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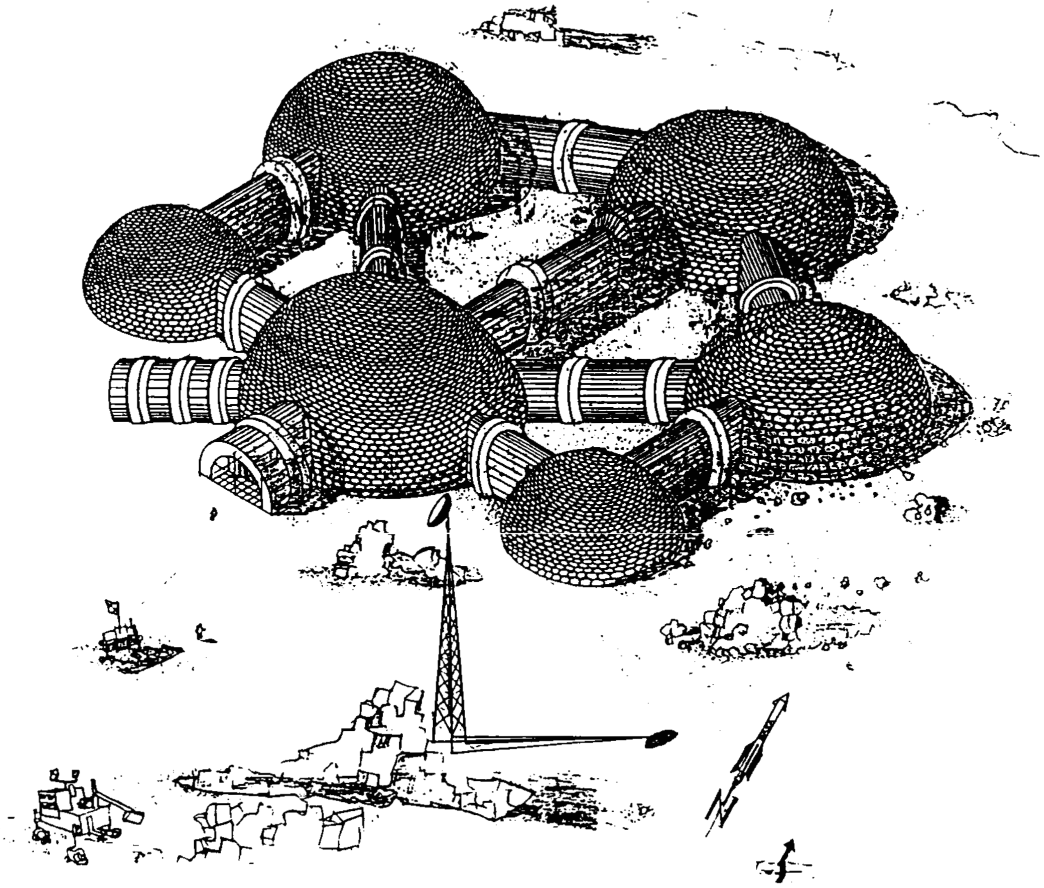
MARS HABITAT

NASA/USRA

ADVANCED DESIGN PROGRAM



DEPARTMENT OF ARCHITECTURE

COLLEGE OF ENGINEERING & ARCHITECTURE

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MARS HABITAT

Special Topics in Architecture 1990-91

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ABSTRACT

The College of Engineering and Architecture at Prairie View A&M University has been participating in the NASA/USRA Advanced Design Program since 1986. The research goal for the 1990-91 year is to design a human habitat on Mars that can be utilized as a permanent base for twenty crew members. The research is being conducted by undergraduate students from the Department of Architecture.

The objective of this study which is the first for the Department of Architecture is to develop a conceptual design for a permanently manned, self-sustaining martian facility, to accommodate a crew of 20 people. The goal is to incorporate the major functions required for long term habitation in the isolation of a barren planet into a thriving ecosystem. These functions include living facilities, working facilities, service facilities, medical facilities, and a green house. The main design task was to focus on the internal layout while investigating the appropriate structure, materials, and construction techniques. The general concept was to create a comfortable, safe living environment for the twenty crew members for a stay of six to twelve months on Mars. Two different concepts have been investigated, a modular assembly reusable structure (Lavapolis) and a prefabricated space frame structure (Hexamars).

Lavapolis, a modular assembly reusable structure (M.A.R.S.) system consists of inflatable cylinders supported at the ends with light weight aluminum rings. The cylinders are made of pneumatic material with a 30 ft diameter. For future expansion additional cylinders can be connected to the habitat without having to depressurize the existing structure. The habitat is organized in a linear pattern in respond to the geometry of the (M.A.R.S.) system and the tubular nature of the site inside a Lava tube which would provide radiation shielding for the entire base without having to move a lot of dirt.

Hexamars, a prefabricated space frame structure consists of a central core and secondary modules radiating from the core. The sphere shaped modules will be partially buried below the martian surface. Interchangeable structural members are utilized in the construction of this habitat. The construction of this habitat will occur in five phases. The space frame structure concept will allow for future expansion by constructing and adding more modules connecting to the existing modules via airlock structures.

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INTRODUCTION

The Research goal for the 1990-1991 year was to design a human habitat on Mars that can be utilized as a permanent base for twenty crew members. The research was being conducted by undergraduate students from the Department of Architecture. During the Fall semester the students were engaged in extensive research and studies pertaining to Mars. Some of the issues that were investigated are: Living and moving devices in space, planetary habitats, the martian atmosphere and terrain, space radiation, construction technology and techniques in space and sources of oxygen and water upon others. The following is a literature review of the above topics.

LITERATURE REVIEW

Living in Space

We are all currently living in space upon the Spaceship Earth, a self sustaining ecosystem in orbit around the sun, which provides it with the energy for life.

Man has created miniature environments to support his life as he ventured into space away from the mother ship.

Skylab was American's first facility that housed astronauts for several months as they observed the dynamics of the sun. We have learned much about long duration space flight from the experience of these missions. Skylab has since been destroyed, as its orbit decayed and it burned up in the atmosphere.

The Soviet Union holds the record for the longest duration space flight in their "Mir" Space Station, which has been in orbit for a couple of years. One cosmonaut stayed on board for over 300 days. They presently have men in space and they have had since the beginning of their "Mir" program.

There are many reasons for the advocacy of the space movement. The Exploration of the unknown, a quest for knowledge of our origin, and conquering the challenge of adventure are all inherent emotions of our species which have brought us, as a civilization, to where we are now.

As societies continue to expand into the solar system and beyond, new resources will be discovered that could be utilized back home. The promotion of trade between Earth and new settlements in space would have valuable economic benefits.

The quality of life on Earth could be enhanced with the application of solar power satellites operated from space. The first space settlers might be involved with the construction of these large facilities.

There are proposals of replacing all the industries on Earth with facilities in space, leaving Earth as a garden playground where no toxic emissions would pollute its environment.

Avoidance of possible disasters on Earth contributed to pollution, toxic waste, exhaust emissions, acid rain, deforestation of the rain forest, over population, and the threat of nuclear war could very well be incentives for leaving this planet for a life elsewhere in the solar system.

Many people argue that we should not spend money on space programs but direct those funds to resolving the problems we face on Earth. Maybe the solutions to these problems can be understood after discoveries and observations are made in space. The possibility of the discovery of new life forms would expand mankind's mind and totally change the way we view ourselves.

Once the decision to leave the planet is made, where do we go? Low Earth Orbit is a starting point, from where further steps into space can be made. The United States Space Station, "Freedom", is proposed to commerce construction in 1994. This facility should function as a transportation hub from where the next space missions will originate.

Lagrangian points are where the moon and the Earth's gravity are canceled, creating relatively stationary points in space, where the placement of large space structures would orbit the Earth and maintain the same orientation to the moon.

Lunar materials would be utilized to manufacture these structures, since shipping up materials from Earth would be expensive due to the large gravity well. The moon is a possible location, since it provides land to build upon. The resources are also there and need not be shipped from the earth.

Mars is the most similar planet to Earth compared to any other in the solar system. It has an atmosphere, there is water at the poles, and its gravity is roughly half that of Earth's. If life existed or does exist anywhere else in the solar system, scientists argue that it would be on Mars. Mars offers the best possibility for terraforming, that is modifying the environment to sustain life as we know it. There are many factors which must be addressed before we can live beyond the comforts of our planet.

In space, the force of gravity is not felt, due to the orbit that the habitat and everything around it is falling at. Some form of downward force is needed for the human body to function properly. Spinning the facility to create a centrifugal force is the most acceptable way to solve the problem, as long as the spin radius is large enough to lessen the sensation of spinning.

The force of gravity is felt less on the moon and Mars than on Earth, so over long periods subjected to a decreased pull, it might be difficult to adjust back to Earth's stronger pull. Solar radiation and flares must be shielded against in space. The atmosphere and ozone layer on Earth protect us against these harmful ultraviolet rays.

Meteorites and space debris are also hazards to be avoided. The absence of air and water, combined with the extreme temperature differences make it imperative to have a sophisticated mechanical system.

An Environmental control life support system is a closed ecosystem that provides fresh air and water, regulates temperature and recycles everything to maintain a balanced loop. The waste heat from these processes will be reradiated back into space.

Solar Energy can be utilized to power these facilities and it is abundant, without any disturbances.

It is important to utilize resources from space to make the colony self sufficient and able to grow as an autonomous unit. Initially, the needed resources will be shipped from Earth, but the transportation cost are emence, so it will prevent a continous supply.

New propulsion systems and technologies must be fully developed before the construction and habitation of space colonies will be a reality.

Once these technologies are provided, the question rests upon the human factors. Can the human body and mind adapt to the harsh and isolated environment of space? Most scientists agree that we can adapt, although they have recognized a few symptoms contributed to long durations in space that must be resolved.

For the initial couple of days astronauts complain of nausea, headaches, and dizziness, similar to the symptoms found in motion sickness. They attribute this to being disoriented, not able to distinguish up from down, combined with the fluids in the inner ear which regulate balance.

The heart does not need to work as hard, so there is noticeable decrease in size. Muscles begin to atrophy because of the lack of load bearing stress.

The bones begin to lose calcium and become weak. These are some of the important physiological effects that must be dealt with before it is possible to stay in space permanently.

The isolation of space combined with the hazardous environment will have major physiological impacts on individuals. Only the most adventurous souls will venture on the journey to settle new worlds.

In Summary the main issues for living and moving devices on mars are:

I. Living on Mars

- A. Explore Surface
- B. Search for Life
- C. Conduct Scientific Research
- D. Establish Base

II. Environmental Constraints and Human Factors

- A. Physiological
  - 1. Weak Gravity
  - 2. Thin Atmosphere
  - 3. Lack of Liquid Water
  - 4. Radiation

- B. Psychological
  - 1. Isolation in Hazardous Environment
  - 2. Communication problems/delays
  - 3. Control of Mission
  - 4. Workload
  - 5. Sex urge

III. MOVING DEVICES

- A. On Foot
- B. Automatic Rovers
- C. Large Manned Rovers
- D. Self Continued Mobil Labs
- E. Balloons
- F. Aeroplane

Planetary Habitats

Planetary Habitats fall into three distinct classification. The first classification involves earth dependent techniques. Among these are prefabricated modules, prefabricated frame structures and pneumatic structures.

The second classification utilizes natural and man-made surface conditions and natural subsurface features. These are craters and lava tubes.

The final classification utilizes natural resources from the planetary environment.

Prefabricated modules consist of self contained pressurized vessels. The vessel is constructed entirely on earth and delivered to the planetary surface ready to provide all necessary operations for survival in the module. These modules will be mainly constructed from lightweight, high strength metal alloys.

Prefabricated frame structures are individual structural members. These members are generally fabricated in metal tubular shapes. The member is usually stressed axially, either in compression or in tension. At the two ends of each member, a standardized connector is installed to allow for ease of construction and expansion. Space frames and geodesic domes are common forms of prefabricated frame structures.

Pneumatic structures are any structures supported by pressure differentials created by gases, commonly air. Pneumatic structures are also referred to as inflatable space structures. The fabric material would consist of kevlar 29, nicalon or nextel.

Craters are considered natural surface features but can also be man-made by mining. The shapes of craters include circular, concentric, elongated and scalloped. A 1:6 depth to diameter ratio is considered acceptable for surface habitation. The crater must be deep enough for interior clearance and sufficient enough in width for natural spans (the crater walls) or supported spans.

Lava tubes are formed by lava flowing during volcanic activity. These tubes carry the lava from the vent to the flows leading edge. When the flow ceases and drainage occurs these tubes form natural underground caverns. Theoretical inside dimensions are up to 300ft in length and roofs up to 30ft thick. They provide sheltered areas when pressurized habitats are placed inside of them and they can be pressurized chambers themselves with the use of airlock and seals.

Hybrid planetary habitats emerge when 2 or more construction methods are integrated. These include an inflatable space structure used in combination with either a prefabricated space structure or lava tube or crater to produce a multi-use environment. A pre-fabricated space structure and an inflatable space structure could produce an air lock or corridor connecting two or more multi-use environments. Prefabricated modules combined with inflatable space structures will provide quick and efficient planetary habitats.

A major disadvantage for prefabricated modules is that as their mass and volume increase, more cargo space is required of the launch system. The standard size for the modules is 6 meters in diameter and 22 meters in length. This size allows for short term adaptability but not long term expansion. When the numbers of docking points increase, potential leakage points also increase. Prefabricated frame structures require little or no planetary surface infrastructure for assembly. However, large EVA time is required for assembly.

One of the major advantages of inflatable space structures is their ability to transport large habitats and other structures for use on planetary surfaces in a compact launch-efficient easy-to-deploy form. Spacious, potentially habitable volume can be created which far exceeds size constraints imposed by launch system payload dimensions. The range of configuration and construction possibilities presented by inflatable space structures promises to be broad and offer a high level of versatility.

An advantage of lava tube applications is pre-existing, covered volume with little cost in energy or manpower. They also provide radiation shielding. However, to find lava tubes, extensive EVA time is required.

Other factors prevalent to all techniques include efficiency, cost, labor and energy requirements, factors of safety, and including radiation shielding and leakage and usable life span.

In conclusion, the techniques for construction the described offer many benefits and all warrant a more detailed analysis before selecting one over another. (Larry Toups)

Space Radiation

Since man first began voyages to Mars, the fear of radiation from unknown sources has always been a main concern of this frontier adventure.

Radiations are caused primarily by high speed protons and electrons in the wind, cosmic rays from outer space and the sun, and energetic penticutes captured by the Earth's geomagnetic field which forms the Van Allen Belts.

Solar flares can create solar particle events that raise radiation levels so high that they are often deadly to human beings. "Because the Earth's magnetic field over the North and South poles dips downward, a polar orbit inside the Earth's magnetosphere is a particularly hazardous region". Most of these events last an hour while rare massive events last hours or days.

The ionizing radiation characteristic of an atom occure when one or more electrons is being stripped away. The extent to which ionizing radiation causes bodily harm depends on the dosage of obsorded energy (dose). On the space station freedom's LEO mission the spacecraft will be exposed to the south Atlantic Anomaly which contains ionizing proton radiation in larger amount than the levels on Earth. This is an added dose of 0.1 rem per day which is equal to approximately 10 chest X-rays in one day.

Radiation effects on some parts of the body are more severe than on other parts. While the skin and the eyes are more accessible to a wide range of energy particles deeper locations like some bone marrow, lungs, liver and pancreas are of great concern because of their susceptibility to cancer. Women face greater cancer risks and damage to their reproductive systems. A large exposure to radiation as high as 300rem can cause early menopause. Such reactions can be dormant or immediately active with symptoms of nausea, vomiting, decreasing white blood cells, diarrhea, fever, hemorrhage and even death. Dormant or delayed symptoms include cancer and birth defects or miscarriages.

To "protect" the astronauts from the severity of radiation NASA established a radiation protection program that determines the number of flights an astronaut can make according to age and gender. The number of rem's range from 100 rems to 400 rems, with a set dose equivalent to deep organs (5cm) being 25 rem in a 30-day period, and an annual period of 50 rem to be spread out over a protected period. For example a 30 to 40 yr old astronaut will have a career limited to 200 to 275 rem.

To counter these harmful doses from solar particle events, a heavily shielded "storm shelter" should be incorporated in the design of spacecraft or base with aluminum as material.

Other protection practices would be:

a. using water tanks to storage inside walls
b. applying thick soil layer ones surface habitats
c. operationally minimize crew exposure by restrict and rotate extra vehicular activity
d. operate LEO space station at lowest practical attitudes
e. Carefully screen crew candidates by (i) selecting people who have low cancer risks and (ii) use older crew with low life time doses (SICSA Vol.2 #3, 1989)

Mars Atmosphere and Terrain

The Martian Atmosphere

A. Composed of mostly carbon dioxide
B. Contains small amounts of:

    1. Water vapor
    2. Nitrogen
    3. Argon
    4. As well as other gases

Temperature of Mars

1. Average near Equator is -60°F (-50°C)
2. By noon 85°F (30°C)
3. At Poles in Winter -240°F (-150°C)
4. Typical daily range from -22°F to -122°F, (-30°C to -80°C)

The Martian Climatic Conditions

A. Seasonal Changes

    1. May be caused by variations in wind blown dust deposits.

        2. Seasonal Changes are meteorological
        3. Biology is not excluded

    B. Seasonal Caps

        1. Southern Hemisphere
            a. Summers are short and hot
            b. Winters are longer and colder

Volcanoes

- A. Similar to those found on Earth
- B. Some are 10 to 20 miles above surrounding plains
- C. Show suggestions of fluid lava eruptions
    - 1. with little ash content
    - 2. chemical composition affects the eventual structure

- D. Olympus Mons
    - 1. Largest Volcanoes
    - 2. 17 miles above local terrain

Martian Dust Storms

- A. Global Dust Storms
    - 1. Spread Rapidly
    - 2. Creates Haze that lasts months

- B. Dust reaches 20 miles above surface
- C. Occur Randomly

Martian Channels

- A. Have meanders and tributaries
- B. Most occur near equator or
- C. Carried by a flowing liquid
    - 1. Believed to be water because of the downward slopes
    - 2. Melted subsurface ice might of caused the "outflow channels"

Site Selection

- A. Ten prime landing sites identified by NASA specialist Committees

- B. Two main sites
    - 1. Kasei Vallis
    - 2. Mangala Vallis
        - a. Both near large equatorial volcanoes
        - b. Both near volcanic plains

- C. Managala Valles
    - 1. Most accessible
    - 2. Located 10°S, 150°W

The climate, terrain, and site selection are very important factors in the long-term exploration of Mars. Structures must be built to withstand the severe dust storms as well as other climatic conditions that occur. The site should be strategically located to allow for exploration of various terrains with out extensive travel. (Race to Mars - 1988)

Engineering, Construction, and Operations in Space

This paper is a continuing study for an inflatable habitat facility. Providing living and working stations for a crew of 12, is the main function for such a constructable habitat. A sphere concept has been chosen for the over all shape of the habitat's structure. Crew and equipment will be transported to each level of the habitat by a vertical shaft located at the center of the habitat.

Primary structure is a spherical pneumatic envelope, and an internal structure (secondary structure) make up the structures for the modules.

Made up of a pressure vessel, the primary structure is designed to withstand high amounts of pressure. The internal structure is designed to support the crew and the equipment that is contained in the module. "The inflatable envelope is a composite of high strength, light-weight multiple ply fabric with nonpermeable bladder inside and a thermal coating on the exterior".

Because of the lengthy amount of time the crew will be in space, it is for the crew's benefit that the chosen concept, be an open plan concept.

Each module will contain at least one of the required functional areas: crew quarters, crew support, base operations and mission operations, internal storage, environmental control, circulation and life support sub-systems.

A system will also be provided for technical growth. "The crew will move vertically through the shaft using a ladder, while equipment and furnishings are hoisted by a block and tackle system, located at the shafts top."

The Habitat is designed to be easily transferred from Earth to Mars, and assembled there on the surface. "The major categories of assembly are the mat foundation, inflatable structure, air supply and inflation system, internal structure, regenerative life support system, thermal control systems and outfitting."

A hole must be created and graded so that the mat foundation can be set. If the atmosphere is safe for construction a crew of four can complete the framing and outfitting.

"Given that the internal architecture of this habitat is an open plan concept, the time required to outfit will be a function of how the furnishings and equipments are delivered."

In conclusion, this study of inflatable modules is the beginning of settlement in space. Although all of the research has not been completed this has allowed room for further in-depth study. (Space 90)

Inflatable Space Structure

The most launch-efficient easy-to-deploy form to transport to outer space would be inflatable space structures.

Space habitats must provide means to curtain internal gases and maintain constant purity and atmospheric pressure to sustain the life. Because the radiation and heat is so intensive on Mars it is important that the exterior surfaces be designed to withstand long-duration exposure. Interior surfaces must be non-flammable and must not give off toxic gas or noxious gases.

Inflatable structures come in a variety of sizes and shapes. Forms for inflatable structures have to meet different types of application requirements. The broad range of configuration and construction possibilities presented by inflatable and inflation deployed systems promise a high level of versatility. Tubes, bladders, and membranes can be combined and integrated within a common structure in combination with hard elements such as air-locks, hatches, and viewpoints. Wall composition and thickness can be tailored to special operational and safety requirements associated with flame retardant, thermal insulations, micro metorile protection, and internal atmosphere.

In conclusion, inflatable structures offer a liveable safe habitat for the crew. It is also one of the most efficient forms for launch. (SICSA Vol. 1 #7 - 1988).

A Survey of Lunar Construction Techniques

This paper outlined the factors that should be considered in designing for the Moon's environment.

First of all, techniques were defined. The first category of techniques includes prefabricated modules, pneumatic structures, prefabricated frame structures, tent structures and tunneling techniques. The lava tube applications along with the crater applications were covered in the second category.

The third category consisted of terrestrial concrete cast basalt, metal structures, and lunar fabricated canopies.

After the techniques were established criteria were set which included those factors that are common in most work dealing with habitation. Major criteria included: energy requirements, labor requirements, earth materials - low tech, earth material - high tech, and regolith. Characteristic criteria was defined as expected usable lifetime, leak before failure behavior, human factors, research and development, radiation shielding, dependence on special equipment, transportability on surface, and functional redundancy.

The assessments and applications section described the application of the techniques and how it would react to the moon's surface. Concrete (cement-based) material structures, metal structures and Hybrid structures were just a few that can be applied to the moon's surface. (Larry Toups - 1989)

Sources of Oxygen and Water

The Design group at Prairie View A&M University conducted three research projects and determined that oxygen and water were two products that could be produced economically under the Martian conditions.

Students from the Chemical Engineering Department designed a breathable-air manufacturing system, a means of drilling for underground water, and storage of water for future use. In the 1987-1988 academic year the team designed an integrated system for the supply of quality water for biological consumption, farming, residential, and industrial use. In 1988-1989 academic year the task of the students from the Electrical Engineering Department was the investigation of the extraction of water from beneath the surface and an alternative method of extraction from ice formations on the surface of Mars.

In addition a system for computer control of extraction and treatment was developed with emphasis on fully automated control with robotics repair and maintenance. (Mars Surface Based Factory).

To conclude, the introduction rendered by NASA and other sources were premisses for programming and designing an early stage habitat on Mars which was studied in the spring semester.

OBJECTIVE AND GOALS

The purpose of this study is to develop a conceptual design for a permanently manned, self-sustaining martian facility, to accommodate a crew of 20 people. The goal is to incorporate the major functions required for long-term habitation in the isolation of a barren plant into a thriving ecosystem. These functions include the living area, research laboratories, medical clinic, greenhouse, command control, materials processing, life support system, power source, and a launch pad. The harsh environment of Mars is not conducive to life as we know it. Cosmic radiation, thin atmosphere, extreme cold, windy dust storms, and the absence of surface water and food are issues which must be resolved for humans to survive on Mars.

GENERAL CONCEPT

The general concept of the design is to create a comfortable, safe living environment for the 20 crew members for a stay of 6 to 12 months on Mars. This self-contained environment would accommodate five main facilities: living facilities, working facilities, service facilities, medical facilities, and a greenhouse. The main design task is to focus on the internal layout while investigating the appropriate structure, materials, and construction of these facilities. Two different concepts an inflatable structure and a space-frame structure have been investigated.

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE (LAVAPOLIS)

Concept

Construct inflatable modules in a lava tube, using the modular assembly reusable structure (M.A.R.S.) System.

Site

The selection of an appropriate site is critical to the long-term success of the Mars base. An equatorial site is most economically accessed from low Mars Orbit, and simplifies rendezvous maneuvers. The most striking geological features, Olympus Mons, the largest volcano in the Solar System and the Colossal Valles Marinares, the colossal canyon, are located there. The site chosen for Lavapolis is at the base of Ceraunius Tholus, a 115-km-wide, 22-km-high Volcano in Northeast Tharsis at 24° N, 97° W, at the area where an impact crater has pulverized a 2-km-wide channel.

Assumption

A Lava Tube exists in the region described that satisfies the requirement for habitability. It must be accessible, have structural integrity, and dimensions of not less than 200 ft. wide, 50 ft. high and 400 ft. deep for this proposed scheme.

Rational for Construction in a Lava Tube

The large covered volumes that are naturally created from the flow of molten lava underground that drains away, can provide radiation shielding for the entire base without having to move a lot of dirt.

The thermal mass regulates the internal temperature to be relatively constant at any time. Year round, minimizing the load on the HVAC System, the environment is constantly calm, protected against the frequent windy dust storms. The time required to locate and prepare a lava tube for habitation is shorter than it would take to cover a base with 3 ft. of soil. Also, the sheltered volumes available in a lavatube are much larger than those which can be constructed, and require less structural mass for the pressurized modules. The indigenous basaltic rock can be processed to form glass structural panels that can be used to seal in and pressurize large segments of the lava tube for future expansion.

Structure

The modular assembly reusable structure (M.A.R.S.) system consists of inflatable cylinders supported at the ends with light weight aluminum rings. (See Fig. 2)

The rings are comprised of 8 segments, 3 ft. wide, which join together to form a 30-ft-diameter circle, and are spaced 30 ft on center. The cylinders are made of pneumatic material and connect the space between two rings, with the same 30-ft-diameter. Attaching the circular walls made of pneumatic material to the rings on either side of the cylinder, forms one M.A.R.S. Module.

The floor joists space the length of the cylinder and connect to a beam spanning the ring. This beam carries the floor loads to the ring, then down to the mat foundation. The floor and ceiling heights are variable depending upon functional requirements and can be easily modified as the needs change. Additional cylinders can be connected to the habitat without having to depressurize the existing structure. The M.A.R.S. System deploys large expandable volumes using reusable, lightweight, modular components, and connections, which require minimum packing space.

Architecture (Exterior)

The organization of the base is a linear pattern, responding to the geometry of the M.A.R.S. system, and contextually with the tubular nature of the site. (See Fig. 3)

The modules are arranged in a functional composition with resulting aesthetics derived from the orientation of the module's flat round, or convex square elevations, juxtaposed with the columns. (See Fig. 9) The oblong form of adjoining cylinders with the repetitive column spacings resembles of a Roman Basilica, creating a sense of traditional architecture.

Architecture (Interior)

The interior spatial complexities are achieved through the variation in floor and ceiling heights, combined with the arrangement of inflatable furniture, and partitions that allow for long views through several open modules or define small intimate spaces. (See Fig. 10) Level changes of a couple of feet can be made with the use of stairs, while ladders and manual elevations are provided for separations in floors of several feet. (See Fig. 5,6) The size of internal volumes are similar to those back on Earth, because any perception of home is beneficial to the psychological well being of the inhabitants. There are two means of progress from every module, one of which will lead to an air-lock towards the exterior. A group of modules can be sealed and isolated in case of contamination or fire. (See Fig. 9)

Tour of Lavapolis

You arrive on Mars and are at the launch pad about 500 meters from the entrance to Lavapolis (See Fig. 3).

In distance you observe the in-site propellant production facility producing oxygen from the carbon dioxide in the martian atmosphere. (See Fig. 3). As you are shuttled to the lava tube you pass the communication satellite, and the large solar array panels and wind turbines which provide power to the base.

Just inside the Lava tube you encounter the construction equipment rovers, and a manufacturing plan producing glass structural panels from the basaltic rock. Being stored along the side of the tunnel are oxygen, water, and ECLSS tanks.

You arrive at a courtyard in front of the HUB, which is the main entrance to the base. You enter through an air-lock along the side of the logistics module.

The HUB functions as a circulation mode which leads to the medical clinic and research labs on the left, the greenhouse straight ahead, and the living area on the right. Located on the first floor of the HUB is the environment control life support system (ECLSS) for the entire base, the third floor of the HUB has storage.

The Medical Clinic has operating tables, sick beds, a Doctor's Office and a lounge on the second floor. The first floor stores medical supplies and the third floor is dedicated to medical research. (See Fig. 5:T, 6:A, 7:K)

The Research Modules contains four laboratories. The Plant and Soil Labs are on the second floor while the Chemical and atmospheric labs are on the third. The first floor is for storage (See Fig. 5:U, 6:B, 7:L).

The Greenhouse modules supply all the food for the base and produces much of the oxygen. It also functions as a garden space with tropical plants and flowing water (See Fig. 5:X, 6:F, 7:O).

The living area is divided into crew quarters, entertainment, recreation, and galley (See Fig. 6:G, H, I, J); in the crew quarter wing, each person has their own room, and there are separate bath rooms for the men and women (See Fig. 6:J); The rooms and hygiene occupy the second and third floor, with storage on the first (See Fig. 6:J, 7:S); The Galley is connected to the entertainment area which has a large screen HD-TV and a pool table (See Fig. 6:I); Above the Galley and the entertainment areas is the kitchen and a quite lounge, and below is an exercise area. (See Fig. 7:Q, R, 8); The recreation modules contains a large multi-use space where many different sports are played (See Fig. 5:Y, Z, 6:G, 7:P); At the far end of the recreation module is an access to the command module where communications occupied the second floor and base operations are handled on the third, with storage on the first (See Fig. 6:C, 7:M).

Future Expansion

The future expansion of the base will entitle the processing of basaltic rock into structural glass panels and connections. Large segments of the lava tube can be sealed and pressurized making it possible to landscape and construct buildings that incorporate architectural styles around the world, to create an international garden city.

Further Research and Development

More research is needed on the M.A.R.S. structural system and the specific materials to be used (i.e. light weight aluminum, pneumatic). Forces on structure, weight of materials, air pressure required to inflate, packed mass and deployed volume need to be calculated. Development of the design connections (tooless) is essential (i.e. ring segments to ring segments, floor joists to ring, floor panels to joists, pneumatic material to rings, ring to mat foundation). The issue of using martian soil for radiation protection as another alternative to utilizing the lava tube. The possibility of sealing a suitable lavatube and entrances for future expansion, and finally processing basaltic rock into structural members.

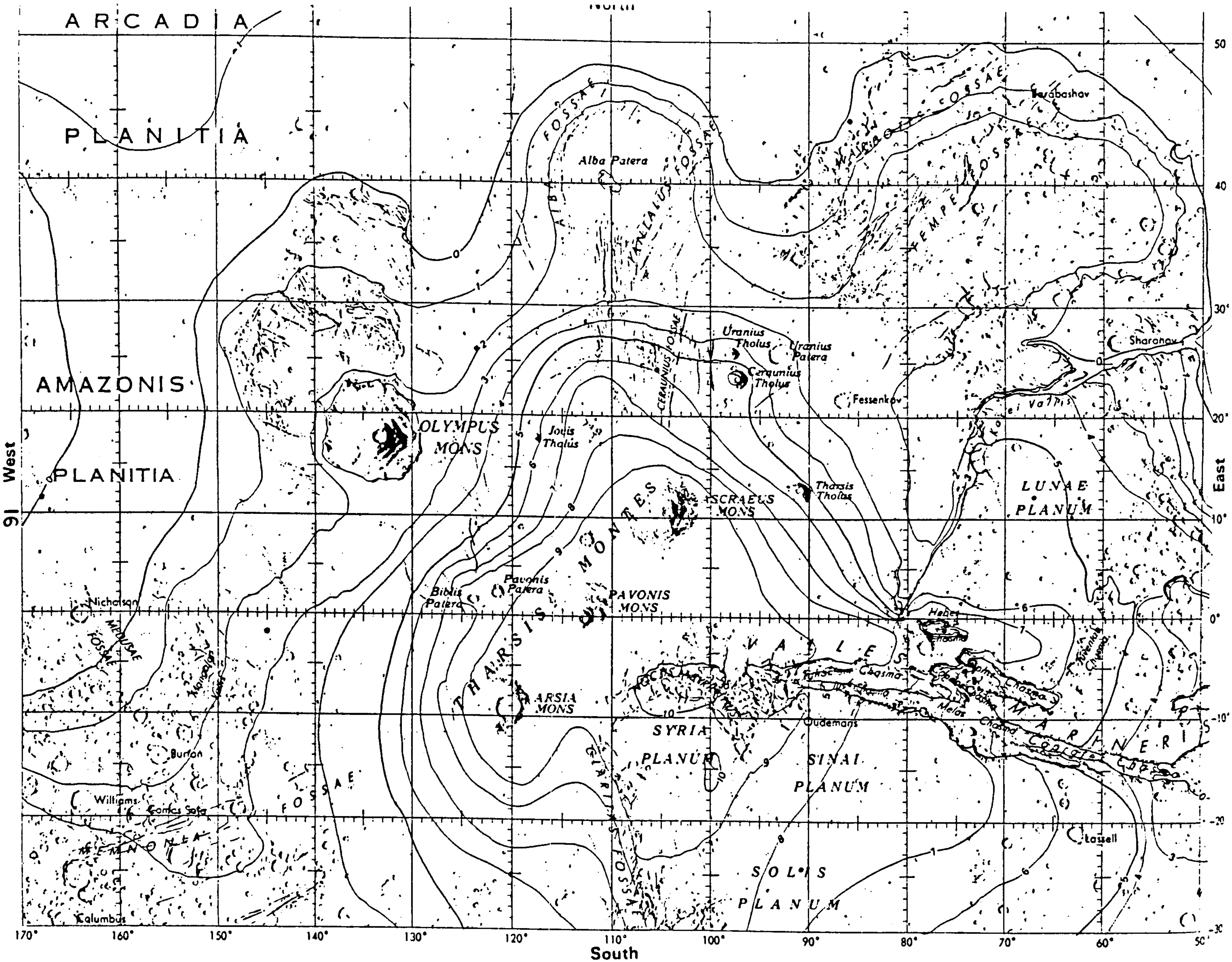


FIG. I. SITE LOCATION - LAVAPOLIS

LAVAPOLIS

MODULAR ASSMBLY REUSABLE STRUCTURE

M.A.R.S BASE

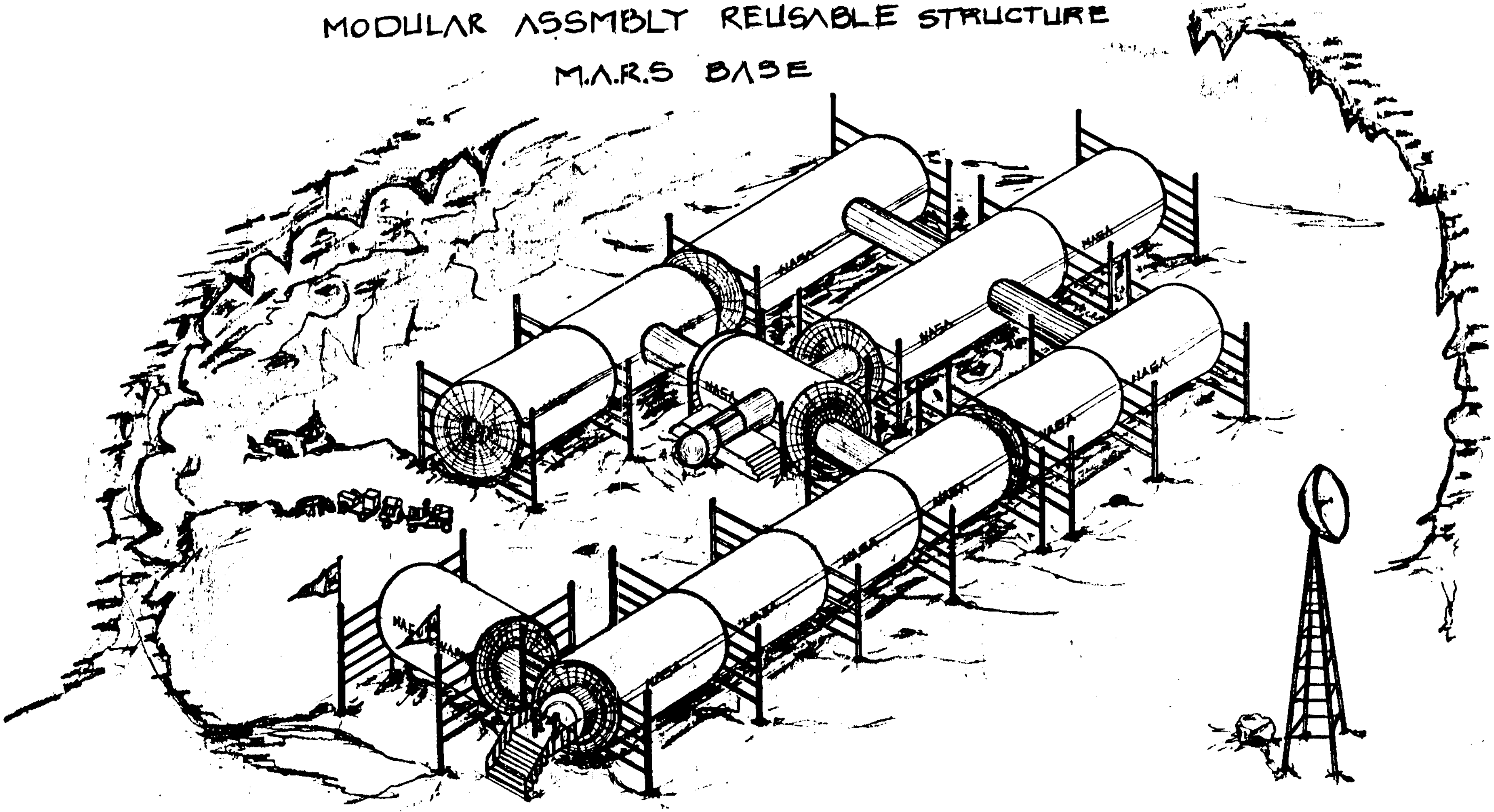


FIG. 2. ISOMETRIC OF LAVAPOLIS

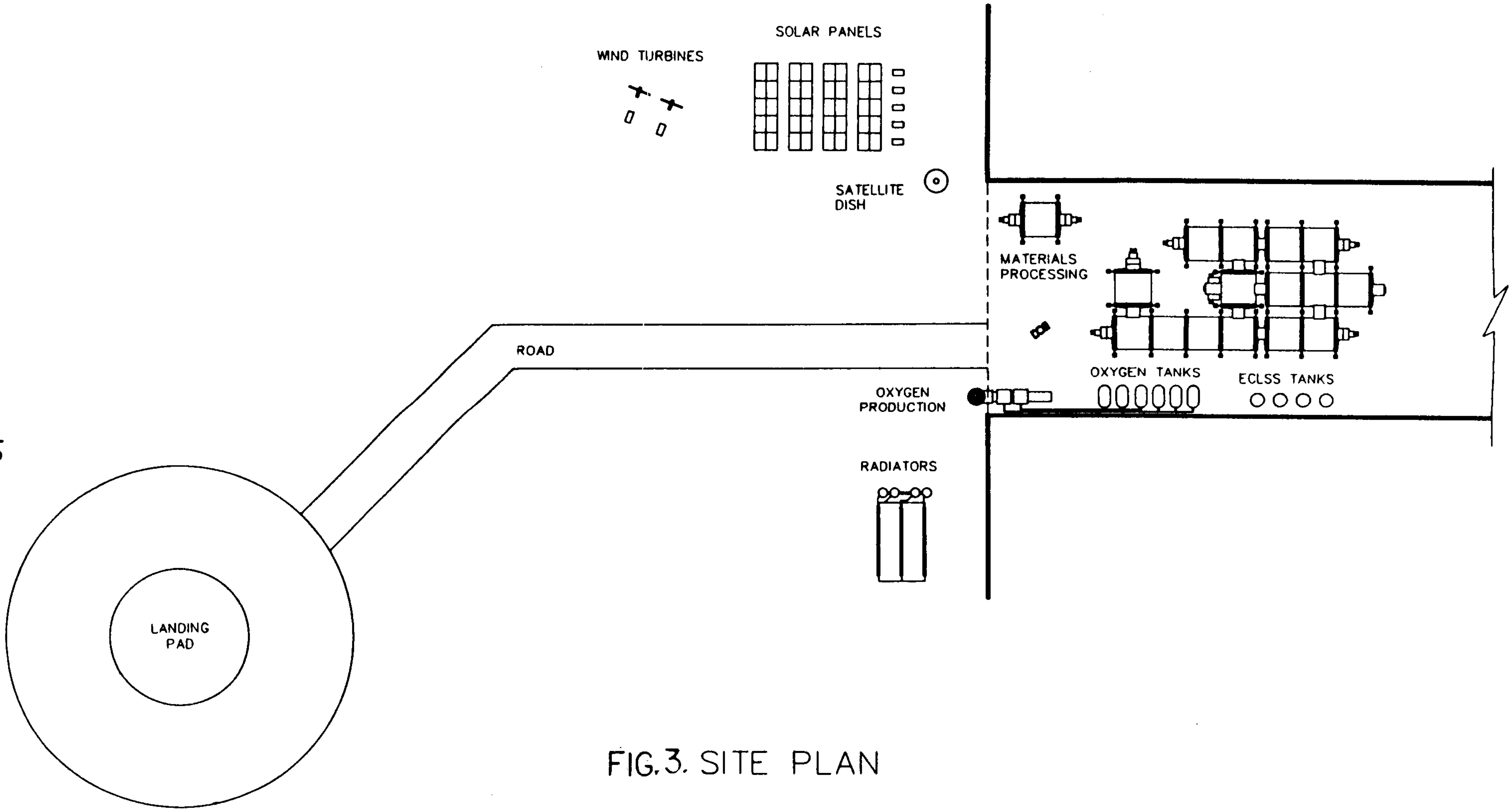


FIG. 3. SITE PLAN

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91

0 40'

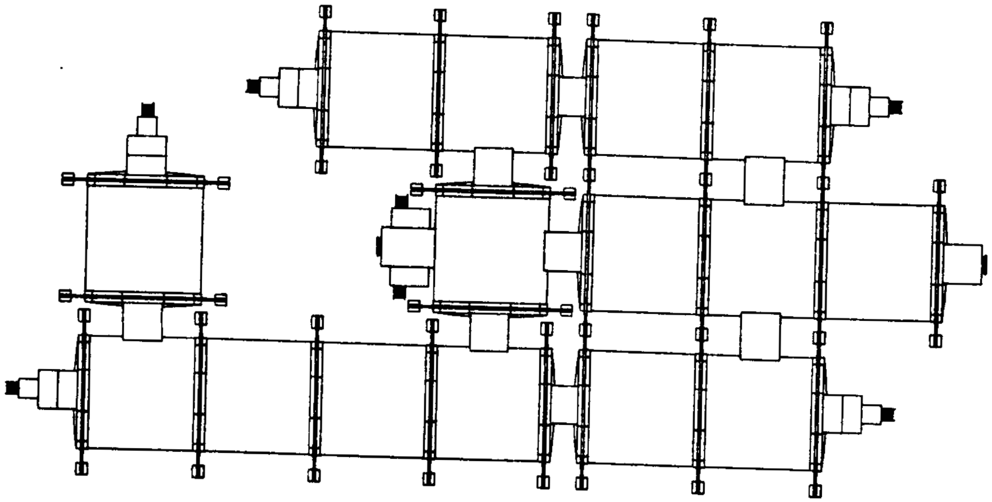


FIG.4 ROOF PLAN

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91

0 16'

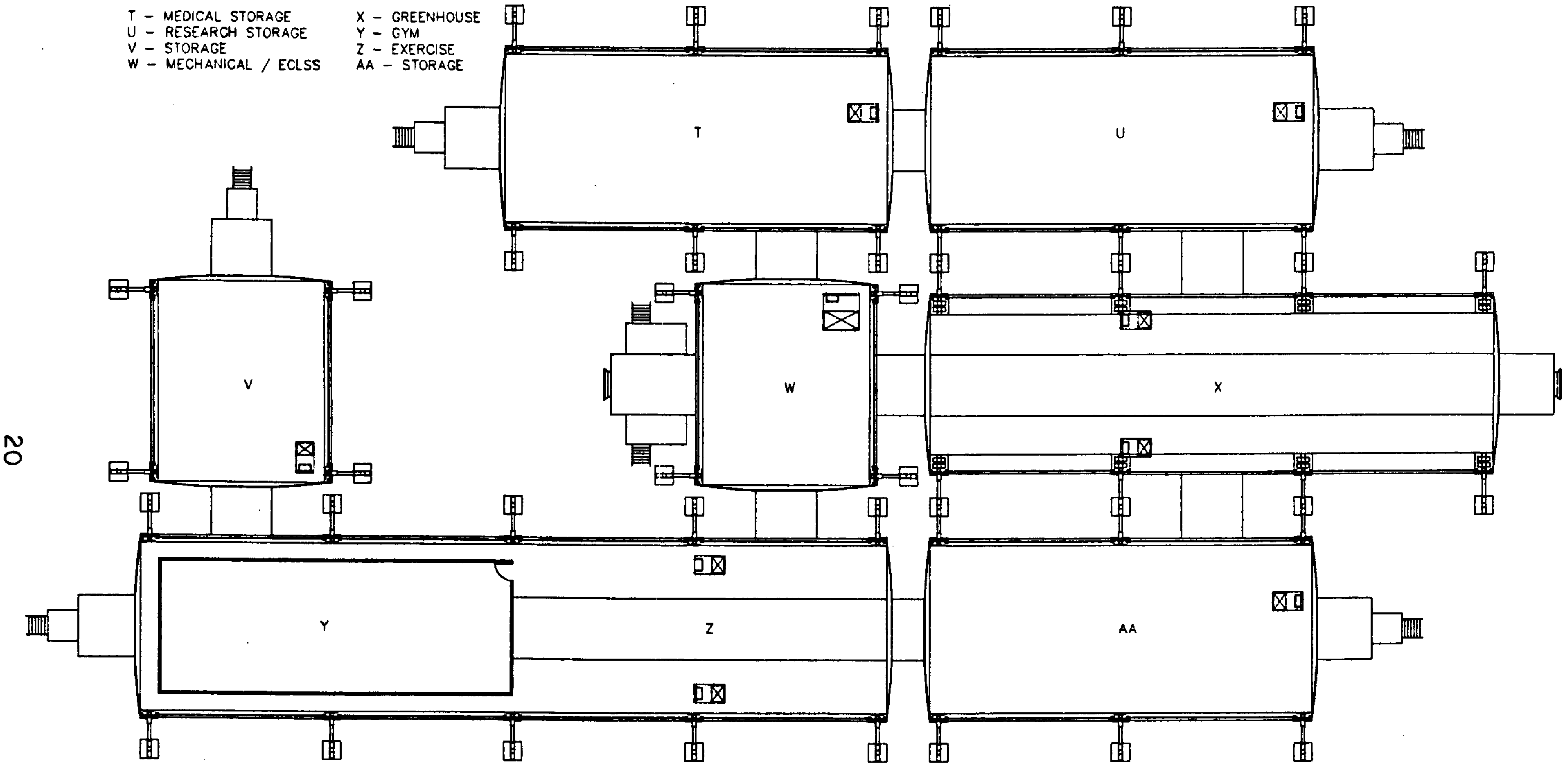


FIG. 5. FIRST FLOOR PLAN

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91

0 8'

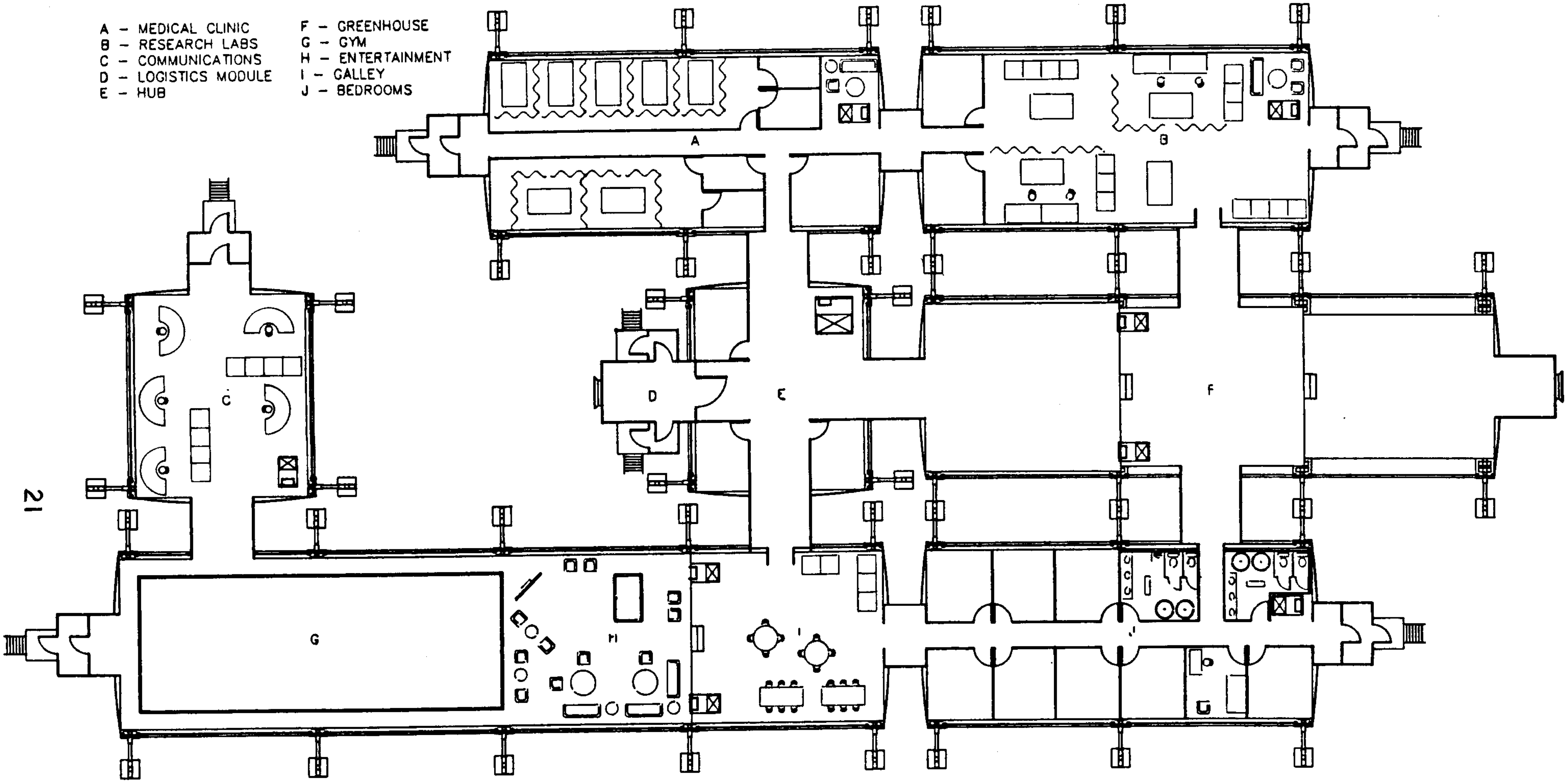


FIG. 6. SECOND FLOOR PLAN

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91

0 8'

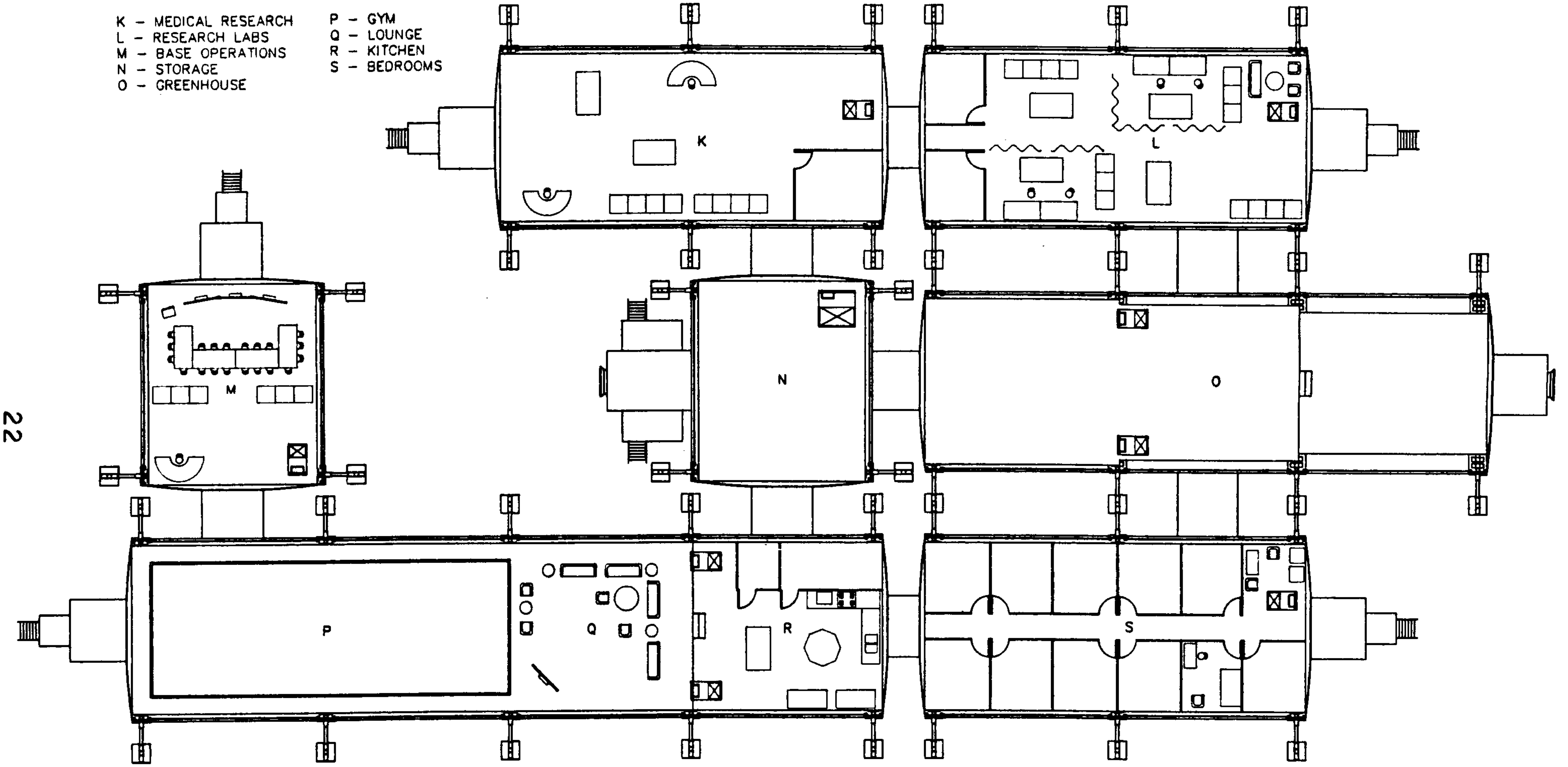


FIG. 7. THIRD FLOOR PLAN

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91
0 8'

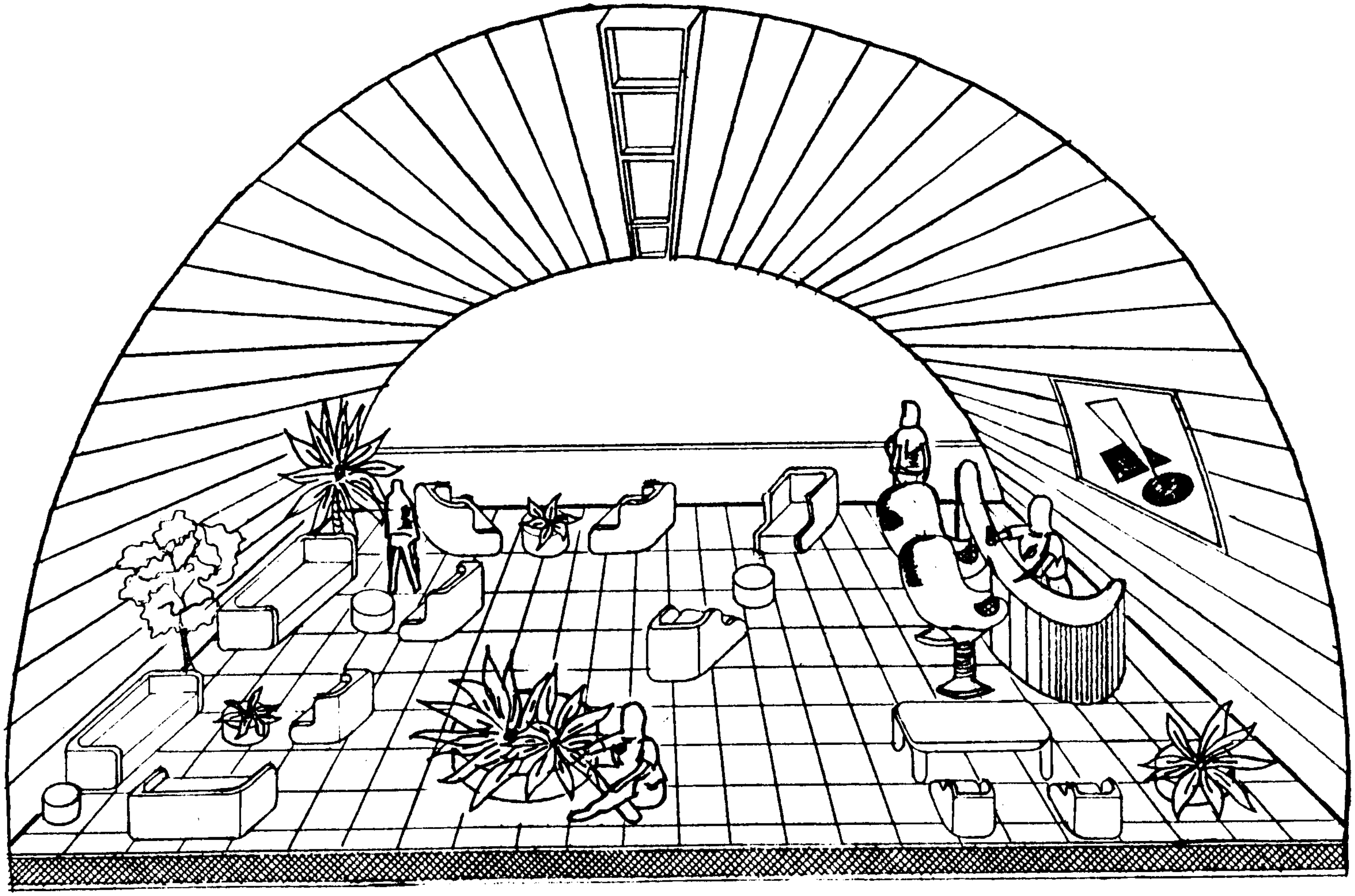
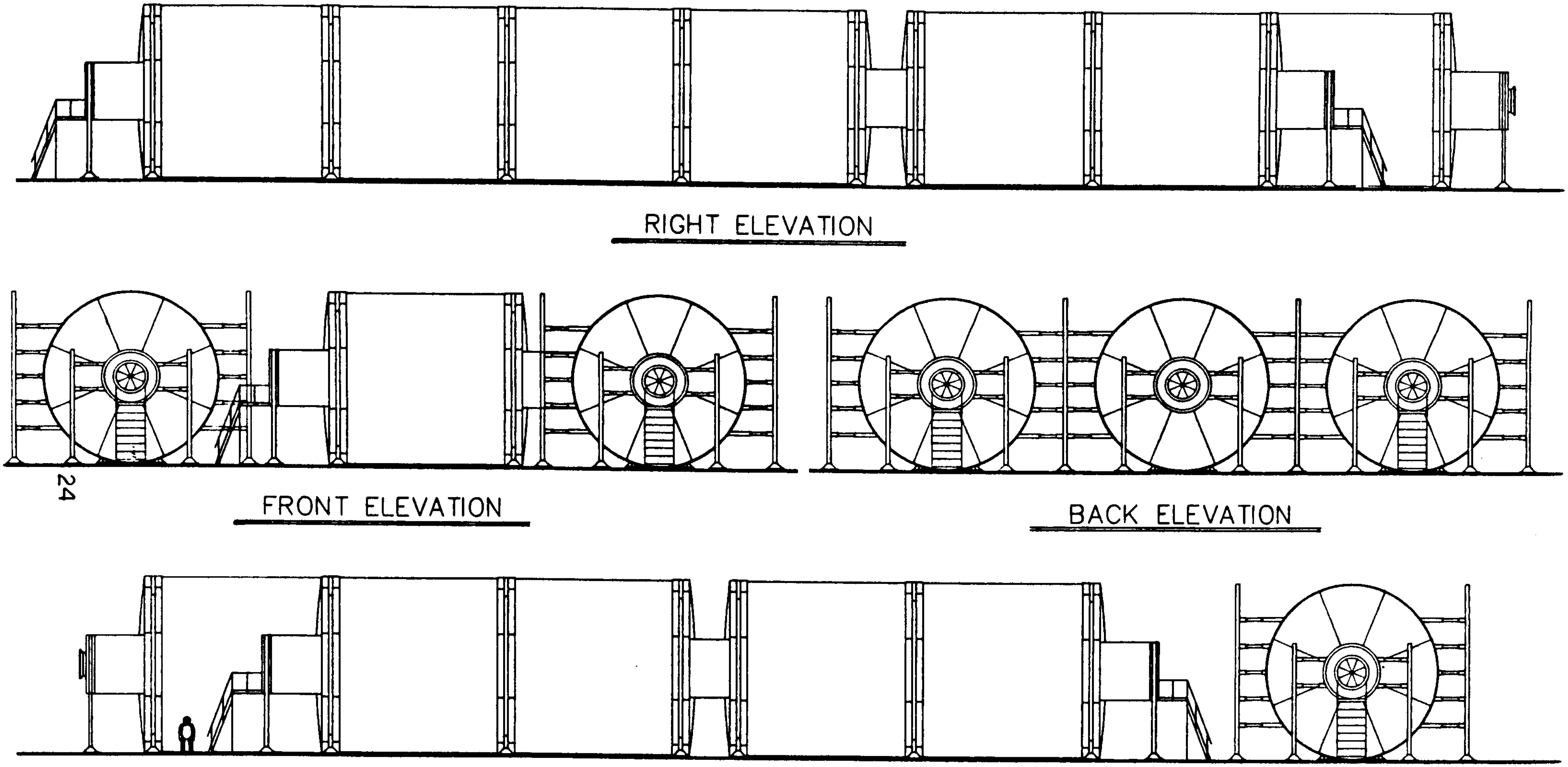


FIG. 8. LOUNGE AREA



RIGHT ELEVATION

FRONT ELEVATION

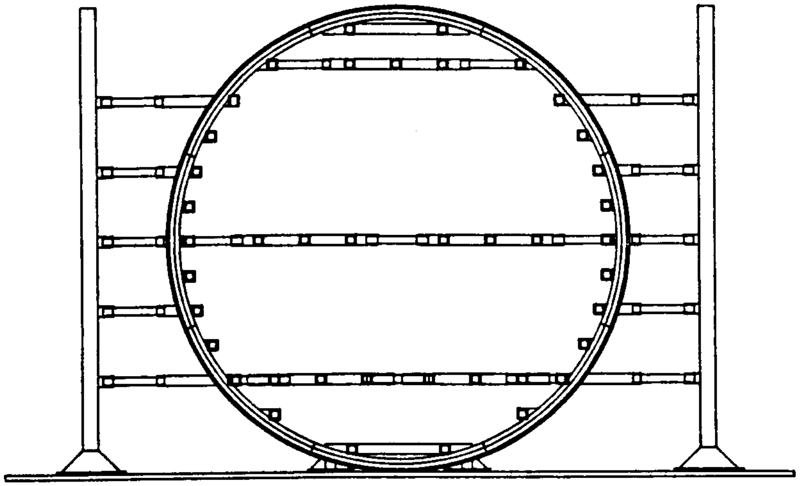
BACK ELEVATION

LEFT ELEVATION

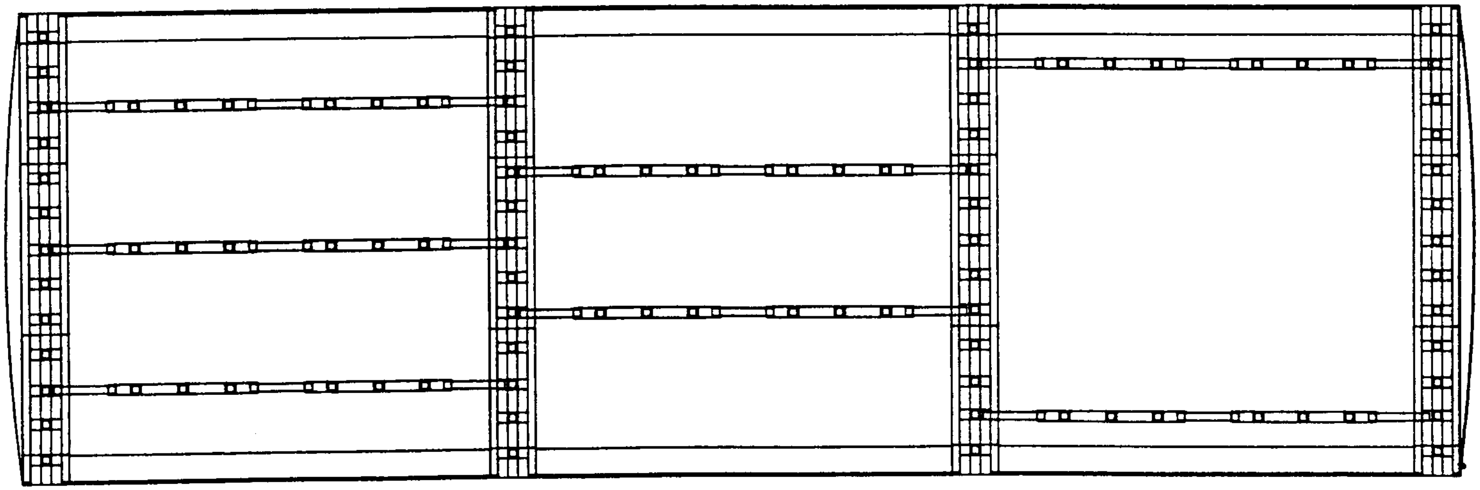
MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

FIG. 9. ELEVATIONS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91



CROSS SECTION



LONGITUDINAL SECTION

FIG. 10. SECTIONS

MODULAR ASSEMBLY REUSABLE STRUCTURE
M.A.R.S. BASE
LAVAPOLIS

PRAIRIE VIEW A&M UNIVERSITY
SPECIAL TOPICS IN ARCHITECTURE
DAVID E. WAYS
4/25/91
0 4'

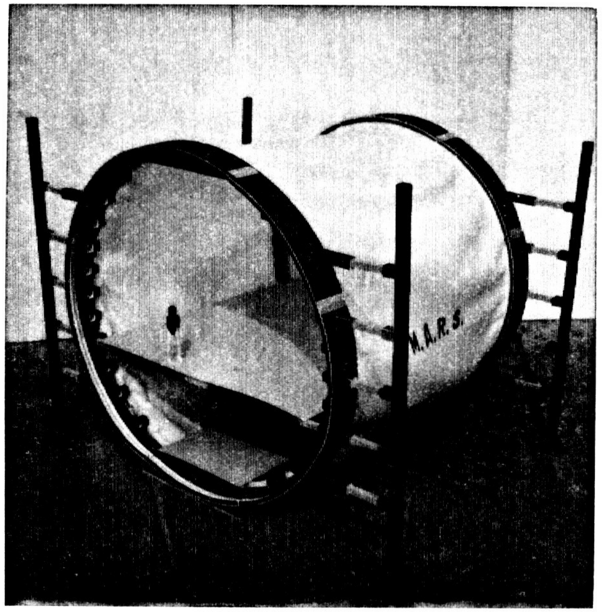


FIG. 11. ONE M.A.R.S MODULE

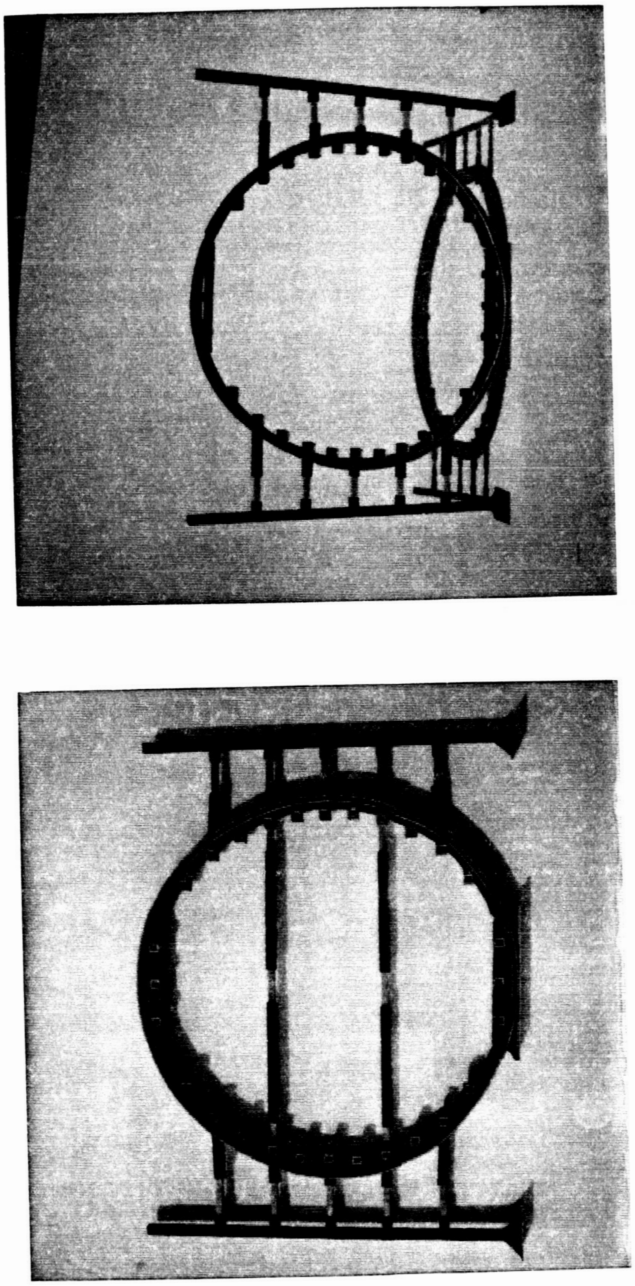


FIG. 12. RING ASSEMBLED

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

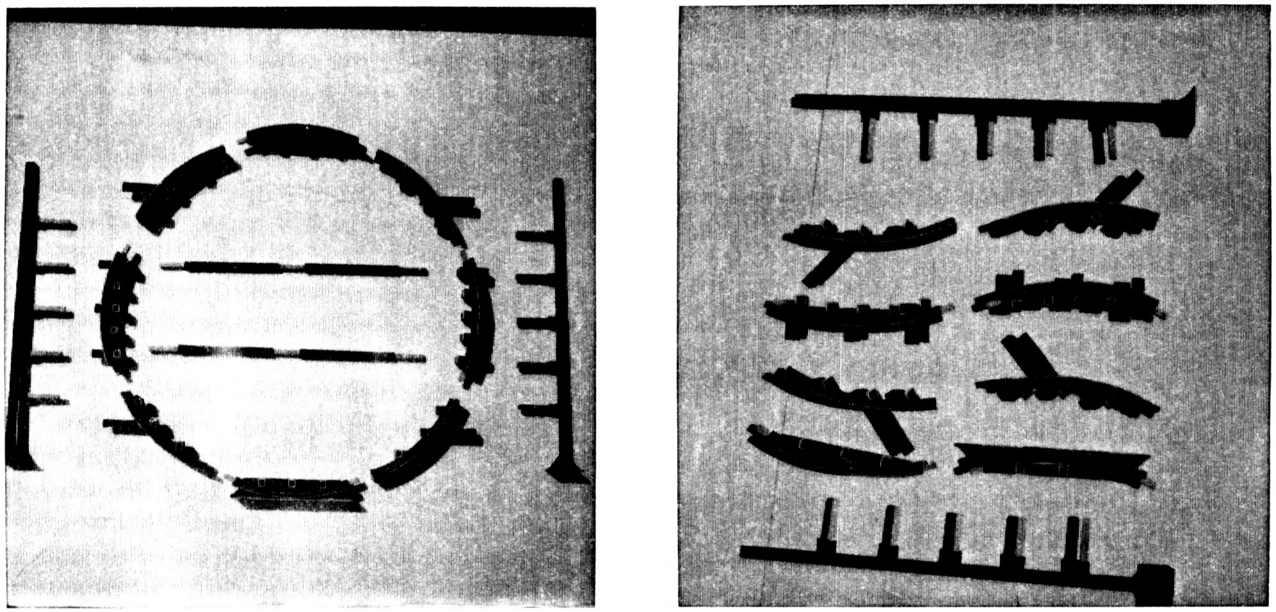


FIG. 13. RING UNASSEMBLED

PREFABRICATED SPACE FRAME STRUCTURES
HEXAMARS

Concept

Construct a space-frame structure that consists of a central core and secondary modules radiating from the core. The sphere-shaped modules will be partially buried below the martian surface. Interchangeable structural members are utilized in the construction of this habitat (See Fig. 14).

Site Location

The site location is 3°N latitude 99°E longitude between Pavonis Mons and Asraeus Mon. The site is compatible to the angle of the space shuttle entering Mars orbit. It is also close to the equator and has comfortable temperature conditions (See Fig. 15).

Assumptions

1. There will be a temporary habitat located near or on the site of an earlier mission that satisfies the requirements for a short-term habitation.
2. Prefabricated space-frame structures as well as other prefabricated material, will be shipped to the site before the long-term crew members arrive.
3. Partial construction and preparation for the long term habitat will be done by crew members or robotics from a previous mission on Mars.
4. The construction of the long-term habitat will occur in phases.

Structure

The Prefabricated frame structures are individual structural members generally fabricated in tubular shapes of metal. Each member is usually stressed axially, either in compression or tension. At the ends of each member, there is a specified connector installed to allow for easy construction and expansion.

The internal structure consist of:

1. Six telescoping hexagonal core columns
2. Six peripheral ribs
3. Radial floor beams
4. Circumferential joists
5. Intermittent floor joint
6. Secondary bracing

A mat foundation transfers all loading of the interior to the exterior support structure from six hard points. (See Fig. 22)

The module shell consist of prefabricated space-frame and titanium panels on the exteriors with Kevlar 29 for the interior module shell wall, Nextel for floor panels and foam-rigidized walls for partion walls. (See Fig. 22)

Methods of Construction

Steps of assembly

1. Create five holes and grade them for the mat foundation to set in them.
2. After the self-deploying foundation is in places the space frame structure is connected to the foundation.
3. Four columns in the membrane structure are connected to the foundation
4. The space-frame structure is packaged with the internal telescopic columns, internal framing, and initial life support.
5. As the space-frame structure is pressurized, the Nextel flooring will be put into position.

The construction of the space frame structure will occur in five phases.

Phase 1 is the safe haven, which includes the dining room and kitchen, exercise room, entertainment, crew rooms, and storage.

Phase 2 will be the crew quarters, which includes the medical facilities, bathroom, wardroom, and storage.

Phase 3 is the transportation bay, which consist of the base command, communication unit, and transportation port.

Phase 4 will be the greenhouse and service facilities. These facilities include plants, animals, oxygen storage tanks, construction equipment, and storage.

Phase 5 will be the laboratories, which consist of soil, chemical, vegetation atmosphere labs, and storage.

Hexamars Tour Directory

On arrival on Mars and not far from the launch pad about several hundred meters is the entrance to Hexamars located on the first floor of the complex. (See Fig. 1.6)

The first module of hexamars to be experienced on this entry plan is module #1, (See Fig. 17) the transportation bay from where access to other facilities begins. Contained inside this module also are the communication facilities and base command in the lower level - plan 2, and storage area in plan 3 (See Fig. 18, 19, 20).

At ninety degrees to the right lies module # 2, (See Fig. 17) which consist of construction equipment space in plan 1 and its storage area in plan 2 (See Fig. 18, 19).

Upon leaving this module through a different air-lock you arrive at the greenhouse in module #3, (See Fig. 17) which in addition contains an office, storage area, and restrooms for the crew. The Green-house will house plants that will be cultivated with artificial lighting while the oxygen from these plants will be recycled and stored for future use (See Fig. 18).

Boarding the elevator for a flight use downwards brings you to the save haven facility which contains a smaller medical facility next to crew quarters, a smaller communication facility, dining and kitchen areas in plan 2 (See Fig. 19), an exercise room, an entertainment area, and restrooms and showers in plan 3 (See Fig. 20).

Housed in module #4-plan 1 are office spaces, restrooms, oxygen storage facilities, an atmospheric lab, and a chemical lab (See Fig. 18). Vegetation lab, soil lab, oxygen storage, restrooms and office areas are located on the lower floor - plan 2 (See Fig. 19).

Through another air-lock the crew can proceed to module #5 which houses an exercise room, an entertainment area, a kitchen, a dining space, and restrooms in the entry level - plan 1 (See Fig. 18). In the two lower levels - plan 2 & 3 you will find the crew quarters which are divided in each level into ten private bedrooms, hygiene areas, and a lounge area.

Module 6 (See Fig. 17) is the last to see before returning to the transportation bay. The medical clinic area including a dental clinic, research area and storage are located on the entry level-plan 1 (See Fig. 18). A sick bay area is located in the lower level, plan 2 (See Fig. 19).

Returning back to module #1 through another air-lock concludes the tour of Hexamars.

Future Expansion

The Future expansion of the long term base will entail constructing and adding more pre-fabricated space frame modules to the existing long term base, therefore creating a colony of pre-fabricated modules with multiple functions.

Future Research and Development

More information and research is needed to determine the actual materials for the prefabricated space frame structure, operating and maintenance for this concept (i.e. EVA requirements, replacement of failed or damaged structures), time required for construction, calculation of weight and cost to Mars, safety consideration, robotics and equipments needed for construction, the effect of the 1/3 gravity on the human movement and consequently on the design of the habitat, environmental control life support system considerations. In conclusion, more research is needed of all issues and requirements to implement this design on the planet Mars.

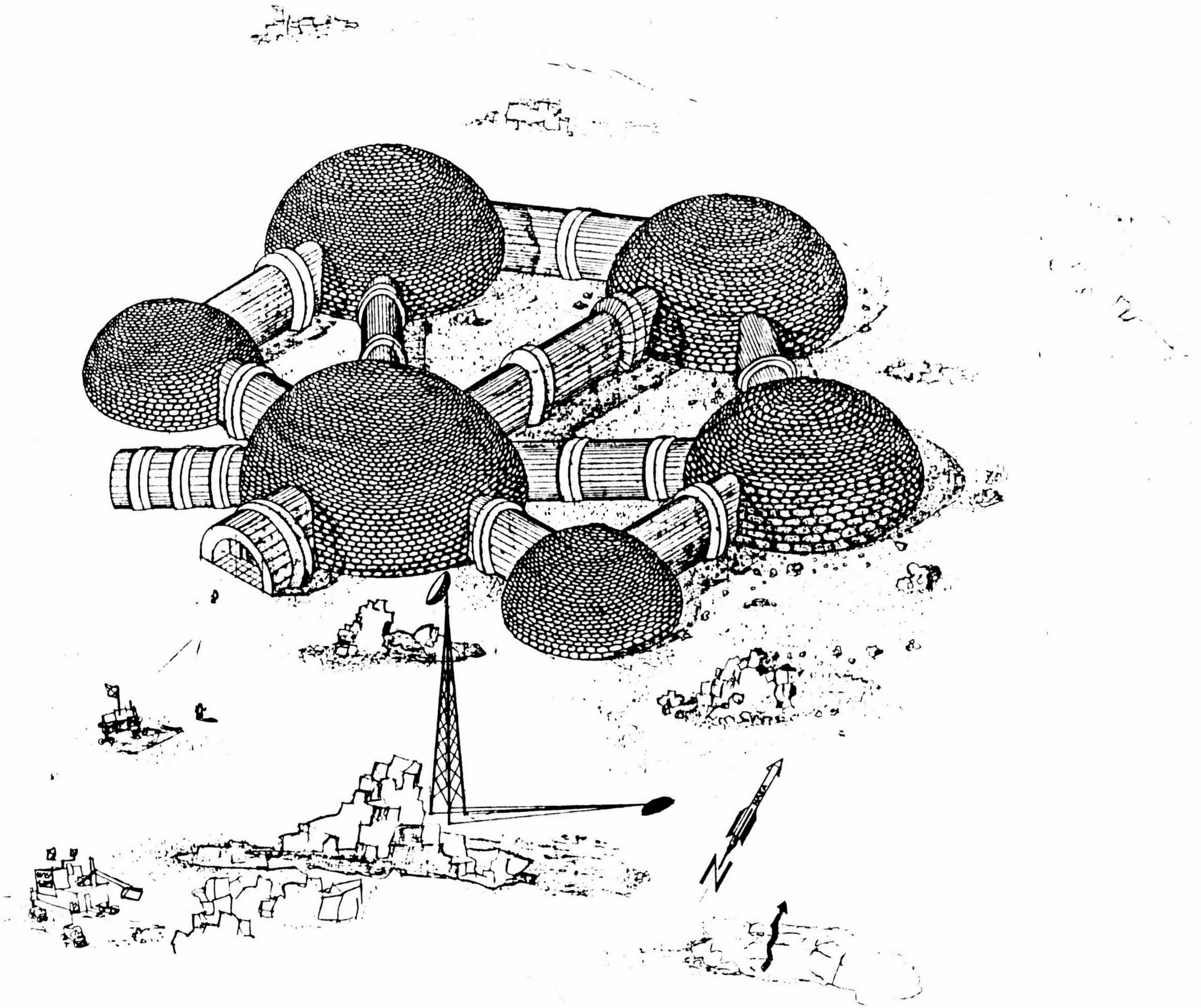


FIG. 14. ISOMETRIC OF HEXAMARS

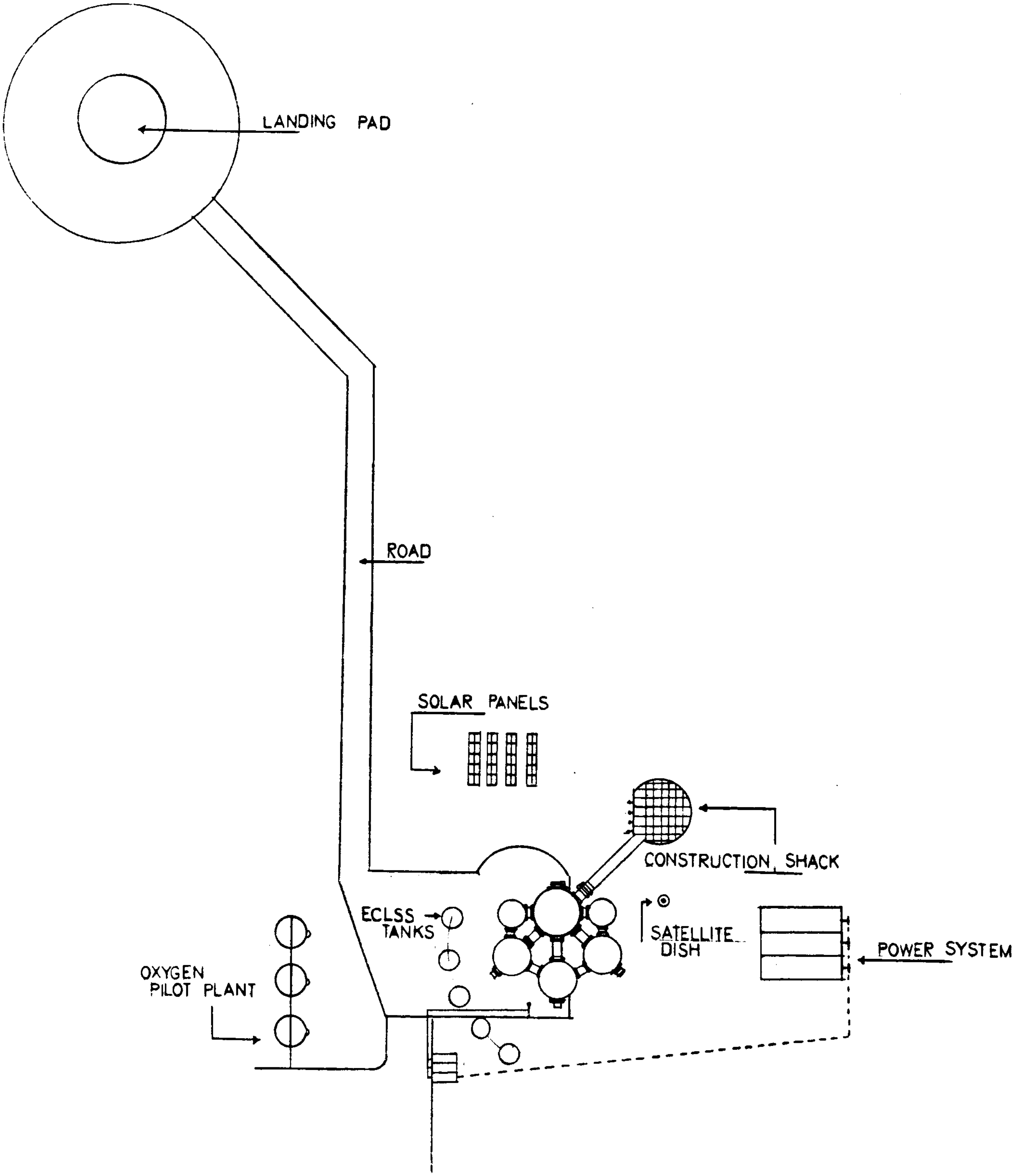


FIG. 15. SITE PLAN

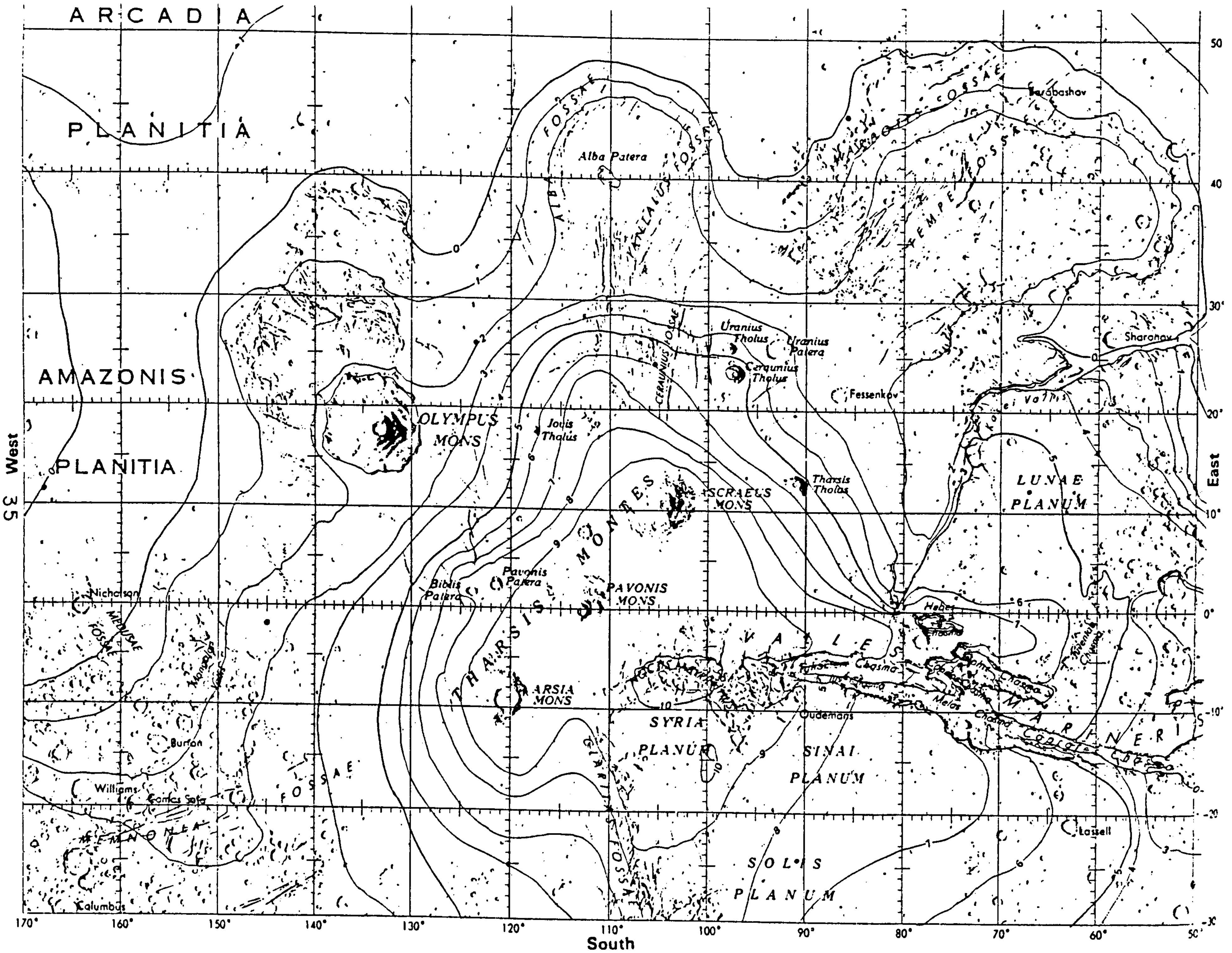


FIG. 16. SITE LOCATION OF HEXAMARS

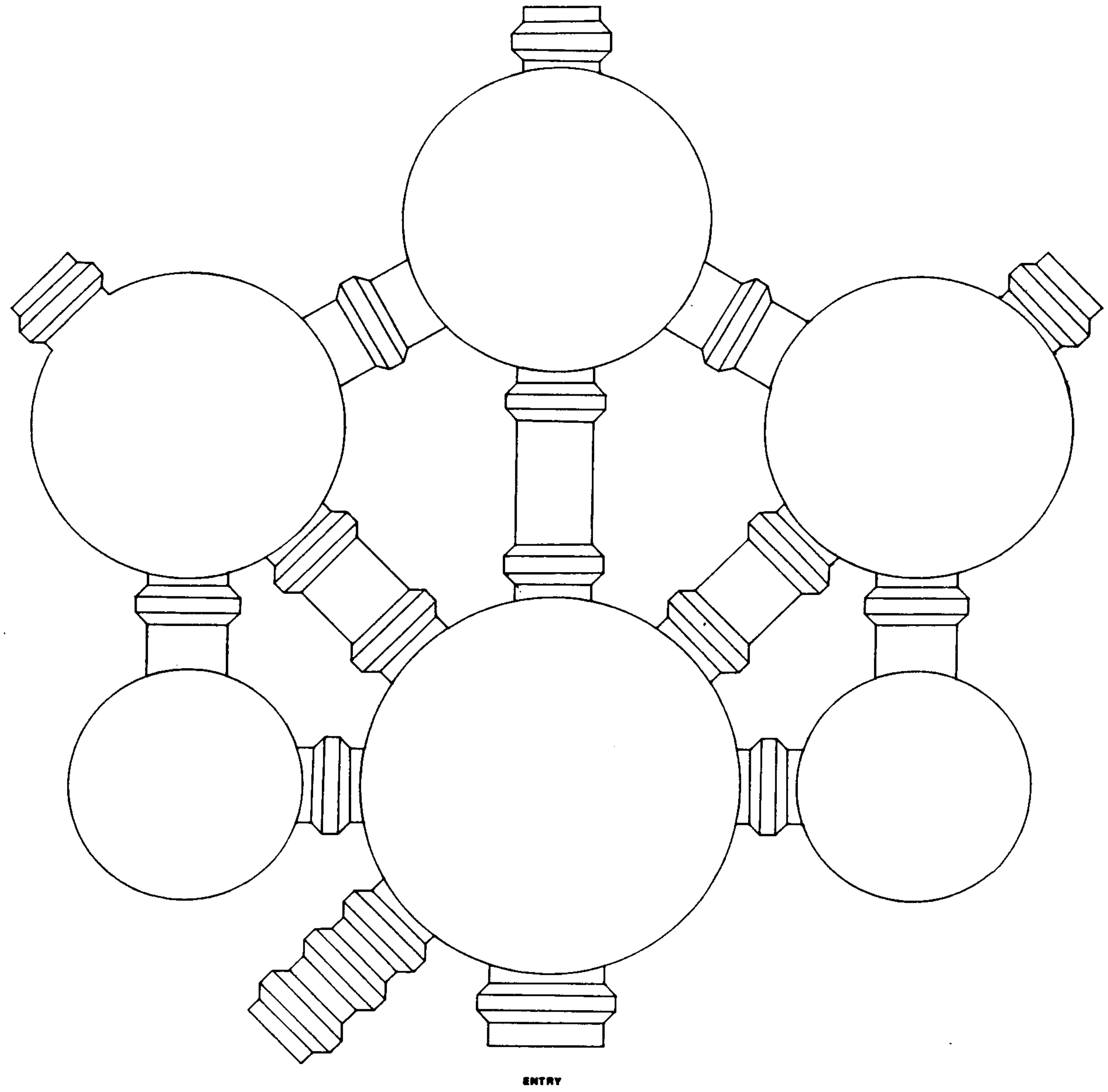


FIG. 17. **ROOFPLAN**

HEXAMARS

LEGEND

A. TRANSPORTATION
B. WORK AREA CONSTRUCTION
C. GREEN HOUSE
D. OFFICE
E. STORAGE
F. RESTROOMS
G. ATMOSPHERIC LAB
H. CHEMICAL
I. EXERCISE ROOM
J. KITCHEN / DINNING
K. ENTERTAINMENT
L. DENTAL CLINIC
M. CLINIC AREA
N. RESEARCH
O. OXYGEN STORAGE

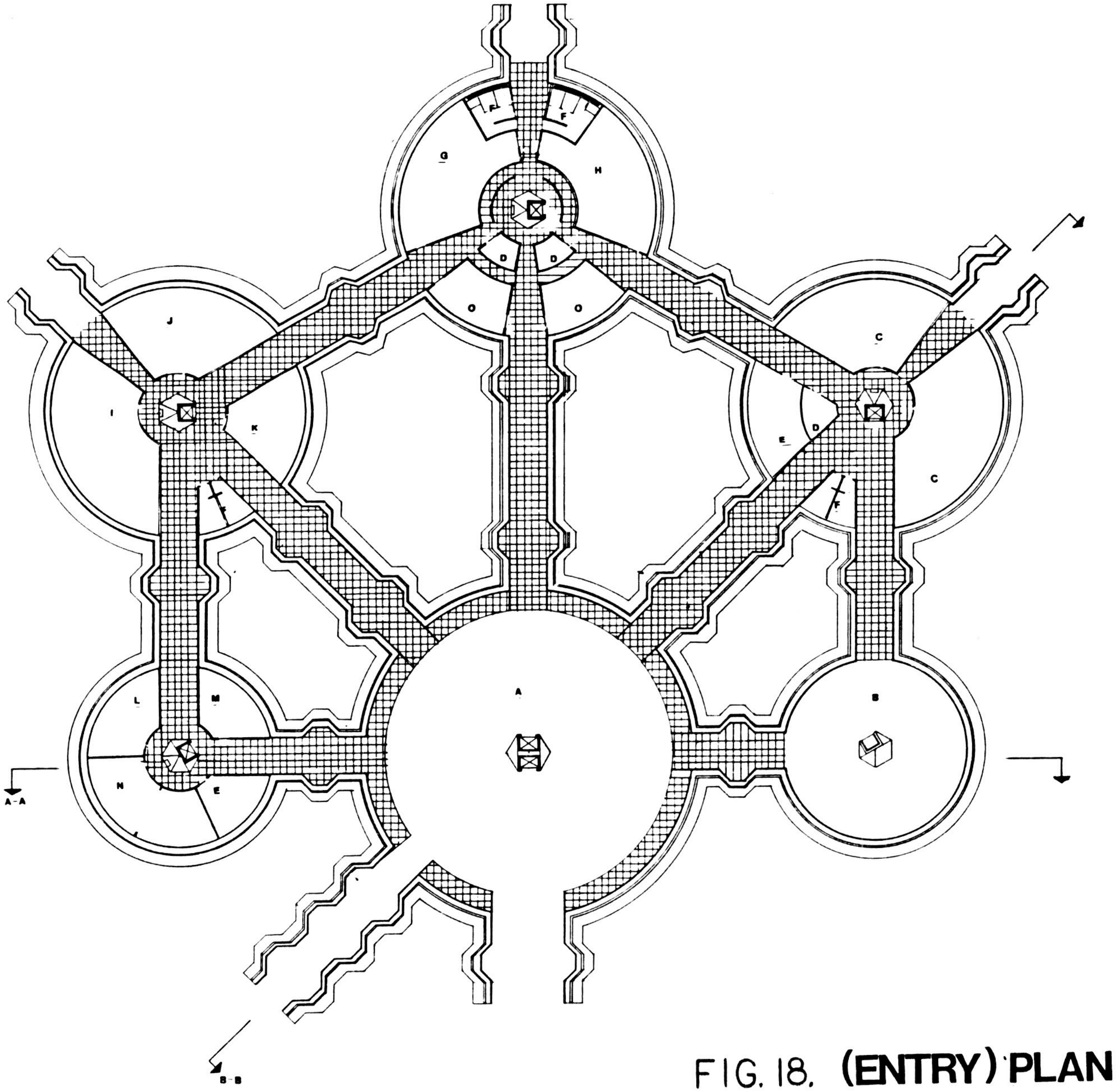


FIG. 18. **(ENTRY) PLAN I**

HEXAMARS

LEGEND

1. COMMUNICATION
2. BASE COMMAND
3. RESTROOMS
4. CREW QUATERS
5. MEDICAL CLINIC
6. DINNING
7. KITCHEN
8. RESTROOMS & SHOWERS
9. SICK BAY
10. VEGETATION LAB
11. SOIL LAB
12. OXYGEN STORAGE
1A. OFFICE
2A. CONSTRUCTION EQUIPMENT STORAGE

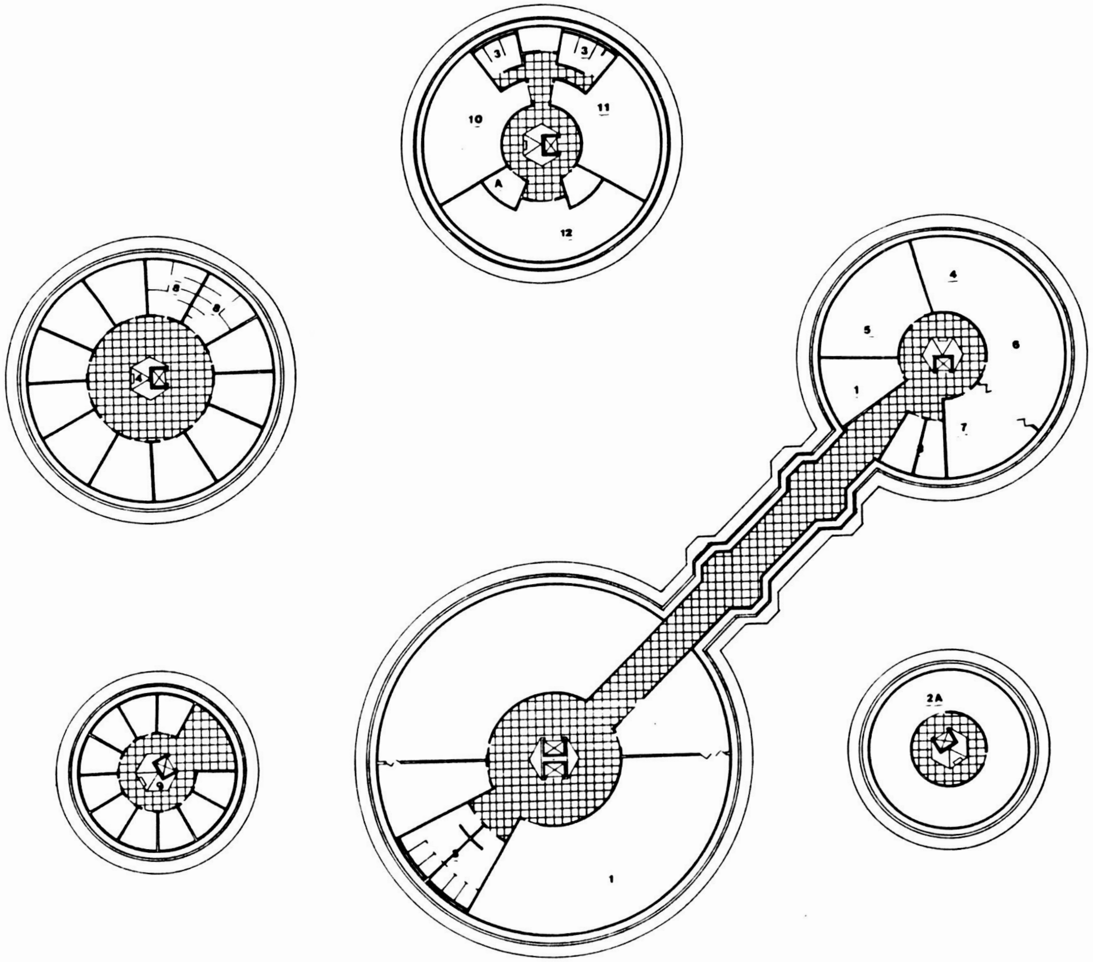


FIG. 19 **PLAN 2**

HEXAMARS

LEGEND

A. OXYGEN STORAGE
B. STORAGE
C. OFFICE
D. RESTROOMS
E. CREW QUATERS
F. STORAGE
G. EXERCISE ROOM
H. ENTERTAINMENT
I. MEN/WOMEN RESTROOMS & SHOWER

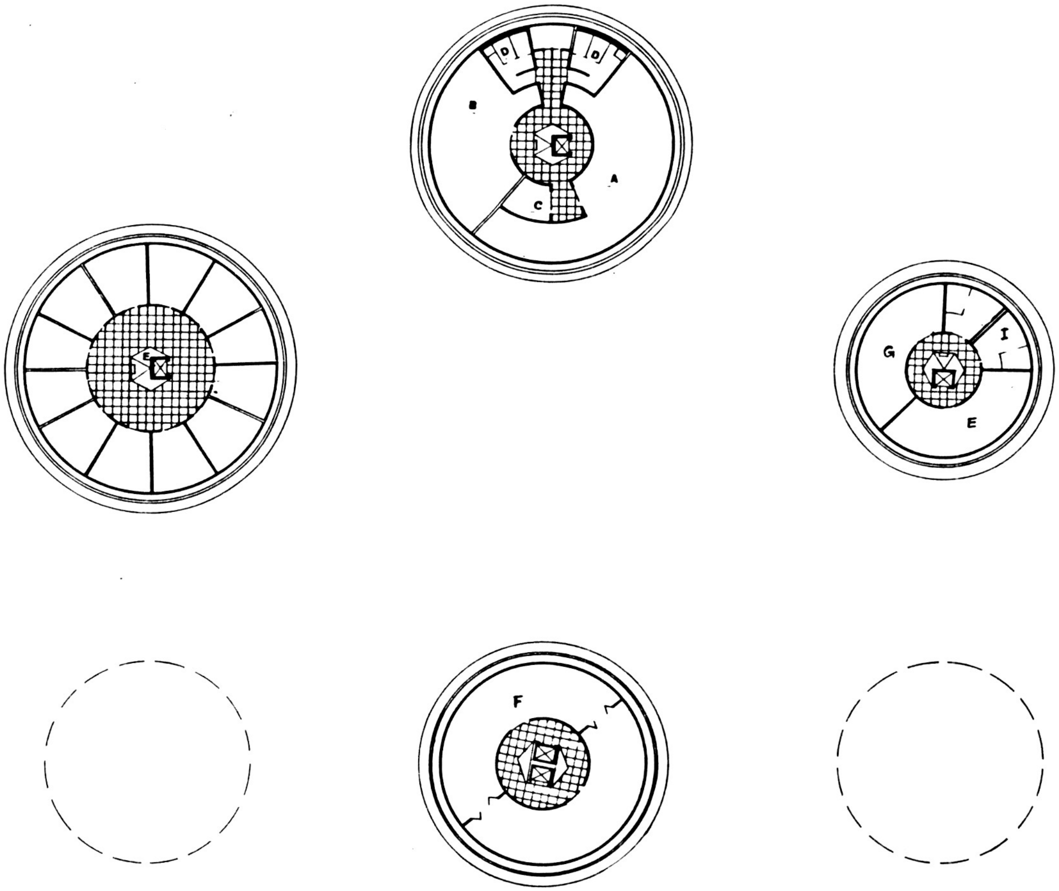
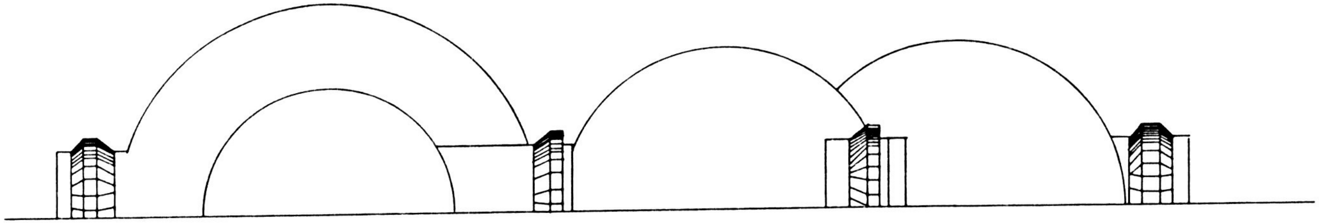
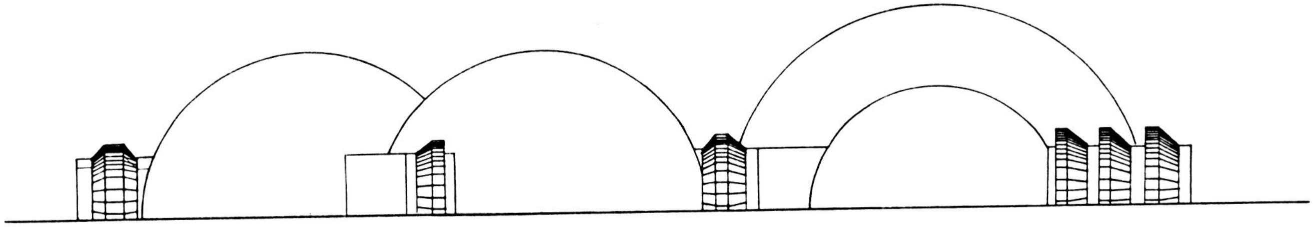


FIG. 20. **PLAN 3**

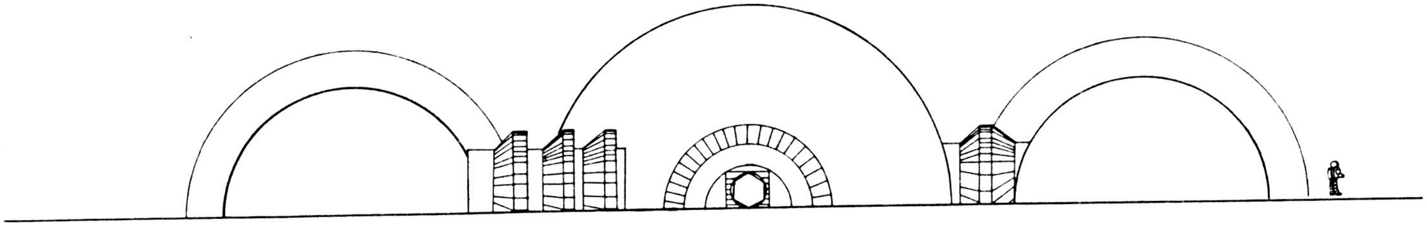
HEXAMARS



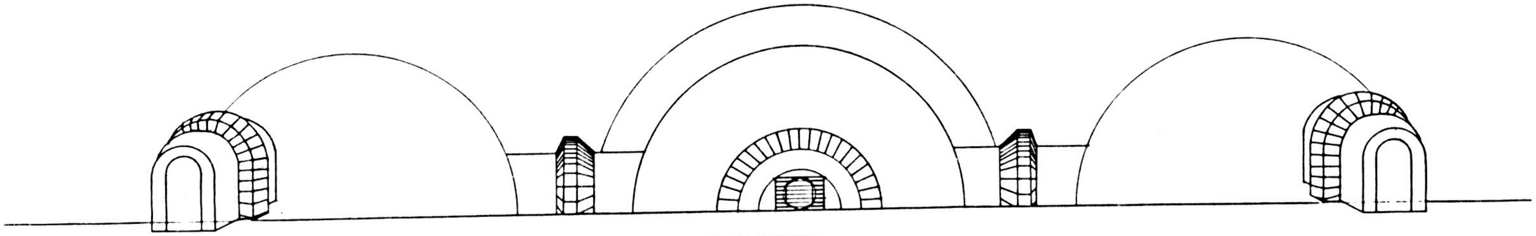
EAST ELEVATION



WEST ELEVATION

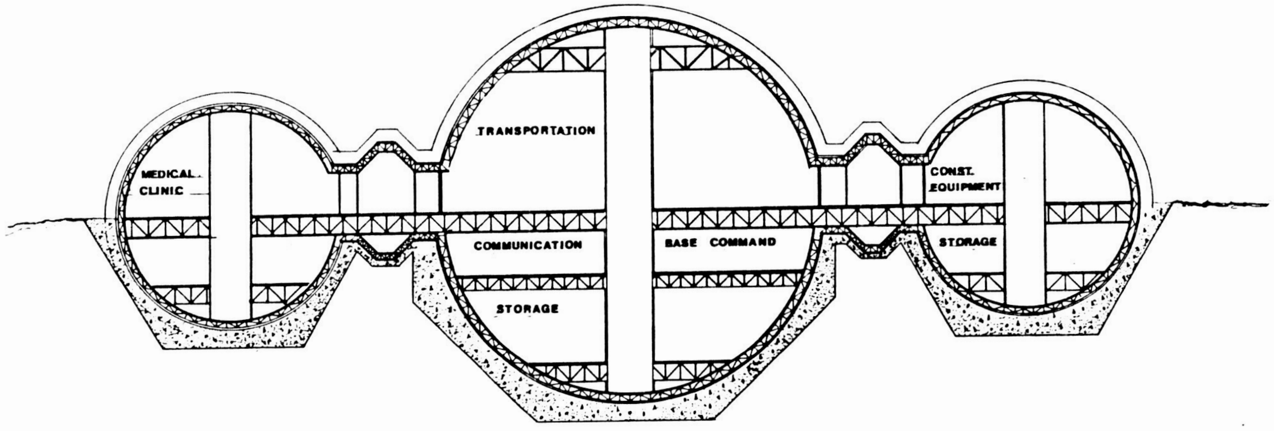


SOUTH ELEVATION

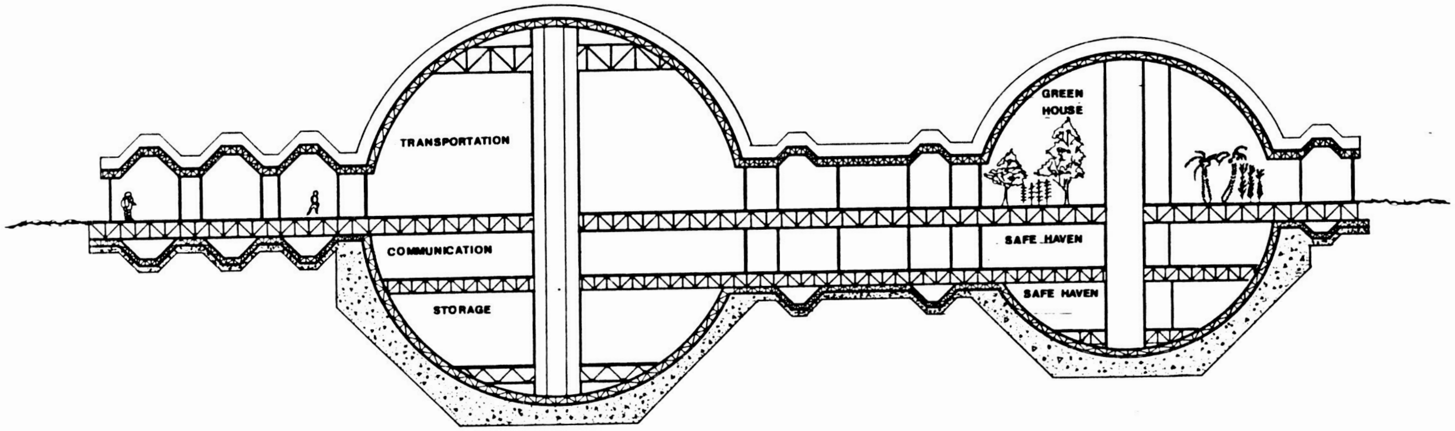


NORTH ELEVATION

FIG. 21 ELEVATIONS



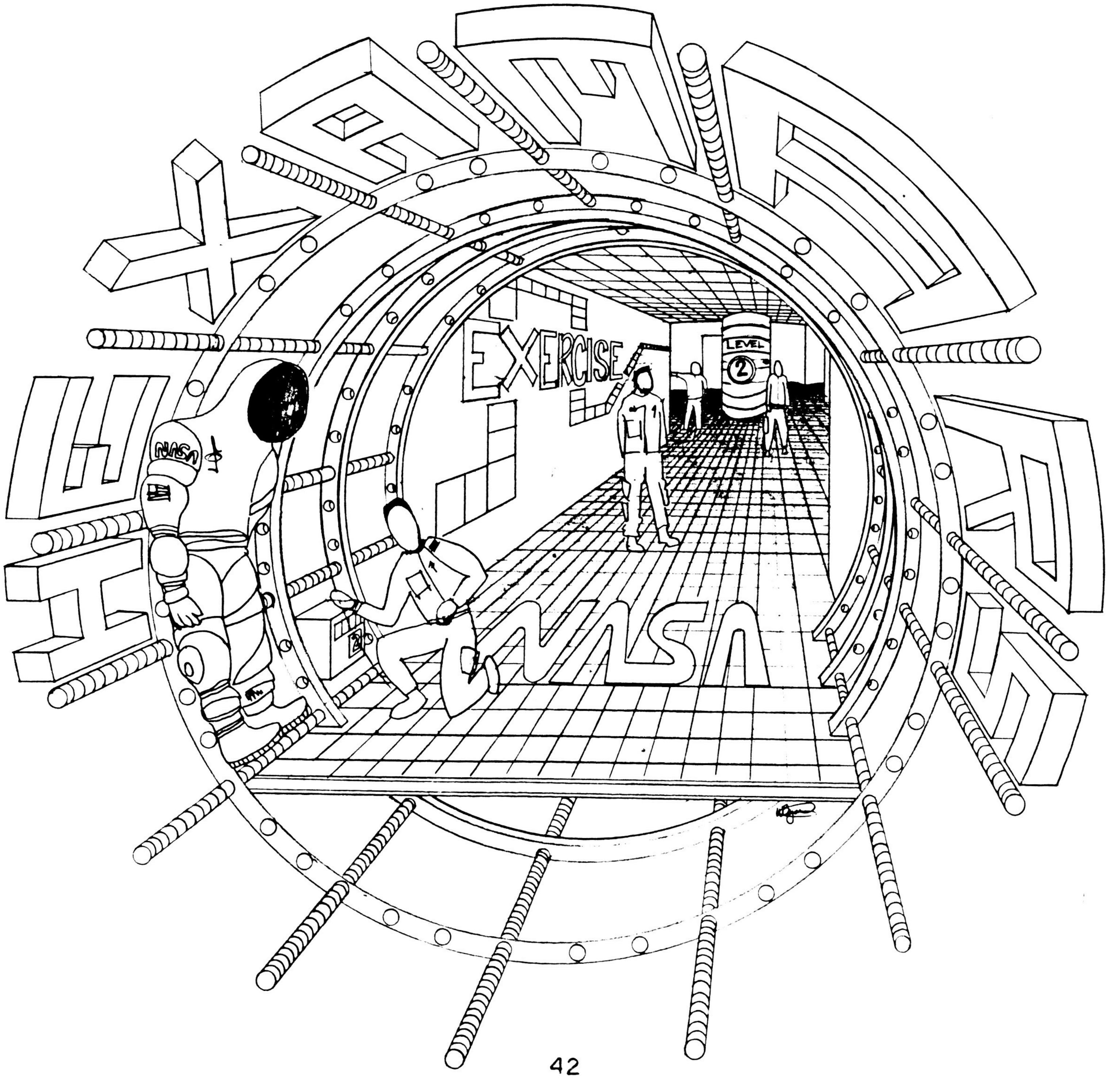
SECTION A-A



SECTION B-B

FIG. 22 SECTIONS

FIG. 23 AIR-LOCK CORRIDOR



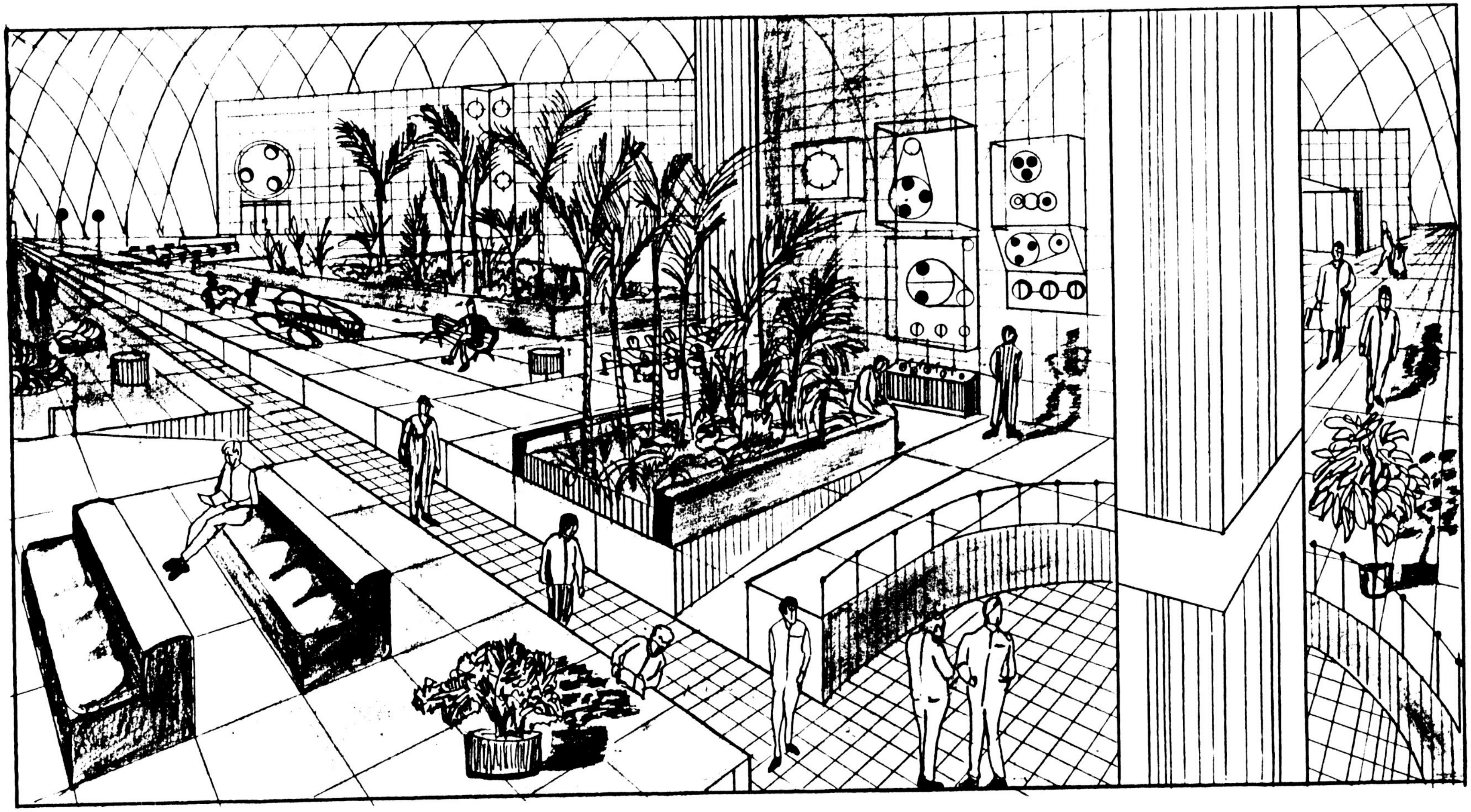


FIG. 24. SAFE HAVEN

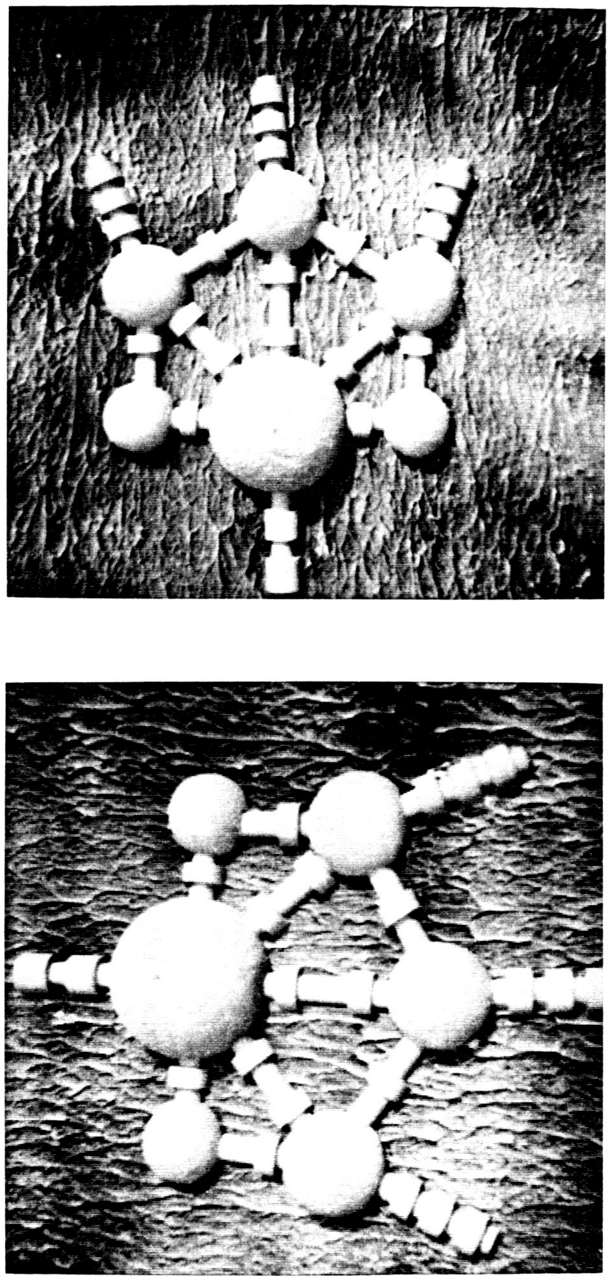


FIG. 25. HEXAMARS

REFERENCES

Carr, Michael H., The Surface of Mars, 1981.

College of Engineering and Architecture. MARS Surface Base Factory Oracle, Arizona.

College of Engineering and Architecture. Replenishable Food Supply on Mars. Prairie View A&M University, Prairie View, Tx., 1990

Connell, Richard B., Joseph P. Fieber, Kerry L. Paruleski, Hernan D. Torres. "Design of an Inflatable Habitat for NASA's Proposed Lunar Base". USRA Design Team, August 3, 1990.

Frassanito, John & Associates. "Inflatable Lunar Habitat Construction Sequence". March 1990.

Franssanito, John & Michael Roberts. Planetary Surface Systems Architecture Options for the MOON & MARS. March 1990. paper.

JSC-24398, Habitation and Human Systems for the 90 day study, March 1990.

JSC-24155, Human Transportation Systems for Lunar/MARS Outpost: Initial Engineering Consideration. May 1990.

JSC-#LBS-88-266. Inflatable Habitation for the Lunar Base. April 1988.

JSC-23613, Lunar Outpost. August 1989.

JSC-24172, Systems, Options, & Scenarios for a Manned MARS Mission. January 1990.

Kenneday, Kriss J. Interior Design of the Lunar Outpost. paper. JSC.

Liebes Sidney Jr., VIKING LANDER ATLAS OF MARS. California: STANFORD. Stanford Univesity, 1982.

Miles, Frank, and Nicholas Booth. RACE TO MARS. New York, 1988.

NASA Conference Publication 2426, Space Station Human Factors Research Review, December 1985.

NASA Contractor Report 3941, Space Station Elements and Issues Definition Study, November 1986.

NASA Contractor Report 4010, Space Station Group Activities Habitability Module Study, November 1986.

NASA-100470, Environment of MARS. Oct. 1988

NASA-4170, Exploration Studies Technical Report. Vol.III: Planetary Surface Systems. 1989

NASA Sp-428, Space Resources and Space Settlements, 1979.

NASA - Report of the 90-Day Study on Human Exploration of the MOOM & MARS. Washington, D.C.

NASA/USRA, Proceedings of the 4th Annual Summer Conference, June 1988.

NASA/USRA, Proceedings of the 5th Annual Summer Conference, June 1989.

NASA/USRA, Proceedings of the 6th Annual Summer Conference, June 1990.

National Commission on Space, Pioneering the Space Frontier, May 1986.

Planetary Society, Poster: An Explorer's Guide to Mars. 1990.

School of Architecture, Habitability Camelot III. University of Pureto Rico. 1989.

School of Architecture. Habitability: Camelot IV. University of Pureto Rico. 1990.

SICSA OUTREACH. "Planetary Missions and Settlements". University of Houston's College Vol.1, No.3: September 1987.

SICSA OUTREACH. "The Space Post Project" University of Houston's College of Architecture. Vol.1, No.4: October-December 1987.

SICSA OUTREACH. "Variable-G Life Science Facility". University of Houston's College of Architecture. Vol.1, No.5: January-February 1988.

SICSA OUTREACH. "Ocean Communities". University of Houston's College of Architecture. Vol.1, No.6, March-April 1988.

SICSA OUTREACH. "Inflabable Space Structures". Unviersity of Houston's College of Architecture. Vol.1, No.7: May-June 1988.

SICSA OUTREACH. "The Antarctie Planetary Testbed (APT): A Planned International Initiative". University of Houston's College of Architecture. Vol. 1, No.8, July-Sept., 1988.

SICSA OUTREACH. "Living in Space: Considerations for Planning Human Habitats Beyond Earth". University of Houston's College of Architecture. Vol.1, No.9: October-December 1988.

SICSA OUTREACH. "Astrotectonics: Construction Requirements and Methods in Space". University of Houston's College of Architecture. Vol. 2, No. 2: Apr-June 1989.

SICSA OUTREACH. "Space Radiation Health Hazards: Assessing and Mitigating the Risk". University of Houston's College of Architecture, Vol. 2, No. 3: July-September 1989.

SICSA OUTREACH. "Experience, Analog and Simulation to Guide Planning for Prolonged Missions". University of Houston's College of Architecture. Vol. 2, No. 4: January-March, 1989.

SICSA OUTREACH. "The Manned Lunar Outpost (MLO): A NASA/USRA - Sponsored Study". University of Houston's College of Architecture. Vol. 2, No. 4: October-December 1989.

SICSA OUTREACH. "Manned Mission to Mars" Planned Bold Journeys into Tomorrow." University of Houston's College of Architecture. Vol. 3, No. 1: January-March, 1990.

Space Biospheres Ventures. Biosphere II: A Project to create a Biosphere. Oracle, Arizona.

STAR * NET STRUCTURES, INC., "Space Frame". 1988

Toups, Larry D., A comparative Catalogue of Lunar Construction Techniques. February 1989.

Toups, Larry D., A Survey of Lunar Construction Techniques. Paper

University of Wisconsin, Milwaukee, Space Architecture: Lunar Base Scenarios, January 1988.