3. DESIGN ISSUES AND REQUIREMENTS

3.1 MARS MISSION SCENARIO

A scenario is an outline of the sequence of activities that will take place in the exploration of the Martian planet. Scenarios consist of a complex set of issues, organized to achieve mission goals. The study of existing scenarios created a base for the scenario leading to Pax.

3.1.1 PUBLISHED SCENARIOS

The first scenario studied is the scenario of Zubrin, Baker, and Gwynne (1991). This scenario, called “Mars Direct,” is primarily directed at the exploration of Mars.

Its plan focuses on exploring Mars to decrease the cost of the Space Exploration Initiative. Over 200 assemblies in low-Earth orbit (LEO) would be needed to recoup the expenses of a LEO construction infrastructure. Therefore, there is no construction in LEO in the Mars direct scenario. Secondly, missions to Mars are limited to ones that provide maximum scientific return. A third suggested way to decrease costs is extensive in situ resource utilization in all missions.

The Mars direct scenario assumes that transportation from Earth to Mars can be accomplished in steps. With the use of a Aries heavy-lift launch vehicle (HLLV), equipment and crew can be lifted into orbit and put on the journey to Mars without assembly in LEO. There will be two launches for every mission to Mars—the first a cargo mission, followed by the crew in approximately two years. The two flights will be aerobraked to the surface of Mars.

The cargo missions will consist primarily of a habitat, nuclear power plant, and in situ fuel production capabilities. The inclusion of fuel production is to lower the costs of the mission. This produced fuel will supply ground transportation, the ascent vehicle, and Earth return transportation.

The second launch will place the crew in direct transit to Mars with a short travel time to minimize the high radiation effects of space travel.

There are two basic flight classes: conjunction and opposition. The basic properties of the conjunction class is longer total mission time, longer surface stays, and lower Earth to LEO masses. The opposition class has a longer flight time with larger masses needed in LEO. Various reasons are given by Zubrin et al. for the choice of the conjunction class for Mars missions:

- smaller delta-V (velocities)
- lower radiation effects by shortening the duration of space travel
- unknown 0g affects on the body are minimized
- time spent exploring the planet surface is 15 times greater than the opposition class trajectory

In the Mars direct scenario, the first crew could launch from Earth in 1999. Upon reaching Mars, the crew of four will have a surface stay for 600 days (approximately). Exploration will be done with combustion engines, supplied with fuel from a precursor mission emplaced production plant that will have been making fuel for two years.

Progression past this to a permanent base is only suggested. It is stated that future missions could connect habitats to provide a larger surface presence.

The second scenario studied is the Synthesis Report, America at the Threshold (Stafford, 1991). This government-funded report discusses the options for America’s Space Exploration Initiative. It broadly proposes all possible aspects of America’s involvement in space over the next 30 years.

Two Mars scenarios are defined in this report. Between them there are several commonalities; closed-loop life support systems, and lowering the cost of missions by lowering logistics demands.

A Synthesis Report mission proposes placing humans on the surface of Mars for approximately 30 to 100 days. This stay is created from an opposition trajectory.

The report addresses the pragmatic issues of their Martian scenario. The first human presence on Mars is suggested to be 2014. The mission will be an opposition class flight. After two of these missions, conjunction class missions will be used to increase exploration capabilities.

The habitation waypoint suggests requirements for different levels of human presence on the surface. The first requirements are for the closure of life support systems. Essentially, when a permanent base is achieved on a planet surface, the systems should be closed with the exception of food which will only partial closed. The closure of food cycle demands large amounts of growing volume. The second requirement is the size of the crew for particular missions. Missions less than six months will have crews of six, while missions
Pax Permanent Martian Base

up to two years will have a crew of 12. Later missions with stays of
two years, will have crews of 20 to 24.

A third scenario was presented at the NASA-JSC ExPO Technical
Interchange Meeting on January 7, 1992 was entitled “SEI Reference
Mission” (Weaver, 1992). It concentrates on lunar human presence,
but is applicable to Martian scenarios.

This third scenario presents staged development similar to the
above-mentioned Mars scenarios. At the “human-tended” stage, the
surface stay duration is similar to the opposition-class mission to Mars.
It recommends a crew of four to seven. These numbers are congruent
with the Mars direct and Synthesis Report scenarios. The next stage of
human presence echoes America at the Threshold, and there must be a
closed life support systems, with the exception of food.
3.1.2 MISSION SCENARIO INTEGRATION

The above Mars scenarios have been integrated into a single scenario that will be adopted in this report. Our analysis suggests four phases to the exploration of Mars:
- Precursor robotic missions
- Expeditionary landing missions
- Human-tended outpost missions
- Permanent base mission

The precursor missions are robotic exploration. This will consist of mapping Mars, basic exploration, and sample returns. The Viking landings started Martian exploration. One reason further robotic missions are needed is to limit the variety of locations for human exploration and habitat emplacement.

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**Figure 3.1.2-1. A recommended integration of previously published Mars scenarios.**
After the precursor missions, humans will set foot on Mars. Expeditionary missions can achieve benefits similar to those achieved in the first Apollo missions — a "large step for humankind." These missions will test our ability to have humans visit Mars. Due to the short surface stay of 30 days, the scientific benefits will be limited.

The human-tended outpost missions will begin to provide noticeable scientific benefits. A surface stay of 600 days will provide the time for in-depth scientific activities. Developing several outposts at different locations on the planet will optimize this phase. The choice of locations will be determined by their potential scientific benefit (see section 3.2). This step is also necessary because it will generate a location for a permanent base. The permanent base will use elements from one or more outposts in a permanent habitat.

The fourth phase of Mars exploration is the permanent base mission. It provides the largest scientific benefits and begins to provide commercial benefits. Its location will stem from one of the human-tended outpost locations. The chosen location will be the one which will provide optimal scientific and commercial benefits.

Growth beyond a permanent base is possible. This evolution would provide primarily commercial benefits. Work done within the aerospace industry has not concentrated on this evolution, primarily because of its distant realization.

This integrated scenario, an outline of the exploration on Mars leading up to a permanent base, is shown in Figure 3.1.2-1.

3.2 CHARACTER OF THE MARTIAN ENVIRONMENT

The Martian environment is undiscovered territory. Many features will be the subjects of intense investigation. To be able to gain the greatest insights, and given the broad scope of missions, the following areas of scientific investigation are expected to be:

- volcanoes
- possible water sites
- craters
- channels

Design Requirements:
- The base should be located in a geologically varied region
- Base should be near possible water locations
- Base should be located at a low elevation
- The base should be located in the northern hemisphere
- The habitat should be shielded from dust contamination and wind

3.2.1 SURFACE AND ATMOSPHERIC ANALYSIS

The Martian atmosphere is predominantly composed of carbon dioxide. An annual event occurring between fall and winter is the forming of clouds composed of carbon dioxide ice particles. This takes place in the polar regions where the gas condenses out of the atmosphere, so much so that the atmospheric pressure decreases nearly 30% in that time frame. At the northern pole, the decrease is less due to the smaller north cap during the winter.

<table>
<thead>
<tr>
<th>Table 3.2.1-1. Martian Atmospheric Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO₂)</td>
</tr>
<tr>
<td>Molecular nitrogen (N₂)</td>
</tr>
<tr>
<td>Argon (Ar)</td>
</tr>
<tr>
<td>Molecular oxygen (O₂)</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
</tr>
<tr>
<td>Water vapour (H₂O)</td>
</tr>
<tr>
<td>Neon (Ne)</td>
</tr>
<tr>
<td>Krypton (Kr)</td>
</tr>
<tr>
<td>Xenon (Xe)</td>
</tr>
</tbody>
</table>

Note: Measurements are fraction by weight. The CO and H₂O amounts are uncertain and variable.

The Martian atmosphere has a similar chemical composition to Earth. Primarily carbon dioxide, the atmosphere is thin and hazy. The day/night cycle is comparable—annual mean temperatures range from -50 degrees C at the Equator to nearly -130 degrees C at the poles, and the summer temperatures rise above 0 degrees C at midday. Mars also has seasons. This is evident in the growth and recession of the polar carbon dioxide "ice" caps. Winds are responsible for suspending dust in the atmosphere causing light to scatter and create a haze (Spitzer, 1980).
Dust storms have been observed to originate in the southern hemisphere, growing in intensity until nearly the entire planet is engulfed. Geologic features are again comparable to our home planet. Enormous canyons are carved into the surface, large dry river beds suggest past flooding, and volcanoes rise to greater heights than known elsewhere in the solar system. Given that Mars is approximately half the size of Earth, and twice the size of the Moon, these features are grander in scale.

Mars is a rich experimental laboratory. Answers to questions centuries old may be determined when exploration of the planet resumes in earnest.

The chart below compares general information about Earth and Mars.

<table>
<thead>
<tr>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,756 km.</td>
<td>Diameter 6787 km.</td>
</tr>
<tr>
<td>149.5 x 10 6 km.</td>
<td>Distance from Sun 227.8 x 10 6 km.</td>
</tr>
<tr>
<td>23° 27'</td>
<td>Inclination 23° 59'.</td>
</tr>
<tr>
<td>24 hr. 00 min.</td>
<td>Length of Day 24 hr. 40 min.</td>
</tr>
<tr>
<td>365 days</td>
<td>Length of Year 686 days</td>
</tr>
<tr>
<td>1013 mb</td>
<td>Atmospheric Pressure 7 mb</td>
</tr>
<tr>
<td>1</td>
<td>Known Satellites 2</td>
</tr>
</tbody>
</table>

The Martian surface offers a variety of landforms suggesting wind-related formation and processes. Most notable of these wind activities are the surface streaks that occur in the southern hemisphere during the summer. These happen when the winds are the strongest, creating major dust storms (Carr, et al., 1980).

The channels etched into Mars are fascinating as well as controversial. Of particular interest is whether these channels could have been formed by water. A very different climate, warmer with a denser atmosphere, would have had to exist to produce these features. The possibility that wind and lava are the cause is being speculated (Carr, et al., 1980). Detailed and finer structures within the channels suggest water was once prevalent. These structures, when compared to Earth-like features, are similar to “teardrop-shaped islands, longitudinal grooves, terraced margins, and inner channel cataracts” (Carr, et al., 1980) found in large Earth flood plains.
Although much of Mars' surface consists of rather simple plains, craters do occur over the entire planet. The composition of the surface is hinted at by the particular type of crater, and its resultant or lack of resultant surface process alteration. The southern hemisphere is more heavily cratered than the northern. Crater densities suggest slow resurfacing processes as compared to Earth.

3.2.2 RADIATION AND RADIATION SHIELDING

The thin atmosphere of Mars does not provide enough protection from radiation to allow the habitat to remain unprotected. The intensity of the radiation is dependent upon location and elevation. Those regions located in lower elevations will have a somewhat greater measure of protection (Zubrin, 1991). There is reason to speculate that less-intensive shielding for structures and equipment will be necessary. Mars does not possess an intrinsic magnetic field with the ability to repel galactic cosmic rays (GCRs). Due to this,
GCRs reach the outer atmosphere. Simple solar wind particles do not pierce the atmosphere, but GCRs will. The dose of radiation the crew will receive while on the Martian surface will depend on season and elevation. As on the lunar surface, solar flare events will require impenetrable shelter.

One plan to protect the crew from injury stems from Gregor'yev (1976, cited in Nicogossian & Parker, 1982). This could consist of one or more of the following:
- increasing spacecraft shell thickness
- using equipment as shelter or shadow
- using electronic or magnetic fields
- protective clothing worn by astronauts
- prophylactic pharmaco-chemical protection

Shielding for the habitat can occur by more than one method. A protective exterior covering over the entire habitat can be used. This might consist of a frames system and advanced technology textile. The Martian regolith might be used to reinforce the protection by introducing a sandbag system. A framing system would be necessary to support the bags and free the habitat structures from undesirable weight. Locating the habitat in an underground facility is possible. It needs to be determined whether a viable geologic structure such as a lava tube exists. Excavating the Martian surface is another option, yet this option would be EVA-intensive for machinery and crew.

Design Requirements:
- Provide radiation protection with safe havens within the habitat that will completely repel solar flare emitters
- Provide additional radiation protection on the base exterior by using regolith and a textile covering system supported by a space frame

3.2.3 MARTIAN GRAVITY AND REDUCED GRAVITY EFFECTS

Long-term habitation of Mars will have an effect on all physiological systems of the human body. Deconditioning will occur without the gravitational “pressure” necessary for our species. Calcium retention for the skeletal system is lessened. To date, sufficient calcium cannot be supplemented in the diet to counteract the problem. It has been determined that pressure on the long bones of the body can assist in controlling calcium loss. To retard muscle atrophy, exercise regimes are being created and tested. As experience in space habitation increases, the long-term effects will be discovered and appropriate measures can be enacted.

Since the gravitational pull of Mars is one-third that of Earth, movement will also be affected. This will have design implications for habitation and laboratory facilities. Locomotion will be affected, as well as traction, speed, cornering, and stopping. Studies of movement on the lunar surface might be conducted. Conclusions drawn from future studies may show a relationship between the movement of the human form in 1/6 gravity and 1/3 gravity.

Design Requirement:
- Provide exercise countermeasure equipment and an exercise countermeasure facility to maintain astronauts’ physical conditioning

3.2.4 SITE PLANNING CONSIDERATIONS

Site planning for a Martian base will depend on a number of critical factors. Precursors missions will narrow the locational possibilities by searching for a varied region to support science and exploration. Scientists are interested in the activity of the Martian volcanoes. A location within the range of a pressurized rover will allow investigation of these surface features.

Dust storms originate in the southern hemisphere. Locating the base away from the origin will assist in protecting the habitat and astronauts. Water location possibilities are theorized to be in the northern hemisphere at approximately 45 degrees N latitude (Carr, et al., 1986).

An issue critical to the safety of the crew is radiation protection. Although the atmosphere is thin, locating the base in a lower elevation may provide additional radiation protection (Zubrin, et al., 1991).

The entire world will witness the endeavors upon the surface of Mars. The astronauts and the population on Earth may need to have an “image” portrayed that will state the intentions of the countries involved in Martian exploration (Hansmann & Moore, 1990). As
there will be little or no colonization, the astronauts will need a recognizable image of their home on Mars (Hansmann & Moore, 1990). Another important consideration will be the care of the pristine Martian environment (Hansmann & Moore, 1990).

**Design requirements:**
- Base location should be away from dust storms of the southern hemisphere, i.e. locate the base in the northern hemisphere
- Locate the base near to an anticipated water supply, i.e. north of 45° N
- Locate at as low an elevation as possible
- Locate the base within rover distance of a volcano
- Terrain for launch and landing should be flat to assist transportation
- Base should portray acceptable appearance for transmitted images
- Should be recognizable as village, outpost, or home
- Base should observe care of Martian environment
- Location should allow for base expansion

**3.3 HUMAN FACTORS AND ENVIRONMENT-BEHAVIOR CONSIDERATIONS**

Primary environment-behavior considerations were dealt with in making Pax as humane as possible. Humanistic considerations such as a sense of place, zoning, solving spatial demands, optimal circulation, interpersonal space, territory, stress, and, anthropometrics were studied in making the habitat as livable and productive as possible.

**3.3.1 ANTHROPOMETRICS**

The measurement of the human form has a relationship to the built environment. Coupled with the economic constraints of space endeavors, anthropometrics should guide the designer to an efficient, accessible environment. As well, future studies of the human form and its movement in 1/3 gravity will dictate dimensioning of heights and stairs and the use of flooring materials to improve traction.

<table>
<thead>
<tr>
<th>No.</th>
<th>Dimension</th>
<th>10th percentile</th>
<th>50th percentile</th>
<th>90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shoulder</td>
<td>14.5 (25.5)</td>
<td>19.2 (29.1)</td>
<td>24.1 (33.1)</td>
</tr>
<tr>
<td>2</td>
<td>Height</td>
<td>74.9 (27.0)</td>
<td>76.4 (28.9)</td>
<td>78.0 (29.6)</td>
</tr>
<tr>
<td>3</td>
<td>Arc height</td>
<td>6.5 (2.5)</td>
<td>6.6 (2.6)</td>
<td>7.0 (2.9)</td>
</tr>
<tr>
<td>4</td>
<td>Elbow height</td>
<td>55.4 (20.3)</td>
<td>55.8 (20.3)</td>
<td>56.4 (20.4)</td>
</tr>
<tr>
<td>5</td>
<td>Seat height</td>
<td>37.2 (6.9)</td>
<td>37.2 (6.9)</td>
<td>37.2 (6.9)</td>
</tr>
<tr>
<td>6</td>
<td>Vest height</td>
<td>105.2 (35.2)</td>
<td>104.2 (35.3)</td>
<td>104.2 (35.2)</td>
</tr>
<tr>
<td>7</td>
<td>Bicep height</td>
<td>106.3 (36.5)</td>
<td>106.3 (36.5)</td>
<td>106.3 (36.5)</td>
</tr>
</tbody>
</table>

**Notes:**
- **Gravity conditions:** the dimensions apply to a 1-G condition only. Dimensions expected to change significantly due to microgravity are marked.
- **Measurement data:** the numbers adjacent to each of the dimensions are reference codes. The same codes are in Volume II of Reference 16. Reference 16, Volume II, provides additional data for these measurements plus an explanation of the measurement technique.

**Notes for application of dimensions to microgravity conditions:**
1. **Stature increases approximately 3% over the first 3 to 4 days in weightlessness.** Almost all of this change appears in the spinal column, and thus affects (increases) other related dimensions, such as sitting height (buttock-vertex), shoulder height-sitting, eye height, sitting, and all dimensions that include the spine.
2. **Sitting Height** would be better named as buttock-vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat “sitting” support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:
   a. Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches)).
   b. Extension of the spinal column as explained in note 1 above (3% of stature on ground).

Figure 3.3.1-1. Projected body size of a 40-year old Japanese female in the year 2000 (NASA, 1987).
To date, NASA has been guiding the design of space-related interiors and equipment to accommodate a range of body sizes. This range is from the 5th percentile Japanese female to the 95th percentile American male. Approximate heights relating to this range are 1.6 m to 1.9 m (NASA, 1987).

The human body will react to the lesser gravitation attraction. Table 3.3.1-1 summarizes the anthropometric changes that are expected to occur between 0-gravity and 1-gravity. Data has not yet been calculated for 1/6G; in the absence of empirical data, our work has assumed a linear interpolation.

**Design Requirements:**

- Provide for a system of working and living spaces to accommodate a range of individuals from 1.5 m to 1.9 m in height
- Volume configuration should allow for ease of accessibility of equipment
- Circulation should allow for anticipated changes in human locomotion
- Stair heights and ceiling heights should reflect the 1/3-g of Mars

**3.3.2 PERSONALIZATION AND PRODUCTIVITY**

One theory has suggested that an adequate work environment does not substantially enhance job satisfaction, but a substandard environment leads to dissatisfaction (Herzberg, et al., 1957; Herzberg, Mausner, & Snyderman, 1959; McCormick & Tiffen, 1974; all cited in Fisher, Bell, & Baum, 1978). Physical comfort and safety in terms of noise control, proper ventilation, or lighting contribute to productivity (Fisher et al., 1978). Should these considerations be lacking or substandard, for example, the lighting be too low or the environment dangerous, a reduced level of production may result.

Personalization of workstations assists in identifying a space as one's own. The addition of personal items can make the space more pleasant, in turn making the user feel better when in the space (Fisher, et al., 1978). The anticipated resultant "good mood" seems to increase people's willingness to help each other (Sherrod, et al., 1977; cited in Fisher, et al., 1978).
Personalizing the workstations may also assist the astronauts in completing their tasks according to specific training prior to the mission. Pieces of equipment dedicated to that task mark an area as belonging to an individual. Personalization of the crew quarters not only delineates personal space and territory. It can also be a place to retreat, rejuvenate, or tend to personal necessities. Private communication with family members may also occur. All crew members must have space dedicated solely to them.

Design Requirements:
- The work environment must be safe
- Astronauts should be able to personalize their work stations
- The work environment should be properly lit
- Buffers should be provided for unnecessary and distracting noise
- Adequate ventilation should be provided
- Each crewmember should have personal space

3.3.3 ENVIRONMENTALLY-INDUCED STRESS

The habitat, as a volume in which people live, has the potential to induce stress. Nine months travel time from home, confinement to a limited volume, and intense work are just three of the many stresses placed on a crew on a mission to Mars. Environmentally-induced stress is derived from stressors acting within terrestrial buildings. It is commonly known (in the architectural world) that a building can cause stress to its occupants. Since people will be occupying buildings on Mars, it may be possible to assume that those volumes will cause stress to their occupants as well.

Many terrestrial stresses may cause stress in a Martian habitat. Therefore, those known stressors should be studied first.

Design Requirements:
- Provide an environment to lessen sensory deprivation
- The environment should not cause sensory overstimulation
- The design should promote protection of personal rights
- Allow control of the environment by the astronauts

3.3.4 INTERPERSONAL SPACE AND TERRITORIALITY

The physical setting of the habitat should promote social interaction among the crew, yet allow for retreat and privacy when desired. The environment should provide for the ability to claim territory by the user, and spaces must allow for desired levels of privacy (Murtha, 1976; cited in Bell, Fisher, & Loomis, 1978).

Space can be defined in terms of territories. The territories can be divided into three categories: tertiary, secondary, and primary. Tertiary areas are sometimes personalized, not owned, control over them is difficult to assert, and they are utilized by a large number of people (Fisher, et al., 1978). A tertiary space will be an open, easily accessible space used by anyone (Alexander, 1977). Secondary territory is used by smaller groups. It may be personalized, is not owned, and will be utilized by a number of qualified users (Altman, 1975, Fisher, et al., 1978). It is a space within an open area that should be partially shielded from public activities (Alexander, 1977). A primary territory is extensively personalized; the owner has complete control, and intrusion is serious (Fisher, et al., 1978). Private or primary spaces are
considered a place where one can retire alone (Alexander, 1977). With these guidelines produced by environment-behavior researchers, and although they are terrestrial-based in origin, their implications for human interaction are necessary and pertinent. Territory will regulate who will interact; personal space will regulate how closely individuals will interact (Sommer, 1969; cited in Bell, et al., 1978).

The need for privacy and solitude is to avoid, for example, overstimulation (Evans, 1974; cited in Bell, et al., 1978). Personal space allows for avoidance of a variety of stresses (Evans, 1974) or for maintaining adequate privacy and an appropriate level of intimacy (Altman, 1975; cited in Bell, et al., 1978).

The promotion of social interaction, intimacy, and privacy can be achieved by:
- Primary, secondary, and tertiary territories
- The ability to personalize space
- A place to escape and relax privately

Design Requirements:
- Provide a built environment that will promote social interaction
- Physical space must be divided into primary, secondary and tertiary spaces
- Astronauts must be able to personalize their personal territories
- Provide spaces for private escape, retreat, and relaxation

3.3.5 OPTIMAL CIRCULATION

Circulation is required to connect the spaces of a habitat. The issues involved with circulation will affect the mission. First is safety, quick wayfinding, and orientation. Second is the issue of minimizing the space designated for the sole purpose of circulation. A third issue, directly opposing the second, is architectural variety and interest often accompanying the circulation routes (see section 3.3.6).

The safety of the crew is a high priority, especially in an emergency. A linear corridor that terminates on exits may be a good solution. That may obviously not be the best solution with respect to the other human factors issues such as spatial variety.

Efficient circulation is required. In relation to terrestrial buildings, the cost of unused, pathway space in a Mars habitat is enormous. A habitat that has an excessive amount of circulation is unacceptable.

Design Requirements:
- Primary circulation should be linear
- Frequently used spaces should adjoin primary circulation
- Circulation should terminate with exits
- Circulation should allow for dual emergency egress
- Circulation should be efficient in terms of area
- Circulation should allow for architectural variation and interest
- Circulation should promote leisurely “walking” throughout the habitat
3.3.6 EFFICIENCY, FUNCTIONALITY, AND SPATIAL VARIETY

With transportation to the Martian surface being costly, efficiency becomes a critical issue. Crew comforts need to be supplied, but in the smallest, lightest volume possible. The ability to have a space serve more than one function is one way to be efficient. Equipment with multiple functions is another. Efficiency can also refer to the way the space is used. Dedicated circulation space should be minimized. This can be done by dual functioning it with usable space within an activity space.

Closely tied to the efficiency of space is the actual amount of space that exists. Volumes must be minimized. Not only does extra volume create extra mass, but it increases the amount of surface area that must be upkept, and the amount of air that must be transported to the base. This results in increased ECLSS equipment to filter and distribute the air, which in turn requires even more volume, and results in more mass.

The volumes within the base should be kept to a minimum while still allowing full functionality and habitability. The actual size of the spaces will depend on a number of factors. Since there are no existing...
Martian bases that can be used as a precedent, proposals for analogous situations can be used to arrive at average spatial requirements. These can be used as a base-line which can be adjusted according to the actual situation.

The nature of a Martian base requires the spaces to be compact. The human requirements are just the opposite, having the need for some expansive spaces. Their are many ways to make a small space seem larger than it really is. One way of doing this is to use curvilinear forms as opposed to very linear spaces (cited in Harrison, Caldwell, et al., 1988). This will create a room in which all surfaces cannot be seen at once, which can make the room seem larger. Allowing visual access between spaces makes them seem larger by extending the sight line of the user.

### Table 3.3.6-2. Square Meterage of Lunar Base Proposals

<table>
<thead>
<tr>
<th></th>
<th>LUNAR OUTPOST (ALRED, 1989)</th>
<th>GBNISIS II (PIEBER, 1990)</th>
<th>PARTIAL GRAVITY SICSA, 1990</th>
<th>Flex Inst</th>
<th>Flex IOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABORATORIES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Lab</td>
<td>21.00</td>
<td>16.40</td>
<td>18.70</td>
<td>28.05</td>
<td></td>
</tr>
<tr>
<td>Biochemical Lab</td>
<td>14.00</td>
<td>13.10</td>
<td>14.55</td>
<td>21.83</td>
<td></td>
</tr>
<tr>
<td>Microbiology Lab</td>
<td>21.00</td>
<td>16.40</td>
<td>18.70</td>
<td>28.05</td>
<td></td>
</tr>
<tr>
<td>Plant Growth Lab</td>
<td>27.00</td>
<td>21.30</td>
<td>24.15</td>
<td>36.25</td>
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<tr>
<td>MISSION CONTROL</td>
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<td></td>
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</tr>
<tr>
<td>Telerobotic Workstations</td>
<td>44.40</td>
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<td>Command</td>
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<td>22.20</td>
<td>33.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CREW QUARTERS</td>
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</tr>
<tr>
<td>Personal Crew Quarters</td>
<td>45.20</td>
<td>45.20</td>
<td>67.80</td>
<td></td>
<td></td>
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<td>Personal Hygiene Facilities</td>
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<td>199.66</td>
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<td>GROSS SIZE</td>
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<td>665.54</td>
<td>998.31</td>
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The functionality of the efficient spaces relates to their convenience and functional proximities. As mentioned earlier, space is at a premium on Mars. By closely relating spaces for similar functions, sharing equipment or dual functioning an area, smooth performance of the suggested function may be obtained.

A place that has many spaces of the same relative size and shape can become monotonous. If a person must spend an extended time in this space the problem is made worse. Spatial variety refers to the creation of spaces that differ from each other in shape and size. By designing a variety of spaces within the base, varying atmospheres can be created, and monotony can be avoided.

With transportation to the Martian surface being costly, efficiency becomes a critical issue. All the comforts the crew requires need to be supplied, but in the smallest, lightest volume possible. The ability to have a space serve more than one function is one way to be efficient. Equipment with multiple functions is another. Efficiency can also refer to the way the space is used. Dedicated circulation space should be minimized. This can be done by dual functioning it with usable space within a room.

Varying floor heights and ceiling heights can also affect the way a space feels. Using light colors in spaces can increase the apparent size of the room by making the enclosure less noticeable. Lighting can also affect the way a space feels. Washing the walls with light can make them appear lighter, which may make them seem further away. Combinations of these methods should be used to not only make the spaces seem larger, but make them more dynamic and pleasing to the user.

The nature of a Martian base requires the spaces to be compact. The human requirements are just the opposite, having the need for some expansive spaces. There are many ways to make a small space seem larger than it really is. One way of doing this is to use curvilinear forms as opposed to very linear spaces (cited in Harrison, Caldwell, et al., 1988). This will create a room in which all surfaces cannot be seen at once, which can make the room seem larger. Allowing visual access between spaces makes them seem larger by extending the sight line of the user. Varying floor heights and ceiling heights can also affect the way a space feels. Using light colors in spaces can increase the apparent size of the room by making the enclosure less noticeable. Lighting can also affect the way a space feels. Washing the walls with light can make them appear lighter.
which may make them seem further away. Combinations of these methods should be used to not only make the spaces seem larger, but make them more dynamic and pleasing to the user.

**Design Requirements:**
- A variety of spaces should be created
- Spaces should dual function
- Equipment should have multiple functions
- Circulation should dual function with usable space in a room
- Volume should be minimized
- Curvilinear spaces should be used
- Visual access should be allowed between spaces
- Floor and ceiling heights should be varied
- Light colors should be used
- Lighting should be used to make a space seem larger

### 3.3.7 ZONING

For human habitation and scientific endeavors to be sustained on Mars, space for various functions need to be designed. To support science, laboratories and associated equipment will be needed. To support human life, a place to live, perform personal duties, eat, and engage in social interaction are necessary. It is suggested that the following spaces be designed to address the human and scientific requirements:
- General Laboratory
- Biochemical Laboratory
- Microbiology Laboratory
- Plant Growth Laboratory
- Telerobotics Control
- Command Center
- Landing Operations
- Crew Quarters
- Hygiene
- Galley
- Food Storage
- Wardroom
- Recreation
- Health Maintenance
- Laundry
- Exercise
- Exterior Viewing Area
- Maintenance
- Safehaven
- Storage
- EVA Stowage

*Zoning*, the separation and grouping of spaces, provides an important organizing element to a Martian base. For example, spaces may be separated for specific uses. Various spaces can have similar uses and requirements and, therefore, be zoned closely. On a macro level, the Martian base should be comprised of habitation, power, and launch and landing zones. These functions should be separated for safety reasons. On a micro level, the habitat should be zoned by defining the spaces and associated functions from noisy to quiet and public to private.

By separating the noisy and quiet functions, stress in the isolated, confined environment may be minimized. Unwanted sound is considered noise and should be removed from quiet areas (Fisher, et al., 1978). Loud, unpredictable, or sudden noises can cause mistakes.
on high concentration tasks (Broadbent, 1954; cited in Fisher, et al., 1978). By zoning the noisy and quiet-functioning spaces away from each other, the crew may be able to work or relax and not be adversely affected by adjacent spaces.

Another method of zoning for the Martian base habitat should be by defining the spaces according to public versus private factors. Public spaces, such as workstations, laboratories, or group gathering spaces should be placed away from private areas. Suggested private areas might be crewquarters or personal hygiene facilities. In order for zoning spaces to be successful, it has been found that work and relaxation spaces should be separate (Ferguson, 1970). By dividing work and crew support functions, a clear boundary is established and will result in reducing stress. In this way crew working will not disturb crew that might be sleeping or just resting. Noise is a major

<table>
<thead>
<tr>
<th>Health Maintenance Facility</th>
<th>General Research Lab</th>
</tr>
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<tbody>
<tr>
<td>Personal Hygiene Facility</td>
<td>Biospherics Lab</td>
</tr>
<tr>
<td>Chapel</td>
<td>Laundry</td>
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<td>Individual</td>
<td>Geophysics Lab</td>
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<tr>
<td>Private</td>
<td>Small Group</td>
</tr>
<tr>
<td>Telerobotics Workstations</td>
<td>Semi-Private/Public</td>
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<td>Library</td>
<td>Public</td>
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<td>Limited Hygiene Facility</td>
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<td>Single Crew Quarters</td>
<td>Library</td>
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<td>Botony Lab</td>
<td>Biotron</td>
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<td></td>
<td>Exercise Area</td>
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<tr>
<td></td>
<td>Briefing/Conference Room</td>
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<tr>
<td></td>
<td>Passive Recreation Area</td>
</tr>
<tr>
<td></td>
<td>Active Recreation Area</td>
</tr>
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</table>

Figure 3.3.7-2. The zoning of public to private on a gradients. The proposed spaces and functions necessary for human habitation support are placed upon the gradient.
contributor of stress and by creating a separation of work and recreation this dilemma is resolved. This leads into a second way of dividing spaces according to functions.

A fine-tuning of zoning gradients, and their associated bubble diagrams, is achieved by the construction of an adjacency matrix. An adjacency matrix is a tool for arraying all spaces in a habitat. These spaces that require close functional proximity (movement of materials, shared equipment, etc.) are so marked. Those spaces that should be separated (due to danger, health, or inappropriate proximity, eg., galley to personal hygiene) are so marked. Interpretation of this matrix will be an essential component for the suggested habitat layout solution.

Figure 3.3.7-3. Bubble diagrams emerge when two functional spatial zoning gradients are overlapped.
Pax Permanent Martian Base

**Design Requirements:**
- The base should be separated by habitat, power, and launch and landing zones
- Work and relaxation activities should be separated from each other
- Habitat functions should be zoned from noisy to quiet

- Habitat functions should be zoned from public to private
- Functional proximities should be determined by creating and then allocating spaces according to a functional proximity matrix

**Figure 3.3.74.** Adjacency matrix for required Martian habitat spaces.
3.3.9 SENSE OF ARRIVAL, SENSE OF PLACE

A sense of arrival and overall sense of place are ephemeral but believed also to be important human factors. The sense of one reaching a space is key to distinguishing between circulation and functional areas. The crew might find translating between spaces without an obvious sense of entering monotonous. Suggestions that a new area has been entered, rather than a continuous and nonchanging space, may make wayfinding easier. Modules and inflatables should therefore be designed to show a clear sense of entry. Once crewmembers arrive at their destination, a sense of place should be perceived. In the designing of individual spaces, the intent is to portray a particular atmosphere. This can be achieved by indicators of color, lighting, and ceiling height changes. These serve as signals for the different spaces as well as the space’s image and function. The sense of place may be achieved by the personalization of spaces. Crewmembers may well bring reminders of home. This has occurred on previous space missions, most notably on the Russian spacecraft Salyut and space station Mir. Here personal items delineated personal territory (Bluth, 1987).

Design Requirements:
- living and working spaces should allow display of personal items
- habitat should be designed with a clear sense of entry into major and minor spaces

3.4 CHANGEABILITY, REPLACEABILITY, AND EXPANDABILITY

A Martian base will be constantly changing. As crew changes occur, the entire function of the base can change also. The base could function as a headquarters for studying Martian geology for a time, and then be switched over to the commercial production of fuel. Because of this constant changing, the base must allow for rearrangement or replacement of existing facilities, and for expansion of the base to add future facilities.

Ways of allowing for changeability and replaceability include the use of a modular system of interior partitions and racks. These will allow rearrangement of spaces and equipment. The spaces within the habitat can be created by the placement of partitions and

Figure 3.3.9-1. A sense of arrival is important in distinguishing between circulation and functional space.

Figure 3.3.9-2. A sense of place is critical in portraying a particular atmosphere.
Pax Permanent Martian Base

racks that divide up the interior. They can become the defining elements of all spaces throughout the habitat. Since these partitions and racks will be used throughout the entire habitat, they must be modular to accommodate all situations. This modularity will also allow ease of replacement and flexibility in the way spaces can be rearranged.

Both partitions and racks should be based on a standard module size that will allow easy transportability and movability. Partitions should allow variations that will make full walls and half walls possible. The racks themselves should also be flexible in their construction. By using modular pieces to form racks, many sizes and options can be created which add even more flexibility to the system.

Expansion of the base can be allowed by providing connecting ports in convenient locations, and a support structure that will accommodate additional structures.

Design Requirements:
- A modular system of interior partitions and racks should be used
- Convenient connecting ports should be provided

- Support structure should be able to accommodate additional facilities
- Partitions and racks should be modular
- Partitions and racks should have a standard size
- Partitions should allow full and half wall configurations
- Racks should be comprised of modular pieces

3.5 SPECIAL CONSIDERATIONS

3.5.1 COLOR

"A measure of the degree to which an environment promotes the productivity, well-being, and situationally desirable behavior of its occupants" (Clearwater, 1986). Color has been known to have an effect on human beings. The behavioral issues regarding color selection have been discussed within the aerospace community. Shown is that color "interacts with illuminants" and affects the following:
- human psychology
- physiology
- behavior (arousal, fatigue, relaxation)
- the circadian rhythm
- visual performance
- perceptual judgments
- information processing and transfer
- perceived spaciousness
- perceived temperature
- emotional well-being
- public image and product identity" (Clearwater, 1986).

The proper selection of colors in interior environments can enlarge a room visually. Space habitats will be confined and isolated. Colors should be used that will enhance the constrained living and working environments. Warm surface colors can cognitively change perceived temperatures by nearly 0.83 degrees C (Clearwater, 1986). Moods, excitement level, boredom or depression can be changed with the use of color. Food and human skin tone are affected and can be enhanced.

Figure 3.4-1. The use of modular partitions and racks increases the flexibility of a martian habitat.
Based upon the color design and recommendations from NASA-ARC, the selection of color for Pax is be selected according to three activity area definitions. A high activity area includes space for a single individual or a group. Suggested are larger wall spaces and surfaces in light, lively warm earth tones and warm pastels. Moderate activity areas are the designated work areas. Calm, low saturation colors augment the spaces. A low activity space creates a quiet, cozy environment yet perceptually increase the space. Light blues and grays are be appropriate.

The general effect of colors can be summarized in the following manner: warm colors energize; cool colors are calming and restful. Pax makes liberal use of gray tones, pale blue-grays, burgundies, taupes, off-whites, silvers, deep blues, and terra cottas. A basic color scheme is chosen for a particular space. The effect upon adjacent spaces is considered if those spaces flow into one another. Providing a continuity of color from one area to another relieves the habitat from appearing “chopped up” and discontinuous. Bright color highlights certain special features, either architecturally or visually. Color also augments the translation pathways throughout the habitat.

**Design Requirements:**
- Bold color should be limited
- Shades and pastels should be used in larger surfaces
- Use contrasting color to break monotony
- Highly reflective colors should be placed above the user
- Allow the personal control and flexibility of color by the crew

### 3.5.2 LIGHTING

Lighting greatly influences how space is perceived. It allows for:
- a change in the mood of a space
- an alteration of the surface colors
- a perception of spaciousness

Pax incorporates a number of lighting systems to increase visual stimulation, add variety, and augment the tasks to be performed. Each area of the habitat that contains special architectural featuring endeavors to highlight that feature. Control by the user is of great importance. Combinations of uniform lighting, uniform wall light-

**Design Requirements:**
- Materials should be easily maintained
- Materials should not be toxic to systems or humans
- Materials should be durable
- Reflective surfaces of materials should enhance the space

### 3.5.3 MATERIALS

Suggested material usage comes from the NASA Man-Systems Integration Standards of 1986. Any material will have gone through a complex testing phase to determine whether outgassing from the product is detrimental to humans or the space environment.

Depending on the space and its use, materials are chosen to facilitate the task at hand. For example, surface materials in the general laboratory allow for ease of the task and easy maintenance. The material’s reflectivity will be studied for its appropriateness in a designated area. Surfaces that will not contaminate, discolor, or unintentionally harm the user are investigated. The durability is another key issue. With economic constraints in space endeavors, rapid deterioration is not desirable. A variety of materials with textural surfaces can be permitted to vary the environment and stimulate visually and tactily. Again, the key to material usage is durability and performance.