PAX: A PERMANENT BASE FOR HUMAN HABITATION OF MARS[1,2,3]

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Abstract

The Advanced Design Program in Space Architecture at the University of Wisconsin-Milwaukee supported the Synthesis Report[1] and two of its scenarios--"Architecture 1" and "Architecture 4"--and the Weaver ExPO report on near-term extraterrestrial explorations[2] during the spring of 1992. The project investigated the implications of different mission scenarios, the Martian environment, supporting technologies, and especially human factors and environment-behavior considerations for the design of the first permanent Martian base. This paper presents the results of that investigation. The paper summarizes site selection, development of habitability design requirements based on environment-behavior research, construction sequencing, and a full concept design and design development for a first permanent Martian base and habitat. The proposed design is presented in terms of an integrative mission scenario and master plan phased through initial operational configuration, base site plan, and design development details of a complete Martian habitat for 18 crew members including all laboratory, mission control, and crew support spaces.

Humans to Mars: Purpose and Objectives

The purpose of this project was to support *America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative* (called the "Synthesis Report"[1]) which recommended that NASA explore what it called four "architectures," i.e., four different scenarios for habitation on Mars.

The Advanced Design Program in Space Architecture at the University of Wisconsin-Milwaukee supported the Synthesis Report and the Weaver ExPO SEI reference mission report[2] by pursuing five objectives:

- explore the implications of different mission scenarios,
- understand the Martian environment,
- analyze supporting technologies, and
- investigate human factor and environment-behavior (EB) considerations for the design of a Martian base.

Procedure

The work was accomplished in an overlapping sequence of eight phases:

1. Mission scenario--analysis and integration.

2. Base design research and requirements--background research and development of design requirements for master plan and site plan.

3. Concept design exploration--schematic design studies to develop and explore different site planning and habitat concepts.

4. Habitat design research and requirements--literature review of the full range of human factors and EB considerations in habitat design, and development of research-based design requirements.

5. Habitat schematic design--schematic designs for each space (laboratories, crew quarters, etc.) in response to design requirements.

6. Interior design development--detailed design development of all interior spaces and refinement of design details.

7. Design integration--final design development and integration across the habitat as a whole, including preparation of various presentations of the project in

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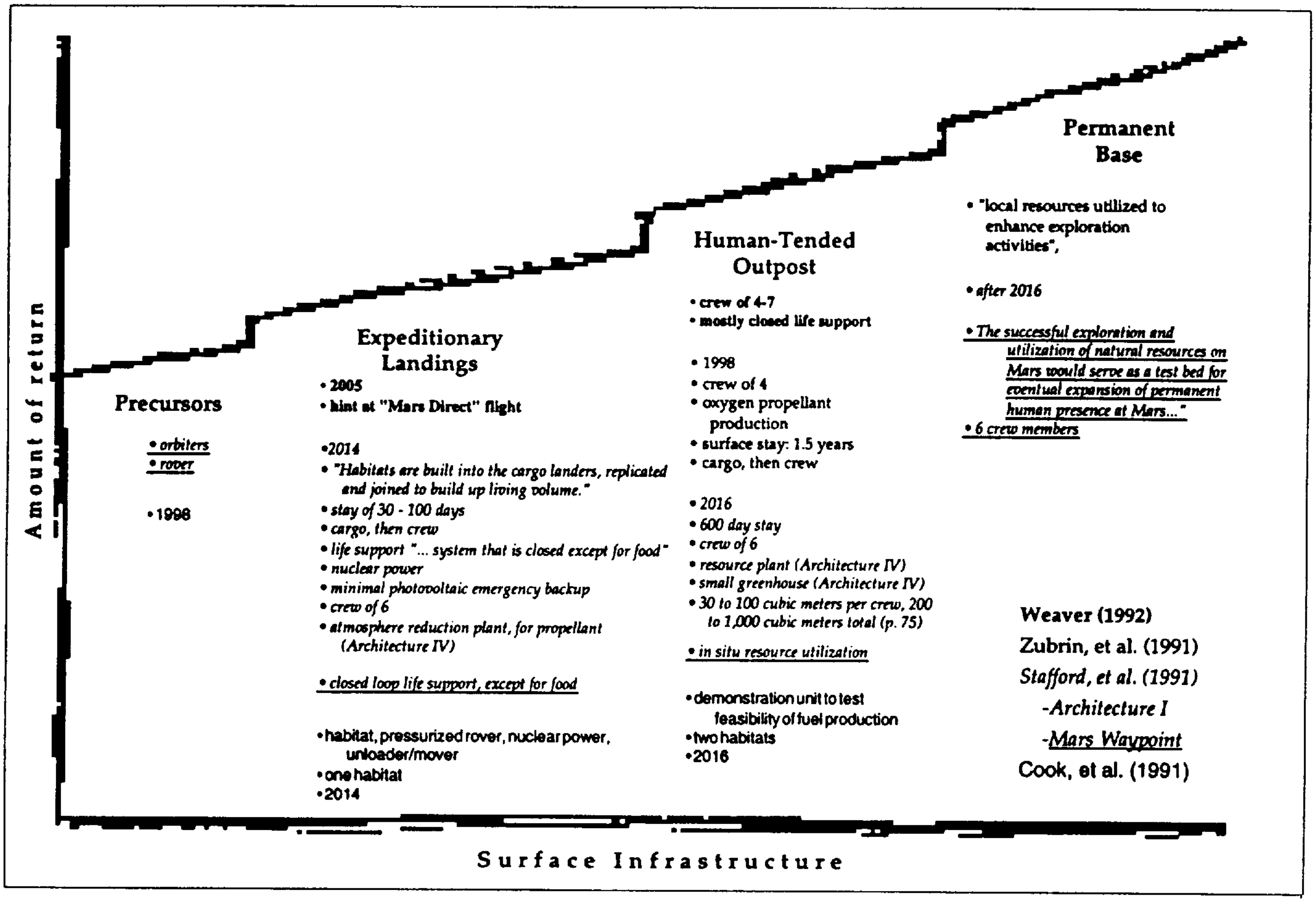

Fig. 1 Integration of previously published Mars mission scenarios.

mid-fidelity models of each module floor showing lighting, colors, and textures and of the habitat and regolith-containment space-frame structure, and drawings of site location, site plan, and construction sequence to initial operating configuration (IOC) and next operational configuration (NOC).

8. Presentations, slides of all models, drawings, and diagrams to explain the EB basis of habitat and base design, technical report, and papers at national and international meetings.

Mars Mission Scenario

Our thinking, based on an integration of the Synthesis Report, the ExPO report, and Zubrin's "Mars direct" scenario,[1] indicates the likelihood of the following four-phase Mars mission scenario:

1. Precursor telerobotic missions around 1998.

2. Expeditionary landings around 2005 to 2014 on the order of 500 days total trip time with a stay of 30 to 100 days.

3. Longer duration missions on the order of 1,000 days with a typical stay time of 500 to 600 days between 2007 and 2016 to establish *human-tended campsites or outposts*.

4. Long-duration missions to establish the initial operating configuration of the first permanent base (IOC) between 2009 and 2022.

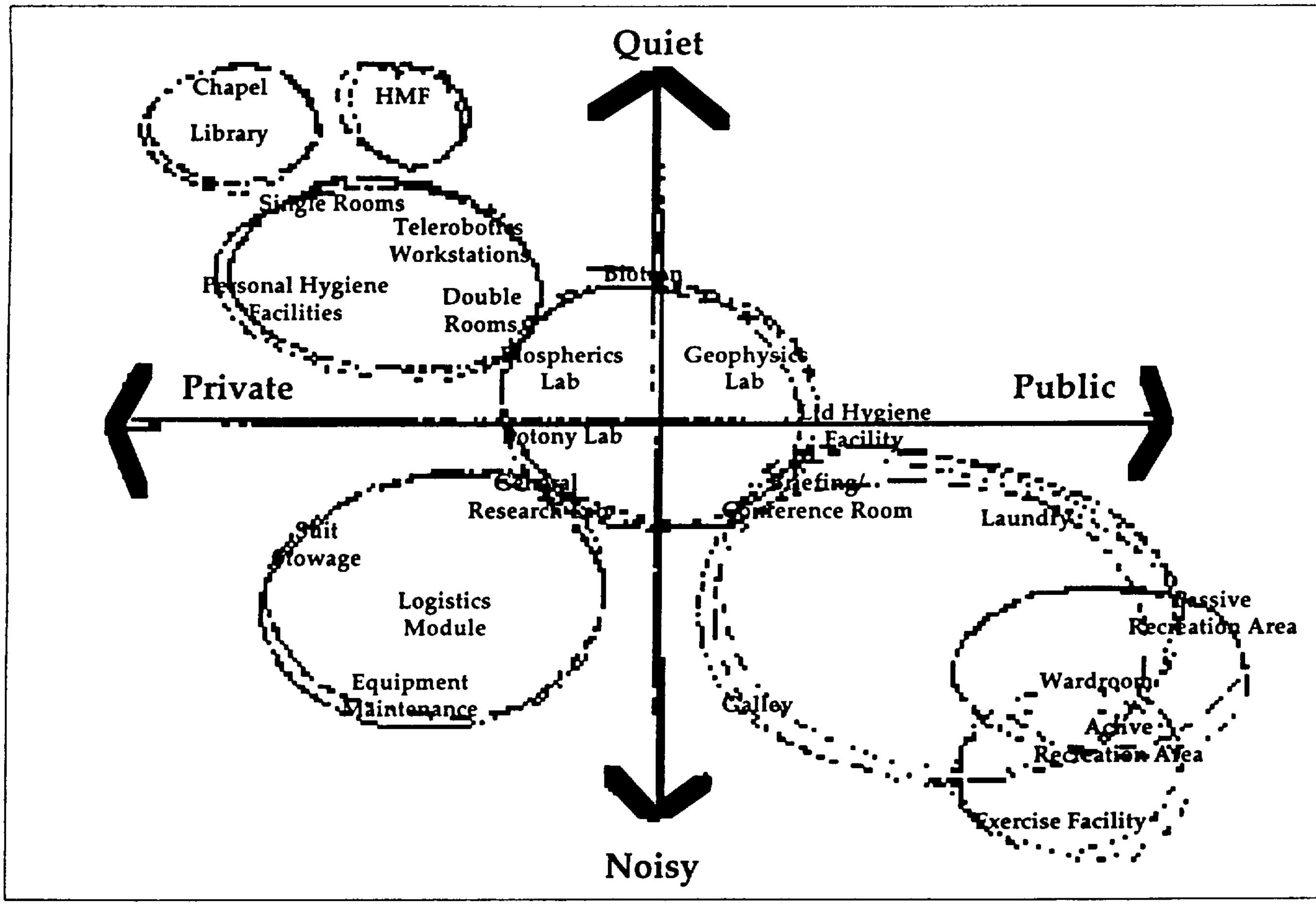

Fig. 2 An example of two EB issues considered in the design of Pax: needs for privacy and for social interaction, and for quiet and more active spaces. The beginnings of the layout of the habitat (a "bubble diagram") emerges from the overlap of these two gradients.

There are significant EB habitation issues to be explored and solved in a long-duration permanent Martian base. The focus, therefore, of our current research and design work has been on the EB determinants of a long-duration permanent base.

Our work built off what the Synthesis Report referred to as the Mars "Waypoint" (by which is meant Mars planetary activities for human exploration of Mars and the Solar System, i.e., as a waypoint to later exploration into the Solar System). We accepted the Synthesis Report recommendations of a crew size of 6 crew members for the initial human-tended outpost and the ExPO recommendation of a crew size of 18 for the permanent IOC base. The base is designed assuming a mostly closed-loop life support system (closed except for food, which will be produced on an experimental basis in a pair of biotrons or Martian greenhouses) and remote automatic emplacement, checkout, and verification of the habitat and life support system.

The Mars waypoint assumes significant transfer of learning from orbital and lunar facilities including evaluation of lunar habitats. Our previous work in the USRA Advanced Design Program was instructive. An early phase of our Martian work was an analysis and critique of the five lunar habitats[4] designed by the Space Architecture Design Group since 1989--especially the two habitats taken into design development--for positive lessons to be transferred to the design of the first Martian habitat.

Fig. 3 Viking 2 mission location at 45° north latitude, 251° west longitude.

Human Factors and Environment-Behavior Considerations

Until recently, human factors and EB considerations were not viewed as significantly important elements for successful extraterrestrial exploration. Instead, science and engineering were paramount in the eyes of the designers. "There is now an increased awareness on the part of planners that design does affect behavior."[5] By studying the effects of human behavior in isolated and confined environments and deriving design requirements, human factors considerations can have a profound impact on the success of extraterrestrial space exploration.

A permanent Martian base will provide for a multi-national, multi-racial, mixed-gender crew for stay times as long as two years. The base will include mission-related facilities such as research labs, mission operations workstations, airlock and dust-off chamber, storage for logistics, and life-support system. It will also contain crew-support facilities such as crew quarters, individual and group passive recreation areas, an active exercise facility, a wardroom for eating, teleconferencing, and meeting, hygiene facilities, and a health maintenance facility, as well as special places for privacy and psychological retreat.

The driving force behind the design of Pax, proposed as the first permanent Martian base and habitat (named for the international Peace Settlement, opposite of the Latin name of the planet, Mars, the God of War) is human factors and EB requirements that impact on habitability for long-duration habitation.

Fig. 4 Pax base site plan showing the central habitat with launch and landing facility each 2.5 km away from the habitat.

A full range of EB issues was investigated, from pragmatic issues of anthropometrics, productivity, and functionality to more abstract issues of community and privacy, imagery and symbolism. Considerations included but were not limited to anthropometric effects of one-third gravity, safety, astronaut satisfaction and productivity, minimization or relief of stress, social interaction and privacy, orientation and wayfinding, perceptual variety, efficiency, functional convenience, and place and identity--the quality of "home."

Site Selection

It is proposed that Pax be constructed at the Viking 2 landing site, 45 degrees N latitude, 251 degrees W longitude, known as Utopia Planitia. The site is near varied geologic surface features important for research. The site is located in the northern hemisphere, away from the origination of southern dust storms during the summer season. The terrain in the immediate area, generally level according to Viking 2 photos, is appropriate for a transportation system and launch and landing facility. The elevation of the site is relatively low with respect to the other features on the surface, thus providing some radiation protection from the accumulated, albeit thin atmosphere. Finally, current theory on water location[6] suggests the search be conducted near the north pole. The proposed site for Pax is on the south edge of the polar cap advance in the winter season.[2]

Base Layout: Site Plan

The base layout follows a north-south axis, with the habitat, solar array fields, and radiator fields being in the center, the auxiliary nuclear power plant 2.5 km to the south, and the launch and landing facility 2.5 km to the north. Winds are from the west and southwest; launch and landing patterns will not endanger the habitat, and any possible nuclear residue will be carried away from the base and habitat.

Habitat Design Concept

Concept or schematic design studies were conducted early in the research and design process of this project to explore different base layout master and site-planning concepts. The implications of four alternative concept designs were explored, analyzed, and then compared at a preliminary design review (PDR). They were:

- hard module habitat partially buried and partially set in the edge of a Martian crater;
- inflatable habitat partially buried and partially set in the edge of a Martian crater;
- Earth-like technology for Martian surface application; and
- space-frame construction spanning between crater edges.

The advantages and limitations of each concept design were analyzed. An attempt was made to combine the best of each concept. From the PDR, it was found that there are considerable advantages for surface construction with a combination of hard module and inflatable structures covered with a space-frame regolith containment system. This was the integrative concept that was adopted and developed throughout this project.

A modular space-frame construction system provides the protective shelter for the habitat itself. This framing system will combine open square and triangular geometries to produce a roof-and-column support system. The proposed system is a kit of components, redundant in size and shape, that will allow the astronauts relative ease of construction. The system will consist of a structural space frame, column support system, textile regolith containment and radiation shielding system, and Martian regolith.

The habitat, or central portion of Pax, will be constructed in several stages. Construction can commence when two rigid modules and six crew members are on-site, and their equipment, rovers, and logistics are emplaced. Additional modules and their crew will arrive, bringing the compliment of rigid modules to four, and the number of crew members to 12.

The habitat for a final crew size of 18 at IOC will be comprised of five operational modules, each two floors in height: a 9-m hard-module entry module for dust-off, suit stowage and maintenance, and full recreation and exercise center; two 12-m inflatable modules, one for laboratories and mission command, the other for crew quarters and the crew support facility; and two additional 9-m hard modules serving as two Martian greenhouses. The fourth hard module, part of the initial deployment, will be transferred elsewhere on the Martian surface to serve as a hazardous laboratory.

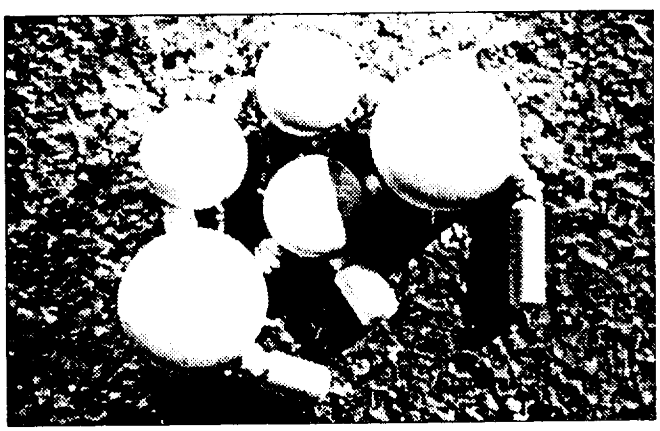

Fig. 5 Model representation of Pax showing the five modules—entry and active recreation flanked by laboratories on the left, crew quarters on the right, and two greenhouses in the background.

Construction Sequence

The sequencing of a Mars mission from initial lift-off from Earth to IOC and NOC is a critical, and early, mission design decision to be made. Based on our analyses, the advantages of Zubrin's "Mars direct" mission scenario, or mission "architecture" as NASA calls it, became apparent. Adopting large segments of this scenario suggested a split-sprint mission, with cargo transportation and initial robotic emplacement preceding the first landing of humans on Mars. Thus the construction sequencing we have recommended proceeds in eight phases:

1. Landing of two 9-m hard modules as the initial campsite or outpost, followed by six crew members who begin to prepare the site for further development.

2. Excavation of the footprint for the IOC Martian habitat.

3. Landing of two additional 9-m hard modules as the second phase outpost, followed by six additional crew members who begin assembly and raising of the space frame and regolith containment system.

4. Emplacement and inflation of the two 12-m inflatable crew support and laboratory facility modules.

5. Moving the rigid entry module from the campsite location and connecting it and a primary entrance airlock to the inflatables.

6. Transporting the fourth and fifth components, both rigid modules dedicated to greenhouse functions, underneath the space frame shelter utilizing a lift and trailer system, and attaching them with flexible connections to the laboratory and crew inflatables.

7. Docking two additional rigid modules, a logistics and emergency airlock module to the crew support inflatable, and a combination laboratory logistics and emergency airlock module to the laboratory inflatable. This completes IOC.

8. Expansion of the base as necessary to various NOCs, e.g., removal of the crew or laboratory logistics module/airlocks and excavation for the emplacement of additional 12-m or larger inflatable modules.

Overall Design Organization of the Habitat

There were seven factors that went into creating the basic *parti* or conceptual framework governing the design process for Pax. They are:

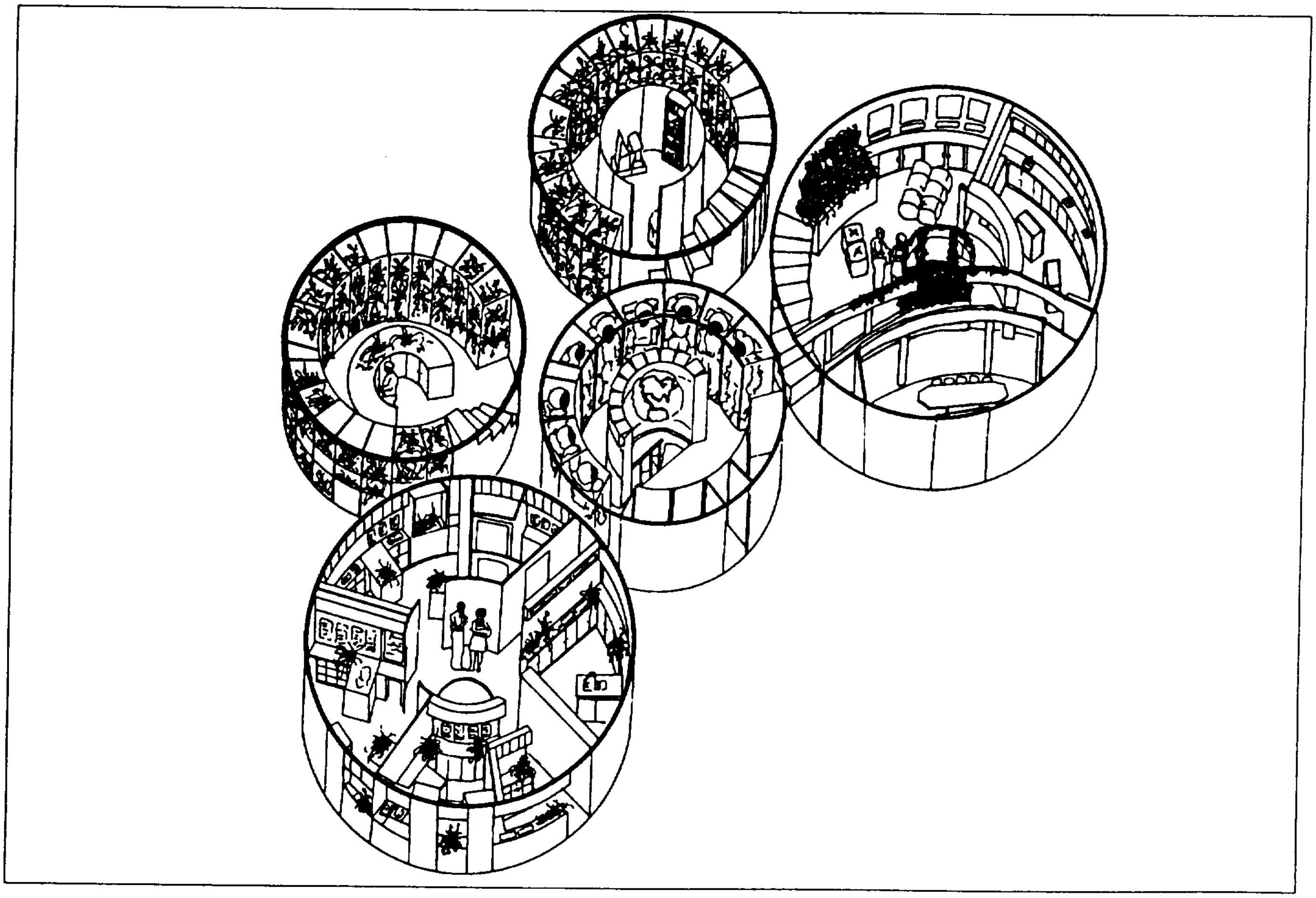

Fig. 6 Axonometric drawing of the main floor (entry level) of Pax, illustrating the embracing entry (center) and separation from crew support facility (lower left to upper right); greenhouse modules are on the upper left.

- embracing entry
- separation of work and play
- circulation efficiency
- dual egress
- creation of a central focus for each module
- homelike environment
- sense of place

Because Pax is to be the astronauts' "home" for two years or more, a designated entrance will mark the "front door" to home. By situating the modules in an embracing formation, slightly set back in the center, crew members will have a sense of "moving within." The indented area is intended to mark a focal point in the habitat. The embracing feature is evident in both the plan and elevation of the habitat. From the surface of Mars, entry into the habitat is a sequential process. The crew will enter under the shelter system to the primary airlock. From this airlock, the crew will pass through a dust-off chamber before entering the primary circulation space.

Since the crew does not egress the habitat to conduct intravehicular activity (IVA), the concept of designing Pax through a separation of "work" and "play" may help the crew differentiate activities. By physically separating the laboratory and crew support spaces, the crew may feel as thought they were going to work, similar to on Earth. Later they have the opportunity to "leave work" and go home for peace and recreation.

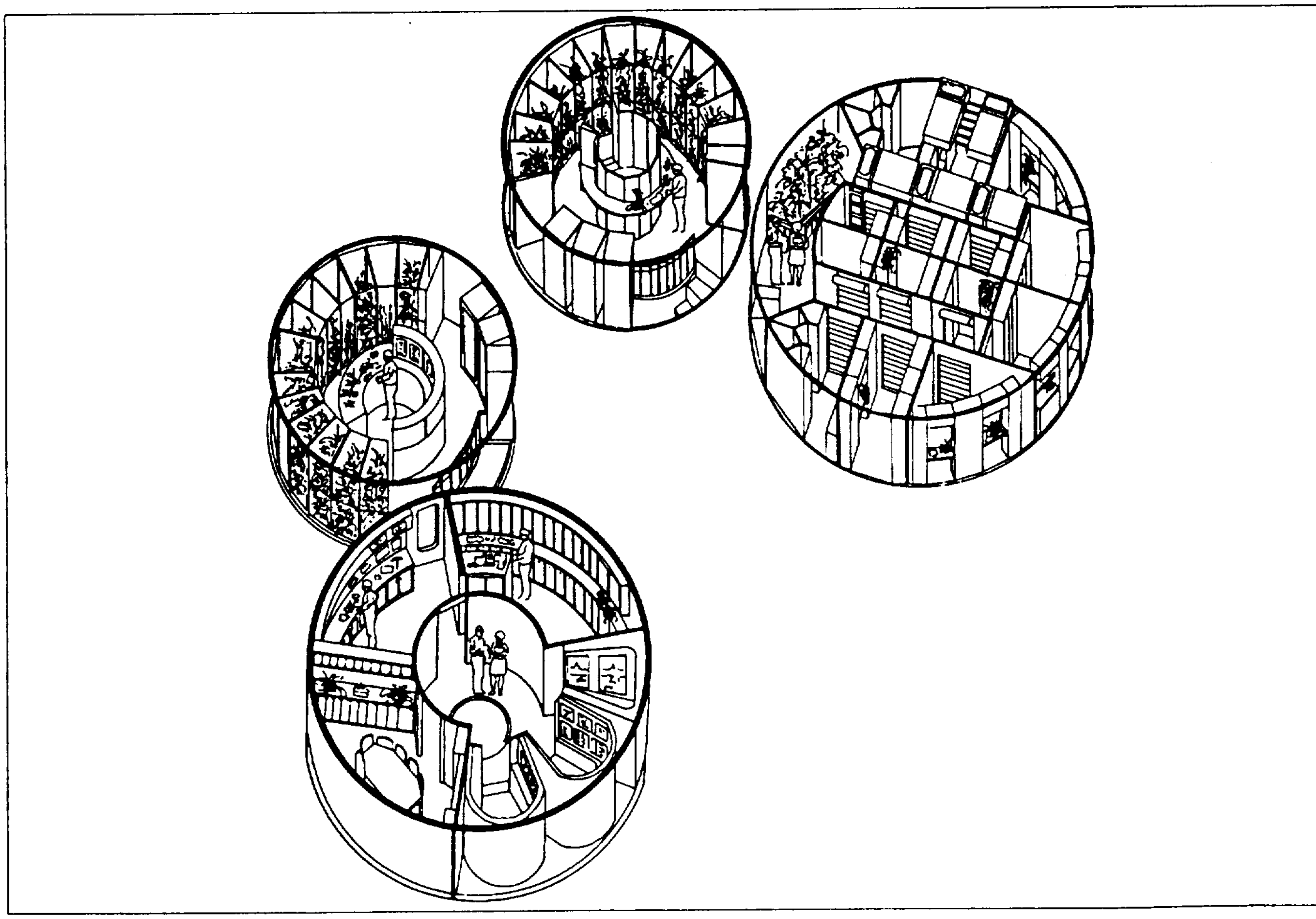

Fig. 7 Axonometric drawing of the upper floor of Pax, illustrating the central focus and group interaction space in each module and the creation of a sense of place and homelike environment in all spaces.

The habitat is organized in an efficient manner. From module to module there are clear, linear circulation paths. Time will not be wasted by excessive walking. Clear circulation and way finding are important in keeping stress levels down. Siting the individual habitat volumes in a straight line would be far too monotonous. Pax is formed in a continuous, looped path. This allows for a variety of circulation routes while still being efficient. As an example, vertical circulation is located either in the center of a module or along the perimeter and horizontal circulation is in the shape of an arc in the crew support module and vertical in the laboratory module.

Dual egress is a critical element in extraterrestrial living. In the event of an emergency, the crew must be able to emergency exit any of the habitat volumes in two opposite directions. Suits and EVA chambers are located in three areas to permit suited egress to the outside.

The entry module acts as the central focus for the habitat as a whole. Creating a central focus in each of the modules and inflatable is also considered important in making Pax livable. It unifies the volume. Each of the five components also has designated focal points in which the crew can gather.

The ability for the crew to personalize the spaces may provide for a more productive mission. Allowing the crew the luxury of bringing pieces of "home" with them is important in keeping stress levels down. The Martian living environment will be different from that of Earth. Yet the crew should live in a comfortable and familiar way. The crew will be able to bring with the a sense of home. For example, the library can be filled with books that the crew has requested, and the crew quarters can each be decorated to suit individual tastes.

In designing individual spaces, the intent is to create a sense of place appropriate to the functions occurring. For example, the galley should give the impression that it is a galley and not mission operations. The private crew quarters should appear quite different in ambiance from a laboratory.

Habitat Components

There are five primary components to the proposed habitat--referred to as the entry module (a 9-m hard module), the laboratory and crew modules (both 12-m inflatables), and two greenhouse modules (the other 9-m hard modules). Two logistics/EVA modules and the entry EVA/dust-off module (all Space Station-derived) make up the balance of the habitat. Each habitat space integrates design issues and requirements with the intention of making each space productive, habitable, and comfortable.

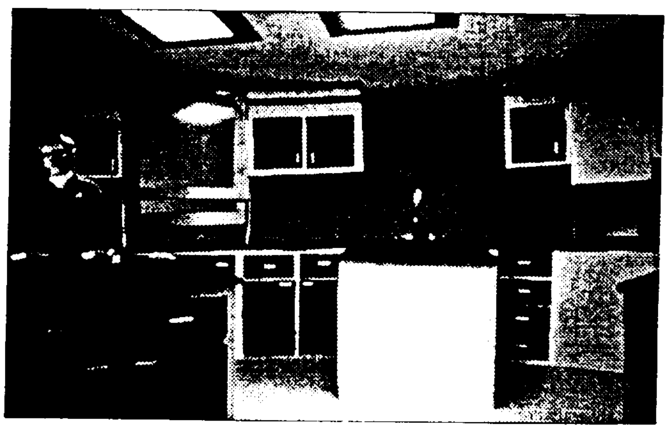

Fig. 8 The laboratories in Pax were designed with efficiency and human factors in mind.

Fig. 9 The greenhouse facilities allow for plant growth for experimentation, food production, or crew recreation.

The entry module will serve several purposes. Dedicated as a major entry point, the module combines utility with a sense of first impression. Safety, cleanliness, and a sense of arrival are incorporated. This area also serves as a decision point for translation to the laboratory and crew modules. The entire crew will utilize this space. Composed of two levels, entrance from the surface of the planet will be into the upper level of the entry module, while active group recreation resides on the lower level.

The entry module is flanked by the two larger inflatables. It is linked to these inflatables by flexible connectors.

One inflatable has been dedicated to mission control and laboratory functions of the base. This 12.5 m-module is composed of two levels. Mission control and the botany laboratories occupy the upper level, while additional laboratories and the health maintenance facility (HMF) are on the lower level.

The crew support inflatable accommodates the basic needs of the crew. This inflatable is located to the right of the entry module when approaching from the surface of Mars. This two-level, 12.5-m habitat is comprised of a galley, wardroom, group recreation space, and laundry facility on the lower level, and personal quarters for 18 crew members and two personal hygiene facilities (PHF) on the upper level. Access to this inflatable is through a flexible connection on the lower level from the entry module. Additionally, a second access point is from another connector on the second level through to private contemplation spaces in the adjacent greenhouse modules.

The two greenhouse modules will decrease the dependency on fresh food supplies from Earth and will provide human factor benefits from access to nature. There are two distinct emphases for the greenhouse modules. One will concentrate on food production and the other will address research and, to a lesser degree, be a place for individual crew members to care for plants. Also included in one of the greenhouse modules are a library and a chapel as retreat areas for the crew.

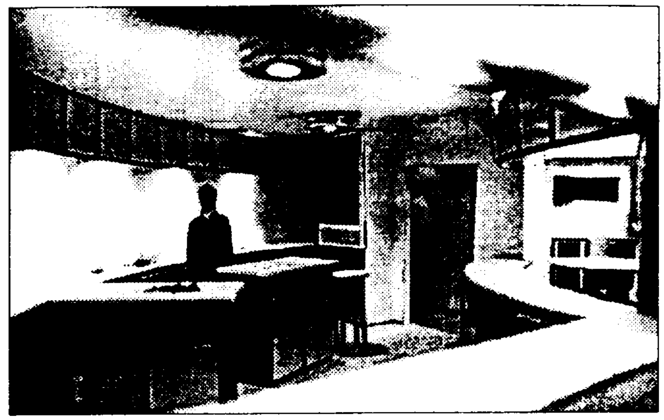

Fig. 11 The galley's design allows for a number of individuals or small groups to use the facility at once.

Fig. 10 The crew quarters provide for single crew members as well as couples.

Fig. 12 A library space within one of the greenhouse modules provides a place for the crew to go to escape from the day-to-day activities of the habitat.

Interior Design Including Considerations of Color, Lighting, and Materials

Seldom have lunar and Martian designs been taken to a level of design development where the particulars of interior configuration and its impact on human productivity and satisfaction can be examined. An important part of our design work, especially in this project for a first Martian habitat, has been to investigate interior architecture and how it impacts on habitability.

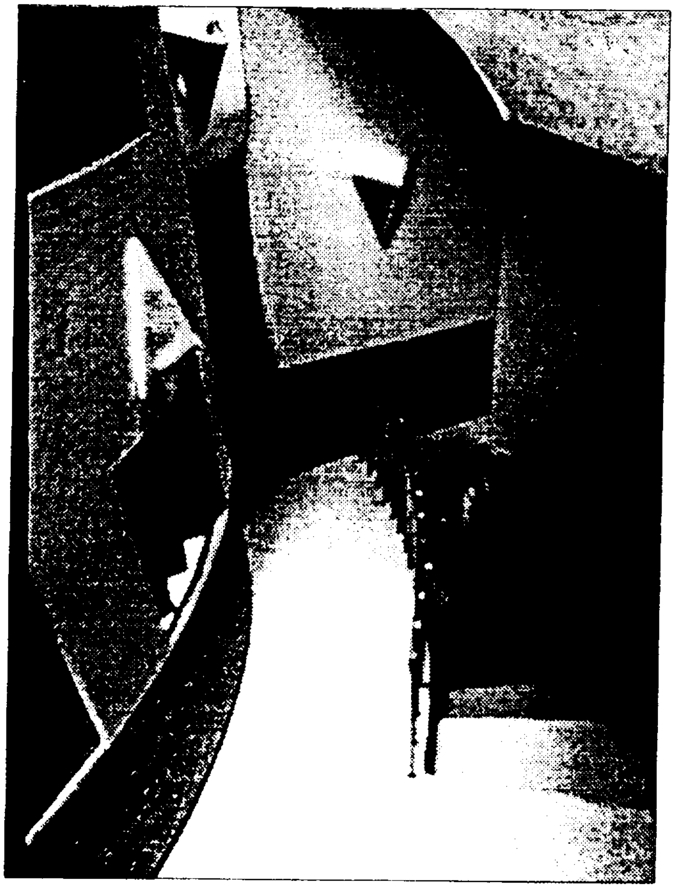

Fig. 13 Use of alternative shapes and sizes within the habitat help to relieve monotony and to create spaciousness.

Careful consideration has been given to technical details, color, lighting, and materials based upon color and material design recommendations from NASA-Ames Research Center and the NASA STD-3000 standards.

The color selection was based on three activity area definitions. High activity areas, e.g., social and recreation spaces, contain large wall spaces in light, lively, warm earth tones and warm pastels. Moderate activity areas, e.g., designated work areas, are finished in calm, low saturation colors. Low activity spaces, e.g., quiet, cozy environments, are finished in light blues and grays.

Pure colors are used rather than drab colors. Bold colors are limited. Shades and pastels are used on large surfaces. Contrasting colors are used to break monotony. Pax therefore makes liberal use of gray tones, pale blue-grays, burgundies, taupes, off-whites, silvers, deep blues, and terra cottas. A basic color scheme was chosen for particular spaces. A continuity of color was provided from one area to another to relieve the habitat from appearing "chopped up" and discontinuous. Bright colors were used to highlight certain special features, either architecturally or visually. Color also augments the translation pathways throughout the habitat.

Similarly, Pax incorporates a number of lighting systems to increase visual stimulation, add variety, and augment the tasks to be performed. Lighting was used to highlight special architectural features in each area of the habitat.*

Material recommendations were derived from NASA Man-Systems Integration Standards. Materials will go through sophisticated testing to determine whether outgassing from the product is detrimental to humans or the space environment. Materials were chosen to aid mission activities and tasks. For example, surface materials in the laboratories allow for ease of task and maintenance. While reflective properties, non-contamination and non-discoloring properties, durability, and deterioration were considered, a variety of materials with textural surfaces are included to vary the environment and to stimulate the confined astronauts visually and tactilely.

Summary: Major Strengths and Limitations of the Design

Uncountably many decisions go into any design. All decisions that are made have the overall objectives of the design as their driver and, hopefully, empirical research as their justification. Sometimes these design decisions conflict with each other. This design, as all design, has strengths and limitations. Following are some of the most notable.

- One of the strong points of this proposed design for the first Martian base is economic in nature. The habitat uses rigid modules already on-site from an initial exploratory landing. The four pre-landed hard modules make up over half of the habitat. Taking advantage of these saves extra mass that would otherwise need to be delivered.

- Another of the large scale elements of the base that works well is the radiation shielding. Its design allows it to be in place before the modules of the base are put in place, providing shielding during base construction. A protected area is provided around the modules giving easy access for maintenance. The structure--being an encompassing space frame--also allows for easy expansion.

- The zoning of the habitat works well. Work is separated from leisure, public from private, noisy from quiet, and active from passive. This can be seen in the functions of the individual modules and in the difference in the floor levels within each module.

- Within the habitat, a number of spaces provide for privacy, a place for a crew member or small group to get away. The crew quarters are the primary location for crew "escape." Passive recreation also can allow privacy. The chapel and library are two more areas that allow for this important need for occasional isolation.

- Spatial variety is another way this design excels. Supplementing the rigid modules with inflatable modules adds variety to the spaces. Although all of the habitat modules are generally the same shape, a number of different types of spaces are created within. While some shapes may be pie-shaped, others are rectilinear, and still others are curvilinear. A variation in ceiling height and floor levels helps further to create this variety of spaces throughout the habitat.

- Active recreation is isolated from other functions within the base, preventing excess noise and vibration created in the space from becoming a problem.

- Using 9-m and 12-m circular modules minimizes circulation space while maximizing net usable activity space and volume.

- The entry EVA chamber is separated from other spaces, helping to keep dust from spreading throughout the habitat.

- Dual egress is allowed throughout the habitat; there are always two ways of escaping any area.

- The modular rack system allows easy changeout, replacement, and rearrangement throughout the habitat, not only at IOC, but also if the habitat is expanded to various NOCs.

- Using a number of enclosures (modules) allows containment of trouble areas in the event of an emergency, yet allows large spaces and easy connection of associated functions.

- The loft-type crew quarters make efficient use of vertical space.

- The connection of the crew quarters to the greenhouse allows convenient access to quiet spaces for the crew during off-hours.

- Situating the library and chapel within a greenhouse creates a restful environment.

- Having two greenhouse modules, each with its own atmosphere, adds to the scientific benefit and productivity of the base.

There are also limitations and other issues where the base and habitat could be improved:

- The site location needs further investigation, e.g., the choice of the Utopia site does not allow direct communication with Earth.

- The habitat may be larger than necessary for 18 crew members, and might be optimized to a smaller volume.

- Spaces exist with no function (e.g., the center of the first floor in the crew support module). While these are desirable aesthetically, they may be extraneous in terms of efficiency, mass at lift-off, and economics.

- Even though the radiation shielding makes views possible, views out of the base are limited to one window in a mission command workstation. Smart windows could also be considered.

- A drawback of the structure is its complexity. A large amount of mass, hundreds of pieces, will need to be delivered to the Martian surface. The structure will likely involve extensive EVA time in assembling the truss-work.

- There is a redundancy of equipment and spaces within the labs; dual functioning could cut down on the amount of space and equipment needed.

- The vertical circulation throughout the habitat needs more thought (e.g., convenience, comfort, practicality, extent of use).

- The nature of the laundry facilities (closet-like) and location (on a major circulation intersection) makes it problematic.

- A more direct connection between the galley and wardroom would be desirable.

- The airlock attached to the labs may be used as much as if not more than the entry EVA. This airlock should therefore have suit storage and a preparation area outside of the equipment lock.

- Consideration could be given to growing plants throughout the habitat to minimize boredom of the dead Martian landscape.

- The means of transportability of the modules from the exploratory site to the IOC site needs consideration, e.g., while the 9-m module can easily be transported to Mars, it may not be able to be moved about the surface of Mars easily.

- The structural and construction systems for each of the modules need careful consideration.

- Mass at lift-off needs to be reduced where possible and quantified in order to be optimized.

Issues for Future Research and Design Development

Four areas of primary research and design development need to be conducted as a result of the above project.**

1. More attention needs to be given to the development of human factors and EB requirements for all scales of Martian campsites/outposts and permanent habitats. Some work has been done on requirements for lunar and Martian bases in our center[7] as well as by Joyce Carpenter and Deborah Neubek at NASA-JSC, but as far as we can determine, no work has yet been done for Martian bases. The first missions will likely be 14- to 45-day missions to the Moon, which will more than likely be a testbed for future Martian exploration and habitation. A full range of habitability requirements for 14- to 45-day lunar missions needs to be developed. An interesting issue would be to investigate, first, the quantitative space demands and then the qualitative habitability requirements for short-duration missions, and how they would change for increasing numbers of crew members and for increasing mission durations. One part of this would be the definition of usable space (e.g., the tables in NASA-STD-3000 on usable volumes), and how it should vary with crew composition, mission profiles, and mission durations. It would similarly be very useful to conduct an analysis of usable space to gross space, and usable space to surface area (i.e., correlated to mass at lift-off).[7]

2. Minimally necessary activity spaces and their minimally necessary sizes (both in terms of m^2 of floor plan and m^3 of volume) need to be investigated. Our work to date has suggested a minimally necessary set of laboratory and crew support spaces, but considerably more work needs to be done to refine this list. Similarly, our work to date has begun to suggest possible spatial allocations for each of these spaces (for 12 and 18 crew members), but again, the work has only scratched the surface, indicating the importance of careful human factors analyses--and perhaps terrestrial simulations--of these quantitative requirements.

3. The design concepts expressed in this paper and companion technical report could be subjected to independent investigation and corroboration. Any design is made up of a variety of design concepts, not just one overarching *parti*. The concepts, sometimes called patterns, are generic, or, at least, the central idea is generic, though the particular form a pattern takes depends on contextual circumstances. These and other patterns[8] could be articulated, assessed qualitatively against existing research literature, and then subjected to empirical tests in simulated environments (using experimental or quasi-

experimental methods). This would result in a series of tested principles that could be applied to the design of any Martian (and perhaps) lunar base and habitat.

4. The implications of different images for the likely crew compositions need to be considered. For example, are high-tech or more homey, Earth-like environments more appropriate for NASA- and related space-agency highly trained, highly self-selected crews? There is an ideological assumption in our work to date, but it has not been tested, that bringing home to Mars is appropriate. The importance of this assumption needs to be questioned, Antarctica and other simulation research needs to be checked, and perhaps first-hand empirical research needs to be conducted with current and recent American, Russian, and other astronauts on the appropriateness or lack of appropriateness of this assumption. Similarly, research needs to be done profiling the personality characteristics of astronauts likely to go to Mars (e.g., possibly a variation of an environmental response inventory with characterization of environmental dispositions), with base design decisions based on these profiles and preferences.

5. Quantitative considerations of structure, construction, efficiency, and minimization of mass a lift-off need to be weighed carefully and balanced against qualitative EB habitability considerations.

A fundamental dilemma underlies all of this needed research and design investigation. First is the advisability of thoroughly investigating a narrow range of issues (e.g., human factors/environment-behavior issues) versus a more comprehensive analysis of the complete range of Martian base issues (e.g., habitability and construction technology, or simultaneous consideration of two or three different prototypes, the latter allowing the exploration of the possibility of major changes during the life of the base, and the possibility of taking concept designs into further design development before capitalizing on certain alternatives while abandoning others). Another way to put it is to ask is it more important at this stage of Martian design exploration to "design society" or to focus on the solution of knowable, manageable issues?

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