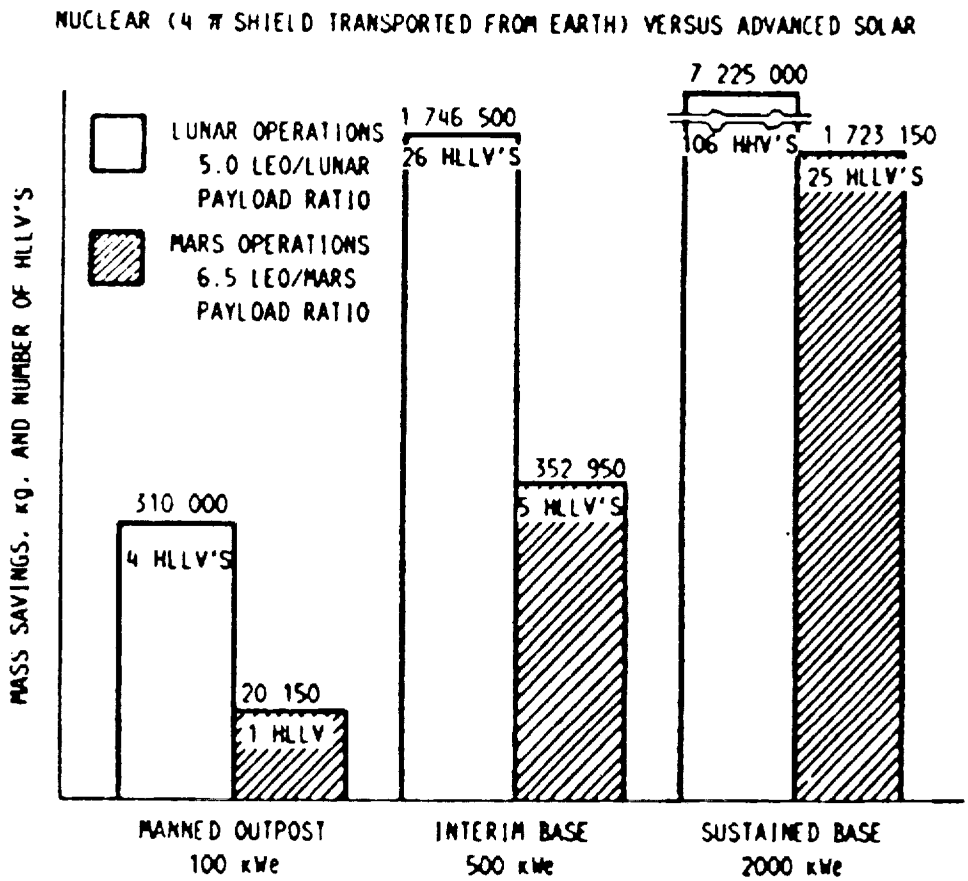

FIGURE 3.7 - MASS SAVINGS FOR MARS OPERATIONS
(Source: Johnson, p. 932)

To maintain base operations on Mars, an estimated 670 kW of power will be required. This total power is an estimate of the peak, with an average continuous supply of 400 kW. The breakdown of anticipated specific requirements is shown in Table 3.5. To allow for expansion, however, the power system should provide approximately 2 MW of power, which could be supplied by two independent power plants, each generating about 1 MW. Having two systems provides redundancy in case of emergencies; that is, if one reactor fails, the complex would still receive power from the other reactor.

TABLE 3.5
ESTIMATE OF POWER REQUIREMENTS

Unit	Power required
Habitat (6-8 crew) modules	30 kW
Manufacturing facility	175 kW
Robots/MARTs-recharging	300 kW
Communications / data storage / monitoring	15 kW
Hangar / garage	20 kW
Lights	3 kW
Thermal control	125 kW
Total	668 kW

The shielding necessary for the safe operation of the nuclear reactors can be provided two different ways. The first is by transporting a prefabricated shield from Earth. The second type of shielding involves using the surface of Mars. Some options include surrounding the reactors with Martian soil, partially covering them, or placing them in a crater or behind some other surface feature. The mass of the power systems using each type of shielding is shown in Figure 3.8 (Johnson, p. 933). From the figure, is can be seen that transporting a shield from Earth would result in an estimated system mass of

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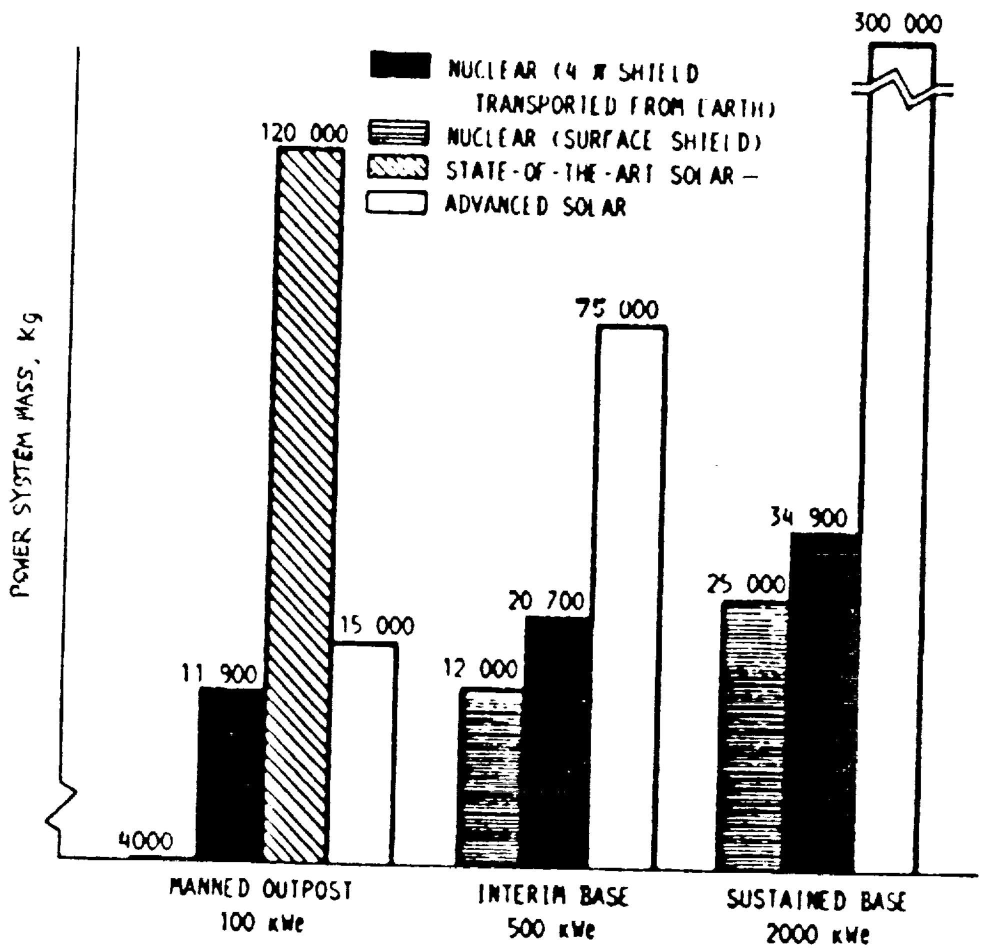


FIGURE 3.8 - MASS OF POWER SYSTEMS
(Source: Johnson, p. 933)

34,900 kg, while using a Mars surface shield would require an estimated mass of only 25,000 kg. Therefore, the reactors powering the Mars complex will use soil or surface features in some manner deemed most acceptable. Furthermore, to ensure protection of the base from any radiation from the reactors, the reactors should be placed approximately 1 km from the habitat portion of the base.

Each reactor will be a self-contained unit using a gas Brayton power cycle for conversion of heat to electricity. The advantages of a self-contained power supply include ease in transporting and starting, and heat transport in the form of steam or other working fluid would not be required; electrical power would be the only output.

Excess thermal energy from the power plants can be distributed and stored using chemical heat pumps. This type of pump uses sodium sulfide (NaS) as a storing agent and as a reactant in a chemical process that enhances the pump's efficiency. At present, eight one-ton containers can store and deliver 8 MW of thermal energy. Sodium sulfide will be extracted or made from the Martian soil. With further research and development, this type of heat transfer will undoubtedly become even more efficient.

4.0 ROBOTICS GROUP

Construction on Mars poses several major problems for humans. Mars lacks a magnetic field and has a very thin atmosphere. This results in potential human exposure to heavy doses of radiation. During a fifteen minute solar flare, a human on Mars can receive radiation doses comparable to the dosage received in the lifetime of a human on Earth. In addition, space suits are bulky and not suitable for many construction tasks. More importantly, human stays on the Martian surface will be limited to only a few days because of radiation. Finally, the question must be asked, what if an accident occurs and a human is killed? The Challenger accident crippled U.S. space activity for two and a half years. We cannot afford a similar delay on Mars (Fowler).

A robotically constructed Mars base is a feasible and realistic alternative. Robots can work on Mars indefinitely. Properly sealed robots can withstand radiation effects, corrosion, and other factors resulting from the harsh environment. Much of the construction skills needed have already been developed. Robotic arms (manipulators) are used extensively in the automobile industry. Welding, riveting, and sanding are all tasks performed by today's robotic arms. There are also many advanced construction machines in operation today. The challenge is to replace the human operator with an artificially intelligent computer. In order to achieve this goal, many advances in robotic technology will be necessary in the coming years.

4.1 ARTIFICIAL INTELLIGENCE

Artificial intelligence is the ability of a robot to "behave" in ways that humans recognize as intelligent behavior. Intelligent behavior will enable robots to navigate and perform tasks in the harsh Martian environment. Computer mapping, sensors, and expert systems will be the tools that robots will use to accomplish their work.

4.1.1 COMPUTER MAPPING

Robots must navigate autonomously through an unpredictable Martian environment . For example, a robot may have to travel one kilometer from a power source to a habitation module. Initially, the robot must map a specified path. This is called global mapping. As the robot traverses its path, it may encounter unexpected obstacles. Thus, the robot must reorient its path. This is called local mapping (Hamel, p. 223).

Global mapping uses permanent features as reference points. Before landing on the Martian surface, robots will be programmed with a global map of the construction site and the surrounding environment. Permanent features such as mountains, large boulders, craters, and other hazardous features will already be known to the robots.

Local mapping is the responsibility of each individual robot. When unexpected obstacles are encountered, the robot must autonomously program the obstacle as a point on the global map to be avoided. A central control will then program all other robots of this new obstacle.

4.1.2 SENSORS

Sensors will enable robots to autonomously respond to a changing environment. Vision, electromagnetic sensors, sonar, and tactile sensors are described as follows:

VISION

For years, architects and engineers have used various views of a two-dimensional object to define the object in three-dimensional space. Robots can use this concept to identify three-dimensional objects on Mars. The process will work as follows: each robotic eye will independently focus on an object and record a two-dimensional image; and each image is derived from a computer analysis of reflectivity, texture, colors, and shadows. Then, the computer uses the method of triangulation (i.e. the principles of geometry and trigonometry) to form a three-dimensional configuration (Beni, p. 277).

In addition, vision can be used for distance calculations by the use of optical parallax (Hamel, p. 228). The computer calculates distances by measuring the relative angles among the eyes focused on an object.

Unlike humans, robots are not limited to two eyes. The Martian robots will have a multitude of eyes. These eyes can either be body fixed, mobile, or both. For example, eyes can be located in the wrists of manipulators. This will enable the robot to accurately position its end effector (robotic hand). Additionally, robotic eyes can be placed on the front, back, and the sides of the robots. Mobile eyes will have the ability to extend from the robot so that a better angle or view may be obtained. Mobile eyes will be limited in range and will be used primarily for manipulation.

ELECTROMAGNETIC SENSORS

The electromagnetic spectrum covers all frequencies and wavelengths of light. The spectrum spans from low frequency, long wavelength radiowaves to high frequency, short wavelength gamma rays (Giancoli, p. 643). Lasers, radar and radio waves are light waves that will be beneficial sensing devices on Mars.

Laser beams, found in the visible and ultraviolet regions of the electromagnetic spectrum, are very intense beams of light (Giancoli, p. 809). This high intensity allows a beam to clearly outline a three-dimensional object. A perfected laser range finder used in conjunction with vision can greatly improve object identification and distance calculations.

Radar, found in the microwave region of the electromagnetic spectrum, can be used for distance calculations by recording the time of flight required for a signal to reach an object and return to a robot. However, short range distance calculations may be a problem because the signal travels at light speed (3×10^8 m/s). For example, from a distance of one meter, a radar signal will return almost as quickly as it is sent. Laser range finders are better suited for short range distance calculations.

Radio waves can be used in a homing device. For example, each module can emit radio waves at varied frequencies; and these frequencies will be encoded in the memory of each robot. Thus, the robots can discriminate one module from another. This concept can also be applied to robotic arm attachments, construction attachments and equipment inside each module.

Electromagnetic sensing devices are promising; however, improvements are needed. Uncertainties exist from laser signals that return more quickly from bright, flat surfaces than from dark, rough surfaces. In addition, laser devices are very complex; and because of size constraints, a radar system is not compatible with today's robots. Nevertheless, we are assuming that most of these problems will be addressed and corrected within the next 30 years (Espiau, p. 319).

SONAR

Sound waves are propagated by pressure; and sound travels at the local speed of sound (Giancoli, p. 309). On the other hand, electromagnetic waves are not pressure dependent and travel at light speed. Thus, the sound spectrum is entirely unrelated to the electromagnetic spectrum.

Sonar propagates best through a dense medium. For example, submarines use sonar very successfully in the dense medium of the ocean. However, sonar does not work well in a less dense medium. In fact, sound cannot travel in the absence of matter (Giancoli, p.309). Mars has a thin atmosphere, thus, sonar may not work well on Mars.

Nevertheless, bats guide themselves with sonar that works quite well in the air. Bats emit sound waves at frequencies five times the audible limit (e.g. 100 kHz). Today, an advanced ultrasonic system has been developed similar to a bat's sonar system. Frequencies are emitted between 80 kHz and 400 kHz. This system can distinguish between objects 1/10 of a millimeter apart from a distance of a half meter. In addition, the system can identify 1000 objects per second (Gosh, p. 42). A similar system can help manipulators perform intricate tasks on Mars. However, sound waves need further study in the Martian environment.

TACTILE SENSORS

The sense of touch is vitally important for task operations. A robot's computer will supervise tasks; however, the computer will need sensory feedback from a manipulator to apply the required output to accomplish a task. Without sensory feedback, the computer has no way to control the amount of output. Pressure sensors, torque sensors, and collision sensors will allow robots to handle fragile objects without slip, to detect when a screw is adequately tight, and to determine when contact is made (Harmon, p. 390).

Eye/hand coordination further illustrates the importance of tactile sensors. For example, if a power plug is to be engaged; vision allows the robot to properly place the plug; and pressure sensors inform the robot when the plug is properly engaged. This example illustrates the dependence that sensors have on one another.

Today, state-of-the-art tactile sensors are at early stages of investigation, comprehension, and competence (Harmon, p. 400). Many advances are required. For example, modern robotic hands have 400 sensory points and six degrees of freedom. The human hand has 3500 touch receptors and 20 degrees of freedom (Harmon, p. 393). Gripper forces must be continually adjusted to determine the minimum new force required to avoid slip. And finally, if teleoperation is performed from Phobos, the teleoperator will need to feel tactile "pressure" to perform more efficient operations.

4.1.3 EXPERT SYSTEMS

An expert system is a program that emulates what a human expert would employ to solve a given problem (Johnson, p. 691). A robot will call on different programs in memory to respond to certain situations. For example, programs will exist for navigation, and other programs will exist for tasks. When a robot encounters a situation to which it cannot respond, the robot will be instructed to terminate its operations and wait for instructions from humans. With the invaluable experience of observing robotic performance in the lunar environment, many of the expert systems needed for the Mars mission will be anticipated.

Computer mapping, sensors and expert systems are an intricate part of robotic navigation and task operations. Robots will use computer mapping for navigation; and sensors will enable the robots to update and revise their computer maps. Increased sensing accuracy will be obtained by incorporating cross-checks in the overall sensing system. For example, for object identification and distance calculations, lasers can check the accuracy of vision. Finally, the robots will call expert systems to address specified tasks. With the mastery of computer mapping, sensors, and expert systems, Martian robots will navigate and perform tasks autonomously on Mars.

4.2 POWER

The power system for the robots must be rugged, compact, dependable, and durable. Also, it should not restrain or hamper the movement or agility of the robot. Two major options for power include rechargeable batteries (secondary batteries) or self-generating power sources in each robot. Some advantages of secondary batteries are their high specific energies, good durability, and reliability. Additionally, batteries are inexpensive and simple. However, current batteries tend to have short lifespans; and, a rechargeable system will require an external power source immediately following the robots arrival on Mars. Some self-generating power sources are fuel-cells, radioisotope thermoelectric generators (RTG's), and solar cells (Angelo).

4.2.1 FUEL CELLS

Fuel cells are a good power source for mobile robotic units because of their relative light weight, high efficiency and a long-life span. Currently, the most common fuel cell is the hydrogen and oxygen fuel cell. Unlike batteries, the reactants of a fuel cell are stored externally to the cell. Electrical energy is produced when the hydrogen and oxygen react with a solution of potassium hydroxide or sodium hydroxide. The product of the reactants is water.

A regenerative system is one that converts water to hydrogen and oxygen for use in a fuel cell. Such a system could have a life time of several years. However, another power source would be needed to provide the energy required to produce hydrogen and oxygen from water (Cochran). A regenerative system would be ideal for our mobile robots.

4.2.2 RTGs

RTG's have proven to be a reliable power source in the past; and they can be safely integrated into a power system (Angelo). Their major drawback is that they have a low specific energy and would have to be quite large to produce the required power output for our robots.

Safety becomes a major concern when nuclear power sources are used. Gamma rays can damage sensitive electronic equipment. If a robot's computer is severely damaged, then the robot becomes virtually useless. A nuclear power unit can be used only if the gamma ray emission can be safely controlled (Cochran).

4.2.3 SOLAR CELLS

A self-contained solar power unit will not be suitable because of the frequent dust storms on Mars. To overcome the dust storms, solar power could be transmitted from an orbiting solar power unit to the Martian surface.

However, MING has opted for a nuclear power base instead of an orbiting solar power system. Therefore, the robots will not use solar power.

In conclusion, fuel cells and batteries are the best power sources. Fuel cells were used successfully in the Apollo program, and are used as power on the Space Shuttle today (Cochran). Because the by-product of a hydrogen-oxygen fuel cell is water, it is a clean and safe power source. With 30 years of technological advancements ahead, more efficient regenerative fuel cells and batteries will provide adequate power for robots on Mars.

4.3 COMMUNICATIONS

The communication system is a very important part of the robotic construction of the base. Although the robots will be autonomous, daily communication with Mars will be necessary in order to periodically update and revise their programming. Unanticipated problems will arise. The robots won't be able to address every unexpected situation. This requires periodic reprogramming by humans from either Phobos, the Moon, or Earth.

Our most desirable option has humans supervising the construction process from Phobos. The time lag from Phobos to Mars is only a fraction of a second, therefore, instructions can be sent rapidly from Phobos. This is much more desirable than communication from Earth, since the time lag varies roughly from eight minutes to forty-five minutes depending on the location of Mars relative to the Earth-Moon system. For constant communication from Phobos, additional communications satellites may be required in Martian orbit.

The communication system will make use of the satellites deployed around Mars that are used for Phobos communication with Earth. Signals from Phobos will be received from a central base communication station set up by the robots during the initial phase of the construction. The signal will then be analyzed and relayed to the appropriate robot through line of sight communication. Each robot, including the small maneuverable units, will be capable of communicating with the central relay station as well as each other.

Before the base station is operational on Mars, the robots will have contact with human monitors via a temporary communication system located on the initial one-way lander. Two of the most important criteria for the communication system are that it must be expandable and very reliable so that a continuous communication link will always be in effect.

Humans will view construction activities through video cameras set up around the site. In addition, humans will "see through the eyes of the robot". Robotic eyes are maneuverable video cameras attached to each robot (Watts, p. 40). If unexpected problems do arise, the robots will be pre-programmed to terminate their current activity, and supervisors will be able to analyze the situation first hand. The robots will then be reprogrammed to address the specified problem.

Phobos will have a man-tenable base; and, humans will be present on Phobos during the major phases of the Mars base construction. Close supervision of precision tasks, such as wiring and repair work, will facilitate the construction process. Teleoperation will be a supplement for the robots to solve unusual problems. Another important reason for having teleoperation capabilities is that once the Mars base is operational, humans will be capable of teleoperating the robots from a station within the base. The robots can then be used for numerous activities other than construction, including scientific experiments, planet exploration, or other terrestrial work too dangerous for the astronauts to perform. In addition, this capability will benefit future construction activities and simplify expansion of the base.

4.4 CONCEPTUAL DESIGN

In some industries today, products are assembled by robots on an assembly line. These robots are stationary, work in a clean environment, and perform one specific task. Work on Mars will not be so simple. The robots will have to be mobile, protected from the harsh environment, and perform multiple tasks.

Martian robots will be responsible for a multitude of tasks. These tasks include the following:

* Excavating and clearing the site.
* Unloading and transporting the modules.
* Assembling the modules.
* Burying the modules with "sandbags".
* Setting up the power and communication systems.

We addressed these tasks by designing large modular robots with detachable arms capable of lifting, digging, and performing other various construction activities. In addition, we designed a trailer vehicle for transporting modules and construction equipment, and a set of small, agile robots capable of performing delicate tasks in and around the modules. Each of the robots will work independent of one another to speed up construction activities. If any one task is too large, two robots may also work in tandem. One of the most important criterion considered was that the robots must be capable of maintaining one another; the small maneuverable robots will specialize in repair.

Construction operations in the Martian environment will require many adaptations of current technology to enable performance under the harsh conditions. For example, since dust storms are common on Mars, advanced seal technology is required to protect the robot's internal hardware from dust and corrosion. Durable, maneuverable, mechanically simplistic robots with multiple capabilities was our major objective.

4.5 LARGE MODULAR CONSTRUCTION UNITS (LMCU)

The ability to move large quantities of Martian soil, transport modules, and excavate the site will be required during the early phases of the Martian base construction. Although soil moving operations are similar to those encountered during Earth construction, the equipment will be different due to several constraints imposed by the Martian environment. We plan on utilizing at least three Large Modular Construction Units. These robots will be capable of performing numerous tasks with their detachable arms. The different modular attachments and tasks will be addressed in a later section.

Many considerations will have to be addressed in the design of these robots. To begin with, the LMCUs will have to be very rugged and reliable. The electronics and other subsystems of the unit will have to be modular and easily accessible so that they can be replaced with redundant parts in case of failure. In addition, the internal systems will have to be protected from radiation and the Martian environment. The major effect of low atmospheric density on equipment is the increased evaporation of lubricants and volatiles (Johnson, p.204). Reliable seals will be placed around all movable joints and openings in the hull. This will protect the internal hardware from dust and dirt and help keep the fluids from evaporating prematurely. The hull itself will have to be carefully designed so that the expansion and contraction of the material used will be able to withstand the large temperature fluctuations that exist on the Martian surface. These fluctuations average about 90 K . If the hull is composed of metal, then the effects of radiation and micrometeorites will be small, as long as the particles are not too large. However, glass and polymer components would be critically affected by long exposure to ultraviolet radiation; consequently, these materials should be protected if they are used in the equipment. Conversely, one benefit of Mars is the absence of an oxygen rich environment. This should help increase the equipment life expectancy, since corrosion by oxidation will not take place (Johnson, p. 205).

Another important design consideration is that the robots must be equipped with lights and video surveillance cameras. These will allow humans on Phobos or elsewhere to monitor the progress of the robots while constructing the base. Each of the LMCUs will have a maneuverable camera and lights mounted on their hull. The ability to obtain specific worksite views is essential, necessitating the capability to pan, tilt, and zoom the vision sensor. Lights are necessary for humans to supervise robotic work around the clock.

There are three basic power systems used for robotic manipulation. They include hydraulic systems, pneumatic systems, and electrical systems (Wolfe, p.11). Hydraulic and pneumatic systems are not well suited to Mars because of the high maintenance requirements resulting from low pressure, high radiation, and dusty environment. All robotic systems will be electrically driven. Electric propulsion offers greater power than hydraulic systems for given weight, and they also require less auxiliary equipment. Larger vehicles using electric drive have already been in use for some time, and the present work indicates that this technology can be scaled down to small size using advanced electric motors (Wolfe, p.16).

Our conceptual design for the LMCUs are shown in Figure 4.1. The mass of the robots is 8000 kg (17500 lbm), which was estimated from the weight of Earth terrestrial construction equipment taking into account the reduced gravity on Mars. The dimensions of the hull are 3.7 m (12.1 ft) x 5.5 m (18 ft) and a height of 3.5 m (11.5 ft). Figure 4.2 shows an LMCU in the process of covering one of the modules with "sandbags".

4.6 LOCOMOTION

The major criterion for the locomotion system is that the LMCUs must be able to operate in any type of Martian soil, and not be affected by obstacles, soil strength, and slope. Modern means of locomotion include wheels, tracks, and legs. Legged robots excel over wheeled robots in both terrain negotiation capability and platform stability; however, wheels and tracks are better suited for travel over long distances, have better traction, and are much faster. Wheels are mechanically efficient and can be designed into extremely reliable lightweight systems. The main drawback with the wheeled system is that the area of surface contact with the terrain is limited, which in turn lowers the vehicles ability to maintain traction under loaded conditions or when traversing slopes or rocky terrain. Tracked vehicles are well suited for this application because their surface contact with the terrain is much greater. However, track systems are less efficient than similar wheel systems, more complicated, and therefore more susceptible to damage (Davis, p 86).

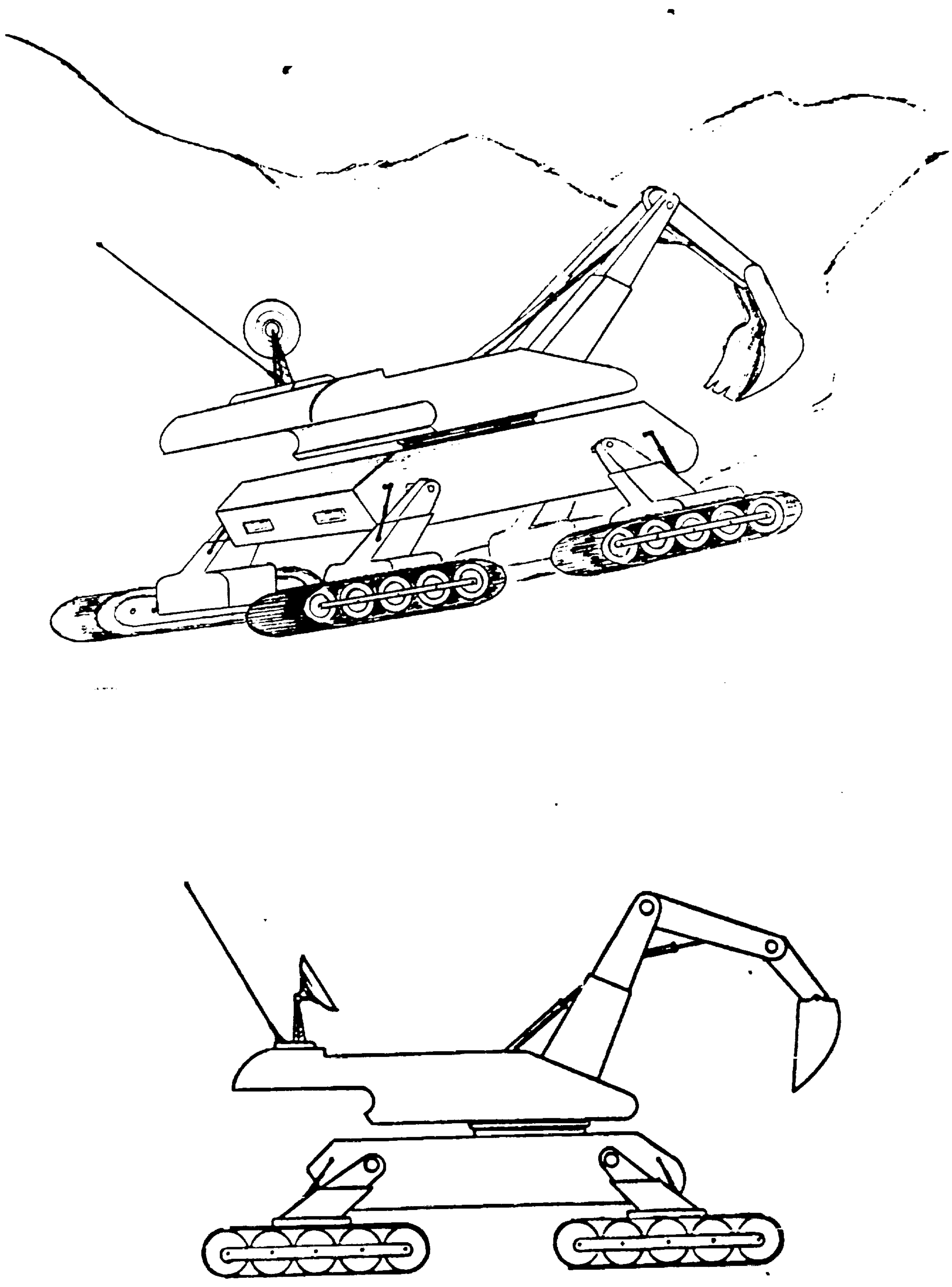


FIGURE 4.1 - CONCEPTUAL DESIGN OF LARGE MODULAR CONSTRUCTION UNITS

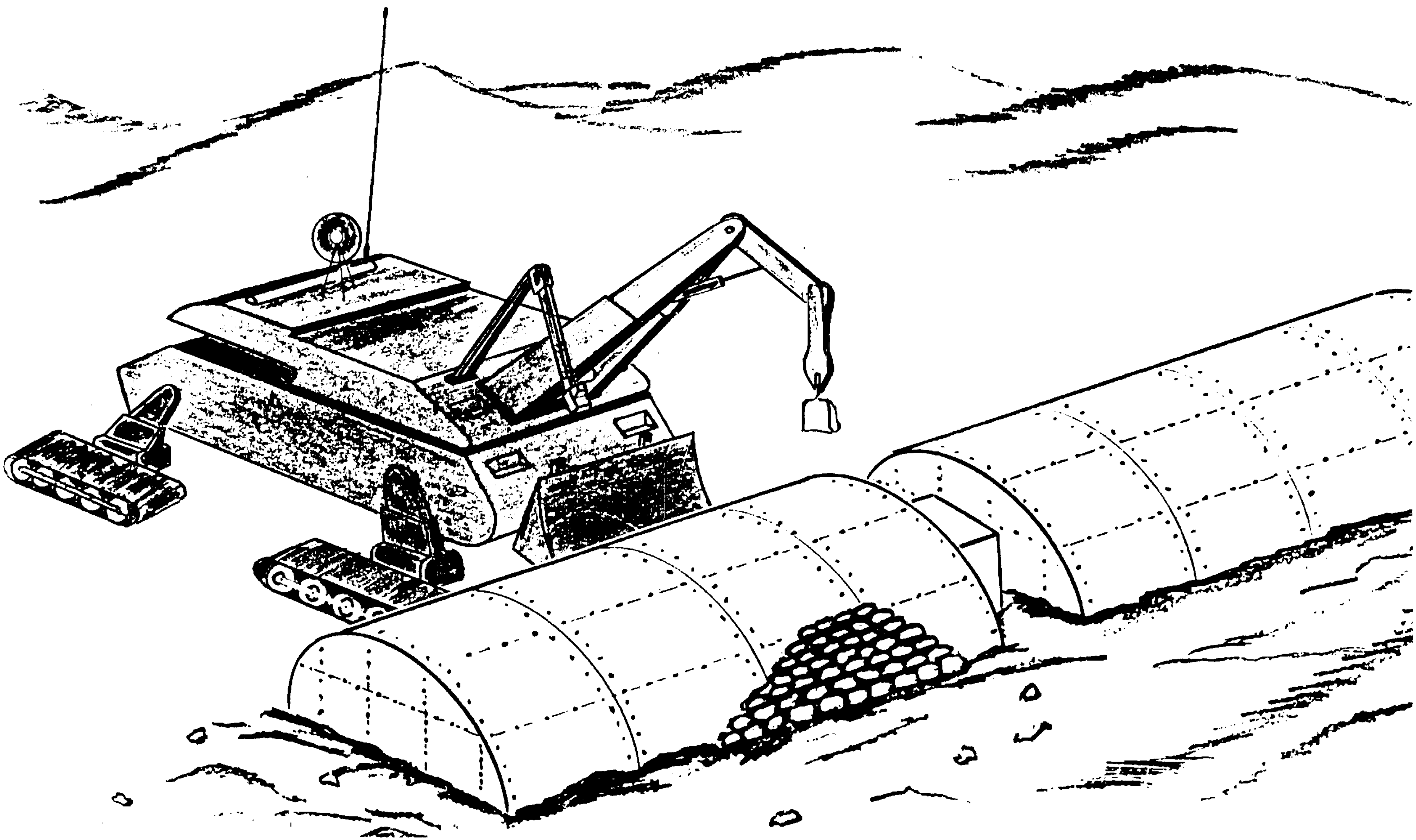


FIGURE 4.2 - LMCU COVERING MODULE

We decided on using a looped wheel configuration for the LMCU's locomotion. Loop wheels retain the advantages of both wheels and tracks and provide better obstacle clearing capabilities (Eagle). These looped wheels will be constructed from durable materials so that they are capable of withstanding the abrasiveness of the Martian soil. The belts which run the tracks will be driven by two main wheels in each of the four looped wheels. A more detailed description of the track configuration, which our system is based on, can be found in an earlier lunar base design by G. Davis, et al (Davis, p. 88).

4.7 MODULAR MANIPULATOR ATTACHMENTS AND EQUIPMENT

The primary requirement for our LMCUs is that they are capable of performing a wide variety of tasks through simple reconfiguration. The different modular attachments are:

Multi-purpose Arms - These are the generic robotic arm attachments which can grasp and hold smaller attachments such as the drill and even the smaller robots. They will be capable of at least seven degrees of freedom in order to have maximum dexterity.

Backhoe - This attachment will be used to scoop dirt and dig trenches for laying wire, etc, and will connect onto the hull of the LMCU.

Bulldozer Blades - This piece attaches to the front of the LMCU and will be used to move soil and smooth out the terrain.

Crane - This attachment will connect to the front of the LMCU and will be used to off load the modules from the lander and to set them into the excavated site. Each LMCU will have extendable booms coming out of the chassis which will counteract any torque created by the load.

Drill - This is a small attachment which connects onto the end of the multi-purpose arm. It will be used to drill the necessary holes for the explosives.

Steamroller - This is an attachment that will be used to compact dirt and smooth out terrain. It will consist of a hollow cylinder during transport to Mars, but prior to operation, it will be filled with any non-reusable materials from the Martian lander in order to give it the mass needed to operate efficiently. The cylinder can also be filled with Martian soil.

Each of these manipulators will either be self-attachable using the LMCU's free robotic arm or else the robots will be able to attach them to each other.

Other necessary construction equipment includes a general purpose utility trailer used to transport the modules and regolith. This trailer, like the LMCUs, will be modular in design so that a variety of trailer beds and fixtures can be attached for different applications (Eagle, p. 76). One trailer function will be similar to that of a dump truck so that it can be used to easily distribute the soil and bury the modules. Another trailer fixture will be the sand-bagging attachment. This is a piece of equipment which connects on to the back of the trailer and continuously fills bags with Martian soil so that they can be used to cover the modules.

In order to protect and support the robots, an unpressurized garage was added as a place to store the attachments, to allow a protected area for storage of all surface vehicles, and to provide a source for utility outlets to recharge the vehicle power systems. The storage facility will be transformed from the initial one-way Martian lander after its cargo hull has been emptied. This garage will also contain a pressurized room which can act as a safe haven for astronauts that is located near the landing sight. This pressurized room will be an inflatable inner structure that is set up in a corner of the lander's cargo hull once the lander is emptied. This is important in case any emergency arises during lift-off or landing maneuvers involving humans. Figure 4.3 shows an LMCU entering the garage either to recharge, or to replace one of its manipulators.

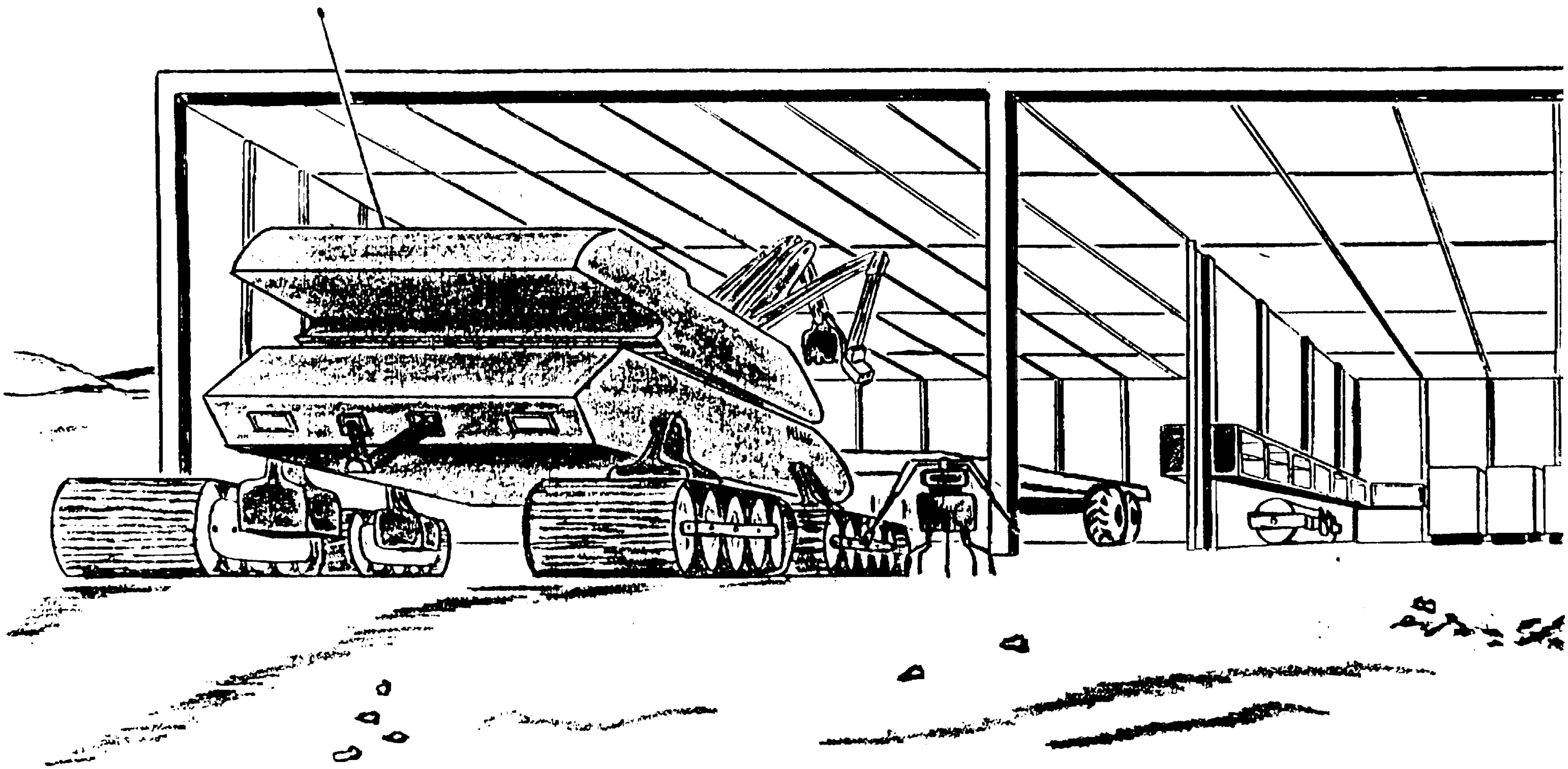


FIGURE 4.3 - LMCU ENTERING GARAGE

4.8 SMALL MANEUVERABLE ROBOTIC SERVICERS

Our design also includes three small maneuverable robotic servicers (SMRS). These SMRSs will be able to perform more delicate tasks in the construction of the base. They will be capable of performing any task that would normally require a suited astronaut . Also, the SMRS will be designed so that the LMCU's robotic arm can lift them in order to reach otherwise inaccessible places.

These small servicers will be equipped with spider-like legs for locomotion. Legs will give them great agility, allowing them to walk radially in any direction, turn about a point, and right themselves if overturned so that they can work in and around the closely spaced modules. Legs will also allow them to have individual mobility without the help of an LMCU. An example of one of these smaller units is shown in Figure 4.4. They will be approximately 1 m high and 0.5 meters wide. An SMRS can also be seen, in the background of Figure 4.3, ready to assist the larger robot.

Some of the jobs that the SMRS will be responsible for are sealing the modules to the nodes after placement, connecting/distributing power cables, performing safety checks on all the systems prior to human arrival, and maintaining and repairing the robots, and communication and power systems. The SMRS will also be equipped with an attachable laser cutting tool. This tool can be used to cut larger pieces of material, such as parts of the Martian lander, so that they can be used for other purposes. The SMRS will have cameras monitoring their work and teleoperation assistance when needed.

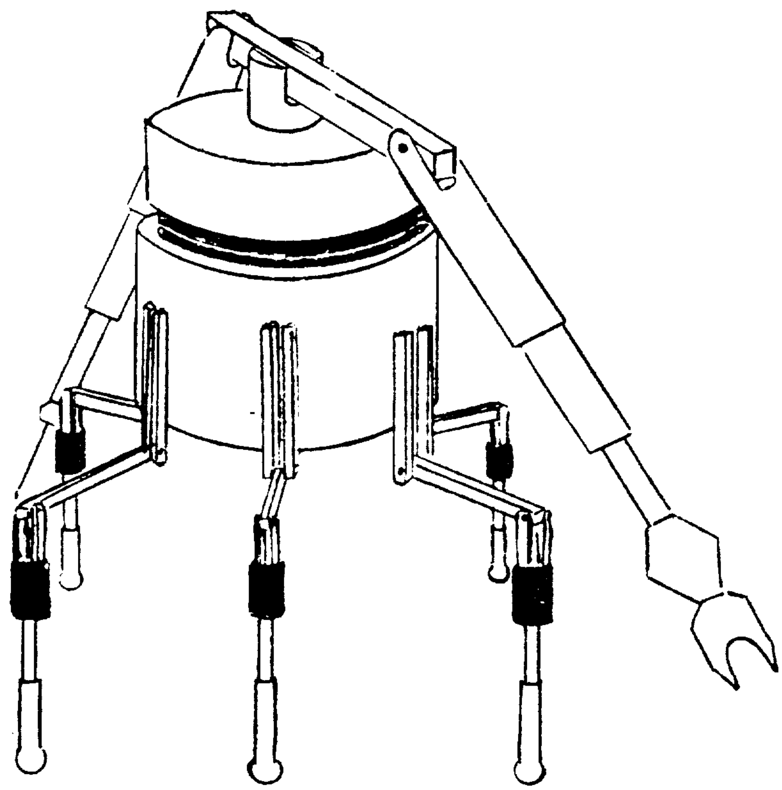


FIGURE 4.4 - SMALL MANEUVERABLE ROBOTIC SERVICER

5.0 HABITAT GROUP

There are three important aspects to the habitat portion of the base. The location will affect the structure and configuration of the base. The purposes of each of the modules must be decided and emergency plans should be taken into consideration for safety.

5.1 HABITAT LOCATION

Two regions have been under study as possible locations for a robotically constructed Martian base. Region one is a wide open flat plain near the equator. The base would be completely buried in this area. Region two is a mountain landscape in which the base would be located in a "room" bored in a cliffside.

Research into both possible base locations has revealed that the flat plain region to be most desirable for robotic construction. A mountain bored base was ruled out for a number of reasons, including the following:

* Insufficient information on the laser boring technique, as well as large potential mass requirements for laser boring equipment

* Possibility of inadequate roof and wall support - fear of cave in

* Limited expansion capabilities.

Similarly, the flat plain offered some disadvantages for base construction; however, the advantages far outweighed these limitations. Advantages include:

* Improved mobility for robots

* Easy robotic excavation

* Quick access for landers

* Unlimited expansion capabilities.

Consequently, the base will be semi-buried in a flat plain region near the equator of Mars. Base construction will proceed in the following manner:

* Controlled explosives will be used to blow a hole with minimum dimensions of 42 meters long by 14 meters wide by 1 meter deep (partially below ground construction).

* Anchoring rods will be placed at the four corners of each module in order to stabilize the structures (University of Texas at Austin, "Bootstrap"). The five modules (plus the sick bay module from Phobos) will then be set in the hole by the robots.

* The robots will connect each module with the connecting nodes and cover the entire system with a 0.5 meter depth of regolith filled sandbags.

The bags will be made of a material resistant to ultra-violet radiation degradation, such as kevlar. The bags will be filled by a robotic regolith bagging machine, and it will take approximately 100 hours to fill enough bags to protect the entire habitat base (University of Texas, "Lunar Split Mission"). Placement of the bags will be accomplished with relative ease, having the robot start at the top of each module and working down to the sides. This system of "base burial" will be plenty adequate for the protection of human life from the harsh Martian environment (solar flares, cosmic radiations, etc). See Figure 5.1 for side view of base construction.

5.2 MODULE STRUCTURE

In order to provide simplicity for the Martian robotic crew, the five habitat modules will be prefabricated in their entirety on Earth.

Each module will be shaped as a half-cylinder composed of the composite Kevlar (K49/514) with dimensions 13 meters length, 3 meters radius, and 13 centimeters thickness. The half-cylinder was selected over the full

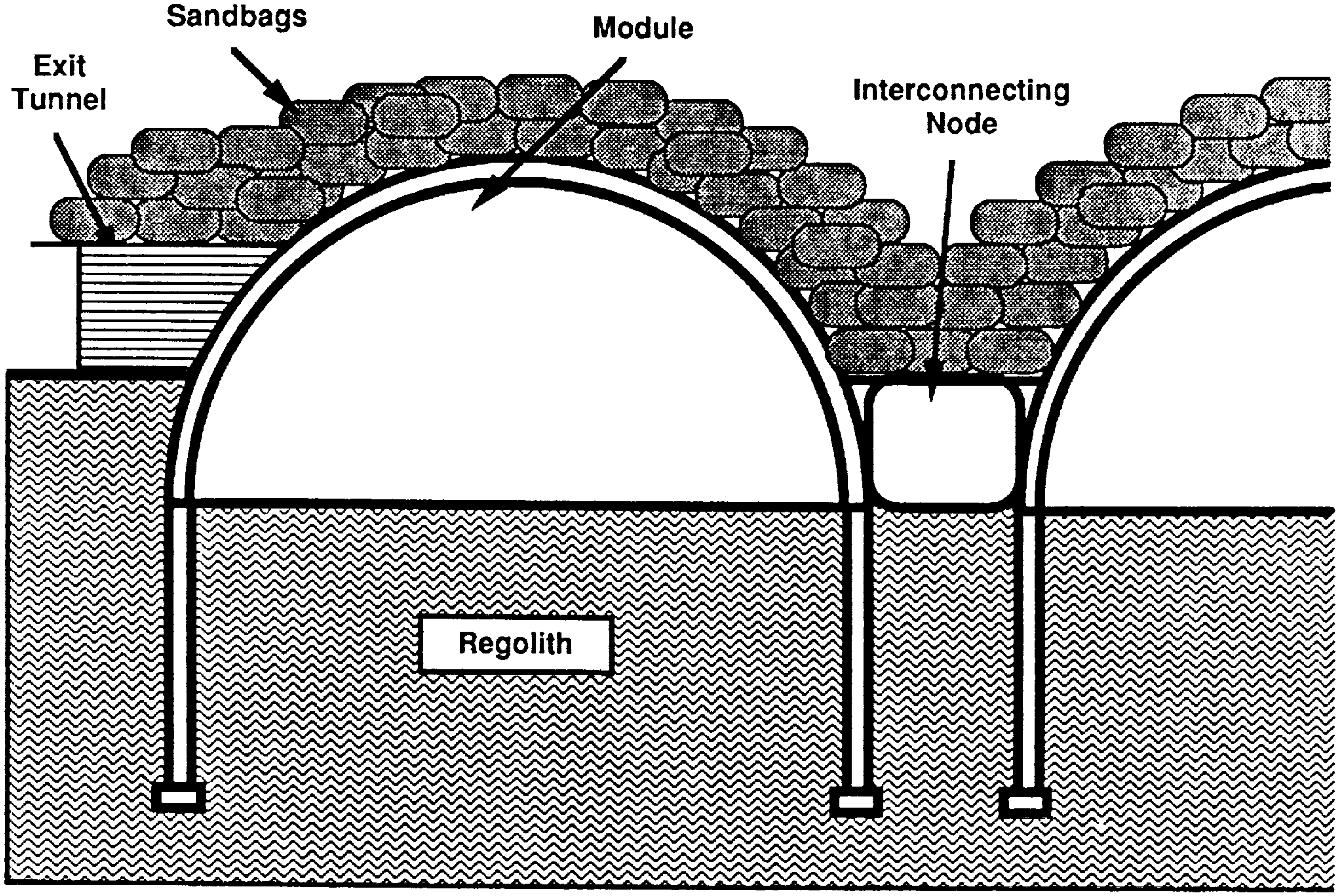


FIGURE 5.1 - SIDE VIEW OF MODULE CONSTRUCTION

cylinder to minimize the weight and volume, aiding the transportation group. The approximate mass of each module is nearly 50,000 kg.

The modules will be connected by inter-connecting nodes. The nodes will be 1.5 meters in length equipped with double doors for redundancy in case of emergency. In addition, the node doors will be airtight so an afflicted module can be sealed off from the other modules. There will also be three exit tunnels to the surface, branching from the science, core, and living quarters modules, where the crew members are more likely to be. Access to the surface is necessary for sudden evacuation, sample collection, and transport to other base sites (maintenance hangar, recreation hangar, manufacturing center, communications dish, and power center). See Figures 5.2 for module and node placement.

5.3 MODULE PURPOSES

The five half-buried modules will consist of a core, biosphere, science, living quarters, and galley/storage. The medical center (or sick-bay) from the Phobos base will also be part of the base as a sixth module. See Figure 5.2 for the habitat layout.

5.3.1 CORE MODULE

The core module, as shown in Figure 5.3, will be located in the central region and will provide communications to Earth, Phobos and the lunar base in the Communications and System Control Sector (CSCS). This sector will also include satellite tracking and surveillance capabilities as well as the systems controls (i.e., thermal control, air purification, power, water and waste regeneration). The module will also contain the following:

* A conference area for all crew members
* A "craft shop" area with tools and materials
* A relaxation/entertainment sector providing a relaxing environment with modular couches, reading chairs, wide screen TV, VCR,

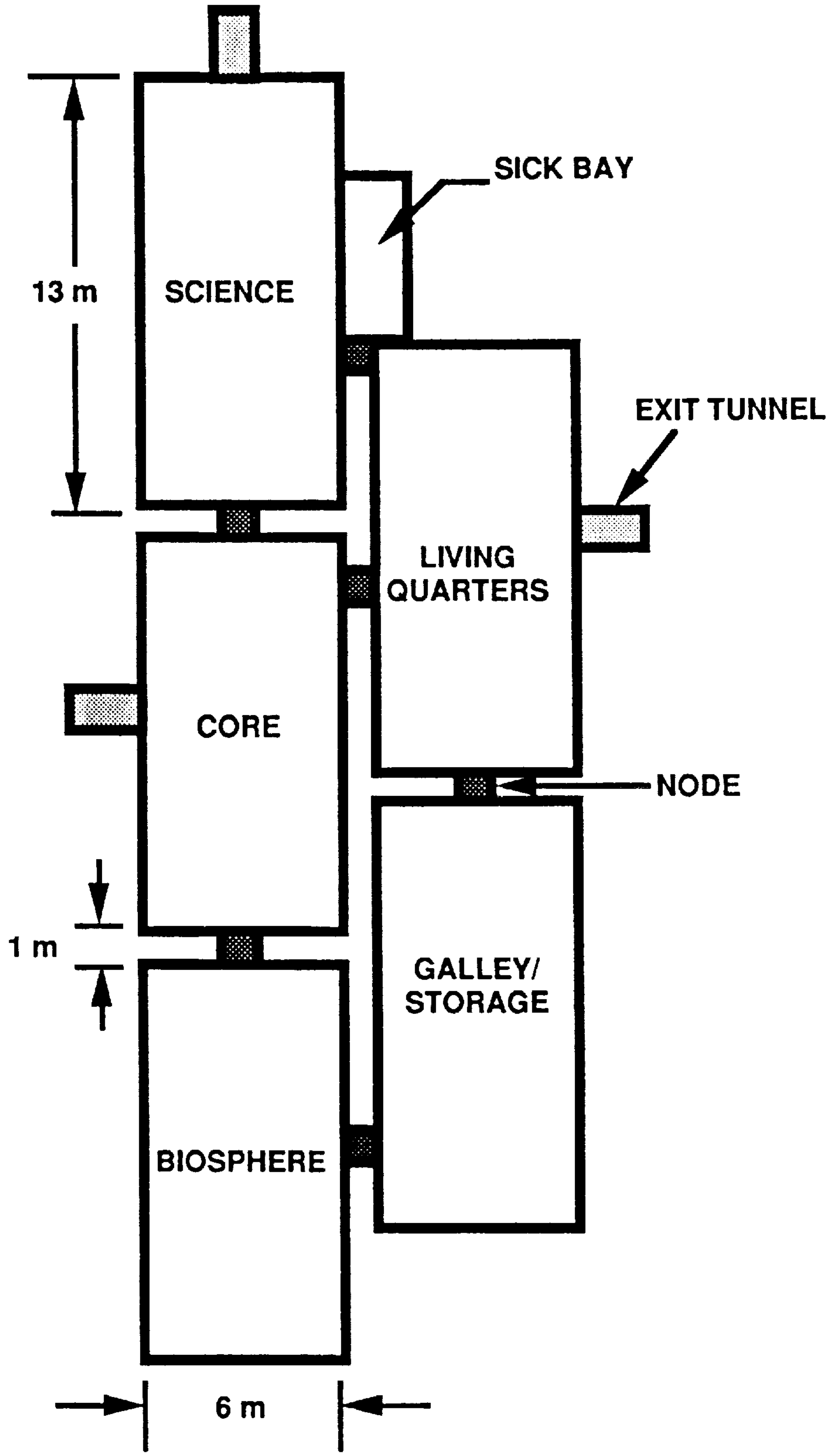


FIGURE 5.2 - TOP VIEW OF HABITAT LAYOUT

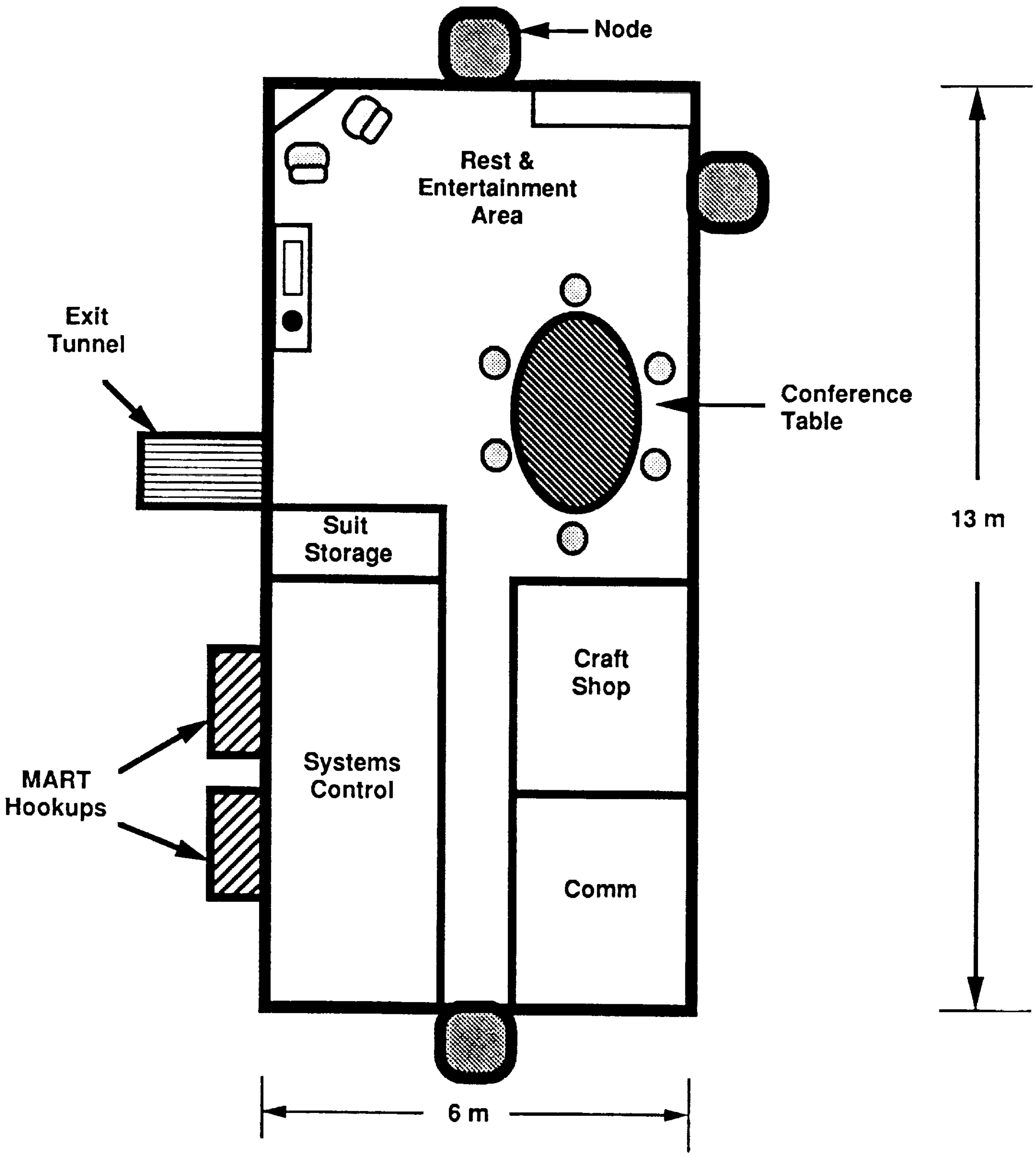


FIGURE 5.3 - TOP VIEW OF CORE MODULE

compact disc player, books and games. It may also house an aquarium to help alleviate stress on the crew members.

New developments in recreation and entertainment will certainly be developed by the actual year of base installation. Thus, it is assumed that the latest Earth inovations will be available to alleviate the crews feelings of isolation from Earth.

5.3.2 BIOSPHERE MODULE

The biosphere module will use plants to produce food, regenerate breathing air, and regenerate waste water. The plants can grow in waste water and produce clean air and food. This is a new technology that has shown promise as a very efficient and effective method of closed environmental control. The growing area necessary for a crew of eight, assuming a caloric requirement of 3000 kcal per day, is approximately 48 m^2 of plantlife. The selected size of the module (78 m^2) would then be adequate (NASA CP 2231). For lighting power requirements, using the efficiency of high pressure with reflectors and the necessary growing area, approximately 32 kW will sustain the plants' growth for a crew of eight ("Lunar Base Study"). Plants will be carefully selected and bred to reach these productivity levels. Algae and higher garden plants are the type of plants to be grown as food. Although algae is more efficient at utilizing energy, it lacks taste and emits toxic gases. Higher plants are the better choice in the psychological point of view. They have a wide variety, good taste, and contain a number of necessary vitamins, while making the base more Earth-like. Plant care may even prove to alleviate stress and be a relaxing way to spend free time. Species of higher plants will be chosen to provide the maximum edible mass per unit area in a minimum period of time, as well as satisfying nutritional needs (proteins, vitamins, and minerals). One study recommended wheat, rice, white potatoes, sweet potatoes, soybeans, peanuts, lettuce, broccoli, strawberries, onions and peas. A strictly vegetarian diet was chosen for two reasons:

* Ease of transportation - minimal volume requirements

* System complexity - decreases food chain by one third (The Case for Mars II).

However, a tank of edible fish may be present. A species, known as tilapia, will survive in fresh water, flourish on a steady diet of vegetable matter or even waste matter, and produce large amounts of food compared to what they consume. The fish is also quite tasty (Lewis). This is called aquiculture.

Two methods of growing the food are hydroponics and aeroponics. With hydroponics, plants are grown in a nutrient solution instead of soil. This is good because Earth or Mars soil does not need to be simulated. Aeroponics allows the plants to grow in air. The plants are suspended from a circulating cable system. At various points in the cycle, the plants are sprayed with a nutrient solution. Plants grown using hydroponics can be grown on the floor of the Biosphere module, while plants using aeroponics can be grown above those. In this way, maximum utilization of the Biosphere module is achieved. A basic floor plan view can be seen in Figure 5.4.

5.3.3 SCIENCE MODULE

The science module will provide a laboratory environment for experiments to be conducted. It will be possible to simulate many different experimental conditions. Table 5.1 describes the science equipment and their characteristics which might be used in the science module (Texas A&M, "To Mars").

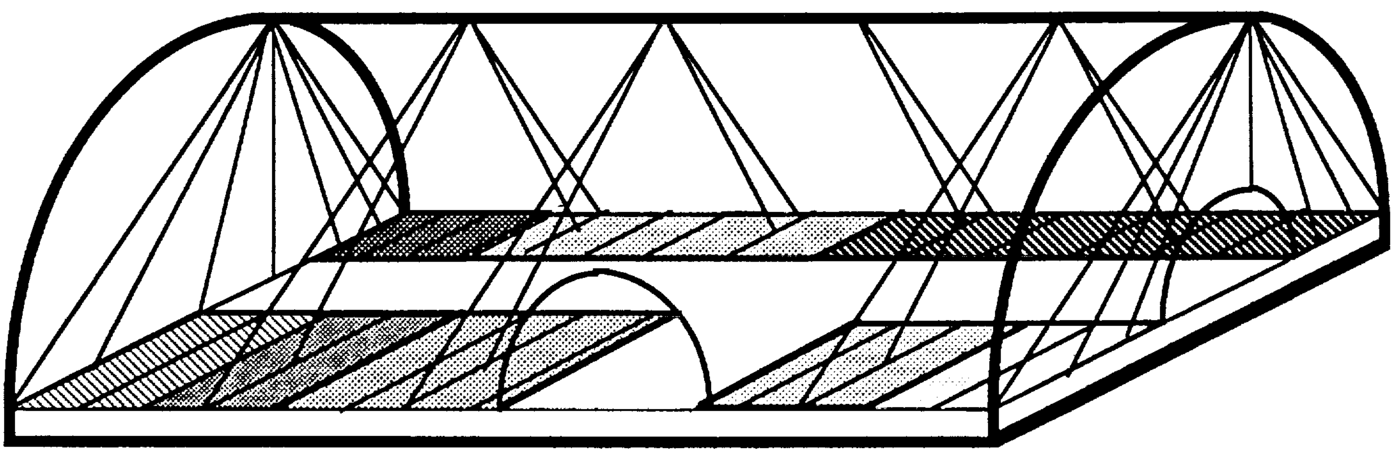


FIGURE 5.4 - FLOOR LAYOUT OF BIOSPHERE MODULE

TABLE 5.1 POTENTIAL SCIENCE EQUIPMENT

EQUIPMENT	VOLUME (m^3)	MASS (kg)	POWER REQ'D (W)
Optical Microscopes and Cameras	0.005	5	20
Centrifuge	0.01	5	20
Polarimeters	0.005	6	5
PH Meters plus Reagents	0.005	8	3
Automated Weather Station	0.2	25	6
Gravimeter	0.1	10	5
Microtome, Slides and Stain	0.005	5	15
Refrigerators	0.1	5	40
Incubators	0.3	10	100
Oven-sterilizer	0.2	20	500
Work Bench of Glassware	0.5	25	N/A
Micromanipulators	0.005	7	5
Ultrasonic Cleaner with Solvent	0.2	25	200
Agitators and Blenders	0.01	3	10
Rock Cutters, Polishing, and Etching	0.01	9	125
Sample Holders and Containers	0.15	30	N/A
Scanning Electron Microscope	0.3	50	200
X-Ray Diffraction Device	0.09	10	10
X-Ray Fluorescence Spectrometer	0.09	10	10
Gas Chromatograph	0.05	5	1
Atomic Absorption Spectrometer	0.09	5	5
Magnetometer	0.15	6	4
Electromagnetic Induction Experiment	0.04	7	25

Emergency equipment, such as fire extinguishers, first aid kits, and emergency communications, will be located in the science module, as well as all other modules.

5.3.4 LIVING QUARTERS MODULE

The living quarters module will contain the private/sleeping compartments. Figure 5.5 shows one possible layout of the module. Each of the six crewmembers has a personal living section, which includes a fold-out bed, desk, chair, personal computer and printer, and storage drawers. Sliding doors will give each member privacy. Two showers, sinks, and toilets are in the same area. In addition, a stacked washer and dryer unit and storage area will be present.

5.3.5 GALLEY/STORAGE MODULE

The galley and storage module will provide for food storage, food preparation, and a dining area. The extra space will be used for general purpose storage. For food preparation, a microwave, sink, convection oven, and a washer should be provided. A table and chairs will provide a place for crewmembers to eat. A system for waste water reclamation should be included.

5.3.6 SICK BAY

Because injuries could occur easily in the science module during experimentation, the sick bay from Phobos will be placed next to the science module and the housing module for easiest access. The sick bay will contain all basic equipment for minor and major emergencies.

5.3.7 TRANSFORMABLE LANDERS

Two of the cargo landers will be utilized as an integral part of the base. One lander will be used as a housing and maintenance hangar for the robots. The hangar will be pressurized, perhaps by an internal inflatable structure, so the crew can work and repair equipment in a shirt-sleeve environment. This lander will be located at the landing field site. A second lander will be used as a "recreational module" for the crew's exercise and game playing. This lander will also be pressurized, again possible by inflation. This lander will be located next to the habitat modules.

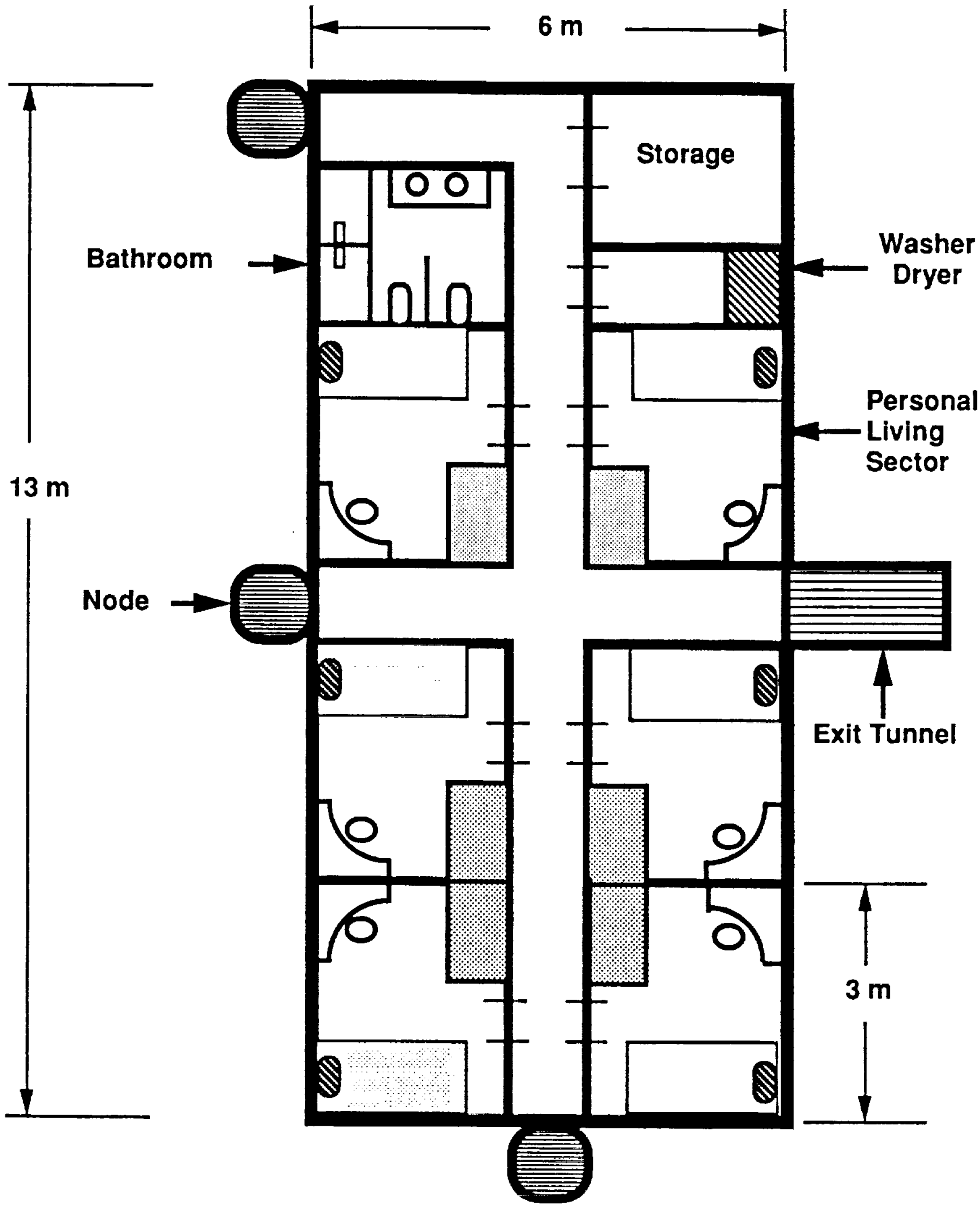


FIGURE 5.5 - TOP VIEW OF LIVING QUARTERS MODULE

One third gravity on Mars causes atrophy, or deterioration of the muscles, bones, and cardiovascular system for humans spending prolonged periods on Mars. Approximately 30 minutes of daily strength training would prevent these problems. Isokinetic exercise applying maximal effort against high resistance would be effective and would inhibit bone demineralization. Figure 5.6 shows an isokinetic exercise unit with dimensions of 137 cm x 122 cm x 61 cm (Case for Mars II).

Treadmills, stationary bicycles, rowing machines, and perhaps a small track are other ideas being considered for the recreation module. In addition, conventional sports, such as basketball, are being considered, while new "Martian games" may emerge. Basketball in one-third gravity should prove to be very interesting and challenging.

5.4 ENVIRONMENTAL/LIFE SUPPORT SYSTEMS

A closed system will be used since it requires no supply from Earth and is the most economical way to sustain a permanent base. The life support system will require approximately 10 kW of power, not taking into account the Biosphere at peak operational conditions ("Lunar Base Study").

As previously stated, the Biosphere module will house plants to purify the breathing air and waste water. Any plant can digest compounds that are highly poisonous to humans in surprisingly large numbers. House plants also manufacture oxygen as a waste product when they consume carbon dioxide, a waste gas exhaled by the human co-dwellers (Mackowski).

The plants can be grown in a charcoal-gravel-potting soil mix. An air pump will be embedded in the mixture and the biosphere module to circulate the purified air throughout the habitat modules (Mackowski).

For sewage purification, some plants will be grown in a vertical plastic trellis through which the sewage (urine, wash water) solution is dripped. The

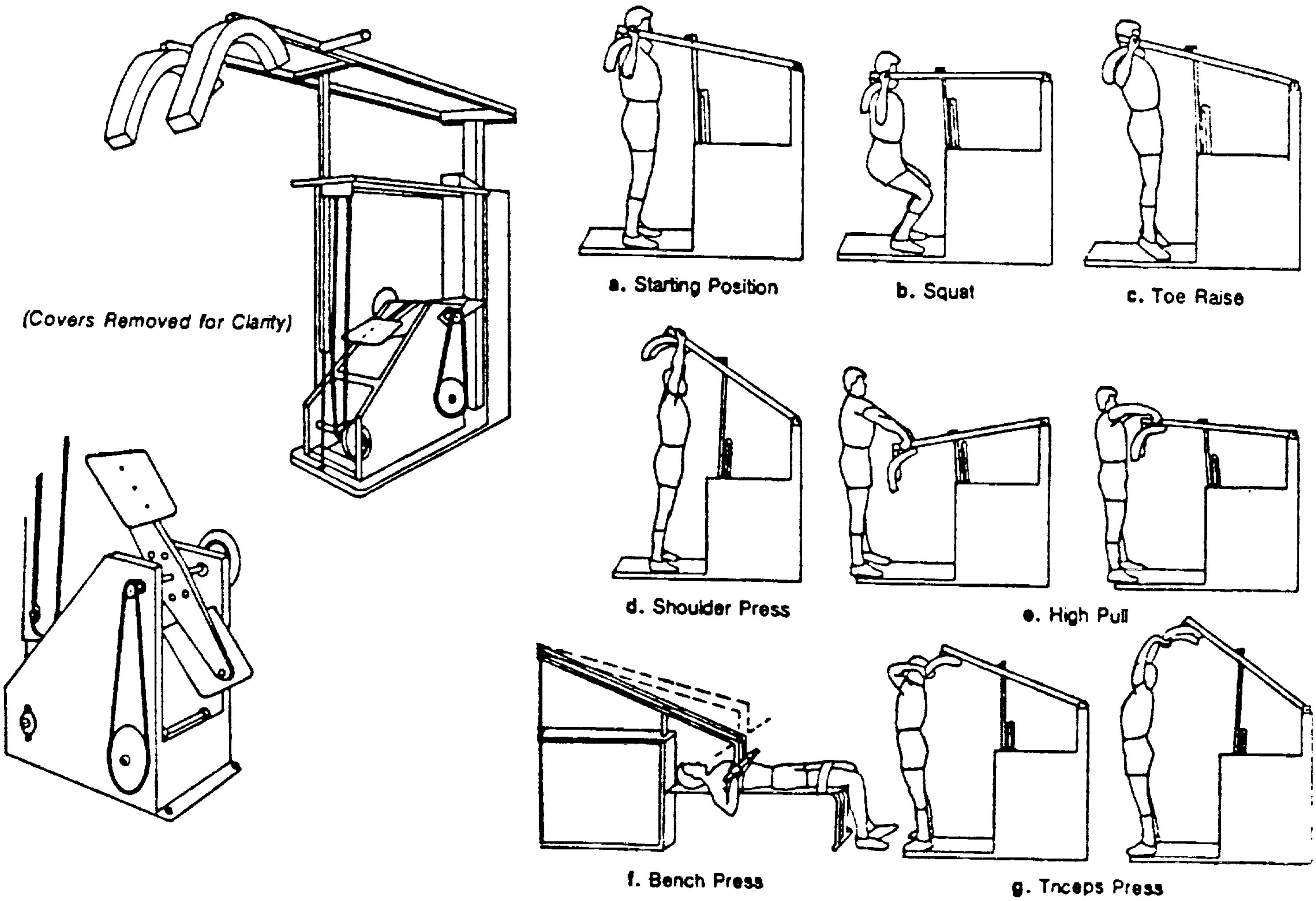


FIGURE 5.6 - ISOKINETIC EXERCISE UNIT
(Source: The Case for Mars II)

plants' roots are used as a purifier, consuming microbes and pollutants and leaving clean water behind (Mackowski). This process will supplement the water purification and resupply from the manufacturing center mentioned in the Environment section. Water can also be obtained from evapotranspiration (loss of water from soil and transpiration from plant surfaces).

The air and water reclamation processes described should provide for a 90% recovery efficiency within the closed system ("Lunar Base Study").

In addition to air regulation, there must be a thermal control system present to regulate the air temperature. Excess thermal energy from working equipment and the human body itself must be accounted for. Excess energy from the module equipment can be distributed and stored using chemical heat pumps. This is how the modules will be heated to room temperature. This type of pump uses sodium sulfide (NaS_2) as a storing agent and as a reactant in a chemical process that enhances the pumps' efficiency. At present, eight one-ton containers can store and deliver 8,000 kW of thermal energy. Sodium sulfide will be extracted or made from the Martian soil. With further research and development, this type of heat transfer will undoubtedly become even more efficient.

To avoid overheating, the Liquid Droplet Radiator (LDR) is one possible design. The lightweight LDR consists of a column or sheet of liquid droplets moving from a droplet generator to a collector. The droplets carry the waste heat produced by the module power systems and radiate this waste heat to the surroundings. The liquid droplets are collected at a lower temperature, reheated, pumped to the generator, and reused to continue to remove waste heat from the thermodynamic power cycle (Johnson, p. 975).

The regenerated air will be circulated throughout the modules with a series of pumps and a piping system. The pipes will likely run along the side of the modules.

Once all the system controls are in place and the modules are pressurized, a robotic check of each will precede any habitation by man.

Considering Mars' great distance from Earth, a planned system of emergency procedures and escape schemes is essential for the ensured safety of crew members. Just as on the shuttle, these emergency procedures must be well-known to the crew in case of problems. The three airlock exit tunnels to the surface of Mars provides not only access to the surface for day-to-day work, but also for emergency escape. Crew members could go to the Recreation hangar or the Maintenance hangar, both of which will have emergency communications and food.

Other contingency considerations incorporated into the Mars Base include fire extinguishers, first aid kits, emergency communication kits, and emergency food. These will be included in every module.

6.0 RECOMMENDATIONS

After the research completed during the contract period, several areas were determined as needing future research or investigation. Since one of the goals of this project was to determine and highlight driving technologies, the following section outlines the recommendations from each group within the M.I.N.G. structure; that is the Environmental Group, the Robotics Group, and the Habitation Group.

6.1 ENVIRONMENTAL GROUP RECOMMENDATIONS

A necessary prerequisite to the establishment of the manned base as proposed is a program involving surface and subsurface Martian probes. These probes should be designed to gather global data to help develop a dynamic model of Mars. The program could begin in the near future using return missions and continue during the Phobos base construction. These return missions will provide actual Mars samples and specific information on the environment. In particular, the soil and atmosphere near the proposed base locations should be rigorously tested in order to determine whether these locations are viable sites with regard to water availability and ground stability. Until these exploratory missions are undertaken, it would be unwise to begin any base construction on Mars.

One of the goals of research before the Mars base is constructed should be the miniaturization of the equipment in the manufacturing facility's subsystems. The robots' tasks would be greatly simplified, if the mass of these subsystems can be significantly reduced from what today's technology would require. Thus, these subsystems should be designed as easily-joined modular structures. Furthermore, with the lower mass, payload demands aboard interplanetary transport vehicles would be reduced.

Another topic which must be examined concerns the construction of a permanent landing site for spacecraft. At this time, the use of concrete in this task is not workable. Because of the near-vacuum pressures and low temperatures of Mars, concrete as we know it could not be mixed or poured onto the desired surface before its water froze or evaporated. An alternative that should be explored is the use of ceramic, thermal insulating tiles laid out over a flat surface to provide a landing pad. The production of a ceramic-like material could be a long-term goal of the manufacturing facility. Another option that should be investigated is the use of polymer concrete which is currently being developed.

There are many technologies which should be explored in the area of power generation. The first of these is in the field of fusion energy. Currently, scientists are racing to achieve controlled nuclear fusion processes which can be used to generate power for civilian use in a cost-effective manner. While achievement of this goal has not been verified, many expect that advances in superconductivity and perhaps even in cold fusion technology will allow for the use of fusion in the 21st century. If such advances take place, fusion as a power source for the Mars base should be seriously considered.

Another area to be addressed by future research is that of energy storage. An efficient method for long-term, large-scale energy storage is necessary to enable a Martian colony to exist and grow. Advances in superconductivity technology will provide for a more efficient method of energy storage. A system currently under investigation combines superconducting magnets and particle accelerators to store energy. This type of system could store large amounts of energy by magnetically suspending and accelerating metal cubes in a circular vacuum chamber. The energy could be retrieved by reversing the process and using the accelerator ring as a generator (Business Week, p. 79). Other energy storage techniques could be developed in the future that would be easier to implement and should be investigated.

6.2 RECOMMENDATIONS - ROBOTICS GROUP

The conditions on Mars will have significant impact on robotic operations. Any mechanical equipment used on Mars will have to overcome the effects of reduced gravity, increased radiation, friction, and evaporation of volatiles due to low atmospheric pressure. The robots should be composed of light-weight materials possibly taking advantage of newly discovered composites in the future. In addition, advanced seal technology should be developed in order to protect all the mechanical equipment from the Martian environment.

In order to power the robots, advanced power systems should be investigated. High energy regenerative fuel cells and batteries should be further developed along with research and development of a compact nuclear power source. A nuclear power source would end the need for recharging and possibly increase the robot's efficiency.

All the robotic systems should be reliable, redundant, and durable. For example, the artificial intelligence system should have cross-checks in order to minimize the error. They should take advantage of the most current advances in automation and telerobotics.

One of the most important recommendations is that all the Martian equipment should be thoroughly tested in a simulated Martian environment on Earth. In addition, the robot tasks should be designed for simplicity taking advantage of ideas such as adhesive connections, twist locks and levers. The jobs can be done more easily and quickly if the manipulator, the components to be manipulated, and the task procedure are designed for compatibility. These include special end effectors, and parts made with grip surfaces that automatically provide indexing, guides or self-aligning parts.

6.3 RECOMMENDATIONS - HABITATION GROUP

The main objective for the future of the Mars Base is the expansion of this preliminary bootstrap base into a full-scale community.

Modules would need to be added to the base. Additional living quarters modules would be needed to accomodate more crew members. Additional biosphere modules should produce food for the entire crew. The biosphere module should also be able to regenerate the air and waste water without relying on other systems. Science modules would be needed to continue the research that the crew will be conducting.

Research should be directed at more efficient, closed life support systems. Waste, oxygen, and water regeneration systems should be extremely efficient and reliable. A Closed Ecological Life Support System should definitely be expanded to accomodate a large crew community.

With the growth of the Mars Base community, psychological factors will be a very important part of the expansion planning. Additional recreational facilities will be needed to maintain a habitable base environment. Movies, games, music, television, and more exercise facilities should be integrated into the expansion of the base layout. As the base grows, the space that the crew actually works and lives in should also grow. Psychological stresses would then be kept to a minimum.

Human mobility on the surface of Mars is also a very important factor to research. Buggies, carts, or monorails need to be developed to make it easier for the crew to travel around the entire base. A transportation system for the exploration of Mars by humans or robots needs to be developed to better utilize the Martian resources. This would also allow for further investigation of the Martian surface and related technologies.

The minimization of the mass that will be transported to the Mars Base should be kept in mind throughout all research and development work. However, the safety and comfort of the crew must play the most important role in development efforts.

7.0 SUMMARY

Human safety is of utmost importance in this project. The construction of a base on Mars is far too dangerous for humans; therefore, robots must be used to build this facility. These robots must be durable, efficient, and able to withstand the harsh environment. Great advances in technology will be necessary before robots of this sophistication will be ready to perform the complex tasks required to construct a Mars base. Once this plateau in robotics has been achieved, human resources may be diverted to other scientific endeavors.

The base as designed will consist of the following: two power plants, communication facilities, a habitat complex, and a hanger, a garage, recreation and manufacturing facilities. The power plants will be self-contained nuclear fission reactors placed approximately 1 km from the base for safety considerations. The base communication system will use a combination of orbiting satellites and surface relay stations. This system is necessary for robotic contact with Phobos and any future communication requirements.

The habitat complex will consist of six self-contained modules: core, bioshpere, science, living quarters, galley/storage, and a sick bay which has been brought from Phobos. The complex will be set into an excavated hole and covered with approximately 0.5 m of "sandbags" to provide radiation protection for the astronauts. The recreation, hangar, garage, and manufacturing facilities will each be transformed from the four one-way landers.

The complete complex will be built by autonomous, artificially intellegent robots. Robots incorporated into our design are as follows: Large Modular Construction Robots with detachable arms capable of large scale construction activities; Small Maneuverable Robotic Servicers capable of performing delicate tasks normally requiring a suited astronaut; and a trailer vehicle with modular type attachments to complete specific tasks; and finally, Mobile Autonomous Rechargeable Transporters capable of transferring air and water from the manufacturing facility to the habitat complex.

New innovations will surely develop within the next 30 years. Our design will be capable of adjusting to these changes without altering the basic structure of the base plan.

8.0 MANAGEMENT REVIEW

In order to complete the required design our company, M.I.N.G., the Mar's Investment in a New Generation, organized under the following corporate structure shown in Figure 8.1. Task responsibilities were divided into these four areas: group leader, liaisons, technical managers, and engineers. The group leader was responsible for group meetings and agendas for those meetings. Records were also be maintained on new ideas and accomplishments. The liaisons kept abreast of all activities in each group within the class. This group representative had to remain informed enough in all group research areas to answer technical questions from the other liaisons and represent our group's interests. The technical managers were responsible for directing research efforts and reporting to the entire group on his respective engineer's accomplishments. Engineers are to research necessary areas and provide new ideas for problem solutions. Note that every company member serves in the engineering capacity.

The timeline-scheduling chart is shown in Appendix A. This chart was periodically updated throughout the semester to adjust for date changes.

The number of hours each member worked was recorded throughout the semester. These manhour charts are presented in Figures 8.2 - 8.4. The projected amount of hours is shown also and was generally followed throughtout the contract period. Figure 8.5 shows the entire M.I.N.G. manhours chart. As seen in the figure, more work was required in the second half of the contract period than initially expected.

Overall, the group effort in compiling this report was successful. Each member completed his or her tasks adequately with few interpersonal difficulties. Also, scheduling was not as much of a problem as might be expected with such a large group. The sub-group division of labor proved to be very beneficial in completing specified tasks. Although there were times when certain members did not apply themselves as much as expected, each member did in some way make valuable contributions to the overall project.

M.I.N.G. COORPORATION STRUCTURE

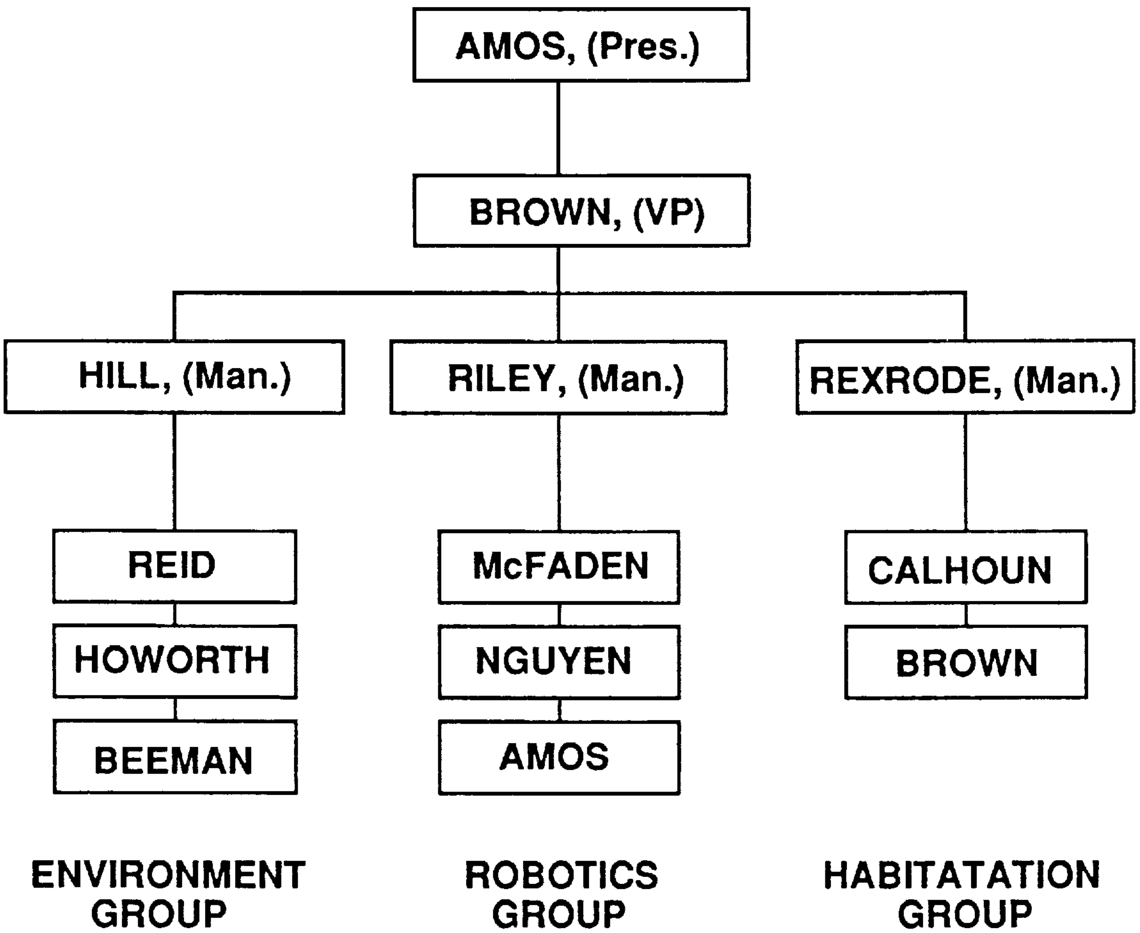


FIGURE 8.1 - COMPANY CHART

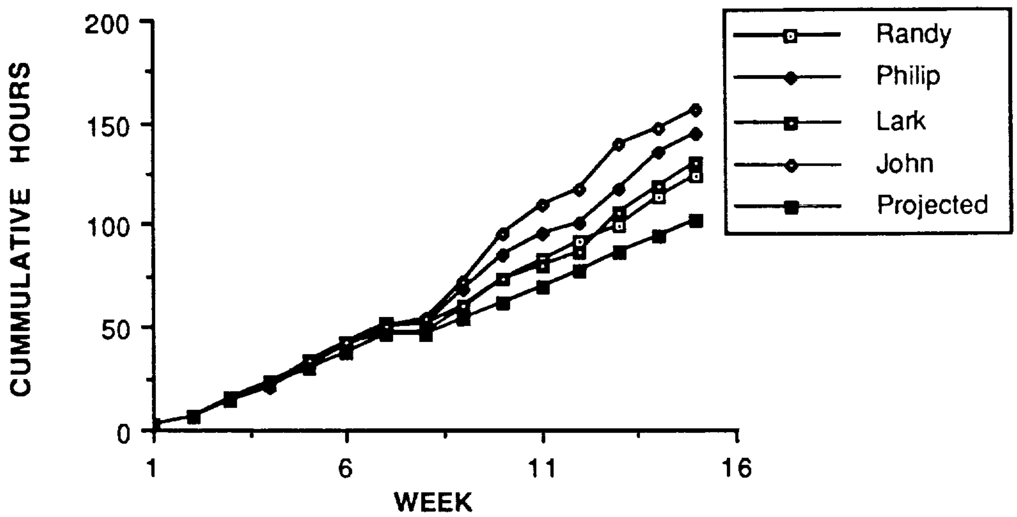


FIGURE 8.2 - MANHOURS CHART FOR ENVIRONMENT GROUP

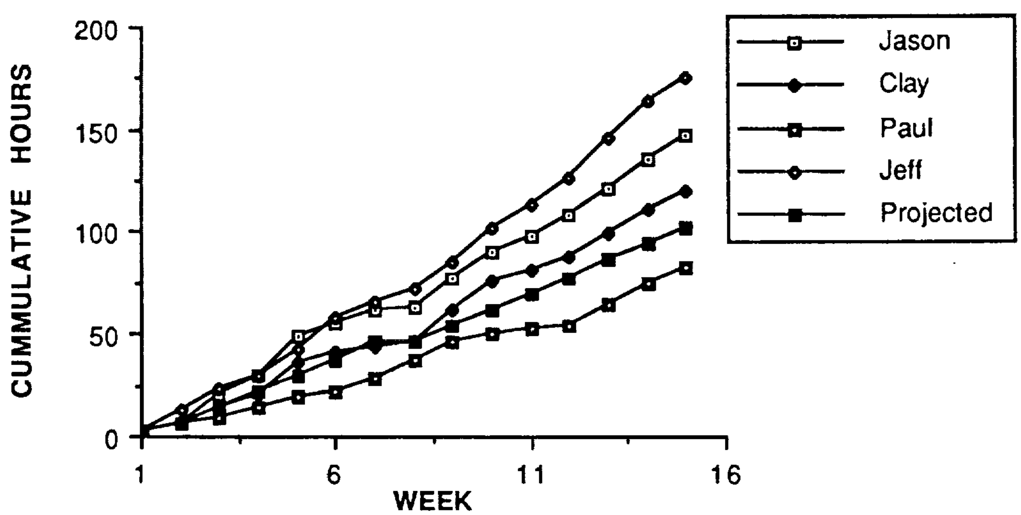


FIGURE 8.3 - MANHOURS CHART FOR ROBOTICS GROUP

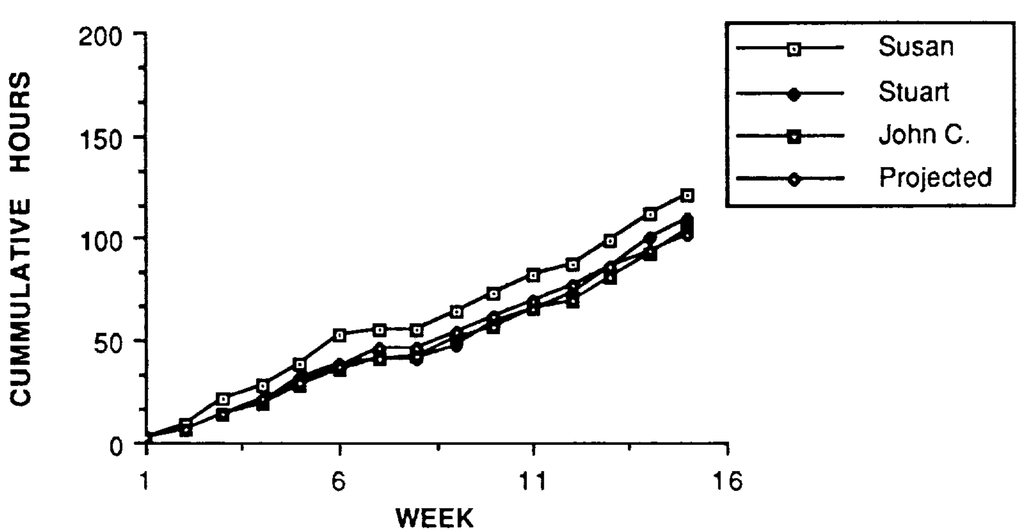


FIGURE 8.4 - MANHOURS CHART FOR HABITAT GROUP

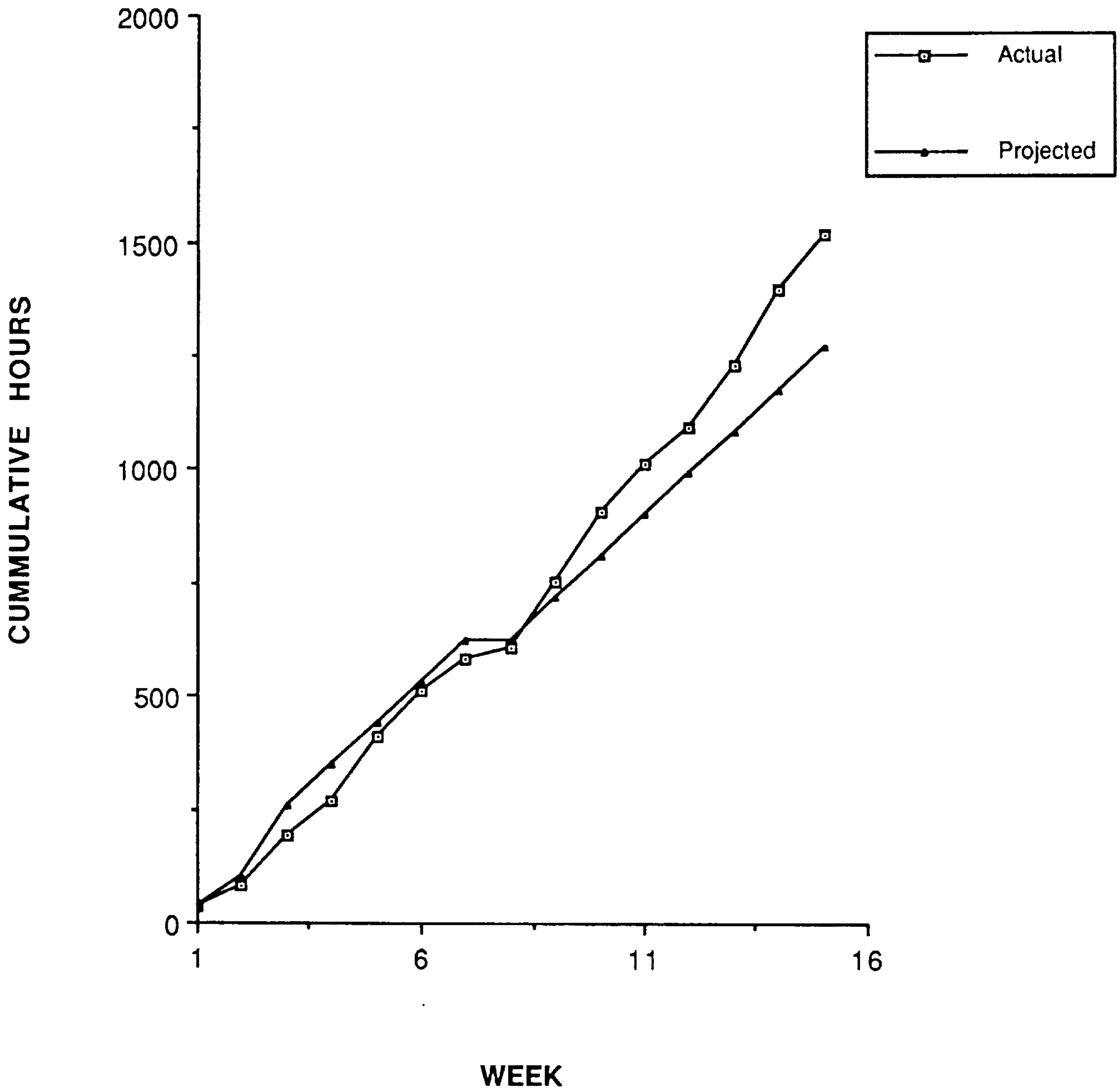


FIGURE 8.5 - MANHOURS CHART FOR M.I.N.G.

9.0 COST REVIEW

The personnel and materials costs required to fulfill this contract are presented in this section.

9.1 PERSONNEL COST ESTIMATES

Using costs given in the Request for Proposal, Table 9.1 outlines our company cost estimate. Throughout the actual contract period more hours were devoted than anticipated. Table 9.2 shows the total actual cost based on the actual number of hours worked by each employee.

TABLE 9.1
PERSONNEL COST ESTIMATES

Employee	Wage (hr)	Hours/Week	Salary/Week
President	$ 25.00	12	$ 300
Vice-President	22.00	10	220
Tech Manager (3)	20.00	10	600
Engineer (6)	15.00	10	2700
Consulting	75.00	1	75
Total Projected			**$ 22, 842.00**

TABLE 9.2
ACTUAL PERSONNEL COST

Employee	Wage (hr)	Hours/Sem	Salary/Sem
President	$ 25.00	176	$ 4, 000
Vice-President	22.00	121.5	2, 673
Tech Manager (3)	20.00	413	8, 260
Engineer (6)	15.00	704.5	10, 568
Consulting	75.00	6	450
Total Actual			**$ 27, 360.00**

9.2 MATERIALS COST ESTIMATE

The proposed and acutal material cost were the same for the contract period. Table 9.3 shows the Material cost, actual and estimated.

TABLE 9.3
MATERIALS COST

Material/Hardware	Total for Semester
1 Macintosh computer/ software and accessories	$ 750.00
1 IBM Personal System II	750.00
Laserwriting Documents	100.00
Photocopies	200.00
Transparencies	75.00
Travel Expenses	360.00
Miscellaneous	400.00
Subtotal	$ 2610.00
Error Estimate	250.00
Total Estimate	**$ 2860.00**

9.3 TOTAL PROPOSED AND ACTUAL PROJECT COST

Personnel Cost Proposed	$ 22, 842.00
Hardware Cost Proposed	2, 860.00
Personnel Cost Actual	$ 27, 360.00
Hardware Cost Actual	2, 860.00
Total Proposed Cost	**$ 25, 702.00**
Total Actual Cost	**$ 30, 220.00**

10.0 REFERENCES

Angelo, J.A. and Burden, D. Nuclear Energy for Lunar Bases. 36th Congress of International Astronautical Foundation: Stockholm, Sweden, October 7-12, 1985.

Carr, Michael H. The Surface of Mars. Yale University Press: New Haven, Conn, 1981.

Collicott, Howard E. and Paul E. Bauer, eds. Spacecraft Thermal Control, Design, and Operation. American Institute of Aeronautics and Astronautics: New York, NY, 1983.

Davis, G., et al. "The Lunar Split Mission: A Robotically Constructed Lunar Base Scenario." NASA/USRA Advanced Space Design Program, August 1988.

Day, David. Construction Equipment Guide. John Wiley and Sons, Inc.: New York, NY.

Department of the Interior U.S. Geoligical Survey. "Shaded Relief and Surface Markings of the Eastern and Western Regions of Mars", Published by the U.S. Geoligical Survey, 1985.

Ed. Business Week 1 July 1985: 79.

Espiau, Bernard. "Use of Optical Relectance Sensors." Recent Advances in Robotics. Eds. Gerando Beni and Susan Hackwood. John Wiley & Sons, 1985, p. 319.

Fowler, Wallace. Personal interview. 1 February 1989.

Garrett, Henry B. and Charles P. Pike. Space Systems and Their Interactions with Earth's Space Environment. AIAA: NY, NY, 1980.

Gerard, Mireille, and Pamela W. Edwards, eds. Space Station: Policy, Planning, and Utilization. AIAA: NY, NY, 1983.

Giancoli, Douglas C. General Physics. Prentice-Hall, Inc.: Englewood Cliffs, New Jersey, 1984, p. 643, 809.

Guest, Butterworth, Murray, O'Donnel. Planetary Geology. Halsted Press: New York, 1979.

Gosch, John. "Robots Get 'Ears' For Better Depth Perception," Electronics Vol. 60, 8 Jan 1987: 42-43.

Hall, Ernest L., and McPherson, Charles A. "Three-Dimensional Robot Vision Techniques." Recent Advances in Robotics. Eds. Gerando Beni and Susan Hackwood. John Wiley & Sons, 1985, p. 277.

Hamel, William, and Charles Weisbin. "Autonomous Robot Navigation; Teaching Robots to Look Before They Leap." Byte Jan. 1986: 227-233.

Harmon, Leon D. "Tactile Sensing for Robots." Recent Advances in Robotics. Eds. Gerando Beni and Susan Hackwood. John Wiley & Sons, 1985, p. 390-400.

"Integrated Water System for a Space Colony", Project Report for the NASA/USRA. Prairie View A&M University, June 1988.

Johnson, Stewart, and John Wetzel, eds. Engineering, Construction, and Operations in Space. American Society of Civil Engineers: NY, NY, 1988.

Liechti, K.M. Personal interview. 11 April 1989.

"Lunar Base Study." Project Report for the NASA/USRA, August 1987.

"Lunar Surface Operations Study," Lunar Base Systems Study Task 4.1, NASA Contract NA59-17878, Report No. 87-172, Eagle Engineering Inc., Houston Division, 8 Dec 1987.

Murray, Malin, Greeley. Earthlike Planets. W. H. Freeman and Company: San Francisco, CA, 1981.

NASA CP 2231.

Pennywitt, Kirk E. "Robotic Tactile Sensing," Byte Vol. 11, Jan 1986: 177-187.

Prairie View A&M University, "Integrated Water System for a Space Colony", Project Report for the NASA/USRA. June 1988.

Rowley, John C. and Hoseph W. Neudecker. "In Situ Rock Melting and Construction." Lunar Bases and Space Activities in the 21st Century. Ed. W. W. Mendell. Lunar and Planetary Institute: Houston, 1985.

Sutphin, Susan. "Lunar Ramblin' Wreck." Space World Apr 1988: 22.

Texas A&M University. "To Mars." Project Report for the NASA/USRA, August 1985.

The Case for Mars II, ed. Science and Technology Series, Vol. 62. July 1986.

University of Texas at Austin. "Bootstrap Mission Base." Project Report for the NASA/USRA, November 1987.

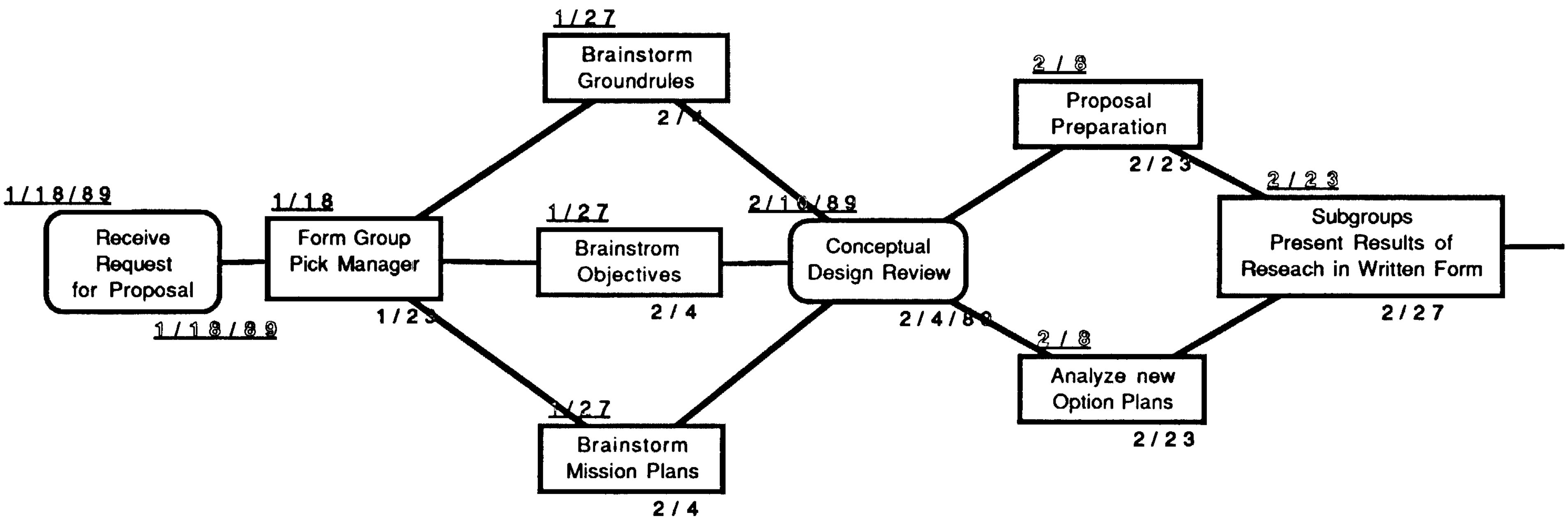
University of Texas. "The Lunar Split Mission." Project Report for the NASA/USRA, August 1988.

Van Vliet, Robert M. Passive Temperature Control in the Space Environment. Macmillan: NY, NY, 1965.

Watts, Susan. "Cross-eyed Robot Starts to See like People." New Scientist Sept. 15, 1988: 40.

Wolfe, W. and N. Marquina. Mobile Robots, The International Society for Optical Engineering: Vol. 727. Cambridge, Mass., Oct 1986.

APPENDIX A



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Brainstrom Objectives
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Brainstorm Mission Plans
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Conceptual Design Review
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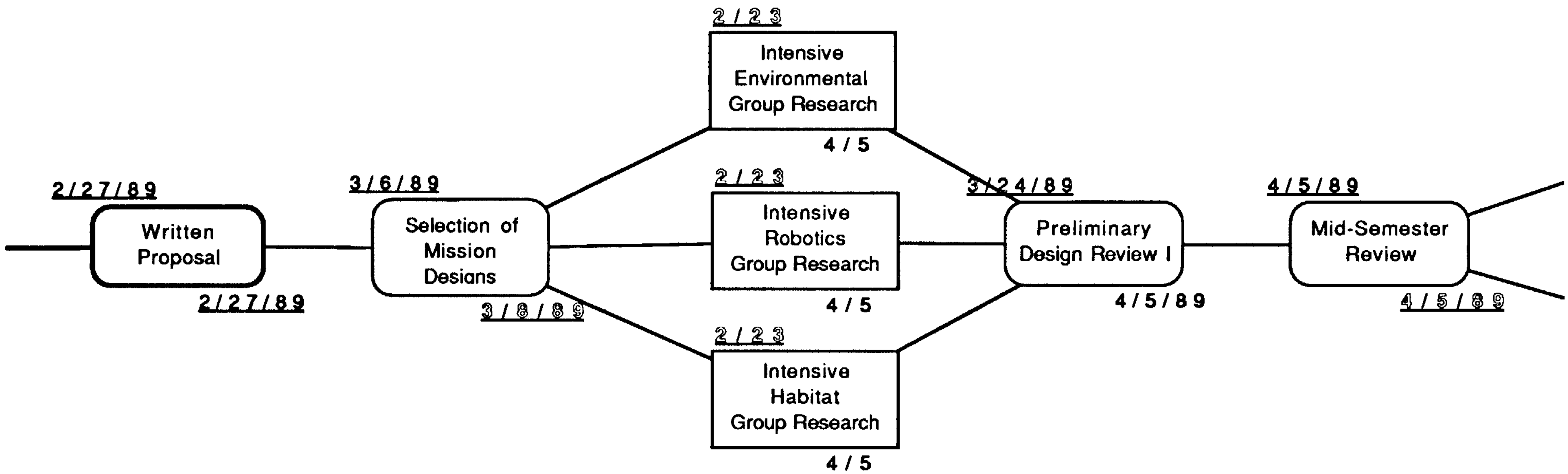
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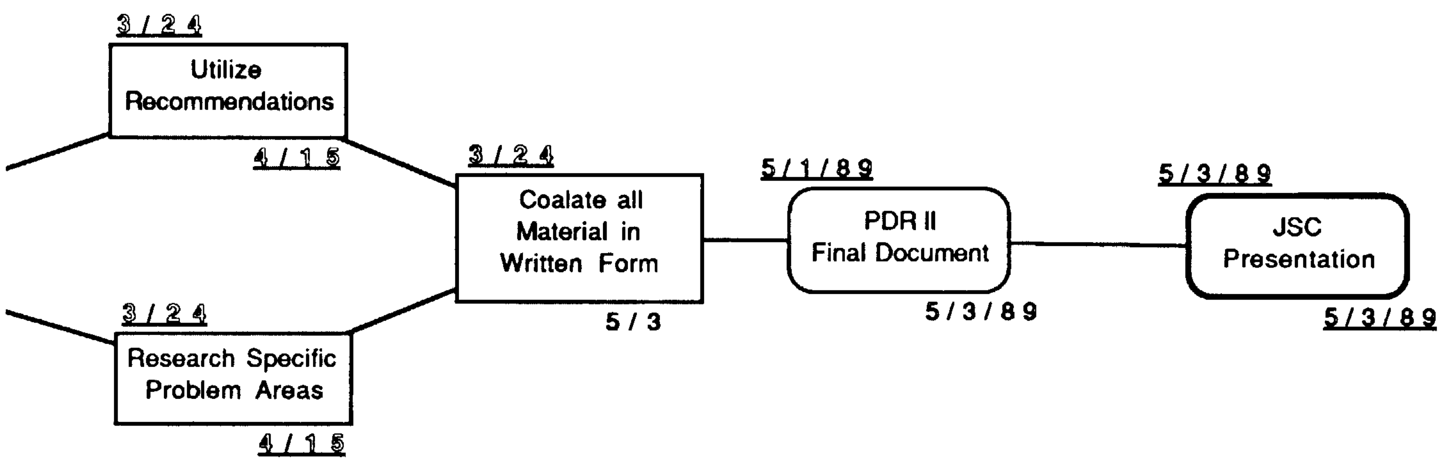
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Coalate all Material in Written Form
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PDR II Final Document
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JSC Presentation
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A PROPOSAL FOR THE ROBOTIC CONSTRUCTION OF A PERMANENTLY MANNED MARS BASE

Written in Response to:

RFP #ASE 274L

Submitted to:

Dr. Botbyl

The University of Texas at Austin

Department of Aerospace Engineering

and Engineering Mechanics

Presented by:

M.I.N.G.

February 27, 1989

EXECUTIVE OVERVIEW

This proposal to the sponsor is in response to the Request For Proposal issued by NASA/USRA (University Space Research Association) in conjunction with the University of Texas at Austin senior design program. M.I.N.G., the Mars Investment Group, has outlined in this proposal the basic methods in which to robotically construct a manned Mars base.

This report includes this company's initial design views and a method for continued planning and research in completing that design over the next two months.

The proposal is divided into the following basic areas: an introduction stating our groundrules and assumptions, a general plan of attack which will allow the M.I.N.G. corporation to accomplish the design objectives, and three separate research areas, environment, robotics, and habitat, presenting preliminary design options. A summary of the conceived base operations and construction concludes the design presentation. Finally, management structures, timelines, cost analyses, and schedule charts are included to show our corporation ability to complete the design project.

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design work in detailing available and existing resources within the time frame of the actual base construction.

A fully operational Moon base of the type specified in the Lunar Split Mission Scenario will be the premier assumption of this design effort. Precursor accomplishments assumed by that design, such as the existence of a Heavy Lift Launch Vehicle, a Space-Docking facility in Low Earth Orbit, and efficient Orbit Transfer Vehicles are likewise presumed. Additionally, following the evolutionary expansion into space, the design will assume that a man-tenable facility is in existence in/or about Phobos.

The time frames inferred from these previously achieved developments have start dates ranging from an optimistic year of 2020 through a pessimistic date of 2045. These frames, posed 30 to 50 years into the future, allows for some creative adaptations of potential technological developments and of current aspirations which may by that time be realized.

Construction of the manned facility will be completed almost exclusively through the use of advanced robotics. The robotic limitations will be examined from both an optimistic and pessimistic standpoint with robots akin to these outlooks.

The assumption will be made to construct a facility which accommodates an initial crew size of six to eight members. A small crew size presents less of a technological problem. But, due to the lengths of time involved, a larger crew results in fewer interpersonal difficulties.

Due to the permanently manned base objective, design considerations will attempt to allow for maximum expansion throughout the lifetime of the base.

The Mars base will utilize as many unnecessary components of the Phobos base as allowed, such as the medical facility and exercise equipment, while maintaining the temporary manned Phobos mission capabilities as specified by the Phobos Design Team, Phobia.

Long term living in space will be assumed to have been studied over the course of Space Station, Moon Base, and Phobos missions, thereby answering

1.0 INTRODUCTION

This document is in response to the Request For Proposal (RFP #274L dated Spring 1989) which calls for the design of a robotically constructed base on Mars. Outlined here are design objectives and basic assumptions. Also presented are construction plan considerations which have been divided into three technical groups: environment, robotics, and habitat. And finally, a management overview detailing company structure and proposed plans of attacking the design problem in fulfilling the RFP requirements.

1.1 OBJECTIVES

The objectives of a permanently manned Mars Base are numerous. Primarily, human presence on Mar's will allow utilization of new resources for the improvement of the quality of life on Earth, allowing for new discoveries in technologies, the solar system, and human physiology. Such a mission would also encourage interaction between different countries increasing international cooperation leading to a stronger unification of mankind. Surface studies of Mars, scientific experiments in multiple fields, the search for new minerals and natural resource production are more immediate goals of the Mars mission. Finally, in the future, colonization of Mars will insure man's perpetual presence in the universe.

The objectives of the M.I.N.G. Corporation in this design effort are to present a feasible plan for the construction of a permanently manned Mars base which will be completed entirely with robotics. Design developments incorporating new and envisioned technologies will be an important aspect of our proposed effort. Identifying driving technologies is an important aspect of our project.

1.2 GROUNDRULES

A set of groundrules have been established in order to determine the scope of our design effort. These initial assumptions specify the course of our most questions on human habitation in space. These known solutions can then be easily applied within the framework of the Mars Base.

Necessary teleoperations will be undertaken from the operational Phobos Base. Communications satellites positioned by the Phobos Installation will be used for Phobos-Mars and Earth-Mars communications.

2.0 TECHNICAL PROPOSAL

For maximum utilization of manpower capabilities in the efficient completion of a comprehensive design, the M.I.N.G. Corp. has been divided into three technical sub-groups. The first group is the Environmental Group which is responsible for geographic investigation, environmental studies, manufacturing facilities, and power generation. The second group, the Robotics Group, covers robot designs, communications, power for robots, rovers, and integrations of the robotic construction. Science facilities, human studies, emergencies, and module installations are the areas studied by the Habitat Group.

The next three sections of the proposal include the initial design considerations and options from each group.

2.1 ENVIRONMENTAL GROUP

The environmental factors will play a key role in any expedition to Mars. These factors will influence decisions concerning site location, resource utilization, communication, and habitat design for a Martian base.

2.1.1 ATMOSPHERE

Table 1 shows the relative composition of the Martian atmosphere. As can be seen from the table, the main component is carbon dioxide. Many of the elements essential for manned base operations not found in the atmosphere can be extracted from the regolith (Carr).

TABLE 1
COMPOSITION OF THE ATMOSPHERE AT THE SURFACE

GAS	PROPORTION
Carbon Dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon Monoxide	0.07%
Water Vapor	0.03%
Neon	2.5 ppm
Krypton	0.3 ppm
Xenon	0.08 ppm
Ozone	0.03 ppm

The surface temperature of Mars is much lower than that of Earth. Temperatures at the surface of Mars depend on several factors such as latitude, season, time of day and the properties of the surface. The temperatures are lowest just before dawn, rising rapidly in the afternoon to a maximum just after noon. The Northern and Southern hemispheres of Mars have different temperatures due to the precessional effects, with milder temperatures in the North (Guest, et al). The lowest temperatures occur at the south pole during the winter where they can fall as low as 148 K. The highest temperatures, at mid-latitudes in the Southern hemisphere, can reach 295 K.

One phenomenon of Martian weather that will effect design decisions is global dust storms. Originating in the Southern hemisphere, dust storms can expand to cover much of the planet, and can last four or five months. The winds during these storms reach 17 m/s with gusts of 26 m/s (Carr, Michael).

2.1.2 GEOGRAPHIC LOCATION

The location of the base should meet several basic requirements. These include:

* "Flat" area for landing facilities
* Traversable terrain from landing site to base construction site
* Shielding from solar/interstellar radiation
* Stable ground (i.e., low probability of landslide, lava flow, etc.)
* Relatively mild weather conditions (i.e., safe from extreme temperature variations, dust storms, etc.)
* Potential mineral and LOX (Liquid Oxygen) mining sites nearby.

Another consideration is a low latitude or near equatorial site to provide lower transportation costs from low Mars orbit. Initial research indicates that the Northern hemisphere fulfills more of the basic requirements listed above.

Physiographic characteristics play an important role in the choice of the base location. Several base configurations are possible, they include:

* Tunneling into the side of a mountain or cliff
* Tunneling into the side of a crater or canyon
* Digging into flatlands or plains
* Building on top of the surface and cover with regolith.

Specific locations which meet these requirements are being explored and will be presented in the PDR1.

2.1.3 MANUFACTURING FACILITIES

To sustain life and maintain base operations, Martian resources must be utilized. Air, water, and fuel are some of the principle needs of the base. Extensive evidence suggests water may exist under the permafrost layer of Mars. Water can also be produced from hydrogen and oxygen extracted from the soil and/or atmosphere.

Air produced for human consumption at the base should be proportionately similar to that of air on Earth. That is, the composition should include oxygen, an inert gas (e.g. nitrogen), and a small amount of water vapor.

A facility will be necessary for the refueling of spacecraft departing to Phobos, Earth or other destinations. It is assumed that LOX will be the propellant used aboard these spacecraft. LOX produced on Phobos will be stored on Mars. The reservoirs will be underground. Some of the options include using old landing vehicles or cargo bays as storage tanks, or chemically coated cavities under the surface; other options are being studied. This facility may be modified if a more viable power source is developed.

2.1.4 POWER

A permanent power source will be essential for the successful functioning of a manned base. The base requires a power source which meets the following conditions:

* Prefabricated
* Long life
* Low maintenance
* Redundant (for emergencies)
* High specific power
* Light weight.

Energy will be needed for the everyday operations such as water and air production, communications, and robotics. Radioisotope Thermoelectric Generators (RTG), photovoltaic (PV), solar dynamic, and nuclear reactor space power systems (NRSPS) have all been used successfully in a nonterrestrial environment. High winds on Mars may make wind power an option, but at this point the air density appears to be too low for modern conventional wind machine designs. A marsquake was recorded by a Viking lander indicating that Mars is internally dynamic, therefore geothermal energy could be another possibility. Technological advances may lead to other sources of power not in current use. The advanced power generating systems are currently being investigated for their potential use in the Mars base. In addition to production, energy must also be stored. Superconducting magnets, fuel cells, and rechargeable batteries are all viable options for energy storage on Mars.

2.2 ROBOTICS GROUP

Construction on Mars poses several major problems for humans. Mars lacks a magnetic field and has a very thin atmosphere. This results in potential human exposure to heavy doses of radiation. During a fifteen minute solar flare, a human on Mars can receive radiation doses comparable to the dosage received in the lifetime of a human on earth. In addition, space suits are bulky and not suitable for construction tasks. More importantly, human stays on the Martian surface will be limited to only a few days because of radiation. Finally, the question must be asked, what if an accident occurs and a human is killed? The Challenger accident crippled U.S. space activity for two and a half years. We cannot afford a similar delay on Mars (Fowler).

A robotically constructed Mars base is a feasible and realistic alternative. Robots can work on Mars indefinitely. Properly sealed robots can withstand radiation effects, corrosion, and other factors resulting from the harsh environment. Much of the construction skills needed have already been developed. Robotic arms (manipulators) are used extensively in the automobile industry. Welding, riveting, and sanding are all tasks performed by today's robotic arms. However, many advances in robotic technology will be necessary in the coming years. A robotically constructed Mars base is a challenging idea. Advances in the following areas are necessary:

* Artificial Intelligence
* Power
* Locomotion and Manipulation
* Communications

2.2.1 Artificial Intelligence (AI)

Robots must navigate autonomously through an unpredictable Martian environment. For example, a robot may have to travel one kilometer from a power source to a habitation module. Initially, the robot must map a specified path. This is called global mapping. As the robot traverses its path, it may encounter unexpected obstacles. Thus, the robot must reorient its path. This is called local mapping. (Hamel, p.223)

Global mapping uses permanent features as reference points. Before landing on the martian surface, robots will be programmed with a global map of the construction site and the surrounding environment. Permanent features such as mountains, large boulders, holes, and other hazardous features will already be known to the robots.

Local mapping is the responsibility of each individual robot. When unexpected obstacles are encountered, the robot must autonomously program the obstacle as a point on the global map to be avoided. A central control will then program all other robots of this new obstacle.

Other path finding techniques include: sonar, radio waves, vision, and lasers. For example, each module can emit radio waves at varying frequencies. Thus, robots can discriminate one module from another. This idea can also be applied to tools, manipulator attachments, and computers. Sonar is used to identify the distance of an obstacle. Lasers and vision define the configuration of an obstacle (Hamel, p.235).

Today, research is being developed in all areas of artificial intelligence. Nevertheless, this research is still in its fundamental stages. A robotically constructed Mars base will require the mastery of all navigational techniques.

2.2.2 Power Systems

The power system for the robots must be rugged, compact, dependable and long lasting. The two major options for power include having individual power sources in each machine, or having rechargeable batteries so that the robots can periodically plug into a central power source when needed. The second option is advantageous because batteries have high specific energies and good durability . However, current batteries tend to have short lifespans, and this will have to be considered in the design. If a rechargeable system is used, a power source will have to be set up immediately upon the robots arrival to Mars.

Some of the self-contained power sources being considered include radioisotope thermoelectric generators (RTG's) and fuel cells. RTG's have proven to be a very reliable power source in the past, and they can be safely integrated into a system (Angelo). Their major drawback is that they have a low specific energy and would have to be quite large to produce the needed power output. More research will have to be done on future RTG designs. Fuel cells appear to be a good power source for mobile robotic units because of their relatively light weight, high efficiency and life span (Davis, p.79). For these reasons, they will be a leading candidate for the robotic power system. Finally, solar power was considered but eliminated due to the frequent dust storms on the Martian surface and the overwhelming size of the system.

2.2.3 Locomotion and Manipulation

In some industries today, products are assembled by robots on an assembly line. These robots are stationary, work in a clean environment, and perform one specific task. Work on Mars will not be so simple. The robots will have to be mobile, protected from the harsh environment, and perform multiple tasks. Since dust storms are common on Mars, advanced seal technology is required to protect the robot's internal hardware from dust and corrosion.

Modern means of locomotion include wheels, tracks, and legs. Legged robots are the most agile. Spider-like robots can walk radially in any direction, turn about a point, walk upside-down, and turn right side up if knocked over (Sutphin, p. 22). However, wheels and tracks are better suited for travel over long distances and have good traction.

Martian robots will be responsible for a multitude of tasks. These tasks include the following:

* Excavating the site.
* Unloading and transporting the modules.
* Assembling the modules.
* Setting up the power system.

We will address these tasks by designing large modular robots with detachable arms capable of lifting, digging, and performing other various construction activities. In addition, we will design a trailer vehicle for transporting modules and construction equipment. Finally, a set of small, agile robots will be designed capable of performing delicate tasks in and around the modules. Some of these tasks might include welding, riveting, and wiring.

Construction operations in the Martian environment will require many adaptations of current technology to enable performance under the harsh conditions. Durable, maneuverable, and mechanically simple robots with multiple capabilities are our major objectives.

2.2.4 Communications

There must be, at least, daily communications with the robots, as the revision of construction tasks needs to be periodically updated. However, unanticipated problems will make much more frequent human communication with Martian robots a necessity. Naturally, the robots won't be able to address every unexpected situation. This requires periodic programming by man from either Phobos, the Moon, or Earth.

Humans could view construction activities through video cameras set up around the site. In addition, humans will "see through the eyes of the robot". Robotic eyes are video cameras (Watts, p. 40). Thus humans will detect and analyze problems encountered on Mars. The robots will then be programmed to address the specified problem.

Our most desirable option has humans supervising the construction process from Phobos. Precision tasks such as those required in and around the modules will be best accomplished by teleoperation from Phobos.

Teleoperation from Earth or the Moon is not desirable. The time lag for communication varies roughly from eight minutes to forty-five minutes depending on the location of Mars relative to the Earth-Moon system.

2.3 HABITAT GROUP

There are three important aspects to the habitat portion of the base. The location will affect the structure and configuration of the base. The purposes of each of the modules must be decided and emergency plans should be taken into consideration for safety.

2.3.1 HABITAT LOCATION

Due to the extreme levels of both solar and cosmic radiation and the potential harsh weather conditions on Mars, the living and working modules for the Martian crew will have to be shielded from such hazards. To accomplish this safety requirement, there are basically two options, each involving extensive excavation, that is, locating the modules underground or placing them into the side of a cliff.

One option is to completely bury the modules in a flat, open surface, utilizing the Martian soil for radiation protection. Excavation for the large hole necessary for this idea could be accomplished by controlled explosives. On the other hand, conventional digging or perhaps bull-dozing techniques could be used. After completing the excavation procedure, the modules would then be lowered one by one into the hole and totally covered with the dug-out Martian soil.

Another option is to produce individual holes for each module connected by bored tunnels. For each module, a curved sheath would be set in notches in the hole wall several feet above the module roof. In addition, there would be space between the module wall and the hole wall. The dirt would then be poured on top of the sheath instead of directly on the module. Advantages include enough space for maintenance on the module outer surface, along with the fact that the strength of the module will not be compromised by the weight of the dirt.

Steep cliffs on the Martian surface could be utilized for module protection. Soil-melting penetrators would be used to form "melted-in-place" glass lining for support. Next, "room" excavation within this support boundary would be completed in order to house the modules (Rowley, p. 473). This idea is advantageous in that it would not require tunnelling through soil, it takes away the dirt recovering procedure, and it provides working space outside the modules. A radiation-protecting sheath would be placed over the open side of the cavern.

2.3.2 MODULE STRUCTURES

In order to provide simplicity for the Martian robotic crew, the five modules will be pre-fabricated in their entirety on Earth or on the designated construction station (lunar surface and/or LEO). In addition, to avoid further complication for the robots, the flexible tunnels that will connect the modules will be pre-attached to the structures in an accordion fashion. The robots will simply release the folded tunnels and connect the open end to the adjacent module. The shape of each module will be a half cylinder approximately 25 feet in length with a circular radius of 10 feet. The half-cylinder is a very practical shape in that its strength to weight ratio as a pressure vessel is desirable. The connecting tunnels will be only 5 feet long to preserve the compactness of the base.

If the underground configuration is chosen for the base, a strong half-cylinder shell of 15 feet radius will enshroud each module. The shell's purposes would be to hold the weight of the dirt while providing working space outside the module wall for the possible repair of pressure leaks, allow additional storage area, and provide protection for the structure of the module itself. The shells could be stacked on one another for transport in the cargo spacecraft.

At present, we believe the module membrane structure will be composed of some type of aluminum alloy for its strength and relative light weight.

2.3.3 MODULE TYPES

Our initial idea proposes the use of five separate, individual modules for the base, connected by flexible tubing. These modules could be of the following types: central command, science, biosphere, living quarters, and galley module types.

The core module will provide communications and television to Earth, Phobos, and the Moon base. It will also provide satellite tracking and surveillance capabilities. There will be controls for power systems, water manufacturing, oxygen regeneration, thermal control, waste regeneration, and other subsystem control. The core will be a central meeting location for the crew. A recreation area will provide exercise equipment, games, radio, television, and other entertainment.

The science module will provide a laboratory environment for experiments to be conducted. Almost any conditions could be simulated in the science module.

A biosphere module will provide an abundance of plants that can be used for oxygen and waste regeneration. Perhaps it could even produce food for the crew. This technology is new and still being researched. But, there are definite advantages to using a plant environment to regenerate the oxygen. Plants can clean the air that will be recirculated throughout the complex. Plants are also capable of using waste water to grow in.

The living quarters module might have bunk beds and bureaus for all 6-8 crew members. The beds could fold out from the wall, with two beds per wall. There should be sinks, showers, and toilets. A small counter in the bathroom, couches, tables and chairs could all be included in the living quarters module providing a home-like environment.

The galley module would provide a central eating and food preparation area as well as storage capabilities. For food preparation, a microwave, sink, convection oven, and a washer should be provided. A counter space will provide convenience. A table and chairs will provide a place for crewmembers to eat. There should be storage for food, silverware, cleaning items, etc. A system for waste water reclamation should be included.

2.3.4 BASE PLAN

The layout of the base needs to allow for expansion and easy access to each part of the base. The Core module is accessible from any of the other modules. This design can easily be expanded by adding modules to continue the trellis structure (Appendix A-1).

Other options include having six or more modules by adding a medical module, another biosphere module, and/or a storage module. Other plans being considered include a pentagon shape or a wheel-like layout. Also, modules from the Phobos base should be used on Mars, i.e. the Sick Bay. The psychological factors, such as providing an earth-like environment for the crew members, should play an important part in the interior configuration.

Redundancy in modules is also important for safety. Each module should be equipped with emergency oxygen, food, tools, first aid, and communications.

2.3.5 EMERGENCY CONSIDERATIONS

Since Mars is far away from earth, a planned system of emergency procedures and escape schemes is essential for the ensured safety of our astronauts. Any unusual circumstances which arise and have not been planned for once our astronauts are on base could be of dire consequence.

At this point the habitat group is concerned primarily with the Martian base. Escape routes will be needed from the very first moment man has arrived on Mars and must be designed into the base structure. At present, the following systems are being considered for escape from an underground base.

* Each of five modules is to have an upward escape hatch

* To eliminate construction complexities, only the central module and one other is to have and upward escape hatch

* Horizontal escape into a radiation protection module with upward escape hatch

The third of these is likely to be used in conjunction with either of the first two. Situations might arise when the astronauts do not want to go directly to the surface. For instance, if the base shield collapsed during a major radiation storm, the astronauts could escape horizontally into the radiation chamber and then later to the surface.

Each of the aforementioned ideas will be investigated in detail as we further concentrate our ideas on a final habitat location and design.

If it is decided to build the base in the side of a mountain or crater, the following are possible escape route systems.

* Tunnels leading directly out the mountain to ground level

* Tunnel leading down and out of the base into a protection chamber

* Simple protected route out the front of the base

The base will also incorporate designs for emergency safety procedures. A few systems likely to be included are: a system of air-locks which will allow damaged modules to be sealed off from those remaining, a fire suppression system, and a system which allows astronauts to perform emergency repairs.

2.3.6 FUTURE BASE EXPANSION

A major requirement for the choice of base location and structure is that it must allow further expansion capability. An underground base could be expanded in the following ways:

* If the entire base is buried in a large hole with a covering sheath, the size of the hole could be further increased by using mining equipment already on hand

* If each module is buried in a single small hole, additional modules could be placed in holes made at later times and then connected by tunnel.

The mountain base could be expanded in the following ways:

* Assuming the structural technology needed is available, a ground level mountain base could be expanded upwards in levels by supporting the ceiling of the first level as the floor of the next and then tunneling around a corner edge.

* Again assuming the structural technology available, the mountain base could be extended further horizontally into the mountain.

2.4 SUMMARY

The environment of Mars must be taken into consideration in determining base design. Aspects such as atmospheric disturbances, temperature changes, and dust storms will affect final base operations. Manufacturing facilities for basic life support requirements such as water, air, and space ship refueling are essential to efficient base independence.

Human safety is of utmost importance in this project. The construction of a base on Mars is far too dangerous for humans; therefore, robots must be used to build this facility. These robots must be durable, efficient, and able to withstand the harsh environment. Great advances in technology will be necessary before robots of this sophistication will be ready to perform the complex tasks required to construct a Mars base. Once this plateau in robotics has been achieved, human resources may be diverted to other scientific endeavors.

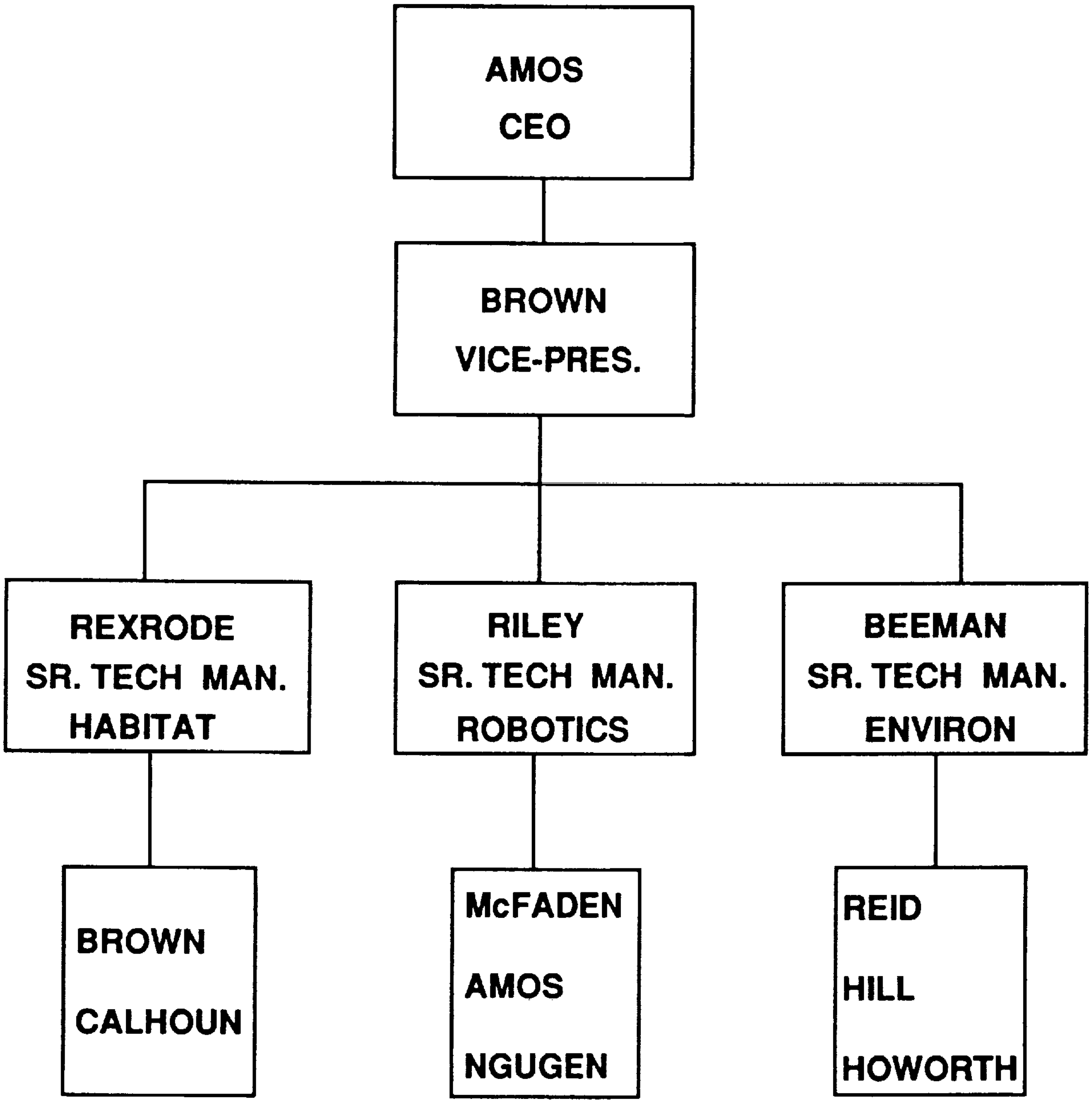
Two specific base configurations are being proposed. An underground base would require either one large excavation or multiple small excavations. The initial design call for five specific module types: central command, science, biosphere, living quarters, and galley. Emergency considerations have been offered for both the underground and cliff-side locations.

3.0 MANAGEMENT PROPOSAL

In order to complete the required design within the remaining time frame of the semester, our company, M.I.N.G., proposes the following corporate structure shown on the next page. Task responsibilities have been divided into these four areas: group leader, liaisons, technical managers, and engineers. The group leader is responsible for group meetings and agendas for those meetings. Records must also be maintained on new ideas and accomplishments. The liaison must keep abreast of all activities in each group within the class. This group representative must remain informed enough in all group research areas to answer technical questions from the other liaisons and represent our group's interests. The technical managers are responsible for directing research efforts and reporting to the entire group on his respective engineer's accomplishments. Engineers are to research necessary areas and provide new ideas for problem solutions. Note that every company member serves in the engineering capacity.

The proposed schedule for the semester is as shown in Appendix B.

M.I.N.G., Inc. CORPORATION STRUCTURE



4.0 COST PROPOSAL

The personnel and materials costs required to fulfill this contract are presented in this section.

4.1 PERSONNEL COST ESTIMATES

Using costs given in the Request for Proposal, Table 4.1 outlines our company cost estimate.

TABLE 4.1
PERSONNEL COST ESTIMATES

Employee	Wage (hr)	Hours/Week	Salary/Week
President	$ 25.00	12	$ 300
Vice-President	22.00	10	220
Tech Manager (3)	20.00	10	600
Engineer (6)	15.00	10	2700
Consulting	75.00	1	75
Total			**$ 68, 925.00**

4.2 MATERIALS COST ESTIMATE

TABLE 4.2
MATERIALS COST ESTIMATE

Material/Hardware	Total for Semester
1 Macintosh computer/ software and accessories	$ 750.00
1 IBM Personal System II	750.00
Laserwriting Documents	100.00
Photocopies	200.00
Transparencies	75.00
Travel Expenses	360.00
Miscellaneous	400.00

Subtotal	$ 2610.00
Error Estimate	250.00
Total Estimate	**$ 2860.00**

4.3 TOTAL PROPOSED PROJECT COST

Personnel Cost	$ 68, 925.00
Hardware Cost	2, 860.00
Total Cost	**$ 71, 785.00**

5.0 REFERENCES

Angelo, J.A. and Burden, D. Nuclear Energy for Lunar Bases. 36th Congress of International Astronautical Foundation: Stockholm, Sweden, October 7-12, 1985.

Carr, Michael H. The Surface of Mars. Yale University Press: New Haven, Conn, 1981.

Davis, G., et al. "The Lunar Split Mission: A Robotically Constructed Lunar Base Scenario." NASA/USRA Advanced Space Design Program, August 1988.

Guest, Butterworth, Murray, O'Donnel. Planetary Geology. Halsted Press: New York, 1979.

Fowler, Wallace. Personal interview. 1 February 1989.

Hamel, William, and Charles Weisbin. "Autonomous Robot Navigation; Teaching Robots to Look Before They Leap." Byte Jan. 1986: 227-233.

Rowley, John C. and Hoseph W. Neudecker. "In Situ Rock Melting and Construction." Lunar Bases and Space Activities in the 21st Century. Ed. W. W. Mendell. Lunar and Planetary Institute: Houston, 1985.

Sutphin, Susan. "Lunar Ramblin' Wreck." Space World Apr. 1988: 22.

Watts, Susan. "Cross-eyed Robot Starts to See like People." New Scientist Sept. 15, 1988, 40.

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6.0 APPENDIX A

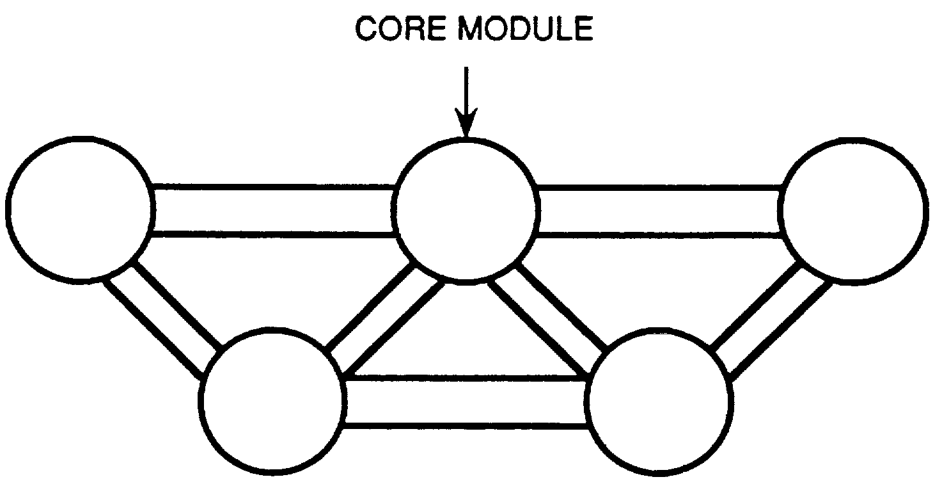
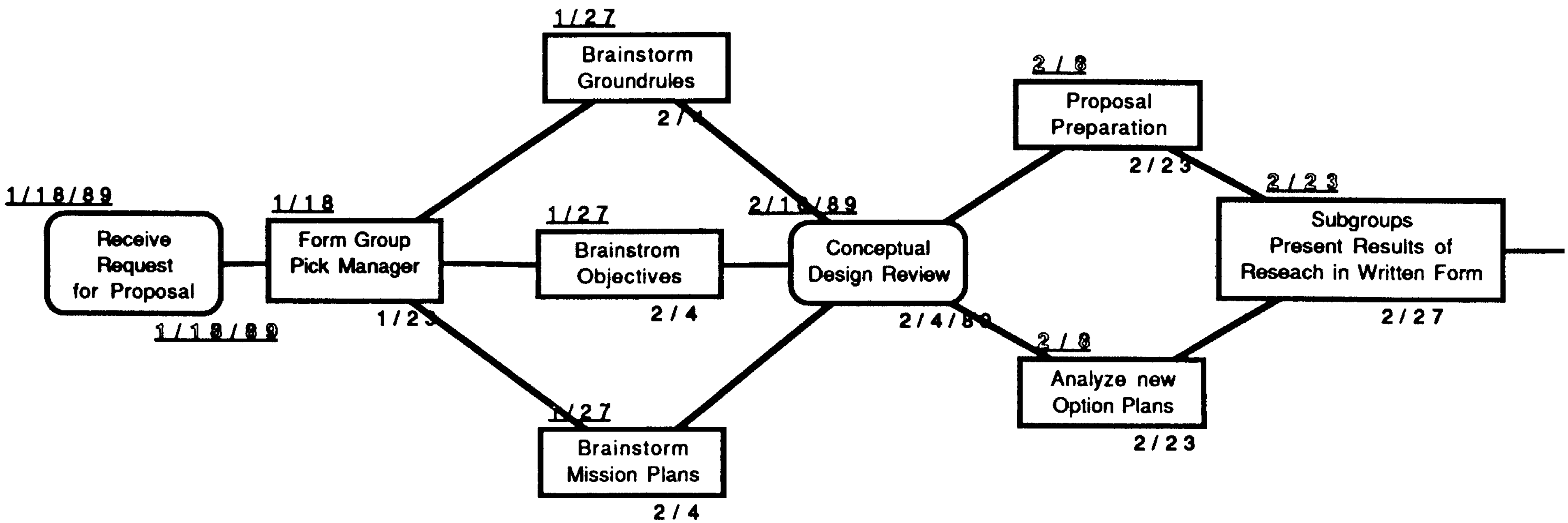
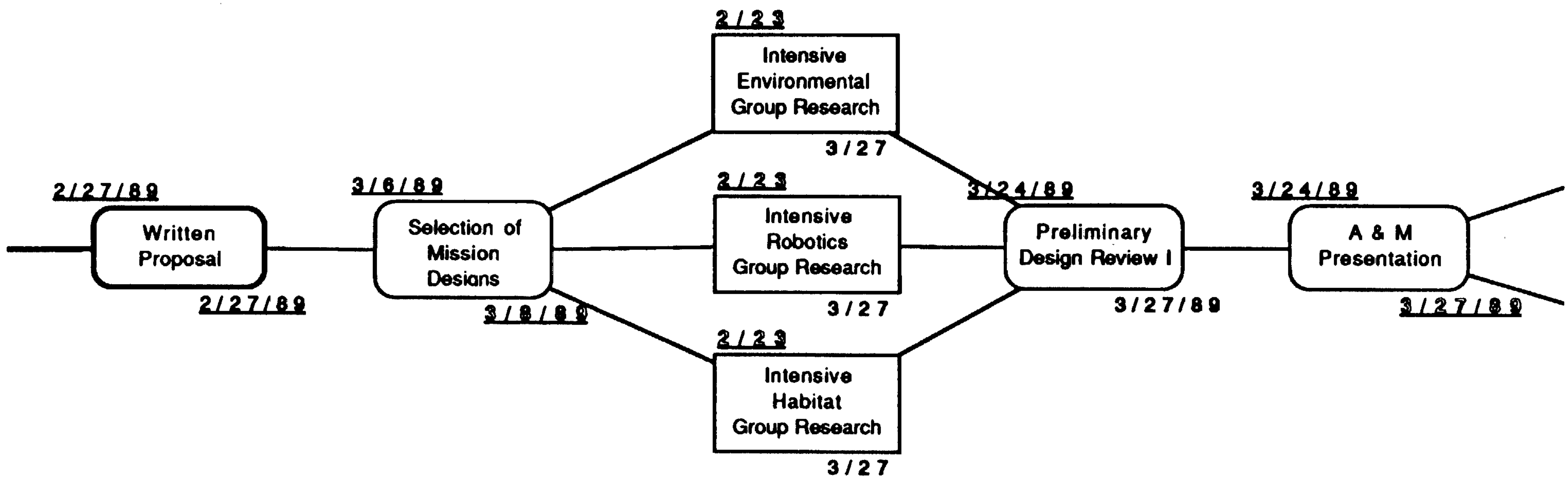


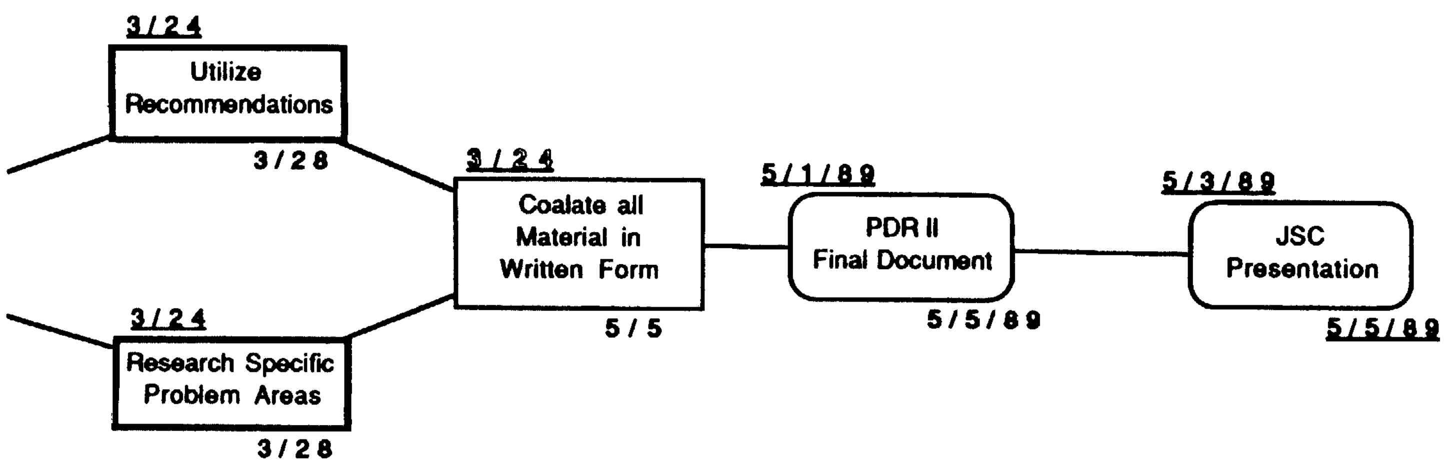
FIGURE A-1
MODULE LAY-OUT

APPENDIX B



1/18/89
Receive Request for Proposal
1/18/89
1/18
Form Group Pick Manager
1/23
1/27
Brainstorm Groundrules
1/27
Brainstrom Objectives
2/4
1/27
Brainstorm Mission Plans
2/4
Conceptual Design Review
2/4/89
2/8
Proposal Preparation
2/23
2/8
Analyze new Option Plans
2/23
2/23
Subgroups Present Results of Reseach in Written Form
2/27


2/27/89
Written Proposal
2/27/89
3/6/89
Selection of Mission Designs
3/8/89
2/23
Intensive Environmental Group Research
3/27
2/23
Intensive Robotics Group Research
3/27
2/23
Intensive Habitat Group Research
3/27
3/24/89
Preliminary Design Review I
3/27/89
3/24/89
A & M Presentation
3/27/89



3/24
Utilize Recommendations
3/28
3/24
Research Specific Problem Areas
3/28
3/24
Coalate all Material in Written Form
5/5
5/1/89
PDR II Final Document
5/5/89
5/3/89
JSC Presentation
5/5/89