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THE DEVELOPMENT OF A LUNAR HABITABILITY SYSTEM

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16. Abstract

A study was made to develop and assess lunar shelter habitability requirements and design criteria. The components of lunar shelter habitability studied are: free volume, compartmentalization, area layout arrangement, area use frequency/duration furnishings, equipment operability, decor, lighting, noise, temperature, and growth potential.

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FOREWORD

In order to support manned lunar missions of the future, concepts for lunar shelters are currently being developed and analyzed. Since men will spend a significant portion of their time within the confines of the shelter, considerations affecting shelter habitability become equally as important as factors associated with mission operations. In designing a lunar shelter to ensure adequate habitability, several problems arise. First, there is no agreed upon definition of the term, habitability. Further, problems usually encountered in habitability design efforts are that habitability criteria are ill-defined or even inappropriate and that a measurement scale of degrees of habitability is not available. Thus a designer has no information on which requirements for habitability are essential and which are only desirable when performing tradeoffs of alternate design approaches. The problems of habitability design are further aggravated by the subjective quality of much of the existing information concerning such factors as free volume, needs for privacy, and interpersonal interactions, etc.

With these problems in mind the Matrix Research Company performed the present study of lunar shelter design for habitability. The purpose for the study is to provide engineers concerned with shelter design, with habitability requirements, and with design guidelines. Whenever possible, these guidelines are described in quantitative terms for three degrees of importance. The degrees in descending order of importance, are: safety guidelines, performance guidelines, and comfort guidelines. The approach taken in the study was an application of the Matrix Research man/systems integration methodology which begins with mission requirements and results in a design concept for the shelter habitability system. This study was undertaken as part of the Human Factors Systems Program, Walton L. Jones, M.D., Director.

The specific outputs of the study are as follows:

- An operational definition of habitability
- A set of lunar shelter habitability requirements
- A listing of applicable habitability criteria or factors which must be considered in a design for habitability
- A set of habitability modules which involve the set of requirements associated with each habitability function
- Design guidelines for each module at three levels of importance: safety, performance and comfort
- A technique for developing module design approaches from design guidelines
- Methodology for integration of modules
- Representative design concepts for individual modules and for the total shelter.

While the guidelines and techniques developed in this study were established primarily for the task of designing a shelter, they are equally applicable in evaluating a specific design for shelter habitability. Used as an evaluation tool the data and techniques enable a design engineer to select more effective design approaches and to identify problems for habitability in any design concept.

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1

1.0 INTRODUCTION

The Matrix Research Company recently completed, for NASA, an investigation of astronaut performance capability in the lunar environment. An output of this study comprised the identification of additional research required to more fully describe and define astronaut performance capabilities on the moon. One of the high priority investigations recommended in the research plan was the determination of lunar shelter habitability design guidelines. The present study was performed to provide shelter design engineers with information concerning astronaut requirements and guidelines for shelter habitability.

The output of the present study consists of design guidelines for shelter habitability. Inputs to the study included, in addition to the earlier Matrix Research investigation, lunar shelter mission information obtained from cognizant engineers at Langley Research Center, Marshall Space Flight Center, NASA Headquarters, and the U.S. Geological Survey. The study itself consisted of developing a method for identifying habitability requirements and integrating the requirements with habitability criteria to achieve design requirements or design criteria for the shelter habitability system.

Objectives of the investigation are:

- To develop and assess shelter habitability requirements
- To develop habitability criteria
- To develop design criteria for shelter habitability systems

1.1 SCOPE

This study is directed toward lunar shelter missions with a planned stay time of 28 days and a crew size of two astronauts with provisions for adding an additional crew member and increasing stay time up to 90 days. The only operations considered in the development of the habitability system were those non-mission oriented functions which involved actual living, moving about, and performing off duty activities. Determination of life support and shelter atmosphere requirements was considered to be out of the scope of this effort primarily since the state of the art in developing these parameters is well advanced, and since determination of other components of habitability is so ill defined. The components of lunar shelter habitability, henceforth termed habitability criteria, evaluated in the study include the following:

- free volume
- compartmentalization
- area layout arrangement
- area use frequency/duration
- furnishings
- equipment operability
- decor
- lighting
- noise
- temperature
- growth potential

1.2 APROACH

The approach taken in this investigation was to view the various components of the shelter which support, sustain, and protect the man as a complete system with defined inputs, operations, and outputs. The inputs include the requirements for habitability, including crew size, mission duration, and a general description of mission activities. The output comprises an environment which does not degrade astronaut performance, has minimal effect on astronaut comfort and which is maximally safe for astronaut habitation.

Approaching the shelter as a habitability system facilitates the development of requirements and design criteria. Requirements include all factors which ensure that the system development will progress from input to output. Design criteria define the constraints on design of means to satisfy the requirements, which constraints are based primarily on man's essential capabilities and limitations.

The essence of the approach is the development of requirements. For the lunar shelter habitability system, requirements include functional requirements, information requirements, performance requirements, hardware requirements, and free volume requirements. Functional requirements are developed for each habitability function. The requirements include sub functions or tasks which make up the function. Information requirements include the information necessary to complete the function. Performance requirements include specific activities and constraints on performance of the functions. Hardware requirements include the general types of equipment required for performance of each subfunction while free volume requirements include the minimum volumes for each subfunction.

The habitability functions considered in this analysis include:

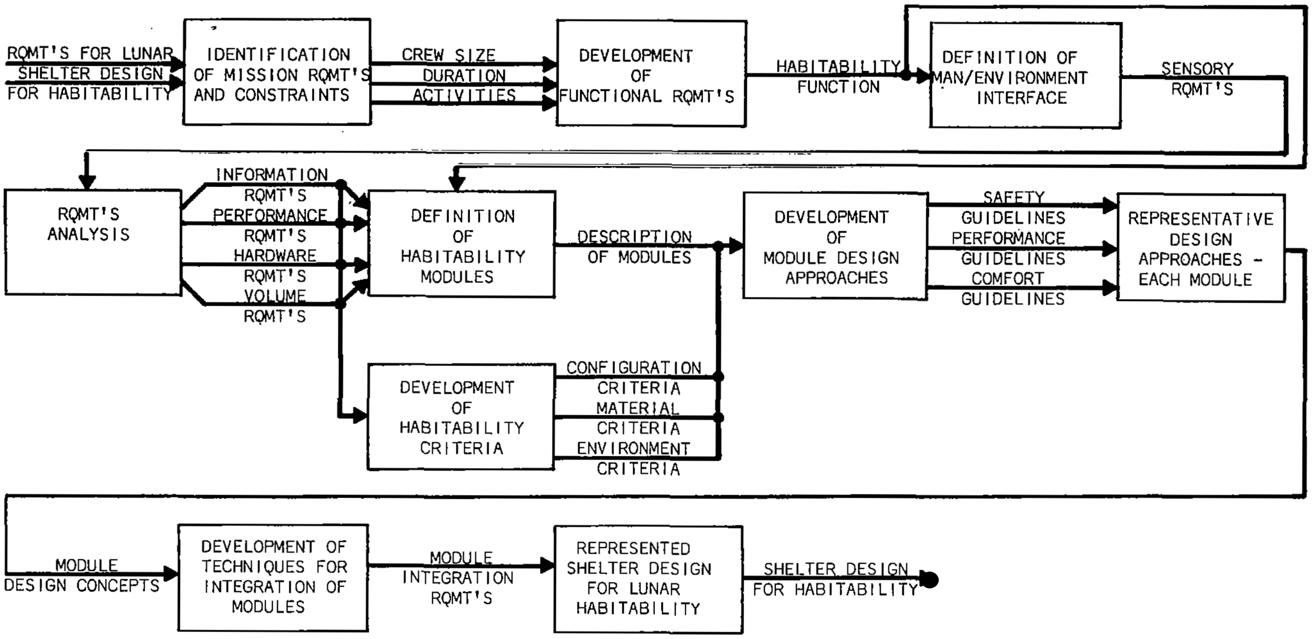
- Sleep
- Nourishment
- Waste elimination
- Rest and relaxation
- Locomotion
- Hygiene
- Personal equipment care and housekeeping
- Air lock activities.

When specific requirements have been developed for each function, these requirements are integrated with habitability criteria to describe shelter area modules for performance of each function. The integration of habitability criteria and requirements, which results in design criteria for each module, is performed at three levels: safety, performance, and comfort. The level of safety defines the minimum allowable requirements to ensure astronaut safety. The performance level includes habitability criteria values selected to assure minimum degradation of performance of habitability functions. The level of comfort comprises the requirements which provide the astronaut with an environment including minimal stresses.

When area modules are described, they are integrated to result in a design concept of the total shelter. This packaging activity is based on an assessment of crew activity levels in separate modules, interface requirements among modules, and a time line analysis.

The final step in the study is to apply the analytical techniques to develop representative shelter design concepts. Description of these concepts is provided to illustrate the activities which comprise the habitability systems development approach and are not to be construed as design recommendations.

Approach Flow Diagram



1.3 SUMMARY

Based on this study it is concluded that:

- habitability is defined operationally as the sum total of shelter design characteristics provided to enable and support the performance of astronaut living functions (sleep, waste elimination, etc.)

- the crewmen must devote 33% of their time to sleeping, 44% to mission work, 13% to personal activities, 9% for eating and related duties, and 1% for housekeeping.

- the most efficient functional area sharing concept includes one compartment for sleep and rest for one astronaut and nourishment for both; another compartment for sleep and rest for the other astronaut as well as mission activities for both; and separate areas for airlock, waste elimination, and hygiene.

- a total volume of 650 to 700 cubic feet is necessary for two crewmen to perform (well within acceptable limits) for up to a 90 day staytime, and (or for) three crewmen for 30 days; this does not include volume required for the airlock.

- there is a critical need for social interaction research which considers privacy versus crew interaction, need for sensory enrichment and territorial behavior.

- the output of this study is a methodology for developing habitability requirements and design guidelines for lunar shelters. An application of the methodology to representative lunar missions is described and design approaches are developed.

2

2.0 LUNAR EXPLORATION

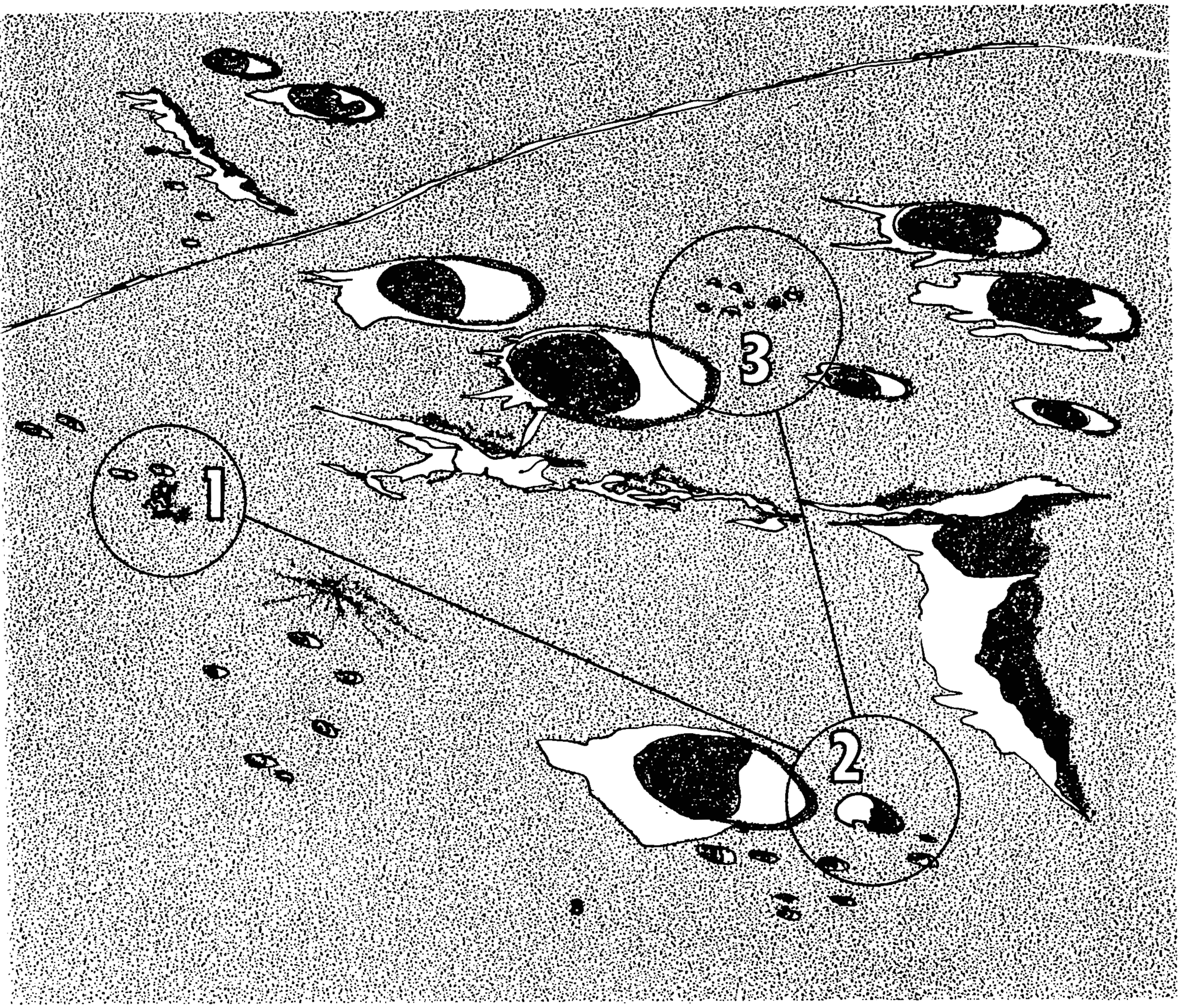
In determining and defining requirements for lunar shelter habitability the total system with which the astronaut will interface must be considered. The inputs to the system comprise mission requirements, such as specification of crew size, mission duration, and operations to be completed by the astronauts during the mission.

Scientific requirements will play a major role in defining the equipment needed for post-Apollo exploration. In the summer of 1965, the Space Science Board of the National Academy of Sciences, meeting at Woods Hole, Massachusetts, formulated the basic questions about the moon for which answers should be sought. Another conference was held at nearby Falmouth. They established eight working groups, four related to the geosciences: geodesy, geology, geochemistry, and geophysics. These groups formulated recommendations for the desired investigations and mission support equipment for lunar exploration.

Future missions will require increased stay times, larger crews, and more advanced scientific equipment. Several shelters have been designed to extend the day and a half stay time capability of the lunar module.

EXPLORATION

Experience suggests a three phase approach to lunar exploration: discovery and conquest, exploration and exploitation.



The first phase, primarily orbital and unmanned probes, is complete with the landing of Apollo XI. It has formed the framework for analysis of the next two phases.

The second phase, exploration, will consist of orbital and surface missions. The primary tool will be man. Observations by astronauts trained as field geologists will be most important in defining the nature of lunar features and processes. Emphasis will be placed on sites which encompass key lunar features for the conduction of geoscientific experimentation supported by contributions from other scientific disciplines.

The third phase, exploitation, will be a self sustaining colony utilizing all of the moon's resources to sustain life and provide supplies, while continuous research is conducted. During Phase II, the exploratory surface missions, the astronauts will need a shelter that will do more than assure safety and sustain life. The shelter must provide work space to support the exploration and scientific experimentation, it must grow with scientific discovery and it must assure effective performance and adequate crew comfort.

2.1 MISSION OPERATIONS

As lunar missions of the future are being planned, a great amount of attention is being devoted toward defining the scientific objectives of the missions and experimental procedures to be followed during each mission. Experiments are being designed in the areas of geodesy, cartography, geology, geophysics, geochemistry, astronomy, bioscience, atmosphere measurement, and particles and fields. These experiments have, as their prime objective, the scientific investigation of the lunar surface, sub-surface, topography, magnetic fields, radiation and thermal environment, and atmosphere. The majority of the experiments currently being designed place heavy emphasis on a human operator, monitor, and decision maker to select samples, identify unforeseen events, deploy apparatus, and observe instruments and environmental conditions.

Crew size and mission duration varies from two men for three days (Extended Lunar Module) to six men for six months. Actual mission planning depends upon detailed engineering that does not yet exist. However, the 1967 Summer Study of Lunar Science and Exploration at Santa Cruz, California suggests some possible missions. The Alphonsus Mission Plan is chosen, although a short duration mission of only eight days, because it exemplifies the typical mission.

2.2 SCIENTIFIC OBJECTIVES

In the summer of 1965, the Space Science Board of the National Academy of Sciences, meeting at Woods Hole, Massachusetts, formulated the basic questions about the moon for which answers should be sought.

STRUCTURE AND PROCESSES OF THE LUNAR INTERIOR

1 Is the internal structure of the moon radially symmetrical like the earth, and if so, is it differentiated? Specifically, does it have a core, and does it have a crust?

2 What is the geometric shape of the moon? How does the shape depart from fluid equilibrium? Is there a fundamental difference in morphology and history between the sub-earth and averted faces of the moon?

3 What is the present internal energy regime of the moon? Specifically, what is the present heat flow at the lunar surface, and what are the sources of this heat? Is the moon seismically active, and is there active volcanism? Does the moon have an internally produced magnetic field?

COMPOSITION, STRUCTURE AND PROCESSES OF THE SURFACE

1 What is the average composition of the rocks at the surface of the moon, and how does the composition vary from place to place: Are volcanic rocks present on the surface of the moon?
2 What are the principal processes responsible for the present relief of the lunar surface?
3 What is the present tectonic pattern on the moon and distribution of tectonic activity?
4 What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?
5 What volatile substances are present on or near the surface of the moon or in a transitory lunar atmosphere?
6 Is there evidence for organic or proto-organic materials on or near the lunar surface? Are living organisms present beneath the surface?

HISTORY OF THE MOON

1 What is the age of the moon? What is the range of the age of stratigraphic units on the lunar surface, and what is the age of the oldest exposed material? Is a primordial surface exposed?
2 What is the history of dynamical interaction between the earth and the moon?
3 What is the thermal history of the moon? What has been the distribution of tectonic and possible volcanic activity in time?
4 What has been the flux of solid objects striking the lunar surface in the past, and how has it varied with time?
5 What has been the flux of cosmic radiation and high-energy solar radiation over the history of the moon?
6 What past magnetic fields may be recorded in the rocks on the moon's surface?

2.3 ALPHONSUS MISSION PLAN

The floor of the crater Alphonsus in the central part of the Moon is an area of great complexity and variety, as revealed by telescopic studies and photographs taken by Ranger IX and Orbiter IV. Alphonsus has about the same diameter as Copernicus (about 90 km), but it lacks the diagnostic impact features that are so clearly evident at Copernicus. It may be an old, considerably degraded impact structure in the central highlands. Outcrops in the 6000-foot crater walls should yield data that will help establish the crater origin and add to the knowledge of highland units and history. Crustal rocks from a great depth below the crater may be exposed in the central peak. The central ridge has been interpreted as volcanic rocks extruded along a major tectonic break that cuts the northern and southern crater walls and continues far to the north through crater Ptolemaeus.

A polygonal set of faults and grabens cut the crater floor and continue into the crater walls. Cark-haloed craters (possibly pyroclastic cones) are distributed along some of the faults. Kozyrev has observed possible volatile emissions in this region. Outcrops in the crater walls may include volcanic ancient highland deposits that may cover a large span of lunar history; the floor appears to be covered by volcanic and impact craters.

The probably complex geology makes this site a prime target for a dual manned launch, not only for the study of lunar history, but for the study of many fundamental geochemical and geophysical problems. The possibility of the existence of effluent gases in the crater is equally challenging.

The following are the primary purposes for choosing the site:

1. To make geological and geophysical observations and to sample selectively in a crater site in an old highland region which offers an optimum combination of important features for establishing a sequence of lunar geological history.

2. To investigate the early stratigraphic history and related processes that formed the highland areas.

3. To investigate the γ-ray and optical environments for examination of the Moon as a possible base for astronomical observations.

The objectives are to make sample collections and field observation in Alphonsus in sorties or groups of sorties and to examine the following:

1. Floor filling and its sequence in the vicinity of the landing site.
2. The central-peak and central-ridge region.
3. Dark-haloed crater and associated structures.
4. Western crater-wall structure and exposures of highland material.
5. Localities of possible recent gaseous emanations.

Also, an objective is to coordinate the mission by an unmanned/manned surface vehicle with automatic sensing capabilities. The vehicle should accomplish the following:

1. Precede a manned mission to reconnoiter geological materials of the western crater floor and collect uncontaminated geochemical and biological samples prior to a manned landing.
2. Provide technical and scientific information for precise landing-site selection.
3. Furnish astronaut transportation.
4. Provide followup reconnaissance of the central ridge and eastern floor of the crater wall for reconnaissance of the adjacent old highland region.
5. Emplace passive geophysical, astronomy, particles and fields, and atmospheres experiements.
6. Proceed unmanned across lunar highlands to the Sabine and Ritter craters.

2.4 EXTRAVEHICULAR ACTIVITIES

On the lunar surface the astronaut will perform mission operations in an environment which is both novel, in terms of earth standards, and constraining in terms of the utilization of full performance capability. The primary elements of this environment are the lunar environment itself and the pressure suit.

Apollo 12 EVA

8 HOUR EVA

The biggest problem, Astronaut Charles (Pete) Conrad, Jr. said, of a "split" lunar excursion period (4 hours each) is donning and taking off the space suits and portable life support system (PLSS) which must be worn during forays away from the lunar module. "Doing the work outside is easy," he said. "Once you step down the ladder (of the lunar module to the surface of the moon) you're on your way."

Conrad said he is in favor of utilizing longer-duration portable life support systems capable of sustaining an astronaut on the lunar surface for periods of up to 9 hr. He said if a way can be devised to "give a guy a drink of water and maybe a shot of food, he can sit down and take a little siesta out there for a half hour in the middle of it." That way, he emphasized, an astronaut could easily do 8 hr. of work on the surface.

"The big thing," he said, "is getting it all on and getting out and getting it all off and putting it all away when you get back in (the lunar module)."

LUNAR DUST

Alan L. Bean said there is a major problem with moon dirt picked up by the astronauts on their clothing and brought back into the lunar module. There was, he said, " a tremendous - just a tremendous - amount of dirt on our clothing... I think that if you are going to work in an environment (like the moon's) for any length of time, you're going to have to tackle this problem and keep it clean."

Dirt was a bane to the astronauts throughout the mission. As Conrad, Bean and their fellow crew member, Richard F. Gordon, Jr., returned to earth in the command module, Yankee Clipper, they still had difficulties with the dusty particles of lunar material. They reported to Houston that they tried for days to filter it out through the command module's environmental control system. But, they said, the amount of dust was such they had to clean the screens entrapping the particles "every 2 or 3 hr." At one point on the lunar surface they were so dirty, they said, that they looked as if they had been wallowing in powdered graphite.

COLOR DISTORTION

"One of the real difficult things about the whole EVA", said Bean, - "the geology part of it - was the fact that there didn't appear to be any difference in the color (of) either rocks or the soil. They all looked about the same. The first day, to me they all looked sort of a dull gray....If you looked real close maybe you could find a white rock now and then or maybe distrub something and get a little darker gray. But they were gray.

"The second day we went out, the same thing that looked gray to us the first day started looking - at least to me - a sort of brown, dark brown or tannish brown. It was really one of the most interesting things of the lunar surface operations, how much that color can change with a 7 deg. or so sun angle change...

"It is going to make geology... more difficult than we see it on earth because the color cues just aren't going to be there...You are going to have to look for texture and fracture and luster and lots of other things that will aid you in determining differences in rocks and minerals."

REDUCED GRAVITY

Bean had these comments about his ability to move about the moon:

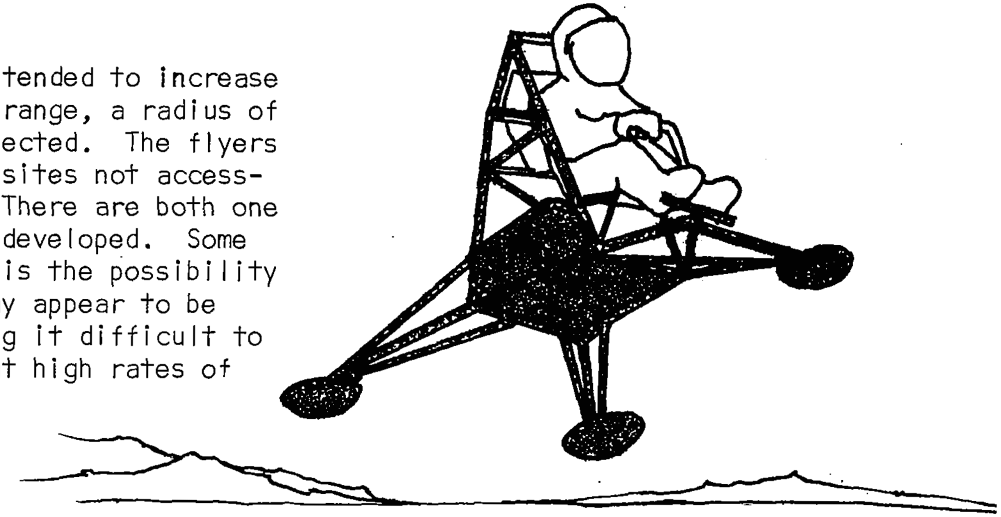
"You know, the funny thing about moving around on the lunar surface, you put on this pressurized suit we wear and if you try to do it on earth with even close to the weight you have on your back on the moon...you get tired very rapidly from the walking. You don't have to walk over, say 200-300 yards, and you're ready for a rest. But on the moon in the light gravity with the same suit on and the same weight, your legs never seem to get tired. I guess when you run up the side of a steep slope you could, but just running around on level ground, you assume some kind of normal pace and you're able to go for long distances without your legs getting tired."

EVA SUIT

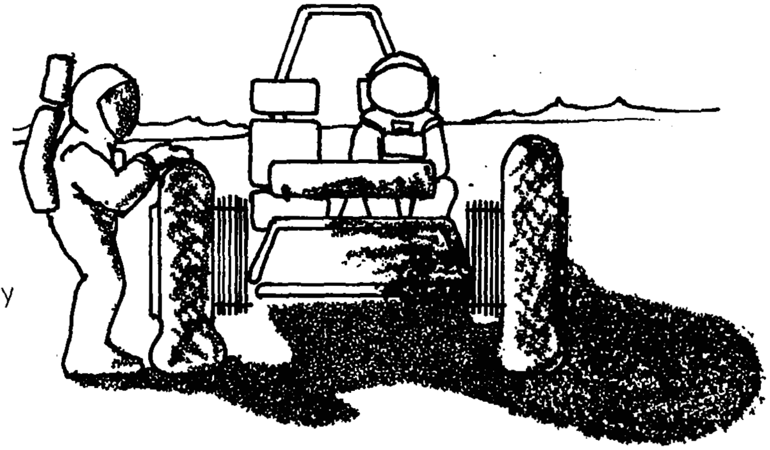
Bean continued, "The suit doesn't always want to bend like you want it to bend. For example, you can bend pretty well at your knee and it bends pretty well at the ankles but it doesn't want to bend up near the thigh, the top of the thigh...."

EVA Equipment

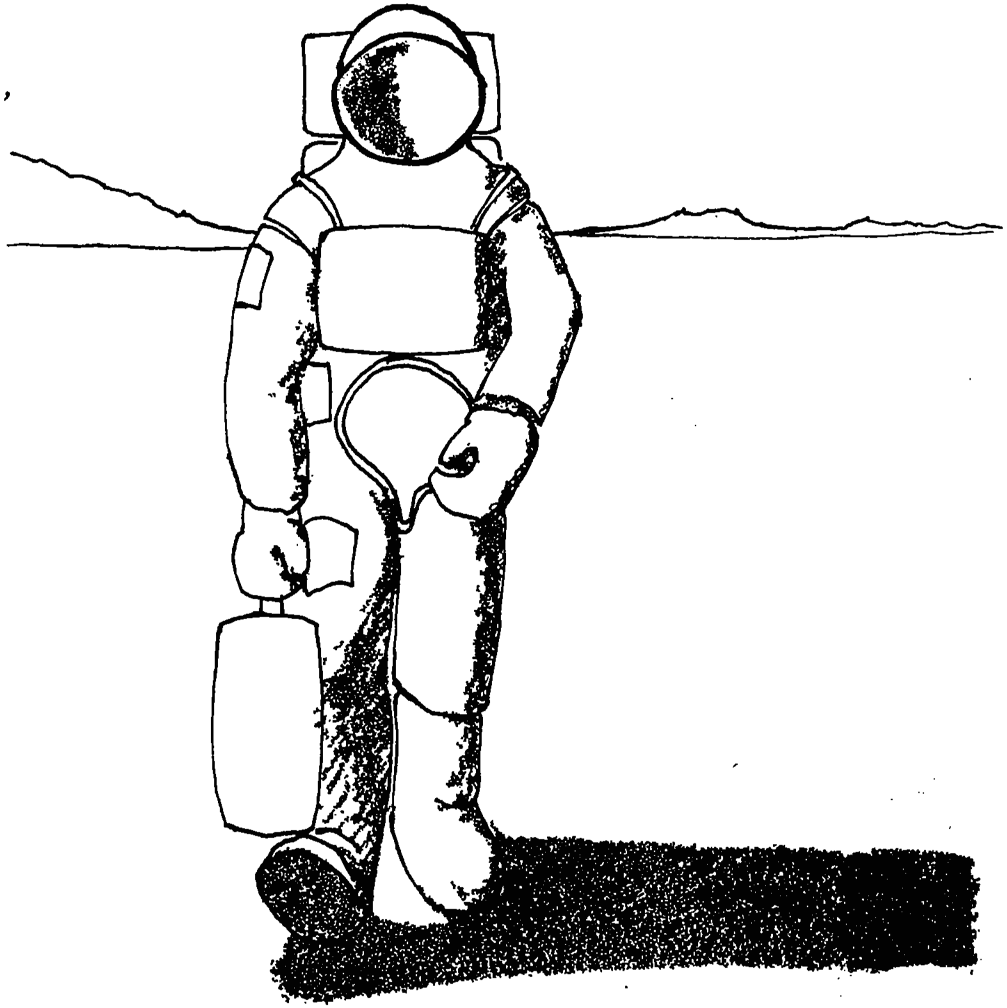
Lunar Flying Units are intended to increase the astronaut's mobility range, a radius of 5 to 10 kilometers is expected. The flyers will also give access to sites not accessible by surface travel. There are both one and two man flyers being developed. Some problems with the flyers is the possibility that the lunar surface may appear to be washed out and flat making it difficult to judge altitude and land at high rates of descent.



The Lunar Roving Vehicle (LRV) is capable of operating in an automatic or manned mode. During the automatic mode it will traverse from one mission location, deploying scientific monitors and picking up surface samples, to the next, the manned mode (capable of carrying two men) might offer an independent life support system (mobile laboratory and Lunex II), and a mobility radius of up to 50 km., from the delivery system.



An astronaut will be able to foot traverse a maximum of 5 km during a 6 hr. EVA period. It will be necessary for two astronauts to carry the scientific equipment. The Apollo lunar surface experiment package contains hand equipment (scoops, hammers, sample bags, core tubes, etc.) maps, cameras, seismic experiment equipment, communications equipment, a gravimeter, a magnetometer, and survey equipment. The two astronauts will have a maximum sample return capability of 140 lbs.



2.5 INTRA-SHELTER ACTIVITIES

The primary environmental condition that is of concern within the lunar shelter is reduced gravity and its effects upon the shirtsleeved crewmen. Findings reported by Hewes et al (1966) at Langley Research Center indicated that walking and running speeds should be greater on the moon than earth by approximately 60% and these actions involve fewer steps. The subject's posture and appendage movements differed for earth and reduced gravity conditions. The most comfortable lunar gait was found to be a lope of about 10 feet per second which is much faster than the natural earth walking gait of about 4 feet per second. Locomotion within the limits of a shelter may prove to be difficult, the LM does not have enough free volume for a shirtsleeved crewman to walk about.

With an expected EVA time of six hours, eighteen hours per day remains. Most of this time is spent in general daily living activities such as sleeping, eating, and resting. As lunar science and exploration becomes increasingly more sophisticated it will be necessary to become more select with the samples returned. The scientific testing, recording equipment and the astronaut/scientist must parallel this sophistication. The shelter will contain a laboratory. The entire area designated laboratory will vary according to scientific mission objectives, (Geology, Geophysics, Astronomy, etc.) the area being explored, (Marius Hills, Copernicus) and the duration of the mission. These guides will also influence the equipment, the operations and the choice of scientist-astronauts.

Some portion of this ISA time must be used for scientific tasks in the shelter laboratory area. Typical tasks will be mapping, general observations, sample measurement and analysis, and recording of data. An example of a geological analysis is presented below:

TEXTURAL ANALYSIS

A polarizing microscope is used in the mineralogical study of rocks and rock fragments for the identification of minerals and for determining rock textures. It is the only experimental technique which will allow the direct analysis of mineral sequence of formation, and it is the most direct method for physical-chemical equilibrium information. Textural analysis will be the best means of screening rock samples which potentially can give direct evidence as to the pre-surface lunar processes. A television camera mounted in the optic train will allow the work of the astronauts on the rock sections to be supplemented by Earth-based scientists.

The optic tube, sample stage, and support for auxiliary equipment for the microscope should be built into the LM walls so that a small amount of bench space on either side of the microscope is allowed and so that the astronaut can sit and view the specimen. The ocular magnification power should be approximately 10 with a crosshair and a metric-scale reticle; the objective turret should have at least three parfocal objectives in the ranges of 2 to 3, 6 to 8, and 40 to 45 power. A second coupled ocular tube is necessary for the vidicon so that a televised image of what the astronaut is viewing can be obtained at all times. Two light sources are required, one below the stage and one above the stage for vertical reflected illumination. Both below- and above- stage specimen-analyzer polarizing attachments are required and should be mounted with the pass direction, one north-south and one east-west. The specimen stage should be free to rotate coaxially with the optic axis. A fixed substage condensing lens is necessary, and diaphragms should be mounted on both light sources and immediately substage. A Bertrand lens is optional but advisable.

A binocular microscope can be used primarily to augment hand-lens information. It allows a limited amount of work on individual mineral grains in a rock sample; such work includes physical characteristics of minerals and some microchemical work. As on the polarizing microscope, optic train of the binocular microscope should be built into the LM.

The microscope should have a total magnification power of 5 to 100, variable in fixed increments. The suggested power increments are 5, 25, 50 to 60, and 100. The microscope should have a sample stage to accommodate 4-inch-diameter specimens and a movable light source in order to illuminate any area of the sample. The microscope should be combined in design with the petrographic microscope.

2.6 SHELTER DESIGNS

Existing or proposed NASA shelter configurations:

LUNAR MODULE

For short duration missions some consideration has been given to utilizing the LM vehicle as a lunar shelter, Extended Lunar Module(ELM). Problems associated with this approach stem primarily from the fact that the LM was designed as a flight vehicle, although, Apollo 12 crewman used hammocks for sleeping and provisions for eating, drinking, and waste management already exist for the vehicle. Still lunar dirt is a prime problem.

STAY TIME EXTENSION MODULE

The Stay Time Extension Module (STEM) is defined as a two man shelter designed for an 8 day stay time on the lunar surface. The system features an integral shelter-airlock structure fabricated of pliable and expandable material which is packaged in a canister connected to the LM vehicle. It is intended to be deployed, erected, and assembled by one crewman.

LUNAR MOBILE LABORATORY

The Lunar Mobile Laboratcry (MOLAB) is designed for two men to drive about the lunar surface, performing laboratory functions such as rock collection and sample measurement. Boeing designed a shelter/vehicle which was comprised of a horizontal cylinder with 210 cubic feet of cabin volume. Bendix designed a similar vehicle with a volume of 452 cubic feet.

LUNEX II

Lunex II was a simulation study to evaluate the effects of an 18 day, two man, minimum volume MOLAB. Ninety-six percent of each subject's time was spent inside the vehicle in a shirtsleeve environment.

EARLY LUNAR SHELTER (ELS)

The "baseline" mission capability determined for the ELS concept involves a two man crew for a fifty day lunar surface mission. A variety of alternate missions can be accomplished with the basic ELS subsystem: 3 man-43 days, 2 man-66 days, and 3 man-20 days in transportable (MOLAB) mode.

LUNAR EXPLORATION SYSTEMS FOR APOLLO (LESA)

The LESA module is three separate compartments - a living area, laboratory, and airlock. The LESA module is intended for a long duration time of six months with a crew of six. As crew sizes increase for lunar exploration mission, the number of modules would increase, creating a permanent lunar base.

BEN FRANKLIN SUBMERSIBLE

Objectives of the Ben Franklin were to explore the Gulfstream, geological survey, oceanographic measure, and navigation and tracking. The sub drifted up the North American East Coast for 30 days with a crew of six men.

TEKTITE

The Tektite habitat was constructed for use under water. It consists of two vertical tanks, each divided into two rooms with an interconnecting tunnel between the top two chambers. One two-story tank contained the command-control room on the upper deck with the crew quarters below. The second tank contained the engine room with a 5 foot cupola on top. The lower deck consisted of the wet laboratory. Access to the water was through the bottom of the wet lab. Four marine scientists lived and worked in the shelter for 60 days.

Shelter Designs

SHELTER	LM	ELM	STEM	LUNEX II	MOLAB	ELS	LESA	BEN FRANKLIN	TEKTITE
Duration	36 hrs.	72 hrs.	8 days	18 days	14 days	50 days	3-6 mos.	30 days	60 days
Crew Size	2	2	2	2	2	2	3-6	6	4
Scientific Objective	Sample pick up & return	Sample pick up & return	Sample Selection	Driving Monitoring Navigation Sample Measurement Audio Balancing	Experiments & Sample Selection	100 ft. drill experiments, Sample Selection	Semi permanent base	Oceanographic investigation & observation	Marine Sciences
ESA	Walking max. 1 km	Walking max. 2.5 km		.5 hrs/man walking	250 mi/ 14 days 6.3 hrs/ day EVA	4.5 hrs/ day walking	LRV	None	
Volume			$410ft^3$		$210ft^3$	$628ft^3$			$2200ft^3$
Free				$115.3ft^3$	$200ft^3$		$3296ft^3$*	$1372ft^3$	
Airlock			$105ft^3$	$48.0ft^3$	$80ft^3$	$122ft^3$	$148ft^3$		

*1421 living, 1875 lab

3

3.0 LUNAR SHELTER REQUIREMENTS

In order to sustain the astronaut, protect him from the radiological, thermal, and vacuum environment of the lunar surface, and enable him to perform mission operations described in the preceding section, a lunar shelter must be provided. The early shelter, which is the configuration to which this study is directed, will be capable of providing for a two man crew for a 28 day mission with a growth capability of up to three men and a mission duration of 90 days.

The present study is not concerned with the physical structure of the shelter or with the engineering requirements dictated by habitability considerations. Rather, the study is directed toward defining guidelines for designers in developing the habitability system.

The first step in generating habitability system design guidelines is to establish requirements for habitability and to describe information, performance, hardware, and volumetric requirements developed for each function. The complete set of requirements associated with each function describes a module of the habitability system specific to each individual function. Thus a sleep module is identified, as well as a rest and relaxation module, waste elimination module, etc.

For each of the modules, design guidelines are developed from specific requirements by identifying factors to be considered in the design of the module for each of several habitability criteria. These criteria include such items as module compartmentalization, free volume, area layout/arrangement, use frequency/duration, growth potential, furnishings, equipment operability, decor, illumination, temperature, and noise.

The guidelines are described for three levels of effectiveness: safety, performance, and comfort. Safety guidelines define the minimum acceptable standards while the comfort level describes the most desirable conditions in terms of psychological factors and user preferences.

The habitability system guidelines will be used in Chapter 4 as the basis for developing equipment design, layout, and packaging concepts. The guidelines and concepts for individual modules are integrated in Chapter 5 which considers requirements for the entire shelter, and then presents recommended concepts for total shelter design.

3.1 HABITABILITY

The first difficulty encountered in developing guidelines for habitability is to reach an agreed upon, consistent and concise definition of the term "habitability".

Fraser (1968) defines habitability as the equilibrium state resulting from the interaction of components in the man-machine-mission-environment complex, which permit physiological homeostasis, performance, and social relationships. Kubis (1965) describes habitability as the sum of interactions between man and environment which interactions include: physical interactions (the physical environment and its interrelation with man), physiological (the homeostatic response of the man in the environment), psychological (the effects of the environment on performance and behavior) and social interactions (interpersonal relations).

The present study uses an operational definition of habitability wherein the term is defined as the sum total of shelter design characteristics provided to enable and support the performance of habitability functions. It is important to keep in mind that the objective of the study is not to provide shelter habitability but rather guidelines for shelter design <u>for</u> habitability.

The design for habitability, like the design for maintainability and operability, comprises a specification of design characteristics which describe the optimal approach in terms of systems effectiveness. Unlike the designs for operability and maintainability, habitability effectiveness parameters, measures, and criteria have yet to be established. Definition of the man-machine interface is more or less straightforward since an ample data base is available concerning optimal design approaches for specific functions. In the development of the man-environment interface, the human factors scientist must rely on data which are usually insufficient, sometimes inapplicable, and occasionally invalid. The problem in developing appropriate habitability data on which to base design decisions is that criteria for habitability have never been clearly established. Techniques for defining degrees of habitability or for even assessing that a structure is or is not habitable have not been developed. Consequently, measures of habitability which serve to isolate deficiencies in a proposed design and which facilitate the decision that the design for habitability is effective or optimal are unavailable. This study attempts to provide the habitability criteria and measures for the design for habitability of lunar shelters.

3.2 SHELTER FUNCTIONS

The Matrix Research approach toward the design for habitability places emphasis on identification and development of requirements. Once mission and system requirements have been defined, they are used to establish design guidelines for the enclosure and to serve as the criteria against which alternate designs are evaluated. The first system requirements to be developed are functional requirements or shelter habitability functions. These include the following activities:

Nourishment - Replenishment of body's building material and energy source. Includes food and drink preparation, consumption and cleanup activities.

Sleep - Area and personal preparation, sleep state, and area cleanup.

Waste Elimination - Biological waste and housekeeping trash disposal.

Rest and Relaxation - Non-duty activity other than sleep directed toward rejuvenation of mental and physical faculties.

Hygiene - Removal of harmful or unpleasant biological organisms or chemical compounds. Maintaining personal cleanliness.

Locomotion - Manual translation within the shelter confines.

Housekeeping and Personal Equipment Care - General cleaning of shelter interior, clothing and compartments and equipment repair.

Airlock - Pressure, temperature and atmosphere facilities.

3.3 RUDIMENTARY REQUIREMENTS

Once habitability functions have been defined, the important considerations in terms of the interface between man performing the function and the shelter environment must be described. The interface is described in terms of the sensory modalities which are operative or dominent during the conduct of a function. These include vestibular, kinesthetic, gustatory (taste), olfactory (smell), auditory, tactile, and visual sensations. The considerations for the interface are described as rudimentray requirements and comprise situations where availability of sensory cues should be increased, decreased, or maintained at a stable state. For example, visual sensation should be decreased for the sleep function, while for rest and relaxation visual sensation should be increased (sensory enrichment) and decreased (periods of rest).

RUDIMENTARY RQMTS

▬ N/A

◓ INCREASE

◒ DECREASE

	VESTIBULAR	KINESTHETIC	GUSTATORY	OLFACTORY	AUDITORY	TACTILE	VISUAL
NOURISHMENT	▬	▬	◓	◓	▬	▬	▬
SLEEP	▬	▬	▬	▬	◒	◒	◒
WASTE ELIMINATION	▬	▬	▬	◒	▬	▬	▬
REST & RELAXATION	▬	▬	▬	▬	◓◒	◓	◓◒
HYGIENE	▬	▬	◓◒	◓◒	▬	▬	▬
LOCOMOTION	◓	◓	▬	▬	▬	◓	◓
HOUSEKEEPING & PERSONAL EQUIPMENT CARE	◓	◓	▬	◒	▬	▬	▬
AIRLOCK	◓	◓	▬	◒	▬	▬	◓

3.4 SPECIFIC HABITIBILITY REQUIREMENTS FOR EACH FUNCTION

Since design for habitability is operationally defined as the sum total of shelter design characteristics which are provided to support and enable the performance of habitability functions, the next logical step in the development of the shelter design for habitability is to progress from functions to design characteristics. An important intervening step in this progression is the development of shelter habitability requirements.

For each habitability function, sub-functions or activities which make up the function were identified. For each sub-function specific requirements were developed which include:

Information requirements or information needed to complete the sub-function

Performance requirements or constraints on sub-function performance

Hardware requirements or enclosure characteristics associated with the sub-function which depend on information and performance requirements

Volume configuration requirements or free volume needed to perform sub-function and the configuration or packaging requirements.

The sum total of these requirements for a specific function defines a habitability area or module. Specific requirements for each habitability function are presented in the tables on the following pages.

Nourishment

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Visual cues	Walk-step	Handrails-door	Body size Stand-step
Unstow-unpackage food and drink	Labels Instructions	Opening stowage Retrieve food-drink Unpackage	Storage areas Area interfaces Unpackaging aids	75 x 30 x 30 Stand-sit
Prepare dining area	Procedures	Set up tables-chairs-utensils-prep equipment	Tables-chairs Utensils Food prep aids	75 x 50 x 30 Stand-bend
Prepare food and drink	State of preparedness	Cook-ice-mix-thaw	Oven Freezer Mixer	75 x 60 x 40 Stand-reach
Consume		Eat-drink	Containers Utensils	40 x 30 x 30 Sit
Measure intake	Measuring device-scale Procedures	Measure intake Record measure	Device and record	40 x 30 x 30 Sit
Package remainder	Procedures	Repackage	Containers	40 x 30 x 30 Sit
Dispose of wastes	Instructions	Collect wastes Store wastes Dispose of wastes	Scrap collect aid Storage of wastes Disposal aids	75 x 50 x 30 Stand-bend
Clean up	Procedures	Clean utensils Clean containers Clean area	Cleaning agent	75 x 30 x 30 Stand-sit
Store equipment	Instructions Labels	Restore equipment	Storage areas	75 x 60 x 40 Stand-reach

Sleep

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Schedule information Visual cues	Walk-step-open door/ curtain	Accessway-doors or curtains Lighting and lighting controls Handholds-stabilization aids	Body size Min access 75 x 30 in. Stand-step
Prepare area	Procedures-instructions Equipment locations Visual cues	Unstow, deploy, assemble, configure, adjust equip Move about area to configure equipment	Stowage containers Equipment packages Lighting Stabilization aids Tools	Body size bending at waist 75 x 50 x 30 Stand-bend
Prepare equipment	Procedures-instructions Checkout information	Prepare equipment for use Verify operational readiness	Equipment includes: Beds and bed clothing and restraints Clothing storage areas System monitoring displays Alarm systems-caution/ warning Biomedical monitoring equipment Lighting, noise control devices Communications system equipment Temperature controls	Body size and reach bending 75 x 60 x 40 Stand-reach
Prepare for sleep	Procedures	Activate contingency and arousal alarm systems Change or adjust clothing Attach and activate biomedical sensors Control light, noise, temperature Deploy restraints Perform hygiene operations Perform waste elimination operations	Interface with hygiene area Interface with waste elimination area Alarm systems-auditory and visual Clothing storage racks and Biomed sensors Controls-lighting-temp Noise control Bed Restraints	Same as above Stand-reach
Enter bed		Ingress to bed Adjust bed clothing Activate restraints	Bed	Standing outside of bed 75 x 30 x 30 Seated upright in bed 40 x 75 x 30 Total 75 x 60 x 75 Stand-sit-recline
Sleep	Reduction of sensory cues	Sleep	Bed	Same as above Recline
Wake up exit bed	Nominal or contingency	Awaken Nominal egress from bed Emergency egress from bed Disconnect biomed sensors Disconnect restraints	Quick egress bed Quick disconnects of biomed leads, restraints	Same as above Recline
Disassemble sleep area	Procedures-instructions	Disassemble beds Rearrange furnishings Deactivate alarms Stow equipment Clean area	Storage areas Packaging of equipment Cleaning equipment	Same as Prepare area

Waste Elimination

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Availability	Access	Entryway	Passage size Stand
Prepare area	Procedures	Control lighting Prepare ventilation Provide for privacy	Lighting Ventilation Door/curtain	75 x 50 x 30 Stand-bend
Prepare equipment	Procedures Feedback	Prepare receivers-stowage compartments-wipes-cleanup equipment Waste handling Waste disposal	Body-waste elimination interfaces-tubes-bag openings Waste storage-temporary-permanent	75 x 50 x 30 Stand-bend
Adjust clothing	Procedures	Remove-modify clothing	Body interface	75 x 50 x 30 Stand-bend
Eliminate feces	Procedures Instructions Indications of inadequate interface-faulty storage-temporary or permanent	Complete interface Secure interface Monitor interface Eliminate waste Monitor integrity of storage Clean body Eliminate wipes	Body interface Temporary storage handling equipment Permanent storage interface Permanent storage Wipes and body cleaners	40 x 30 x 30 Sit
Eliminate urine	Procedures Indication of failure	Apply interface Same as above Measure output	Same as above Measuring device	75 x 50 x 30 Stand-bend

Rest and Relaxation

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Schedule information Visual cues	Walk-step-open door/curtain	Accessway lighting controls Stability aids	Body size 75 x 30 Stand-step
Identify R & R activities	Schedules Available activities Activity constraints Time to perform 1 or 2 man activity Requirements for unscheduled rest	Rest Whole body Seated Relaxation Reading Games Music/film Mission related activity-notes, filing	Provisions for resting Bed Chairs ID markings	Body size 75 x 30 x 30 Stand
Prepare area and equipment	Procedures-instructions Equipment location	Unstow equipment Unpackage equipment Deploy equipment Arrange furnishings Control lighting, noise, temperature	Equipment storage Aids for deployment of equipment Chair with arm, head, foot rests Table for games, etc. Shelves Controls: lighting, temperature, noise	Bending-reaching 78 x 50 x 30 Stand-walk-bend
Rest	Scheduled and unscheduled rest period criteria Duration of rest period Impact of rest on subsequent activities	Whole-body rest in bed Seated rest	Bed-sleep function Chair and foot rest Provisions for music, movies	Bed area 75 x 60 x 75 Chair area 75 x 50 x 60
Relax	Recreational activity performed Biomedical data required Duration of period 1 or 2 man activity Info concerning the last R & R activity of the crewman Safety provisions	Read book-view film-videotape Play games-sedentary and active 1 or 2 players Mission activity Laboratory Data management Communications Music Exercises Gymnastics 1/6 g orientation Muscle conditioning Biomedical monitoring Attach Activate Verify	Books-film-tape, etc. Games Sedentary, 1 or 2 players Mental skills Motor skills Perceptual skills Active, 1 or 2 players Motor skills taylored to 1/6 g Exercise hardware Gymnastics Muscle conditioning: Counter-force springs Bicycle in place Biomed monitoring equip	Sedentary relaxation: Chair area 60 x 40 x 30 Table and storage area 20 x 20 x 20 Active games: Equipment area Body area Exercise: Body equipment area 78 x 60 x 50 Biomedical monitoring: Body area only
Disassemble area	Same as Prepare area and equipment	Same as Prepare area and equipment	Same as Prepare area and equipment	Same as Prepare area and equipment

Hygiene

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Area availability Schedule information Visual cues	Walk Step Open door/curtain	Access Door/curtain Lighting Lighting control Handholds-stabilization aids	Body size Min access 75 x 30 Stand-step
Prepare area	Equipment locations Preparation procedures Visual cues Instructions	Unstow equipment Deploy equipment Assemble equipment	Storage containers Equipment packages Lighting	Body size-bending at waist 75 x 50 x 30 Stand-bend
Prepare equipment	Equipment identification	Arrange equipment Configure material for use	Table area to support equipment	Same as above Stand-bend
Prepare body	Procedures	Remove/adjust clothing	Clothing temporary storage Soiled clothing storage Foot rests-seats	Body size and reach-bending 75 x 60 x 40 Stand-bend-sit
Perform activities-washing	Water quantity/availability Water temperature indications-hot/cold	Wash and dry hands and face	Water dispenser, container, disposal Soap and towels	Body size-bending at waist 75 x 50 x 30 Same as above
Perform activities-bathing whole body	Same as above	Wash/rinse/dry whole body	Tub or shower Handholds Water dispenser-disposal Soap and towels	Body size Standing 75 x 50 x 40 Sitting 60 x 40 x 30 Lying 60 x 40 x 30 Standing envelope 75 x 50 x 50 Stand-sit-lie
Perform activities-shaving	Mirror image Water quantity/availability Water temp indication-hot/cold Quantities of expendables	Lather Shave Wash/dry face	Mirror Razor Towels Water dispenser-container-disposal	Standing 75 x 36 x 33 Stand
Perform activities-teeth care	Same as above	Tooth brush/cleaner use	Water dispenser-disposal Tooth brush-tooth cleaner	Same as above Stand
Perform activities-hair-nail-ear foot care	Procedures	Clip hair-nails Clean ears-feet	Chair for seated tasks Clippers Ear cleaners Foot powders-cleaners	Same as above Sitting 60 x 40 x 30 Sit-stand
Perform activities-First Aid	Equipment location Procedures Diagnostics	Prepare equipment Prepare patient Treat for burns, wounds, fractures, illness, nausea, pains, virus, colds	First Aid kit Lighting-special Layout area-equipment Layout area-patient Special equipment-heat lamps, splints	Two crew members A. One standing-bending-sitting B. One sitting, lying prone A. 75 x 50 x 30 B. 60 x 75 x 30 75 x125 x 60 Stand-sit-lie two men
Clean area/ equipment	Locations to be cleaned Cleaning method-procedures Water quantities/availability	Access areas to be cleaned Clean areas Verify cleaning	Accessibility of all areas Lighting Cleaning utensils-agents	Standing, bending, reaching 75 x 40 x 40 Stand-bend
Reconfigure area	Original configuration procedures	Store equipment Disassemble	Storage areas Packages Lighting	75 x 50 x 30 Stand-bend
Adjust clothing	Donning procedures	Don/adjust clothing	Temporary storage for clothing Soiled clothing container	75 x 60 x 40 Stand-bend

Locomotion

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Prepare for locomotion	Procedures Intended destination	Determine route Identify steps along route Identify equipment to be carried Control lighting	Equipment carrying aids	75 x 60 x 40 Stand-reach
Move through shelter	Visual cues	Avoid obstacles Carry equipment Control lighting	Lighting controls Handrails Stabilization aids	75 x 40 passage Walk
Terminate locomotion	Visual cues	Identify destination Unload equipment Store equipment	Access way Storage compartments	75 x 60 x 40 Stand-reach

Housekeeping and Personal Equipment Care

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Enter area	Area location (previous training - labels)	Locomotion	Entryway Handholds	75 x 30 x passage length Stand-walk
Prepare area	Operational procedures for preparation (previous training labels, checkout lists, manuals)	Environmental control (light, heat, sound) Erect equipment	Environmental controls, task associated prep. hardware, tools, work bench, seat	75 x 50 x 50 Stand-bend-extend
Checkout equip.	Operational procedures for equipment checkout (training, labels, manuals, etc.)	Adjusting, testing and calibrating	Equipment checkout hardware, workbench, seat, tools	75 x 50 x 50 Stand-sit-bend-extend
Perform function	*Operational procedures* for function performance (training manuals, checklists, labels)	*Task dependent*	*Primary function equip* support equip, workbench seat	75 x 50 x 50 Stand-sit-bend-extend
Stow equip.	Stowage location and procedures (training, checklists, labels)	Disassemble, carry, lift, insert	Lockers, shelves, tools, workbench, seat	75 x 50 x 50 Stand-sit-bend-extend
Exit area	Exit path (previous training)	Locomotion	Entryway Handholds	75 x 30 x passage length Stand-walk

Airlock

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Open Airlock/ Shelter Door	Location of locking mechanism & procedure for opening (labeling)	Grasping, twisting, pushing, pulling latch and door	Lock mechanism, door, handholds	75 x 30 x 30 stand
Ingress Airlock	Height of step and body clearance (visual feedback)	Translation through entryway	Hatch, handholds	75 x 30 x 30
Close Airlock/ Shelter Door	Location of lock mechanism & procedure for securing (labeling)	Grasping, twisting, pushing, pulling	Lock mechanism, handholds, door	75 x 30 x 30 stand
Prepare Equipment	Location, preparation procedures (manuals, checkout lists, labels & previous training)	Unstow suit, prepare PLSS, checkout PLSS	Hangers, shelves, checkout gear	75 x 50 x 50 stand-extend
Don Suit	Location & operational procedures for necessary zippers, buckles, snaps, connectors, etc.	Put on and secure suit	Handholds, bench, shelves & specialized suit support hardware	75 x 50 x 50 stand-extend
Don PLSS	Same as above (previous training and labeling)	Mount backpack, adjust straps	Handholds, shelf, specialized PLSS support hardware	75 x 50 x 50 stand-extend
Pressurize Suit	Location & operational procedures for suit pressurization, controls and displays	Initiate pressurization, monitor suit pressurization	Controls and displays	75 x 30 x 30
Checkout Suit	Same as above (manuals, checkout lists, labeling, previous training	Check flaps - openings - pressures	Valves, gauges, conductors, etc.	75 x 50 x 50 stand-extend
Depressurize Airlock	Location & operational procedures for pressurization controls, displays, & checkout hardware (manuals, labels & previous training)	Perform purge operations, verify suit pressurization	Valves, gauges	75 x 30 x 30
Open Airlock/ Outside Door	Location & operational procedures for door lock (labeling)	Grasping, twisting, pushing, pulling latch and door	Lock mechanism, door	75 x 30 x 30 stand
Egress Airlock	Height of step & body clearance (direct visual feedback)	Step through & avoid striking entryway edges while translating through	Hatch, handholds	75 x 30 x 30 stand
Close Airlock/ Outside Door	Location & operational procedures for door lock (labeling)	Grasping, turning, pushing, pulling latch and door	Lock mechanism, door	75 x 30 x 30 stand
Open Airlock/ Outside Door	Same as above	Same as above	Lock mechanism, door	75 x 30 x 30 stand
Ingress Airlock	Height of step & body clearances (direct visual feedback)	Step through and avoid striking entryway edges while translating through	Hatch, handholds	75 x 30 x 30 stand

⇨

Airlock (cont.)

SUB-FUNCTION	INFORMATION REQUIREMENTS	PERFORMANCE REQUIREMENTS	HARDWARE	VOLUME/ CONFIGURATION [h,w,l (inches)]
Close Airlock/ Outside Door	Location & operational procedures for door lock (direct visual feedback)	Grasping, twisting, pushing, pulling latch and door	Lock mechanism, door	75 x 30 x 30 stand
Pressurize Airlock	Location & operational procedures for pressurization controls, displays & checkout hardware (manuals, checklists, labels, previous training)	Airlock pressurization operations	Pressurization hardware (valves, gauges, etc.)	75 x 30 x 30 stand
Doff Suit & PLSS	Location & operation of necessary buckles, snaps, etc. (previous training, labeling)	Remove suit and PLSS	Pressure suit, PLSS, benches, handholds	75 x 50 x 50 stand-sit-extend
Clean & Store Equipment	Location & operation procedure of cleaning hardware (manuals, checklists, labeling, previous training)	Identify cleaning requirements, perform cleaning, store suit and PLSS	Hangers, shelves, cleaning apparatus, lockers, suit dryers, etc.	75 x 50 x 50 stand-extend
Open Airlock/ Shelter Door	Location of lock & unlocking procedure (labeling)	Grasping, twisting, pushing, pulling latch and door	Lock release & door	75 x 30 x 30 stand
Egress Shelter	Height of step & body clearance (direct visual feedback)	Translation through opening	Hatch, handholds	75 x 30 x 30 stand
Close Airlock/ Shelter Door	Location of lock & locking procedure (labeling)	Grasping, twisting, pushing, pulling latch and door	Lock release & door	75 x 30 x 30 stand

3.5 HABITIBILITY CRITERIA

Having defined the requirements for habitability for each function, the next step is to develop habitability criteria or features of the shelter design which are developed from the requirements. The habitability criteria themselves comprise the important characteristics of each module for which design guidelines will be developed in the following section.

The habitability criteria are classified according to those associated with the configuration, materials and the environment. For each class, the criteria are:

- Criteria associated with configuration

  - free volume
  - compartmentalization
  - layout arrangement
  - use frequency/duration
  - growth potential

- Criteria associated with materials

  - furnishings
  - equipment operability
  - decor

- Criteria associated with the environment

  - illumination
  - temperature/humidity
  - noise

Each criteria is described and discussed on the following pages of this section.

Configuration

FREE VOLUME

One of the more important considerations in the determination of lunar shelter habitability requirements is the free volume needed by the crew for off duty and living activities. The primary effect on the man of insufficient free volume is overconfinement. As presented by Davenport et al (1963) overconfinement adversely affects human performance in three dimensions: the physical, physiological, and psychological. The primary physical effect is a reduction of the mobility envelope which restricts man's manipulative and control capability. The main physiological effect of overconfinement is physical debilitation such as cardiovascular anomalies and muscle atrophy. Psychological effects of overconfinement include anxiety, withdrawal, aggression, depression, and perceptual problems (hallucinations).

It has been generally agreed that the primary determiners of free volume are crew size, mission duration, and crew activities. Several investigations have been conducted where volunteers have been confined in an enclosure of fixed volume and measures of perceptual-motor performance and biomedical status over time have been recorded. Those studies conducted for orbital spacecraft applications (Manned Orbiting Laboratory, early space station), for missions of 30 days and two man crews, have recommended free volumes ranging from 90 to 260 cubic feet per man. The average of these estimates is about 150 cu. ft./man which in fact was the free volume recommended for the MOL in an analytical study performed by Matrix Research.

One problem with the estimates of free volume for spacecraft, aside from the wide variation in recommended quantities, is that crew activities are usually not considered. The operations performed by crewmen in a compartment or enclosure, with the duration of occupancy and number of men simultaneously inhabiting the area, comprise the most important determiners of required free volume. In an attempt to define free volume requirements for different activities, Davenport et al (1963) recommended the following volumes for a three man crew and a thirty day mission:

Activity	Free Volume (cu.ft./man)
Maintenance	30
Special mission operations	60
Crew personal operations	70
Locomotion and access	50
Sleep/privacy	25
Average	112

Estimates of free volume derived from orbital mission simulation studies are not directly applicable to lunar shelter design since in orbital flight the crew members are confined to the interior of the vehicle for almost all of the mission time, except for infrequent and relatively brief extravehicular excursions. On the moon a significant portion of the crewman's day will be spent external to the shelter exploring the lunar surface and retrieving samples. Since the lunar astronaut will therefore inhabit his shelter for less time than his orbital counterpart, and since he will also be afforded the opportunity for exercise and experiencing a varied visual scene, he will require less free volume in his enclosure then that estimated for orbital operations.

Studies which should approximate the lunar shelter conditions include submersible missions where crewmen egress the vehicle to perform underwater operations and actual simulation investigations of lunar shelter missions. Submersible studies which evaluated confinement include the cruise of the Ben Franklin and Tektite I while one of the very few carefully controlled lunar simulation studies was the Lunex II investigation conducted by Honeywell in 1966. This latter study had two men confined for 18 days in a simulated mobile lunar laboratory which provided 58 cubic feet/man. One half hour each day was spent outside the vehicle simulating lunar exploration.

Results reported from these investigations agree that a motivated crew can accomplish the specific mission in confined quarters without significant degradations in performance or biomedical status. Such findings have led some investigators to conclude that "for moderate periods confinement does not contribute directly to any perceptible decrement in the performance of complex tasks" (Davenport et al pg. 11). Such conclusions could easily lead a shelter design engineer to conclude a) that the 58 cu. ft./man free volume provided in Lunex was equally as effective as the approximately 200 cu. ft./man volume of the Ben Franklin and b) that, given a motivated crew, providing minimal free volume (at least down to 58 cu. ft./man) presents no problems for the crew.

In spite of reports of little or no effect of the confinement resulting from available volume, adverse effects were observed in several submersible and simulated lunar missions. These effects usually comprised problems in interpersonal relations and crew integration. In post mission debriefings, the crew of the Ben Franklin even complained of the inadequate free space provided them and the lack of privacy. Problems therefore do exist and the potential impact of such difficulties on future lunar shelter missions has yet to be determined.

Other problems identified in confinement studies such as those described above are that few if any investigations include free volume as an independent variable and that the measuring instruments seem to be insensitive to the social conflicts and psychological difficulties observed in the studies.

In the present study the approach taken in determining free volume estimates is to develop requirements at three levels; those which impact crewman safety, performance, and comfort. At the safety level determination is made of the free volume necessary to ensure safe completion of all nominal and contingency operations for each habitability function. At the performance level the volume required for successful completion of mission activities is defined. At the comfort level an estimate is made of the volume which is sufficient to prevent the occurrence of psychological stresses such as feelings of confinement and isolation. These levels are developed for each habitability function by considering the activities comprising a function and the duration and frequency of performing the function.

COMPARTMENTALIZATION

When all functions to be conducted within the shelter have been identified, requirements for segregating certain activities must be established. To date these requirements have been dictated almost totally by engineering considerations with no real investigation of crewman needs in terms of privacy, social interactions, locomotion etc. The present study attempts to develop shelter packaging concepts based primarily on crew requirements. These requirements are presented in three levels, safety, performance, and comfort.

Safety requirements to be considered for compartmentalization include:

Ease of emergency egress from the shelter: Inclusion of walls and partitions must not impede crewman escape from the enclosure.

Ease of locomotion: Locomotion within the shelter could prove difficult in the one-sixth gravity of the moon and should therefore be kept to a minimum.

Ease of communication: Use of walls and partitions should not interfere with reception of verbal warnings in emergencies.

Performance requirements include:

Effective use of available space: Walls provide areas for temporary storage of equipment.

Control of locomotion: Walls comprising corridors serve to confine the crewman while he is translating.

Control of lighting and noise: With several compartments lighting can be controlled for each which is not possible in a single compartment.

Comfort requirements include:

Needs for privacy: Psychological stress is reduced if a crewman is able to be alone for some period of time during the day.

Needs for social interaction: Provisions should be made for spending some off duty time with other crewmen.

Avoidance of feelings of confinement and isolation: The shelter design and the mission schedule should consider confinement problems. Feelings of isolation can be offset in part by providing varied visual stimulation with different functions, an approach which is difficult in single compartment shelters.

The problems which exist for free volume are the same for compartmentalization. Quantification of the crew requirements based on empirical data is impossible. Identification of specific problems itself is difficult. The report on the cruise of the Ben Franklin concludes that, for the 30 day mission and six man crew, both privacy and the separation of activity areas were inadequate. These conclusions probably were extracted from crew member opinions and comments. The Lunex II two-man crew felt that the 58 cubic feet/man single compartment available to them for their 18 day confinement study was adequate. The two man crews of the lunar module on both Apollo XI and XII expressed opinions that the single compartment free volume available to them for a stay of less than 24 hours was definitely not adequate. A method of defining, measuring, and scaling degrees of "adequacy" of compartmentalization is clearly required.

LAYOUT ARRANGEMENT

Layout arrangement of the shelter refers to considerations of interrelationships of separate areas and integration of equipment within a specific area. The requirements associated with layout arrangement include the need to reduce locomotion, to ensure ease of equipment accessability, and to provide for flexibility of equipment layout such that a crewman is given some freedom in modifying an existing arrangement.

While it is closely associated with compartmentalization, the layout arrangement criterion should assist in determining where to locate functional areas or modules within the shelter and how different areas are interrelated. In the development of each module the criterion produces guidelines in terms of packaging of equipment, storage areas, and working areas.

USE FREQUENCY/DURATION

In considering the requirements for shelter habitability the time spent at each function and frequency of performing function must be specified. In general, areas which are occupied for longer durations or with greater occurring frequencies should receive more attention. The estimates of duration and frequency made for each functional module serve as the basis for developing the integrated crew mission timelines. The timeline represents one of the essential steps in integrating modules into a complete shelter concept.

Factors which affect use frequency/duration of separate modules include the following:

Biological needs and diurnal cycles. There is a wealth of evidence to indicate that man usually eliminates waste 3 to 4 times a day and performs best when provided with at least six hours of uninterrupted sleep in a 24 hour period.

Work/rest cycles. To ensure adequate performance and safety during long periods of sustained exertion frequent rest periods should be interspersed in the work schedule.

Past experience. Schedules during lunar missions should generally conform to schedules which the astronauts are accustomed to, such as three meals a day, one sleep period a day, and one moderate to long period of actual work per day.

GROWTH POTENTIAL

While the shelter under consideration in this study is sized primarily for a two man 28 day mission, it must be capable of enclosing an additional crewman for periods up to a maximum of 90 days. The first impact of this growth capability is on free volume since an increase in crew size or mission duration must increase volumetric requirements.

Materials

FURNISHINGS

Furnishings required for each functional module must be designed for the 1/6 gravitational field of the moon and must require minimum space for storage, deployment, and actual use. Consideration of the gravity constraint led to the recommendation that all beds be designed such that sleeping surfaces are no higher than 18 inches from the floor. Furnishings were also evaluated to identify techniques of multiple use wherein the same physical component is used in different ways for different activities, thereby reducing the total volume required by equipment required for each habitability function.

An equipment list is presented with each function. This list identifies the general equipment type and not a specific equipment item. Characteristics of equipment are described in table 3 for each function for the levels of safety, performance, and comfort. Safety factors include potential hazards associated with equipment and furnishings. Performance factors include consideration of equipment design which should enhance performance. Comfort characteristics include aspects of furnishings which should reduce the occurrence and effect of stresses.

EQUIPMENT OPERABILITY

Operability is defined as the degree to which a design concept can be operated by men in a simple, safe, and timely manner. For the lunar shelter equipment operability considerations are important for the design of equipment which interfaces with man. The nature of this interface is defined by the activities performed by man with the equipment, which could include:

Unstowage
Assembly
Set up/preparation
Deployment
Calibration - adjustment
Checkout
Activation
Use
Deactivation
Disassembly
Stowage

Requirements associated with each activity which impact design of equipment must be specified. Where possible the requirements which can be identified based on existing knowledge are defined in this study.

DECOR

The decor of the shelter includes such characteristics as paint schemes and materials provided for decorative purposes. The importance of decor is to provide varied visual stimulation in different areas of the shelter.

Perceptual problems observed in confinement studies are usually attributed to sensory deprivation. As stated by Davenport et al (1963) the designation 'sensory deprivation' is actually a misnomer and a better description would be sensory invariance. According to these authors, it is reasonable to expect that perceptual aberrations experienced during periods of sensory invariance would be eliminated by providing sensory enrichment. This sensory enrichment is the objective of the shelter decor. As is the case of free volume, it is not as important for lunar shelters as for orbital space vehicles since lunar based astronauts do spend some portion of each day outside the shelter on the lunar surface where the visual field is, if not enriching, at least different from that experienced in the shelter.

Environment

ILLUMINATION

The most important determiner of the visual environment of shelter interior is the artificial illumination available. The shelter in all probability will not include windows to provide solar illumination or earth shine as a lighting source since such an approach would severely constrain the orientation and emplacement of the shelter structure. Important considerations for shelter lighting include the following:

Adequate general illumination must be provided for locomotion about the shelter and gross activities such as equipment deployment.

Sufficient directed or localized illumination must be delivered to work surfaces and areas where the perception of detail is required.

The spectral composition of the lighting must not interfere with detection of color coded alarm indicators and with adaptation levels while exterior to the shelter.

The lighting must be located to avoid performance degradations due to glare and non uniformity of brightness levels.

The lights themselves must be designed to ensure their accessibility for maintenance. They must also be designed to avoid breakage in the event of their being contacted by the astronaut's body.

The field of illumination of each light must be as large as possible to minimize the total number of lights required while at the same time ensuring uniform illumination of shelter surfaces.

Back-up lighting systems must be provided for the situation of power failure or primary lighting system failure.

Lighting controls must take into account the light levels required for each function (minimal for sleep) and those required for emergency conditions (i.e., situations requiring rapid egress from the shelter).

Lighting must be considered in the development of requirements for shelter decor, shelter furnishings, and equipment operability.

TEMPERATURE/HUMIDITY

An important determiner of crew comfort and even crew performance in confined areas is the ambient temperature. One of the crew complaints reported for the Ben Franklin mission was that temperature and humidity of the vessel interior was too extreme for crew comfort.

Whenever optimum temperature levels are being specified, humidity extremes must also be described. Usually humidity does not present problems if maintained within 30 to 70 percent. Temperatures at levels where adaptation is not complete usually create problems for comfort first and for performance only after some period of time or if levels become more extreme. Even at levels where only comfort is supposedly affected, temperature impacts performance since it seems to distract the crewman's attention from the task at hand.

In terms of human response to temperature two types of temperature can be identified: the ambient temperature which comprises the general environment of the man; and surface temperature which affects man only when he touches a physical object. Surface temperature in the shelter will probably not pose much of a problem given that walls which enclose the interior of the structure from the external temperature extremes are designed to impart a temperature to the touch which is within the limits of the ambient temperature. Ambient temperatures in the shelter must be uniform throughout the interior and must be controllable, within limits, to meet requirements for the comfort of the crew.

NOISE

It is not clear at this time just what the noise levels within the shelter will be or what will be the primary noise sources. Maximum levels of noise intensity are specified for each habitability function which are selected to avoid damage to the ear, and prevent interference in the reception of verbal communications and warning tones. Means of controlling noise are also described in this report which include isolation of sources and sound proofing of areas where levels should be minimal (sleep modules).

3.6 DESIGN GUIDELINES FOR EACH MODULE

Module design guidelines were developed for each function by *ordering* requirements for each habitability criterion measure along three levels of effectiveness: safety, performance, and comfort. Safety comprises design guidelines essential to protect astronaut life and physical well-being. Performance includes the guidelines required to facilitate his performance of habitability or mission functions. Comfort includes the design features which minimize the probability of stress acting on the astronaut. Stress here implies psychological, physiological, and physical stress.

Design guidelines are presented on the following pages for each habitability module. These guidelines essentially include recommended design approaches to satisfy requirements associated with specific habitability criteria for each module. Whenever possible the guidelines are expressed in quantitative terms and, where numerical limits are not available or appropriate, in descriptive text.

Nourishment

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Serves to contain fires. Should not hamper quick egress.	Provides walls to support equipment-tables-storage areas.	Provides different visual field.
	Volume	81 x 30 x 30 or 42 ft³/man.	81 x 60 x 40 or 113 ft³/man.	
	Layout arrangement	Area laid out for rapid egress.	Two men dine simultaneously to reduce set-up/clean-up time.	Two men dine simultaneously. Good time for companionship.
	Use-frequency/duration	At least once a day.	Three times/24 hours - 30 minutes per period.	Three times/24 hours - one hour per period.
	Growth potential		Consider fabricating some functional equipment/furnishings from edible material.	Max of two men dine at a time. Switch off pairing of dining mates.
MATERIALS	Furnishings	Non abrasive-cutting-breaking. Designed not to trip crewman or to tip over.	Table for eating, drinking. Platform to hold utensils, storage containers. Heating area to heat food. Storage areas for equipment, food wastes. Chair-bench-seat.	Use padded seats with arm, head, back and leg rests.
	Equipment operability	Reduce chances of fire, electric shock, abrasions, use of non-digestible materials, burns. Non-fracturing materials should be used. High-temperature areas should be enclosed.	Food preparation should be quick, simple, with minimal steps. Mixing, blending, etc., completed prior to flight to the extent possible.	Utensils should enable segregation of foods. Storage for 2.5 lbs food/day, 1.5 liters liquid/day for each man.
	Decor	Non-flamable materials.	Color coding for storage areas.	Color code entire area-color walls differently from other areas. Use warm colors-yellow, rose, pale orange.
ENVIRONMENT	Illumination	Indirect lighting. White lighting to avoid confusion in reading color codes. At least 10 ft c.	10 - 30 ft c variable.	10 - 50 ft c variable.
	Temperature	55° to 80° F.	65° ± 10° F.	
	Noise	Max intensity 120 db.	General level less than 50 db.	Level less than 20 db.

Sleep

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Presence of walls should not significantly decrease time required to egress the area and move to airlock, work station or to the assistance of another astronaut.	Use of walls to support equipment-racks-beds.	Individual compartments provide privacy and noise control. Compartments also allow individual temperature control.
	Volume	If sleep area will be used for medical care, must accommodate *two men simultaneously - one* in bed and one next to bed. Min vol 81 x 50 x 72 - 281 ft^3.	One-man area 202 cu ft 81 x 60 x 72 *Two-man area 304 cu ft* 81 x 90 x 72	One-man area 255 cu ft 81 x 72 x 76 *Two-man area 383 cu ft* 81 x 108 x 76
	Layout arrangement	Furnishings should not interfere with rapid egress. Reduce obstacles, obstructions in traffic pattern.	Minimize locomotion requirements by centrally locating all equipment near the bed.	Heads of sleepers should be separated sufficiently to reduce disturbing effects of snoring, etc., yet be close enough that each astronaut can be heard by the other in an emergency.
	Use-frequency/ duration	Alternate sleep periods to ensure that one astronaut is awake at all times.	Simultaneous sleep periods to maximize time when both crew members are available. Minimum of 6 hrs once every 24 hrs.	Simultaneous sleep periods to reduce noise levels. Eight-hour sleep period once every 24 hours.
	Growth potential 3 men, 90 days		Need a third sleep area if all three men sleep simultaneously	
MATERIALS	Furnishings	Storage areas should be accessible without extensive reaching or bending.	One bed per man. Personal bed clothing. Storage area for bed clothing, personal clothing. Caution/warning panel to alert the sleeping astronaut. Alarm and clock for normal arousal.	
	Equipment operability	Top of bed should be no more than 16 in. from the floor to facilitate rapid egress. Non-abrasive, non-cutting surface.	Deployment-set up operations-simple. No forces greater than 25 lbs. One-man operation.	Operations should be familiar.
	Decor		Use matte wall-ceiling surfaces to reduce glare.	Use restful blues, greens, or browns. Identify storage areas, drawers, etc., with color coding.
ENVIRONMENT	Illumination	Maximum illumination level in area for waking operations - 80 ft c. Minimum during sleep periods - .5 ft c to ensure sufficient light for egress while not interfering with sleep. Use indirect lighting to avoid body/bulb contact. Use white lighting to avoid confusion of color codes.	Lighting to all parts of area for clean up tasks. Lighting level adjustable via rotary control coded for different levels. Use indirect lighting to avoid glare. Position light control to be accessible from the bed. Position the light to deliver 50 ft c to the bed area for reading while in bed. Provide control for emergency lighting adjacent to the bed.	Illumination variable from .5 to 100 ft c. Indirect lighting.
	Temperature	Should never exceed 85° F or be less than 50° F.	Should not exceed 75° F or be less than 55° F.	65° ± 10° F adjustable. Humidity between 35 and 70%.
	Noise	Maximum intensity - 120 db.	Maximum of 85 db should not interfere with sleep if constant (non intermittent and unvarying frequency).	Maintain levels less than 25 db with minimum changes in amplitude/frequency. Consider use of music to mask noises of equipment hum, etc. Consider rugs to dampen noise.

Waste Elimination

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Must not impede emergency evacuation.	Use of walls to support equipment - contain odors.	Provide privacy during elimination.
	Volume	81" height 30" length 30" width.	Allow space for reaching 81 x 60 x 30.	Allow freedom of movement while adjusting clothing - handling storage equipment 81 x 60 x 40
	Layout arrangement	Area laid out for quick egress.	Area should be dedicated and not shared with any other area. Area contains waste disposal interfaces, temporary storage, and body/area clean up equipment. Area contains racks for clothing & lighting/noise/odor controls.	Area should be located adjacent to the sleep area and, if possible, the hygiene area. Consider use of permanent waste storage for other shelter expendables/wastes-paper waste, hair-nail clippings.
	Use-frequency/duration	Crewmen should not have to rush to eliminate or rush through the act of elimination.	Urination duration 9 to 47 sec. Urination frequency 4 to 6 per day. Defecation duration 1 to 3 min. Defecation frequency 1 to 3 per day.	Elimination area should be available within 5 minutes. Means should be provided to inform one crewman in the area that another crewman desires entry.
	Growth potential		Increase waste storage provisions.	
MATERIALS	Furnishings	Avoid sharp corners.	No need for individual equipment-interfaces and temporary storage containers-disposable.	
	Equipment operability	Interfaces should be quick disconnect in the event of emergency. Interfaces should not severely limit body movement since such control could be difficult in the 1/6 g environment. Permanent storage should be remote from all living areas to decrease chances of contamination.	Temporary storage must contain 600 ml of urine and .3 lbs of feces for each elimination. Permanent storage must be sized for 2 liters/day urine .6 lbs of feces/day (wet) Temporary storage containers should ensure that no wastes remain on the body or in the area. Measuring devices should be integrated with storage containers.	Temporary storage must contain odors and ensure no contact between astronaut's hand and wastes. Shift from temporary to permanent storage should be automated. Wipes should ensure against hand-waste contact. Cleanup methods other than hand wipes should be investigated. Permanent storage containers should be remote from all living areas to decrease odors.
	Decor		Due to short occupancy per period - no special problems. Select paint to reduce glare.	Color code controls, storage areas, instructions. Restful color scheme - blue or green.
ENVIRONMENT	Illumination	Sufficient to safely perform all operations - 20 ft c. Indirect recessed lighting to avoid body-light contact. Use white lighting to avoid confusion of color codes. Provide backup light in event of failure.	Lighting to all parts of area for cleanup - variable from 20 to 60 ft c. Indirect lighting to avoid glare. Consider short duration blinking of lights as alarm signal from working astronaut.	Lighting variable from 20 to 80 ft c. Indirect lighting.
	Temperature	Between 50° and 85° F.	55° to 75° F adjustable.	Humidity 35 to 70°.
	Noise	Should not mask alarms. Maximum intensity 120 db.	Noise associated with waste elimination equipment should be of short duration - maximum of 85 db.	Maintain noise at less than 25 db.
	Odor control			Temporary storage should enclose wastes and gases.

Rest and Relaxation

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Walls should not affect emergency communications among crewmen nor impede one crewman assisting the other. There is no safety requirement for walls.	Walls for noise control-can be achieved by other methods, i.e., ear phones, plugs, etc. Walls for mounting handholds, equipment racks.	Provide a period of privacy for the crewman. Provide a visual field different from the work area. Remove crewman from field of view of other crewman.
	Volume	Walls should not confine to the extent of causing injurious impact. Minimum size for safety-resting mode-seated 81" height, 40" width, 30" depth - 56 ft^3/man.	Area should include provisions for exercise 81 x 50 x 50 - 122 ft^3. 2-man simultaneous exercise - 480 ft^3. 2-man seated relaxation - 245 ft^3.	Area should provide for active games 81 x 84 x 84 - 343 ft^3.
	Layout arrangement	Area laid out to facilitate rapid egress or assistance from another crewman. Obstacles in the traffic pattern should be minimized.	Minimize locomotion requirements in resting mode. Locate control console near the chair for: Environment control Film-tape controls Caution/warning-alert indications	Provide for privacy of individual crewman.
	Use-frequency/ duration	Short rest periods must be integrated into timeline especially during heavy physical activity and immediately following EVA. Period duration - at least 5 minutes. Actually depends on work difficulty and duration.	An extended R & R period should be scheduled once a day for at least two hours.	Integrate light, mission-related work with R & R and extend period to 4 hours with rest breaks interspersed throughout day.
	Growth Potential 3 men-90 days		Provide furnishings for 3 men to relax simultaneously.	
MATERIALS	Furnishings	Chair-bed design should not impede rapid egress.	Provide furnishings for 2 men to relax simultaneously.	Provide means for individual or group relaxation.
	Equipment operability	Use of excessive force (greater than 25 lbs.) should be avoided in setting up equipment. Use of breakable material should be minimized. Non-abrasive, non-cutting surfaces should be used. Walls-ceiling-equipment should be padded if extensive body motions are required.	Setup should be a one-man operation. Minimum number, complexity, time to perform: Unstow/stow Unpackage/package Deploy assemble/disassemble Activate/deactivate Use Maintenance	Operations should be familiar. Chairs for resting should facilitate resting - padded, contoured, arm, head, leg rests. Control of lighting, noise, temperature should be provided at the chair.
	Decor		Use matte wall-ceiling surfaces to reduce glare.	Select wall color different from that used in other areas. Use restful blues, greens, or browns. Identify storage areas, etc., with color coding.
ENVIRONMENT	Illumination	General 10 ft c minimum. Indirect lighting to reduce body-light contact. White lighting to avoid confusion with color codes.	Variable 0 to 50 ft c general area. 0 to 100 ft c directed light-reading, etc. Indirect lighting to avoid glare.	Use indirect lighting - soft white.
	Temperature	Limits 85° and 50° F.	Adjustable between 55° and 75° F.	Adjustable between 55° and 75° F. Individual R & R area control separate from controls at other areas.
	Noise	Maximum intensity 120 db.	Maximum of 25 db during rest, 35 db during recreational activities.	Less than 25 db. Use rugs on floor to dampen noise. Confine noise.

Hygiene

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	For first aid functions-enable isolation of area from remainder of shelter.	Walls provide mounting for handholds, racks for hanging clothing and layout of equipment.	Period of performing hygiene functions a good time to provide privacy.
	Volume	95th percentile man stature about 73 in. Add 2 in. for clearance. 75 in. minimum ceiling height. Allow 6 in. more to account for over-reactions in 1/6 g environment. Ceiling height 81 in. Walls shouldn't confine to the extent to cause injurious impact. Minimum size for safety 81 in. height, 40 in. depth, 30 in. width, 56 ft³/man - one-man operation. For two-man operation (first aid) 405 cu. ft.	Objects on three walls should be accessible to the man standing in one spot. ∴ width is 68 in. and depth is at least 35 in. with height to 81 in. Free volume is 112 ft³ for one-man occupancy.	Enough space should be provided to allow the man one step to each side and one step backward from the worksite. This requires an area width of 80 in. and a depth of 65 in. Free volume of 244 ft³.
	Layout arrangement	Area laid out to facilitate emergency egress. Minimize obstacles and obstructions in traffic pattern.	Minimize requirements to maneuver about the area. Most activities should be performed at single worksite. Most activities require accessibility to water supply.	
	Use-frequency/duration	First aid - as required.	Three periods per day, one of which will include whole body cleaning which should follow periods of excessive activity (EGA) and should last 15 minutes.	Whole-body bathing, shaving, hair/nail, ear care once every 24-hour period - 30 min./man. Washing, teeth cleaning three times a day - 10 min./man.
	Growth potential to 3-man, 90-day	Except possibly for first aid functions, all hygiene functions should require only one man in the area at a time. Therefore, the addition of a third man or extension of mission duration to 90 days will have little effect on the hygiene module.		
MATERIALS	Furnishings	Electrical outlets and wires should be guarded. Furnishings should not have sharp corners or edges Table areas should be waist high for easy access to equipment and to avoid tripping.	Water dispensers should be coded to display quantity remaining. Chair should be provided for seated activities-removal of shoes, foot care.	Storage areas should be coded to facilitate identification of personal equipment. Personal equipment (razors, etc.) should be coded. Wastes should be packaged for easy removal.
	Equipment operability	Lights should be designed to minimize body/bulb and body/wire contact. Use of force greater than 25 lbs. should be avoided. Use of breakable materials should be minimal. Electric shock hazards should be eliminated. Non-abrasive, non-cutting materials should be used.	One-man operation. Minimum number and complexity of operations for: equipment unstowage/stowage deployment/breakdown assembly/disassembly use	Operations should be familiar.
	Decor	Ceiling should be padded if there is any possibility of contact due to overreactions in 1/6 g environment. Wall texture should be smooth and non-abrasive.	Use matte surfaces to reduce glare, reflectivity of 20-40%.	Colors shall be selected to reduce tension and feelings of confinement. Use yellow or brown - highly saturated.

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Hygiene (cont.)

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
ENVIRONMENT	Illumination	Whole-area illumination to reduce contact with obstructions. Adequate lighting for reading labels, etc. General Illumination min. of 10 ft c. Directional illumination for reading, shaving, etc. At least 50 ft c. Indirect lighting reduces probability of body-bulb contact. Provide emergency lighting to facilitate safe area egress in the event of a lighting failure.	Use white light to identify color codes and for most rapid light adaptation. Use indirect lighting to avoid glare. General illumination levels for area cleanup minimum of 40 ft c. Locate on/off control, if required, at area access.	Provide brightness adjustment controls.
	Noise	Maximum noise intensity no greater than 120 db for short durations (5 minutes).	Maximum noise level 95 db.	Maximum noise level 60 db.

Locomotion

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Passageway walls must not inhibit escape of crewman. Passageways easier to keep clear than free space routes.	Passageways serve to channel locomotion.	Passageways provide more orderly locomotion. Also provide differing visual stimulation.
	Volume	Ceiling height minimal 81". Consider passageway ceiling of 84" to ensure that overreactions while walking do not cause contact with ceiling. Padded ceiling-padded top of access.	Width optimal for contact with 2 handholds on either side - 40".	
	Layout arrangement	Passage free of obstructions.	Passage-minimal number of turns-minimal length.	Convex ceiling.
	Use-frequency/duration	Use should be minimized due to potential hazards.	Use should be minimal due to energy expenditure.	Use should be minimal for convenience.
	Growth potential	No problems.		
MATERIALS	Furnishings	No obstructions in the passageway.		
	Equipment operability	Handrails should be provided to offset exaggerated motions in 1/6 g.	One horizontal handrail on each side, and running the full length of passageway.	Handrails waist high - 45" above floor. Rectangular in shape.
	Decor	Use material covering or padded walls to reduce chances of injuring the hand while using the rail.	Color code accessways to different locations. Use low reflectance materials.	Provide rug or other floor covering for locomotion in bare feet.
ENVIRONMENT	Illumination	Minimum of 20 ft c at all times. White light. Indirect lighting to avoid contact. Provide emergency lighting.	Illumination controlled from 20 to 40 ft c. All areas of passage illuminated. Indirect lighting to reduce glare.	Soft white light.
	Temperature	Between 50° and 70° F.	65° F ± 5°.	
	Noise		Ensure that locomotion noises are not distracting at work area.	

Housekeeping and Personal Equipment Care

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization		Use partitions for storage of housekeeping & personal equipment care devices. Design of housekeeping equipment must be considered.	Requirements for privacy and varied visual stimulation.
	Volume	Envelope large enough to ensure freedom of movement.	All equipment should be accessible.	Prevent feelings of confinement-isolation.
	Layout arrangement	Obstacles in traffic pattern *should be minimized.*	Provide equipment hangers, work *surfaces & associated equipment* in functional grouping to reduce reach & translation time & effort. Should permit efficient traffic flow through area.	Provide seating and body support *as often as possible while* performing functions.
	Use-frequency/ duration	Sufficiently often to control contaminants	Minimize requirements for housekeeping and equipment care to maximize time allowed for mission activities. Perform every 3 days.	Minimize requirements to reduce mobility requirements and energy expenditures.
	Growth potential 3 men - 90 days	Determine affects of adding third man.	Modify housekeeping and equipment care schedules - once every day.	Assign one man to these activities.
MATERIALS	*Furnishings*	*Must not encumber or intrude* into traffic patterns.	*Should provide facilities for* inhabitants to sit, steady themselves, & work surfaces where possible. Should be easy to clean & care for. Should accommodate up to 3 men.	*Should minimize requirements for* bending over, stooping, kneeling, while housekeeping.
	Equipment operability	Should not require operational forces greater than 25 lbs or present danger from electrical shock, chemicals or puncture.	Should be of minimum complexity & require only one man to operate, set up, store, etc.	Tools should be designed to operate in man's most comfortable posture, i.e., limbs in most relaxed position.
	Decor	Should be non-flammable, non-fouling, non-abrasive, etc.	Matte wall-ceiling surfaces for homogenous lighting & reduced glare.	Consider providing capability of periodically changing decor.
ENVIRONMENT	*Illumination*	*10 ft c indirect white light* minimum.	*10 - 100 ft c variable indirect* white light.	*Indirect, variable, non-glare,* between 10 - 100 ft c.
	Temperature	Limits 50° and 80° F.	Adjustable between 55° & 75° F.	Same as performance.
	Noise	Maximum Sound Pressure Level (SPL) 120 db.	Below 95 db sustained SPL. Below 120 db brief SPL.	Between 40 - 60 db SPL.

Airlock

	AREA CHARACTERISTICS	SAFETY	PERFORMANCE	COMFORT
CONFIGURATION	Compartmentalization	Crew should not be separated during suit donning so that each may get assistance from the other in emergencies.	Single compartment airlock allows astronauts to assist each other in suit donning/doffing.	Maximum comfort will be achieved in an airlock with no interior compartmentalization.
	Volume	Airlock should accomodate 2 *astronauts at the same* time in pressurized suits. 81" high, 60" wide, 60" long (free volume).	Airlock free volume should *be free of obstructions* which impede suit donning/doffing.	81" high, 60" wide, 90" long.
	Layout arrangement	Must facilitate rapid emergency ingress/egress.	Provide handholds & work surfaces against which to lean or rest gear while preparing to enter or exit shelter.	Should limit movement while suited to a minimum.
	Use-frequency/duration	Will be utilized each time inhabitants enter or exit shelter for purpose of donning or doffing suit and other life support gear.	Should allow 30 minutes for suit donning/doffing.	Up to 45 minutes should be allocated for suit donning/doffing.
	Growth potential 3 men - 90 days	Should provide facilities for three men to don and doff suit simultaneously.	Should provide facilities for two men to don and doff suits simultaneously.	Should provide facilities for one man to don and doff suit
MATERIALS	Furnishings	Should not present hazards over which inhabitants may stumble or which could cause injury or suit damage through impact, puncture or abrasion.	Make provision for shelter inhabitants to sit, steady themselves & have access to work surfaces or shelves while suiting or unsuiting (2 men simultaneously).	Furnishings should be designed to prevent the astronaut from having to bend, stoop, or sit.
	Equipment operability	Should not require greater than 25 lbs force. *Design handholds, handles, etc.* to be operable in suited condition. No rough or abrasive surfaces. Pad walls, ceilings & equip. Should be operable by one man.	Keep complexity of equipment operation to a minimum & *design to operate within* limits of suit movement. Provide means to clean suits and equipment of lunar dust.	Position so that extensive repositioning of limbs & *torso is not required.* Provide means of keeping the airlock free of dust.
	Decor	If any, should be non-fouling, puncturing & abrasive.	Use matte wall-ceiling surfaces to reduce glare. Color code equipment storage by function.	Color code each astronaut's suit storage area.
ENVIRONMENT	Illumination	10 ft c minimum. Indirect white light.	Adjustable to 100 ft c for maximum acuity and speed. Uniformly illuminate all areas.	Use indirect, soft white.
	Temperature	Ambient - limits 85° and 50° F. Surface - 65° ± 5°.	Ambient - Adjustable between 55° and 75° F.	Keep humidity between 30 and 70 percent.
	Noise	Maximum Sound Pressure Level (SPL) 120 db.	Sustained levels should be below 95 db. Brief levels should be kept below 120 db.	SPL should be kept at 40 - 60 db.

3.7 SOCIAL INTERACTION REQUIREMENTS AND INTERPERSONAL RELATIONS

The social interaction requirements which result in habitability design guidelines have been neglected in the foregoing sections due mainly to the ambiguity associated with such requirements. This ambiguity in large part results from the fact that the adequacy of interpersonal relations during confinement is much more of a function of the personalities of the participants than the design and layout of the enclosure. Another problem in identifying and describing interpersonal conflicts during confinement studies is the tendency for investigators to avoid discussing such difficulties in the report since the participants are known to the scientific community. A third problem is the fact that degrees of interpersonal cooperation are not easily qualifiable and existing measures such as psychological tests are suspect due to their inapplicability and low validity.

Although social interaction requirements were not adequately considered in this study, for the reasons stated above, they were identified in the few areas where sufficient adequate research has been conducted. Areas included in these considerations include:

Privacy versus social interaction
Need for sensory enrichment
Territorial behavior

In terms of privacy vs. social interaction, Celantano and Amorelli (1963) cite research which demonstrates that cramped living quarters, with little privacy, can cause fatigue and poor morale with a consequent reduction of performance efficiency. A U.S. Navy habitability survey (1953) reported that adequate space and privacy are important factors in the maintenance of morale.

On short missions crews can operate with a minimum of privacy as demonstrated by a 14 day Gemini mission and the 18 day Lunex simulation. In both situations two man crews lived and worked together in enclosures which placed them in extremely close physical proximity with very little privacy. Based totally on these two situations it is evident that two men crews can endure an almost total lack of privacy with little discernable debilitating effect. This absence of privacy however applies to physical privacy, i.e. minimal isolation of one crew member from the presence of the other for a significant time. A second type of isolation can be conceptualized which will be termed psychological privacy. Psychological privacy refers to the state in which the individual is not required to actively cooperate or communicate with other crew members and mission control and is free to pursue individual activities which may be operative, informative, or contemplative. In the absence of physical privacy the needs for psychological privacy must increase, however, it is not possible to ascertain from present knowledge the frequency and duration of private periods during the day. It is evident however that for two man crews the periods will coincide at least to the extent that reducing inter-crew communications for one crew member has the same effect on the other. Work periods should not be considered private periods due to the need for sharing information and consultation.

The periods immediately prior to and following the sleep period should be designated private periods and this procedure is assured by physically isolating the crewmen by means of a wall, curtain, or other means of removing one crewman from the visual field of the other. Voice communication should be possible however which lends support to the use of curtains rather than rigid sound deadening walls. However, some degree of sound attenuation must be maintained to reduce sounds of one crewman moving around or of equipment operating through the sleep period.

It is recommended that the sleep area be segregated from the rest of the shelter by means of walls or curtains. This provides for a change in visual environment when the crewman enters the area and also is consistent with his past experience wherein sleep was had in an enclosed space rather than in a relatively open area where other daily activities are performed.

The need for sensory enrichment during isolation follows from a desire to avoid restricting the mind as well as the body. Sensory deprivation studies have demonstrated that placing severe constraints on the availability of sensory stimuli has definite adverse effects such as impaired thinking, immature emotional responses, disturbed visual perception, and marked alterations in brain wave activity. These studies support the psychoneurological tenant that normal brain function depends on continual arousal action and fairly constant sensory bombardment. Sensory stimuli have the general function of maintaining arousal and lose this capability if limited to the monotonously repeated stimulation of an unchanging environment.

Based on the requirements for sensory enrichment a multiple compartment shelter is to be recommended over a single room enclosure with the decor of individual compartments providing significantly different visual stimulation. Such an approach was evaluated with some success in Tektite I where different color wall paints were used for different activity areas. The lack of such differentiation was cited in the Ben Franklin as a source of problems.

One significant source of sensory enrichment is the presence of and interaction with other men in the environment. This providing for social interaction has the dual purpose of supplying needed group relationships and of increasing sensory stimulation.

In terms of territorial behavior research results indicate generally that men in socially isolated groups show a gradual increase in territorial behavior and a pattern of social withdrawal which is reflected in increased time spent alone rather than in joint activities. There is a developmental sequence of territorial behavior with fixed geographical areas and highly personal objects subject to jurisdictional control first, and more mobile less personal objects later.

Research results also demonstrate that living in a confined, isolated environment stimulates man's need for human interaction, group involvement and co-habitability. Thus while the isolated subject has a need to define certain areas and objects as his own, he also has the need to participate in group activities which might involve sharing of his territory or furnishings.

4

4.0 DESIGN

Each area module has specific design characteristics. These characteristics are function dependent configurations, materials, and environments. The next step is to design these area characteristics utilizing the information given in the area guidelines. Safety comprises the design guidelines essential to protect astronaut life and well being. Area modules designed to this measure of criteria will only allow for the astronaut's ability to return to earth safe with no harmful effects. This does not assure mission completion. Performance includes the guidelines required to facilitate the astronaut's execution of habitability and mission functions. Area modules designed to performance criteria will assure the completion of the total mission. Comfort includes the guidelines which will minimize the probability of psychological, physiological, and physical stress acting upon the astronaut.

The design approach of the modules is similar to the criteria. Designs are function dependent upon the criteria associated with configuration, materials, and environment of the area module, that is, a methological approach. Within limits, all possibilities must be considered. How many possibilities are there in which two beds can be arranged within an area? How many possibilities if the two are to be separated? What is the growth potential of the arrangement, a third astronaut? All possibilities for material and the environment should also be considered. Refer to area guidelines for the design criteria.

4.1 NOURISHMENT MODULE

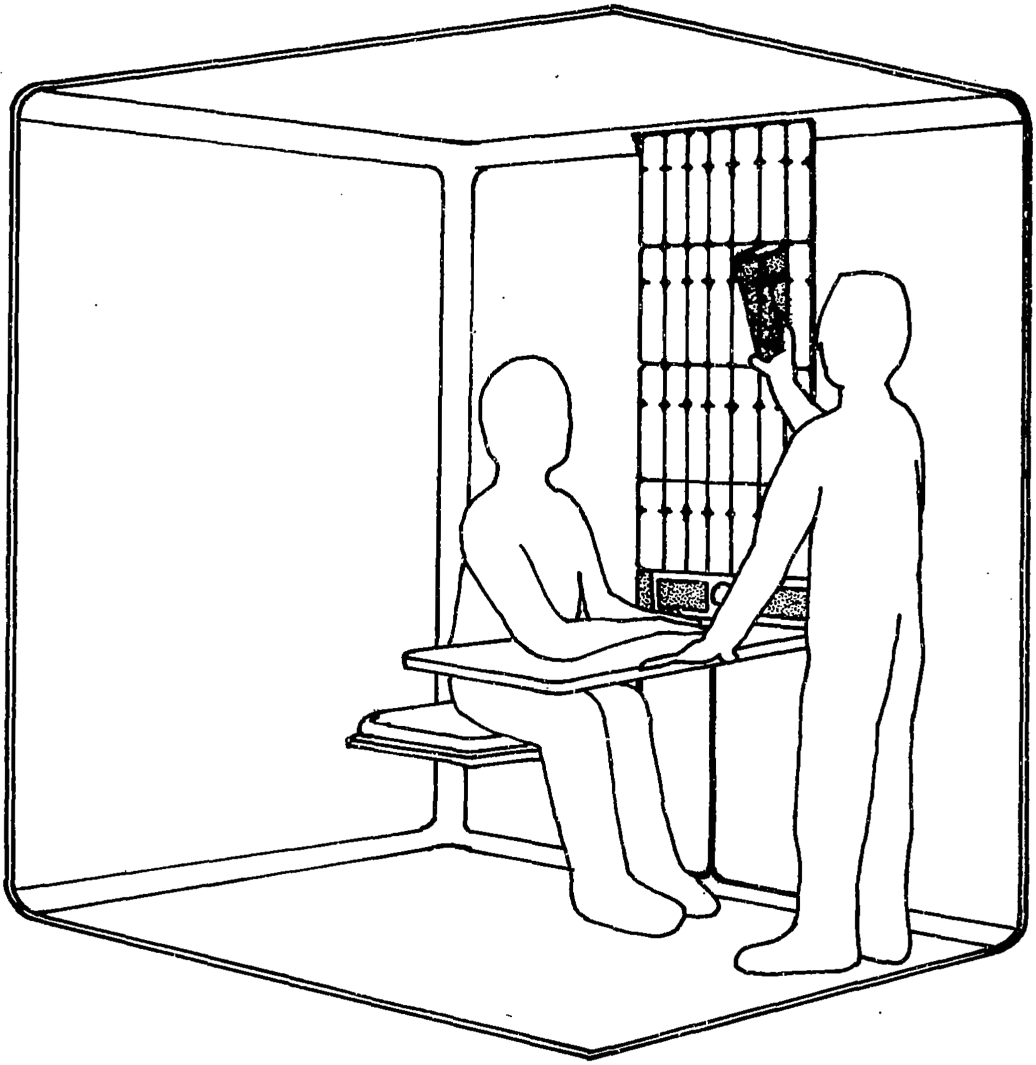
NOURISHMENT MODULE CONTENTS

The nourishment module must contain the following items:

- Chairs
- Tables
- Heating Unit
- Hot Pads
- Napkins
- Paper Towels
- Storage
- Food Freezer
- *Food Mixer
- Food Chillers
- Container for measuring intake
- Food Cabinet
- Food Storage Containers
- Seasoning
  - Salt
  - Pepper
- Eating Utensils
  - Knife
  - Fork
  - Spoon
  - Cup
  - *Plate
  - Napkin
- Preparing Utensils
  - *Preparing Trays
  - *Heating Pans
  - *Serving Spoons & Forks
  - *Serving Knives
  - Paper Towel
- *Unpacking Aids
  - Scissors
  - Knife
  - Openers
- *Waste Receptacle for food waste
- *Waste Receptacle for paper wastes

*Notice that the food container concept alleviates these items.

MODULE

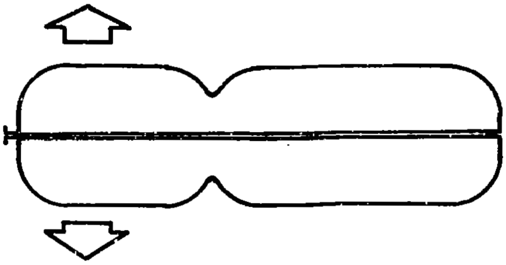


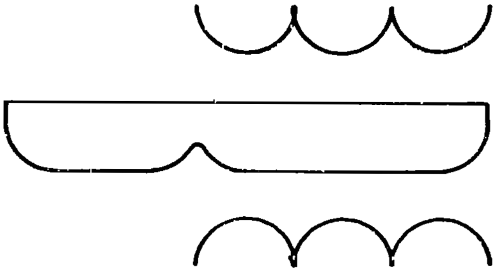
NOURISHMENT PACKAGE

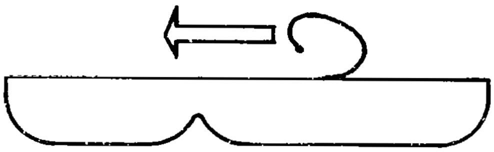
Pictured as a design concept is a food storage container that will be stored in order of meals, that is, all breakfasts together and all dinners together. This will provide the astronauts with a choice at most meals.

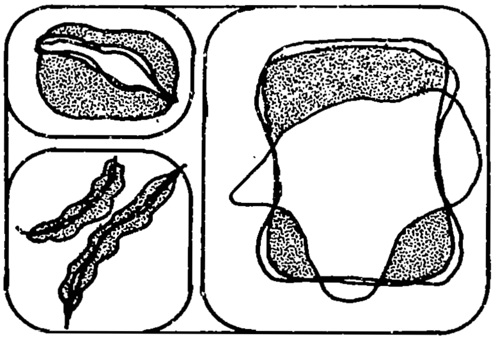
The package is two full meals, it is separated by pulling apart and then each plate on container must be either thawed or reconstituted. Directions for amount of water and time will be printed on each container, but an effort should be made to standardize this. After reconstitution the remaining water should be poured through a filter and into the reconstitution tank. The container should be made of such a material that it can be heated in part or whole. Simply zip off foil protector to reveal warm meal. When the meal is complete, left overs, utensils and napkins should be placed into the dishes which are then snapped together making them seal tight. They should then be placed back onto the shelf. They should be noticeably different than the fresh package.

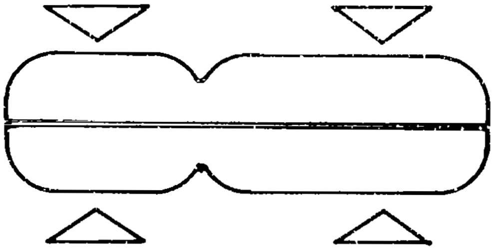
CONCEPTS









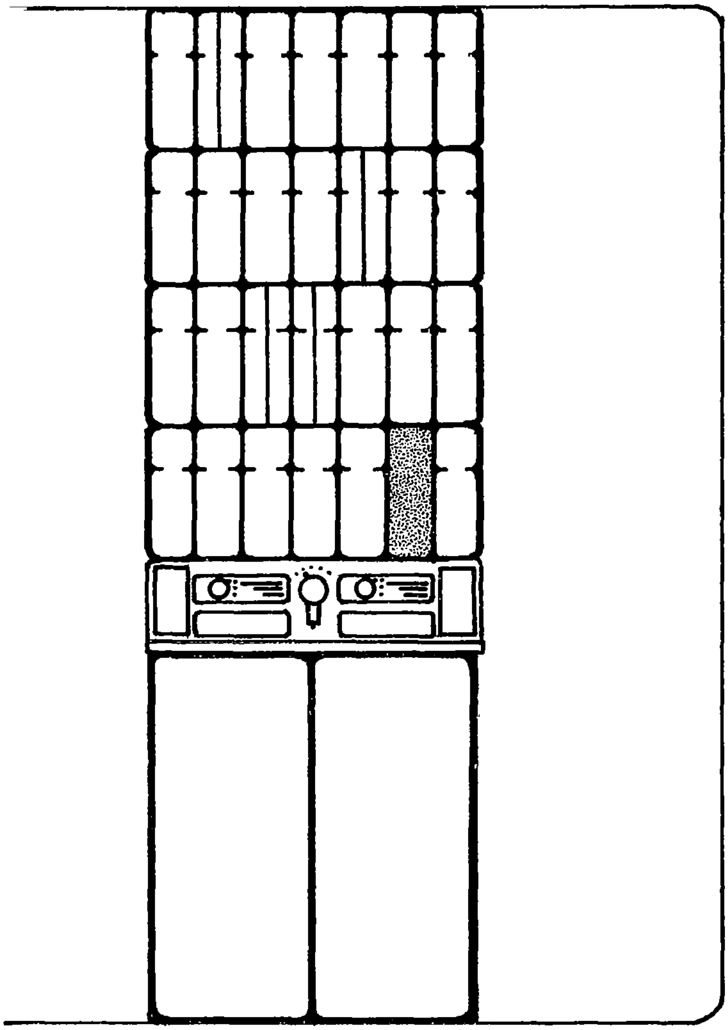


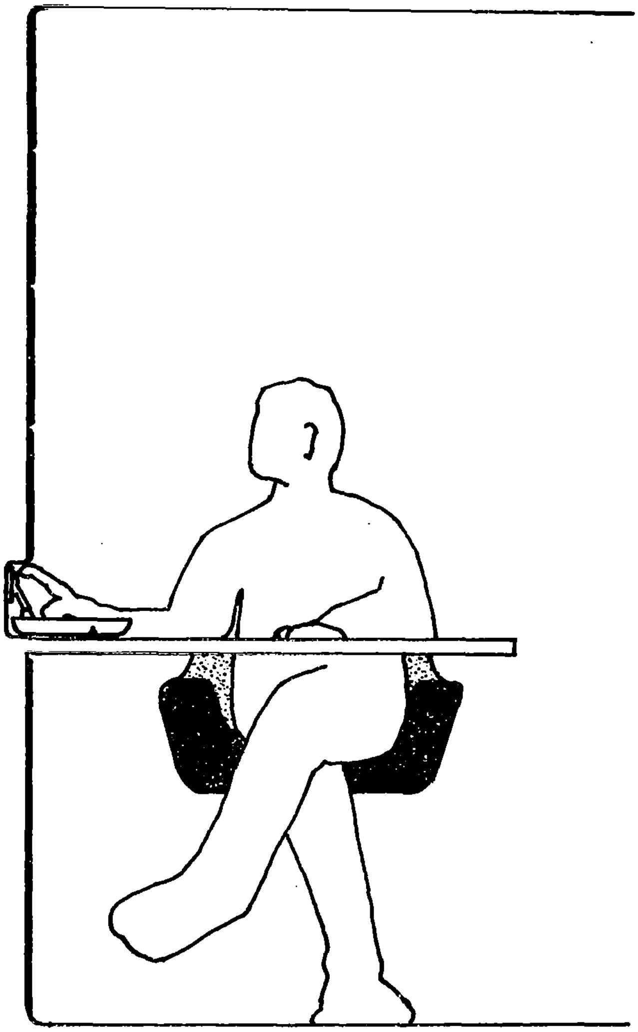
NOURISHMENT WALL

Meal containers, preparation area, and dining table and facilities should be at one locale. This is so that the preparation activities are kept at a minimum.

The total wall concept provides a pull-down dining table which exposes the stored food containers, preparation equipment, several liquids with metered flow, heaters and utensils. The containers with the line indicators are completed meals and leftovers stored in the nourishment package. Below table height is emergency food storage.

WALL



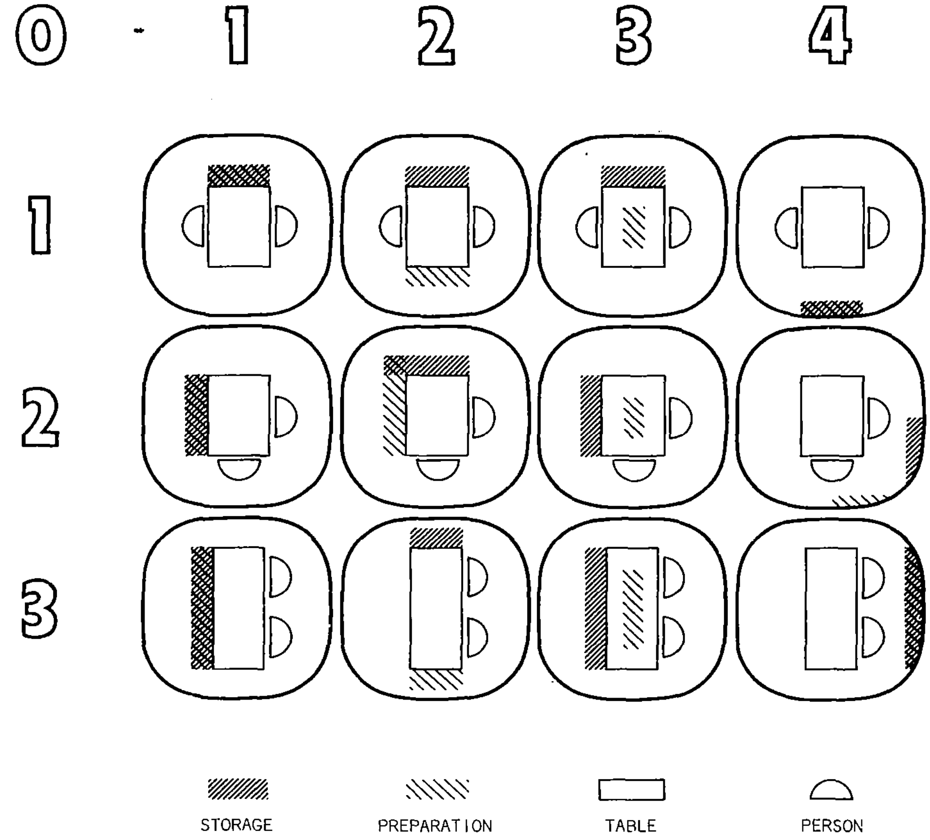


NOURISHMENT CONFIGURATION

There are at least twelve different configurations that can be considered when chosing a nourishment module. Configuration I,I is chosen for several reasons:

> crew members sit across from each other thereby making conversation easier, reducing probability of crowding or cramped table space, and allowing each to prepare meals with equal ease.
>
> a third crew member can easily be added.
>
> the configuration uses the least amount of floor space.

CONFIGURATION



4.2 SLEEP MODULE

SLEEP MODULE CONTENTS

The sleep module should contain the following items unless inherent in the design:

- Bed Clothing
  - sheets
  - pillow
  - blanket
  - mattress
- Sleeping Attire
- Privacy Partition
- Bed Restraints
- Equipment Storage
- Lighting Controls
- Noise Control
  - curtain wall
  - music

SLEEP MODULE CONCEPTS

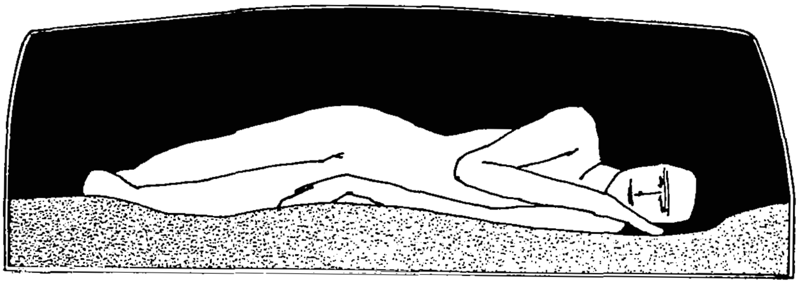
The first sleep module concept pictured - is a total enclosure design that gives the crewman total privacy and environmental control. Storage may be difficult unless the enclosure hood could be made erectable, perhaps inflatable. Sound control should not prevent the crewman from hearing his companion in an emergency situation.

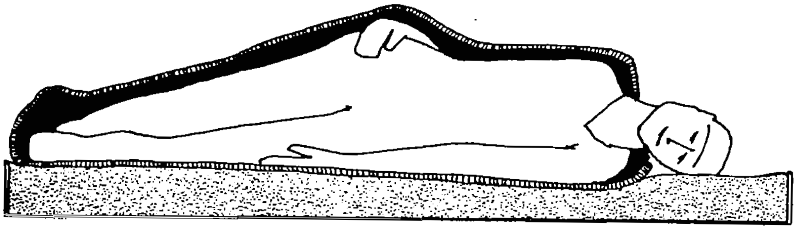
The second design is a simple sheet and blanket approach. A sleeping bag is not suggested because of the possible difficulty in an emergency egress. Temperature control could be similar to a commercial electric blanket.

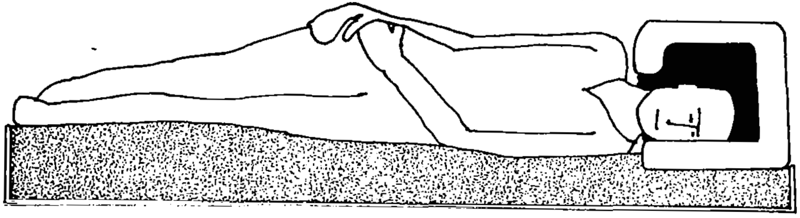
The third design covers the crewman's head only, giving him visual and sound privacy. Temperature control is by sleeping attire on the shelter's temperature control system.

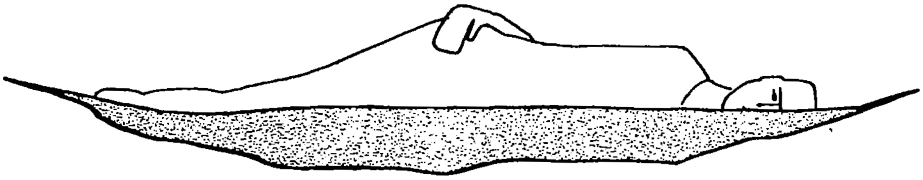
Concept four is a hammock which is not recommended because it is difficult to ingress and especially difficult to emergency egress.

MODULE









SLEEP MODULE CONFIGURATION

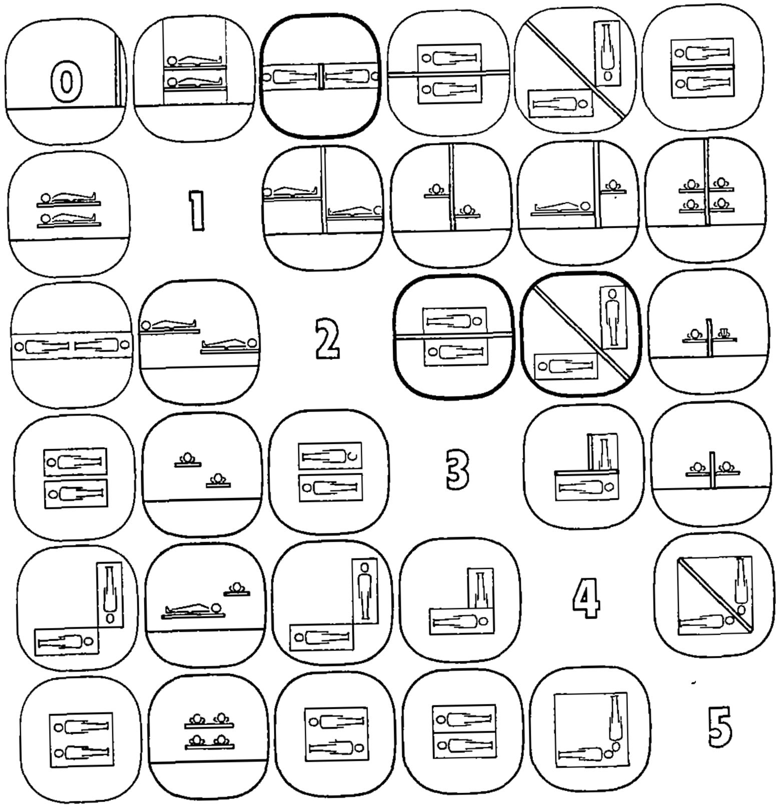
Pictured are fifteen configurations in which two crewman can lie prone, sleeping. The upper right diagonal fifteen configurations are shown with a wall or separator; the remaining without. The design guidelines (sleep, furnishing, safety) recommend an 18" maximum mattress-floor distance, therefore all bunk designs should not be considered.

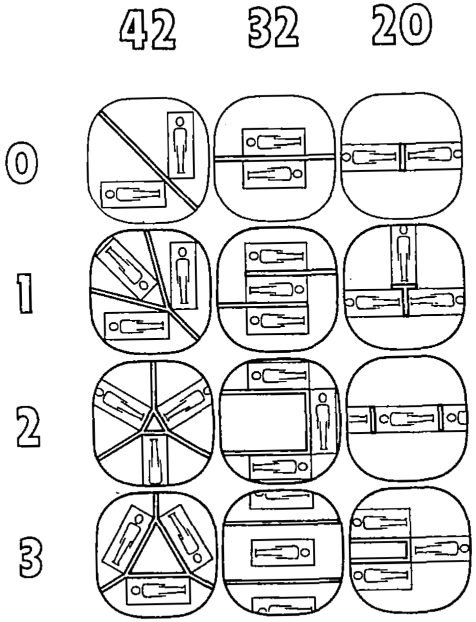
Recommended configurations are 2,0 (Column 2, Row 0), 3,2 and 4,2. Reasons for choosing these concepts are: they offer privacy, maximum head to head distance, and are good examples of layout possibilities.

GROWTH POTENTIAL

Several possibilities of growth potential for the recommended configurations are shown.

CONFIGURATION





THREE

4.3 WASTE ELIMINATION MODULE

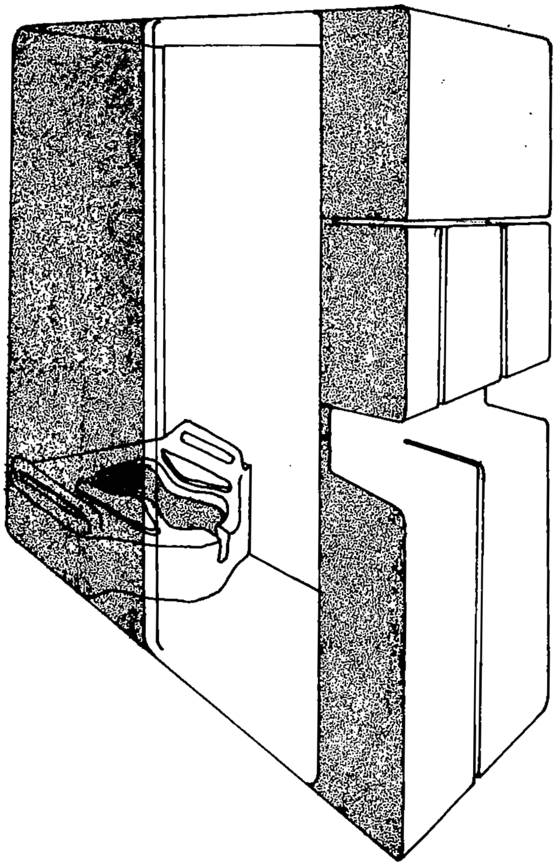
WASTE ELIMINATION MODULE CONTENTS

The waste elimination module must contain the following items:

- Collection bag dispenser
- Collection Bags
  - Urine Bag
  - Fecal Bag
  - Urine Sample Bag
- Utility Wipes Dispenser
- Utility Wipes
- Vacuum Cleaner
- Waste Management Supply Cabinets
- Specimen Return Containers
- Odor Removal Filter
- Waste Processor
- All Purpose Tissues
- Fecal/Urine Collector

This list is comprised with data from the AAP-Orbital Workshop waste elimination system, December 1969. McDonnell Douglas Astronautics Company.

MODULE

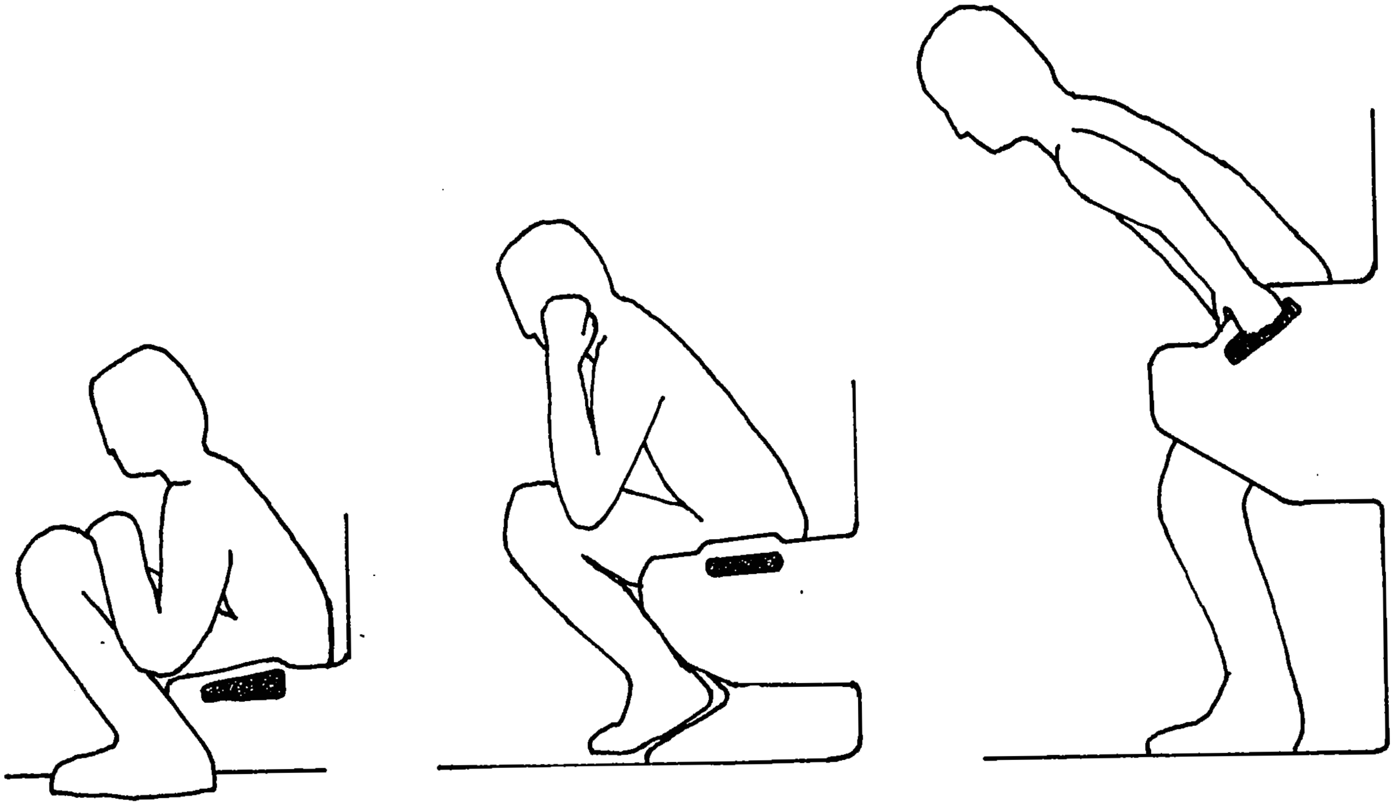


MAN/WASTE COLLECTOR INTERFACE

Present day response designs require the crewman to set up receptacle, empty the collection bag and process waste specimens. An effort should be made to design a receptacle that measures and processes the fecal and urine specimens without requiring the crewmen to participate.

Pictured are three designs based on postural consideration. Proper posture can contribute substantially to ease of defecation. A full squat position, nine inch high seat, as shown in the first drawing might be difficult and uncomfortable to assume and then sustain in the reduced gravity. The second design is similar to the standard receptacle, 15 to 18 inches, with integral foot rests so that the feet can be brought up to assume a squat position. The third design is a "lean-on" receptacle. Its height (24 - 26 inches) offers an advantage of eliminating any sitting and rising problems.

CONCEPTS



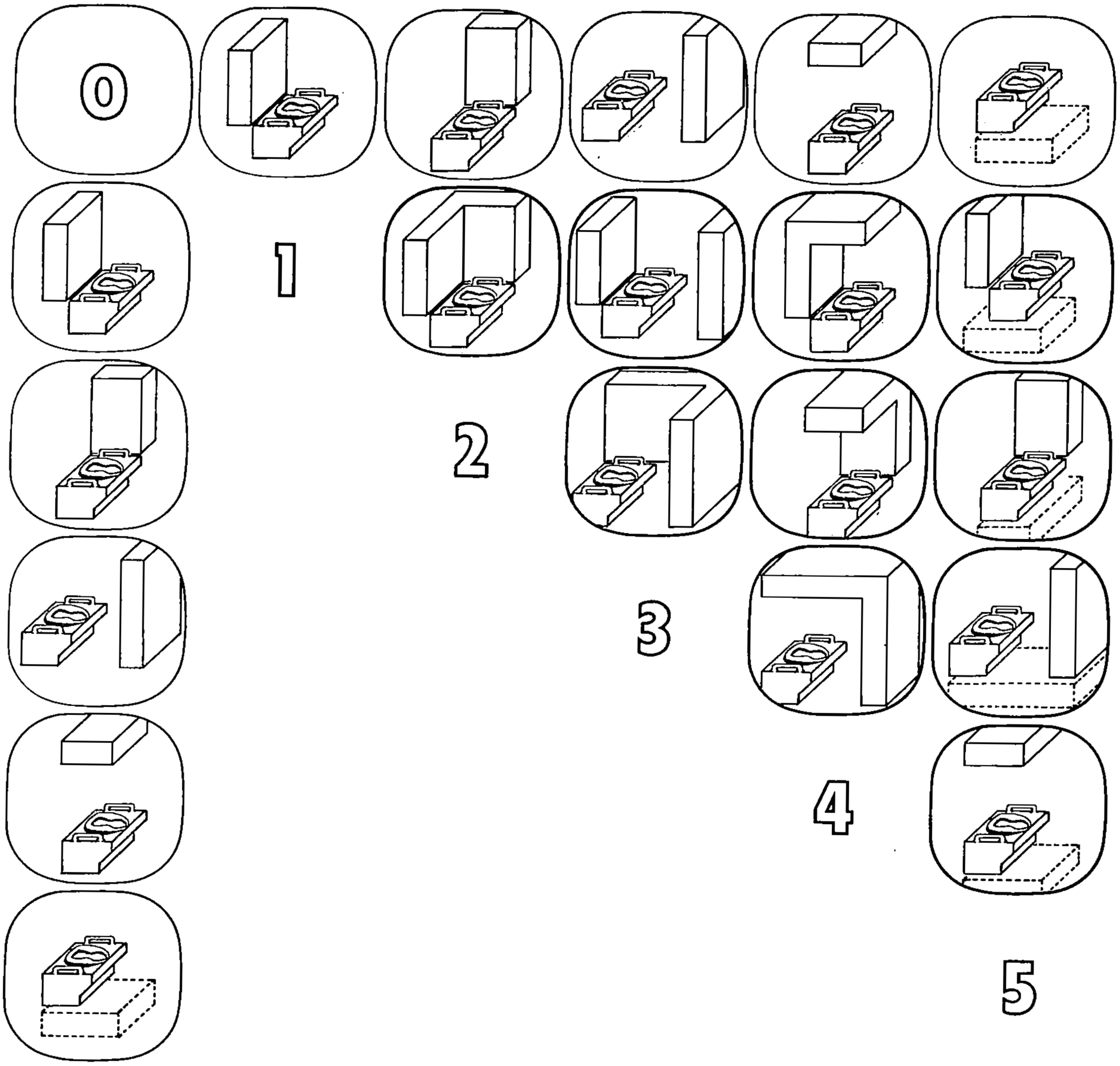
WASTE ELIMINATION CONFIGURATION

Pictured are fifteen configuration concepts for placement of the waste receptacle and storage area for collection bag dispenser, wipes, waste specimen storage/ processor, etc.

Number 3,0 module (storage area directly in front of seated crewman) is chosen because it offers the crewman easy access to the storage while in a sitting position. As in some of the other configurations (1,0, storage behind seated astronaut, 5,4, storage above and below seated astronaut, etc.) configuration 3,0 does not require the crewman to twist or turn while gaining access to wipes or recording data.

If the crewman must set up and empty receptacle as in the "state of the art" designs, configuration number 3,1 is good because it allows a standing crewman to face receptacle and storage/processing area at the same time, and also, while sitting he has access to more storage for wipes, etc.

CONFIGURATION



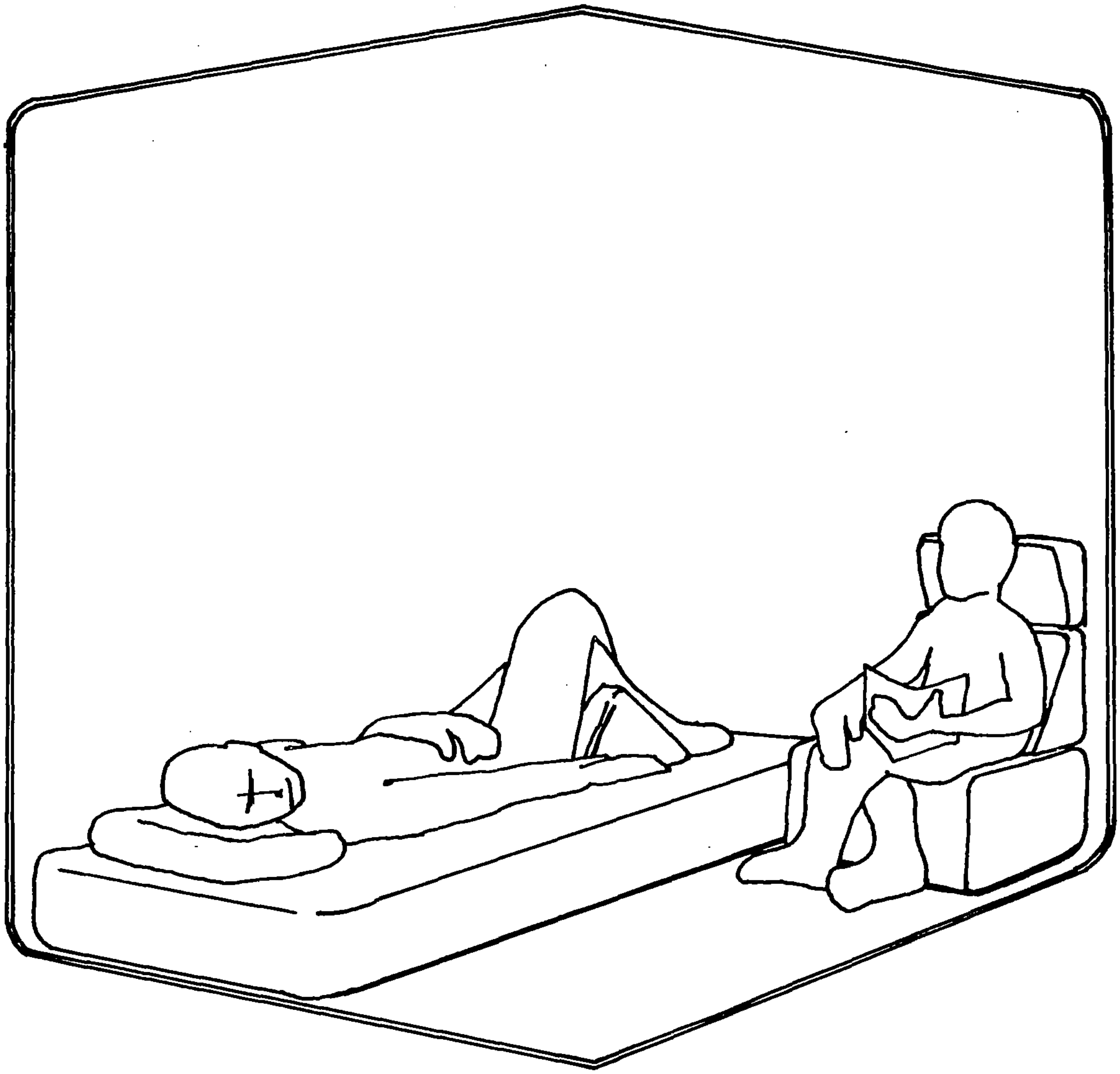
4.4 REST AND RELAXATION

REST AND RELAXATION CONTENTS

The rest and relaxation module should provide each crewman with the following items:

- Music
- Reading Material
- Exercise Facilities
- Lighting Controls
- Seats
- Games
  - single player and two player
  - mission oriented
- Table
- Mattress

MODULE

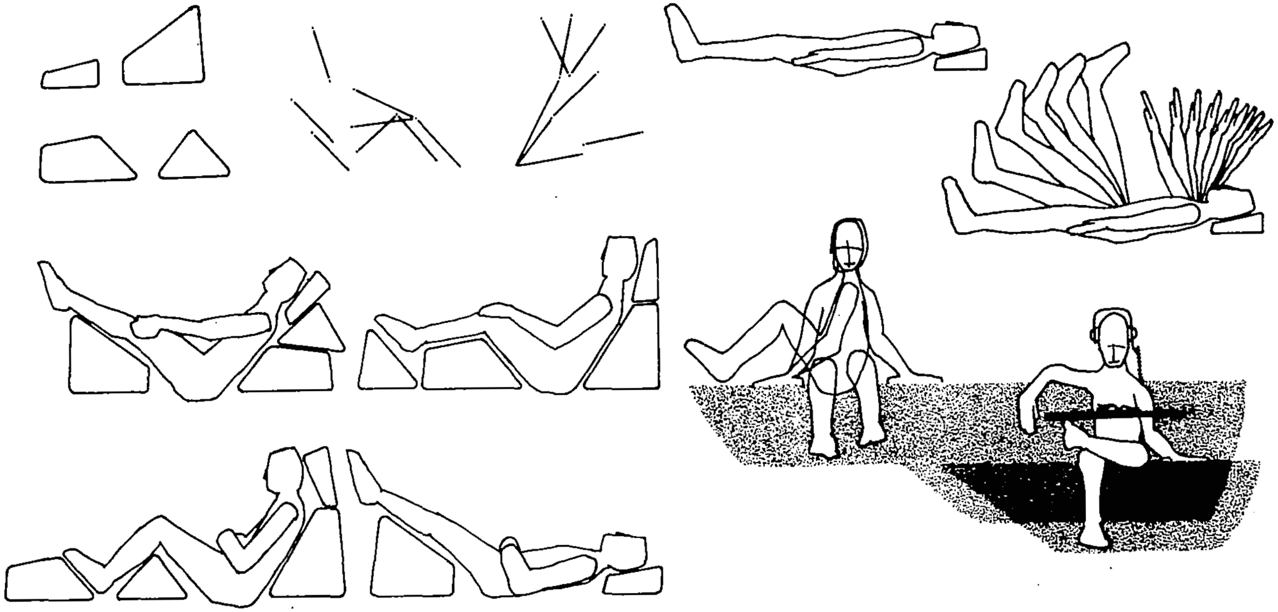


DESCRIPTION

Pictured as design concepts are four inflatable cushions of varied geometric shape which, used together with a pallet or mattress, may be employed as a means to support the human body in a number suggested restful positions. Imaginative use of these cushions, together with some work surface and appropriate area lighting, will provide a facility ideally suited to enhance such activities as reading, writing, mild calisthenics and resting the body.

In addition to these hardware items, some measure of control should be provided over the area's visual-audio-thermal environment to further enhance a wide variety of rest and relaxation activities. Included as a part of this environmental control should be means of varying both light intensity and pattern, regulation of ambient room temperature, and the means to select a variety of audio and visual programs.

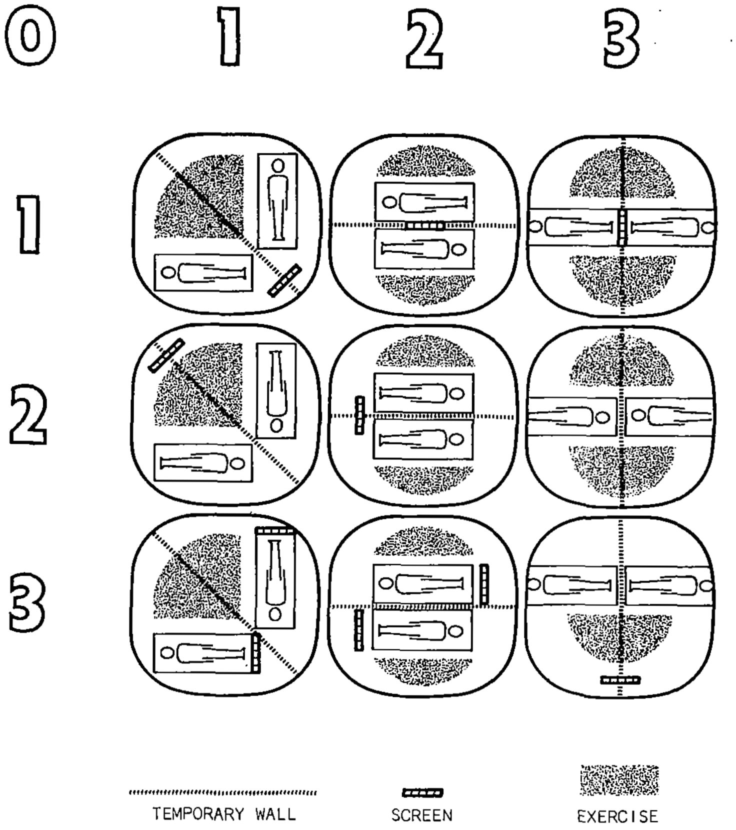
CONCEPTS



REST AND RELAXATION CONFIGURATION

The rest and relaxation module configuration is derived from the recommended sleep module configuration. This is because in all probability, the two module areas will be shared. That is, the functions will be performed in the very same space and in much the same manner.

CONFIGURATION



4.5 HYGIENE MODULE

HYGIENE MODULE CONTENTS

The hygiene module should contain the following items:

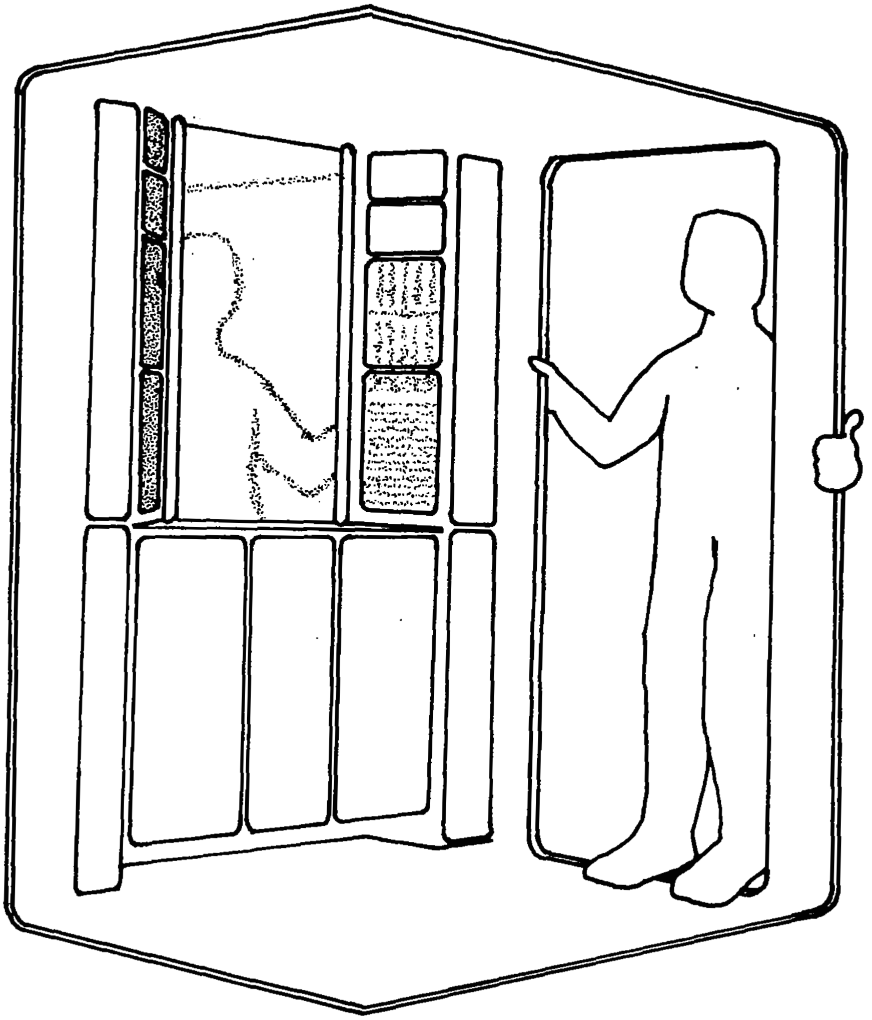
- mouth and teeth cleaner
- nail clippers and file
- deodorant
- body/hand lotion
- soap
- tissues and dispenser
- swabs
- hand wipes
- body wipes
- face towel
- hair dressing
- comb
- brush
- shampoo
- bench
- storage
- mirror & magnifying mirror
- waste receptacle
- lighting controls
- bath towel

The Apollo first aid kit:

- pain killer -
  - parenteral meperidine hydrochloride
- relief of motion sickness -
  - parenteral cyclizine hydrochloride
- pain killer -
  - dextropropoxyphene hydrochloride
- relief of diarrhea -
  - diphenoxylate hydrochloride
- decongestant -
  - pseudoephedrine hydrochloride & triprolidine hydrochloride
- analgesic -
  - acetylsalicyclic acid
- antihistamine -
  - diphenhydramine hydrochloride
- analgesic -
  - paracetamol
- nasal emollient -
  - botanical oils
- nasal spray -
  - oxymetazoline hydrochloride
- eye ointment -
  - polymixin B. sulphate, neomycin, sulphate & gramicidin
- eye drops -
  - methylcellulose
- skin cream -
  - first aid cream

- bandage compress
- bandages
- oral thermometer
- tweezers
- laxative
- splints

MODULE



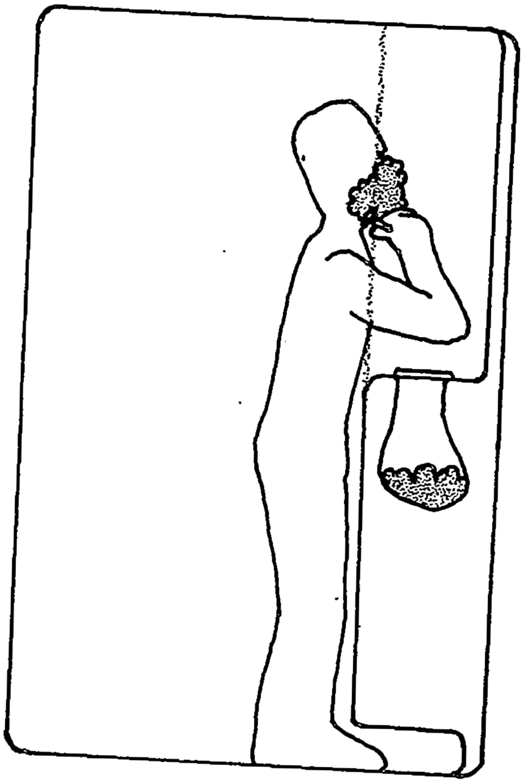
HYGIENE WALL

The hygiene wall contains all hygiene equipment within easy reach of the crewman. The design pictured is an arrangement of the hygiene contents on a wall. In the center is a mirror with two vertical adjustable lights at each side. On the outside of each light is each crewman's mouth care equipment, personal hygiene equipment, shaver, hairbrush, and also that which will be used frequently such as: hand and face wipes, towels, and first aid.

Water is not necessary in the hygiene wall. Cleansing of hands and face will be by wet wipes. Provisions should be made to dispose of them. Waste collectors are shown rather than a wash basin. This receptacle should have a cover or a quick seal top. It should not need to be emptied or replaced. This surface will also serve as a temporary shelf, for supporting the shaver or brush, etc. It should be 40 to 42 inches from the floor. This height offers the crewman comfort while cleansing, and minimizes the need to bend or stoop.

Below the shelf is a general storage area for towels, replacement wipes, and collection receptacles if necessary.

WALL



TOTAL BODY CLEANSING

Some provisions should be made for total body cleansing. A shower is recommended because it cleans and rinses quickly and it also relaxes the crewman. Pictured are four concepts.

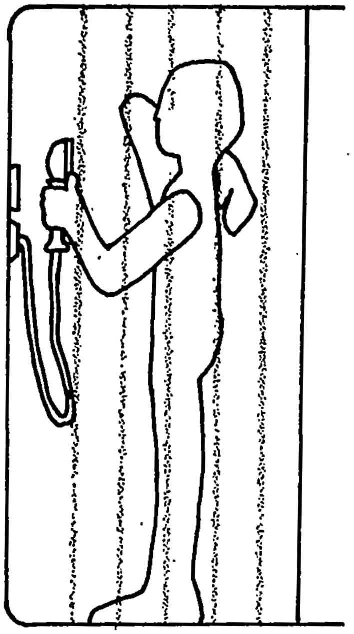
The first is an erectable or more precisely a fold out concept. It will fold out of the wall, contain and recirculate the water, and include handholds and bench. This concept is shown in more detail on the following page.

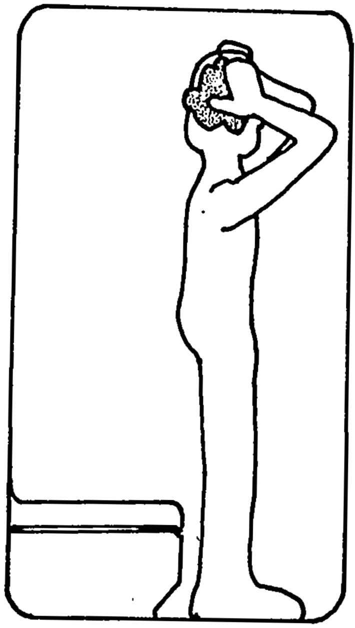
The second concept shows the personal waste elimination module. This requires the crewman to wipe dry the walls and floor after use; also, most equipment should be covered.

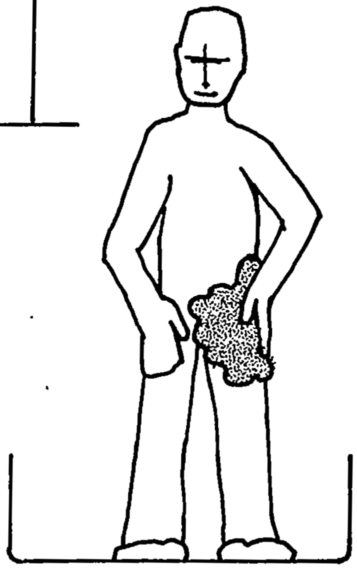
The third is a large wet wipe suitable for total cleaning. Perhaps, two cleansing wipes, one for hair - a shampoo wipe, and the other for cleansing the remaining parts of the body. A third wipe should rinse.

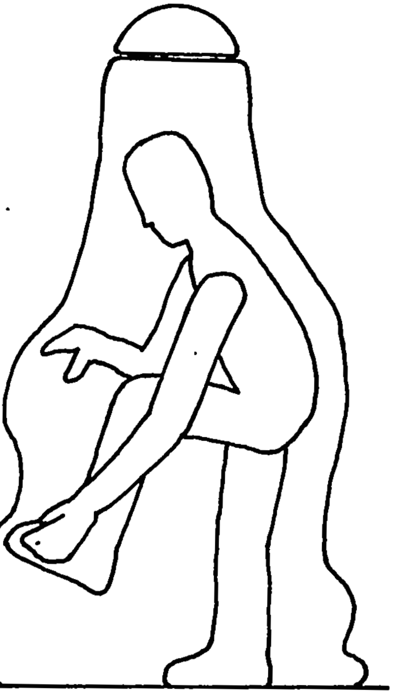
The fourth concept is a bag shower. The bag is erectable and easily set up. It will capture all the water and recirculate it. The bag should be translucent for lighting and incorporate handholds and a bench.

CONCEPTS





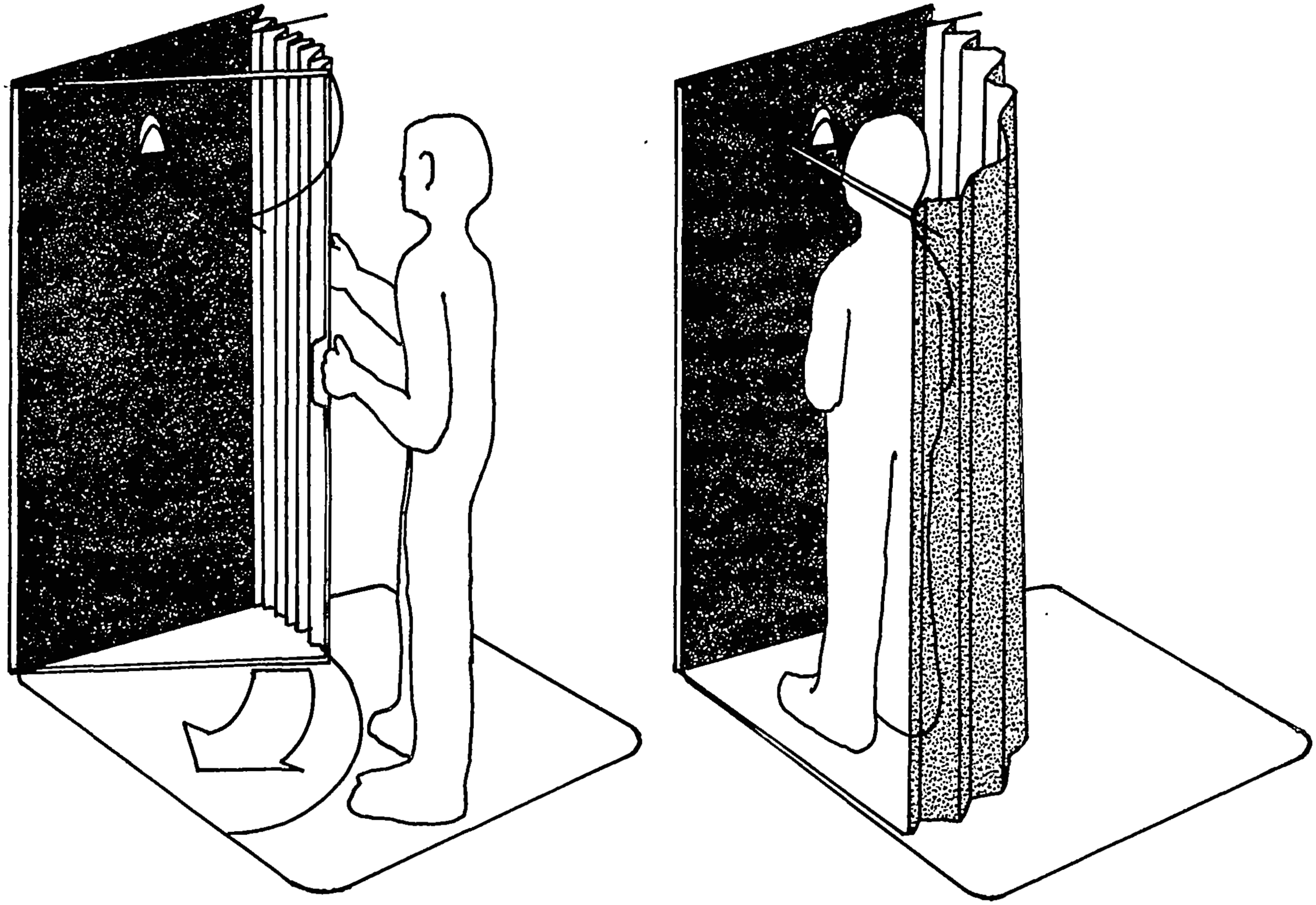




FOLD-OUT SHOWER

Crewman opens door and pulls out curtain wall with a sealed floor and ceiling for recirculation of water. He enters by unzipping the curtain wall. The permanent wall includes handholds and shower head. The door wall includes a fold-up bench.

WALL



HYGIENE CONFIGURATION

Pictured are four configuration concepts for the hygiene and shower modules. The hygiene wall is shown in plan view. The mirror is the double line with the lights and personal equipment storage flanking it on each side. Two waste collectors are shown on the shelf. Across from the wall is a bench with handholds.

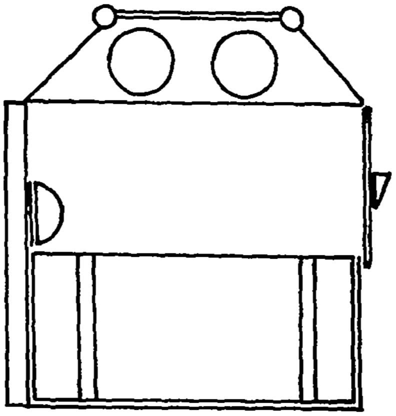
The first concept shows the shower head on the wall next to the hygiene storage wall and bench. This is a sharing concept and requires a door to prevent water from escaping. The module will need to be wiped dry after use. Perhaps the personal waste elimination receptacle and the bench could be the same unit, sharing shower, hygiene, and waste elimination.

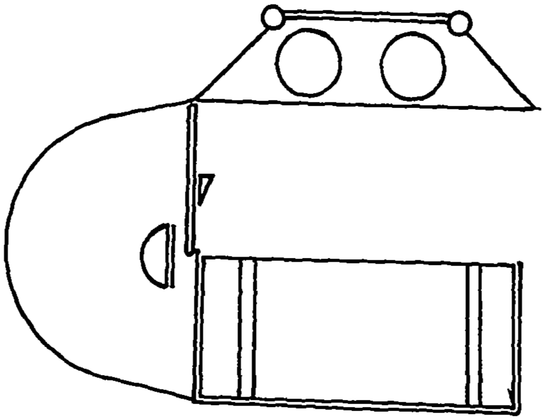
The second concept separates the shower from the hygiene wall. The door is moved to seal the shower for capturing the water. A door is not needed in the hygiene area unless shared with the waste elimination module.

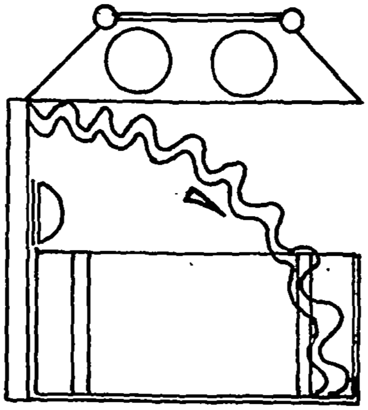
The third concept shares the hygiene wall and bench with a curtain wall fold-out shower unit. This has the minimum volume of the first concept without the requirement to wipe dry or cover the hygiene module.

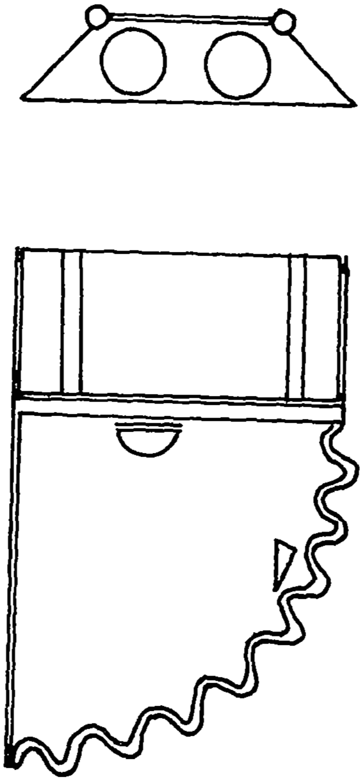
The fourth concept uses a fold-out curtain wall shower unit in a separate but nearby location. This allows one crewman in the hygiene area and the other in the shower area at the same time.

CONFIGURATION





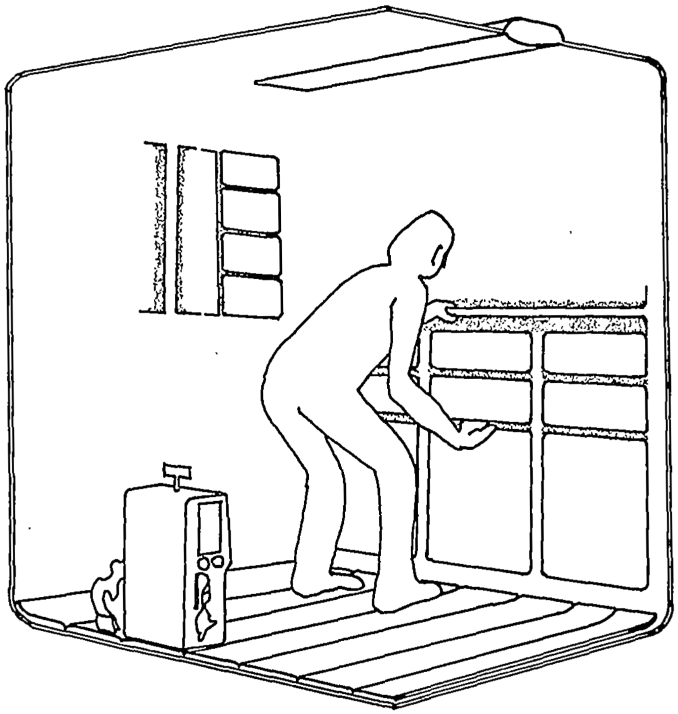


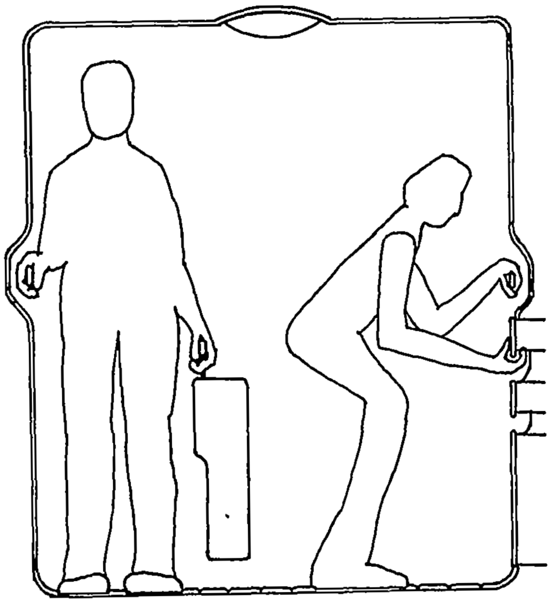


4.6 LOCOMOTION AIDS

Pictured are several locomotion aid design concepts. These include use of sure-grip flooring to provide non-slip surface and comfort, (perhaps spongy surface) to crewman in shoes, socks, and barefeet. Handholds/handrails to stabilize and support walking, stooping and reading are recessed so that in the event of a fall they are less likely to harm the crewman or equipment that he might be carrying. Pip-pin type handles (removable) are recommended if the handle is not an integral part of the equipment design. Careful placement of handles for balance and carrying attitude should be considered. Drawers and door pulls should be recessed as shown to avoid catching on clothes and equipment. Lighting fixtures should be flush with the surface or covered with a flexible or pliable material. All corners should be avoided and, if possible, all surfaces should be padded.

CONCEPTS





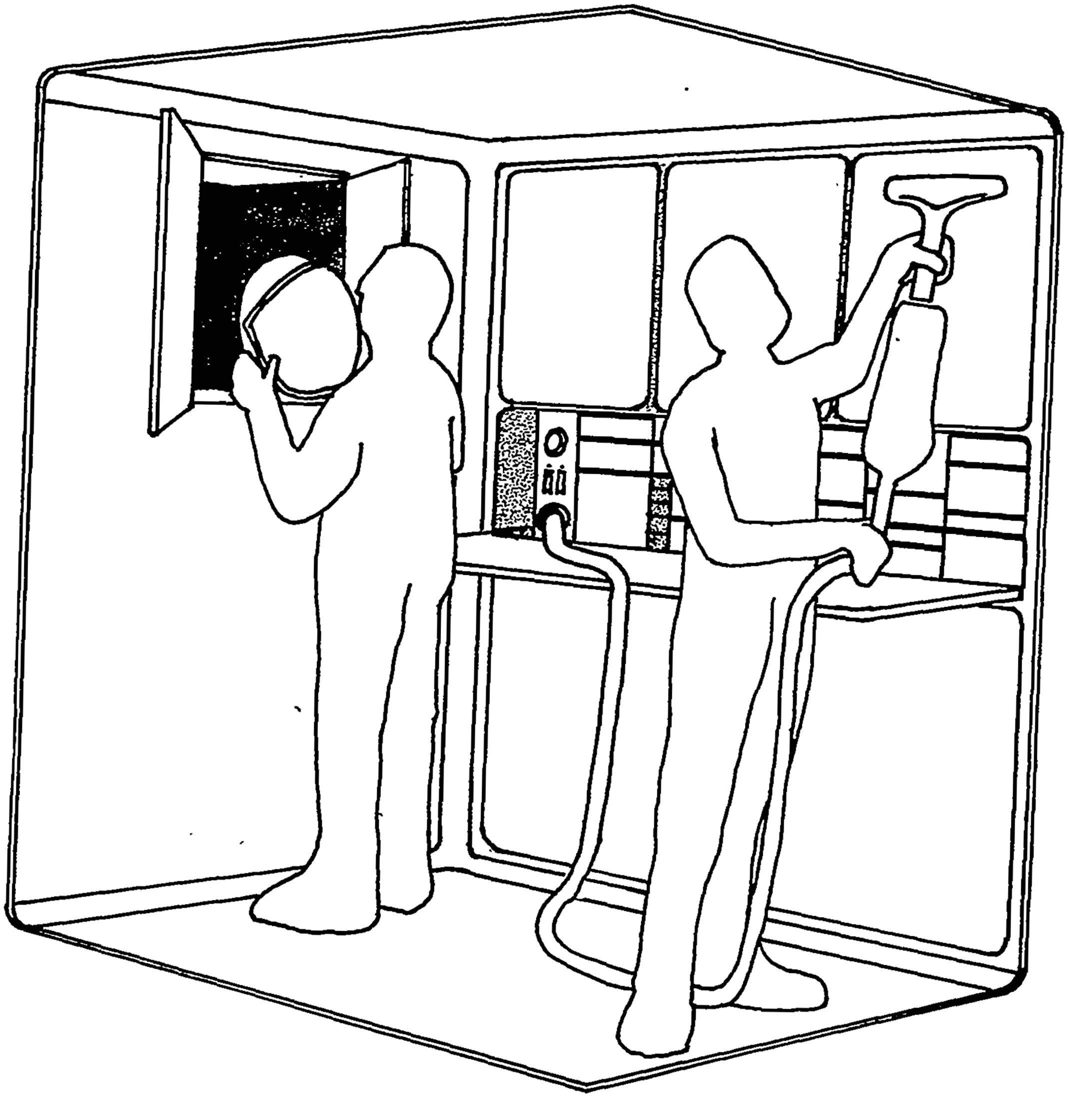
4.7 HOUSEKEEPING AND PERSONAL EQUIPMENT CARE MODULE

Pictured is the housekeeping and personal equipment care module. The general housekeeping and equipment care equipment should be located together in a compact storage area containing tools, work bench, vacuum, work stools or seats, equipment checkout gear, repair manuals, and cleansing agents. The design incorporates all this equipment on one wall.

The work bench is folded down from the wall exposing the tools, etc., the seats and large equipment are stored below. The crewman on the right is vacuuming the shelter, a task that will be necessary several times during the mission to help keep the lunar dust from building up too heavily.

Cleaning and drying machines for clothing and other personal gear must be provided. However, with a stay time of 28 days for 2 crewmen, a supply of fresh clothing weighs less, requires less volume and necessitates no maintenance.

MODULE



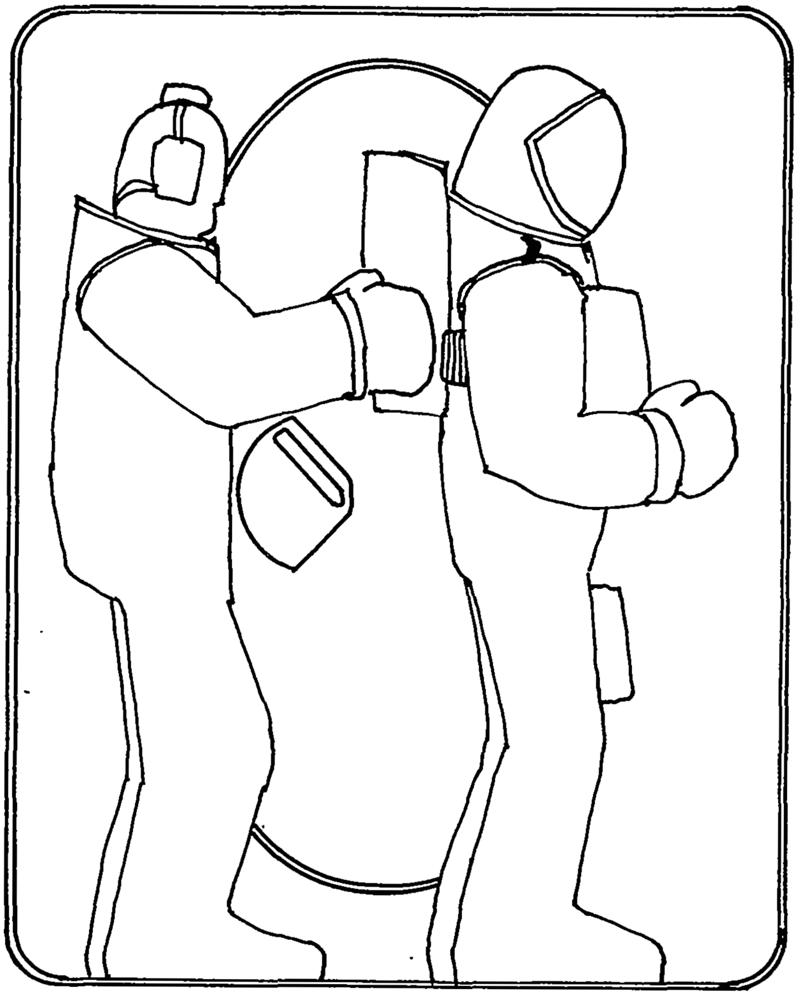
4.8 AIRLOCK

AIRLOCK CONTENTS

The airlock module should contain the following items:

- Lock Mechanisms
- Handholds
- Bench
- Pressurization Hardware
  - Valves
  - Gauges
  - Alarm Systems
- Pressure Suit
- Portable Life Support System (PLSS)
- Suit and PLSS Storage
- Hangers to hang suits full length
- Check Out Equipment
- Lights for shirtsleeve suited astronauts

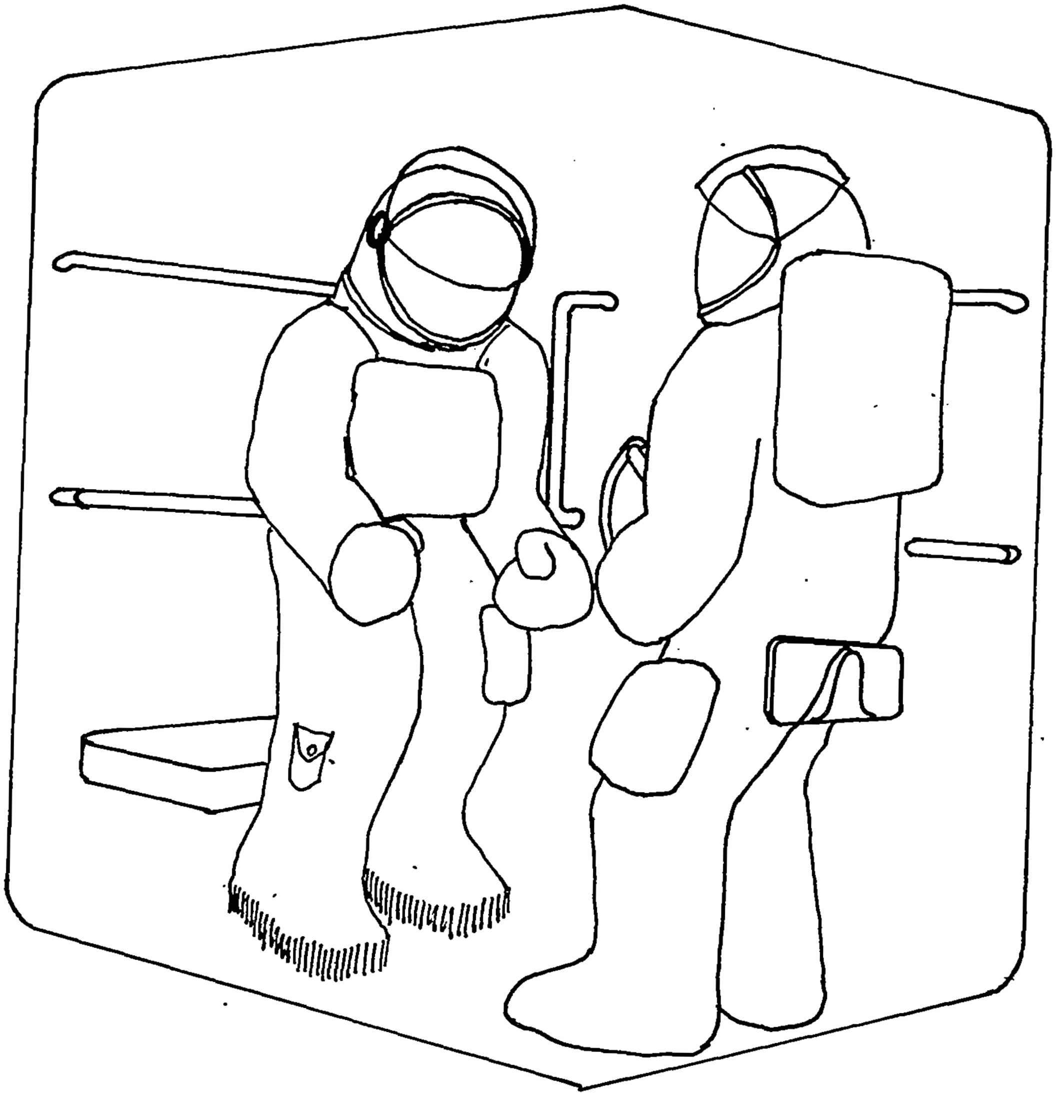
MODULE



AIRLOCK DESIGN

The airlock module must offer both the shirtsleeve crewman and the pressure suited crewman with acceptable habitability. Handholds are designed differently. They are not recessed as suggested in the locomotion designs because they must be used by both the shirtsleeve crewmen and the suited crewman with his clumsy EVA cover glove. Two types of benches are shown: one for the shirtsleeve crewman and one for the suited crewman to rest on while he waits for repressurization of the airlock after a long exhausting six hour EVA. Two types of lighting are necessary: one the unsuited condition and the other of higher intensity for the suited crewman to be acclimated and position his sun visor shields during pump down of the airlock.

CONCEPTS

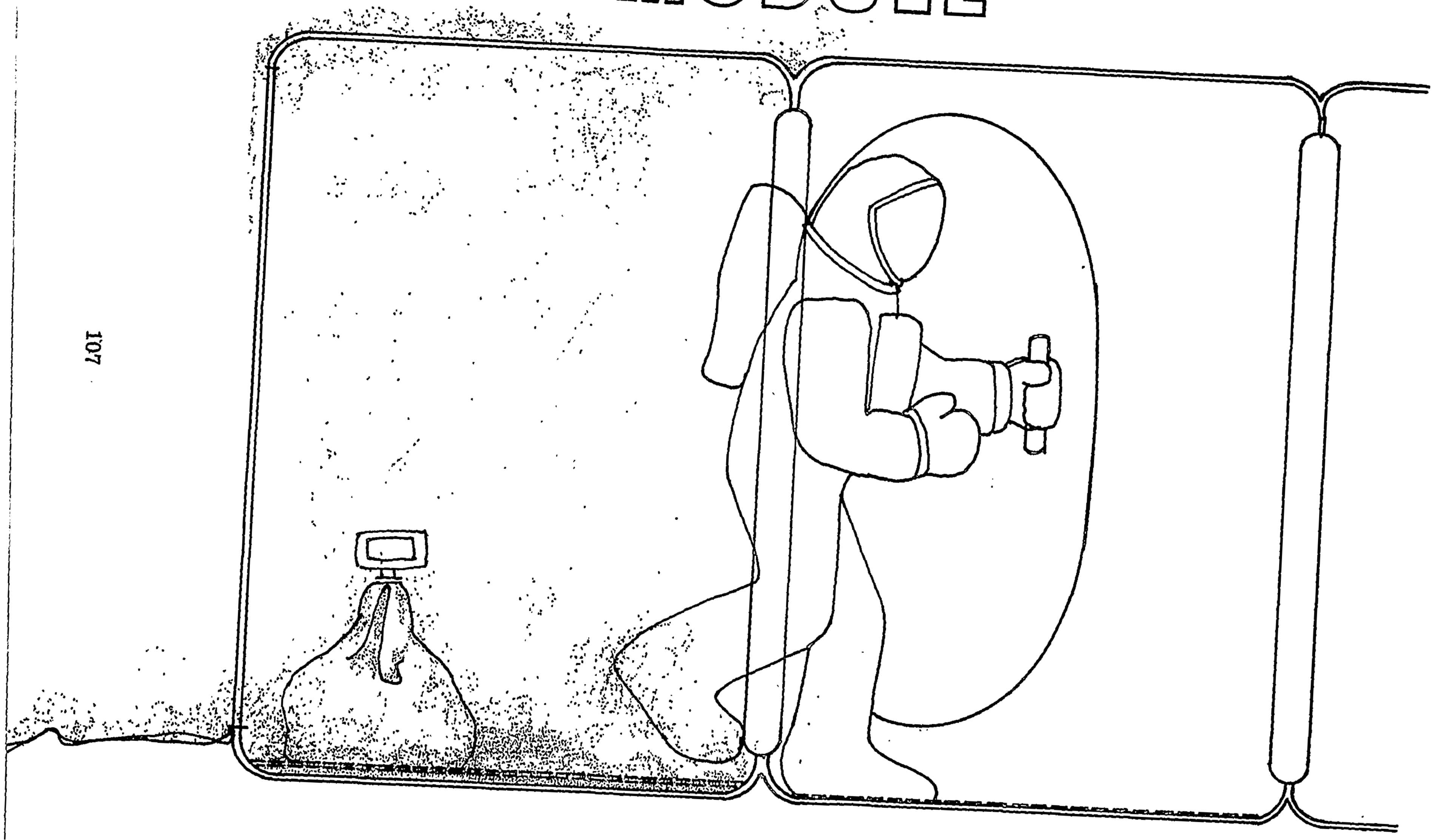


DUSTER MODULE

Lunar dust was proved to be a problem and a menace to the habitability system and general comfort of the astronauts of Apollo XI and XII.

Pictured as a design concept is a duster module. This module is at the ESA entrance of the airlock. The ESA crewman must enter the duster module and dust himself or the other crew member. The duster module is not a pressurized environment, just a stopping station to dedust by whatever means can be provided. Methods for ridding the dust from the suit and other equipment should be researched.

MODULE



5

5.0 INTEGRATION OF MODULES

With the development of guidelines for individual modules, the next step is to integrate the modules into a total shelter concept. The primary considerations for achieving this integrated concept include the time spent at activities associated with each module, the sequence of activities involving different modules, the frequency of interfaces (entry, exit) among modules, and the requirements for the sharing of module activities in the same physical areas.

The assumptions and ground rules underlying the integration of modules include the following:

- The total space required for the shelter will be kept at a minimum given that safety, performance, and comfort demands can be satisfied
- Both astronauts will sleep, work, and eat at the same time
- Sleep areas will be segregated
- A six hour EVA (extra vehicular activity) period is assumed once every 24 hours which is performed simultaneously by both astronauts
- Periods of privacy can be provided prior to and immediately after sleep, during waste elimination and personal hygiene, and occasionally during rest and relaxation
- Astronauts will be provided with an eight hour sleep period which includes a relaxation period before and after actual sleep
- Time spent on mission activities will be maximized given that off duty requirements can be adequately satisfied

5.1 TIMELINE ANALYSIS

The timeline for the crew is presented as a single sequence of activities on a time scale. This timeline applies to both astronauts (and to the third astronaut when applicable) and assumes that sleep, nourishment, work and rest and relaxation activities will be conducted simultaneously. It is also assumed that while one astronaut is eliminating waste the other crewman is performing personal hygiene.

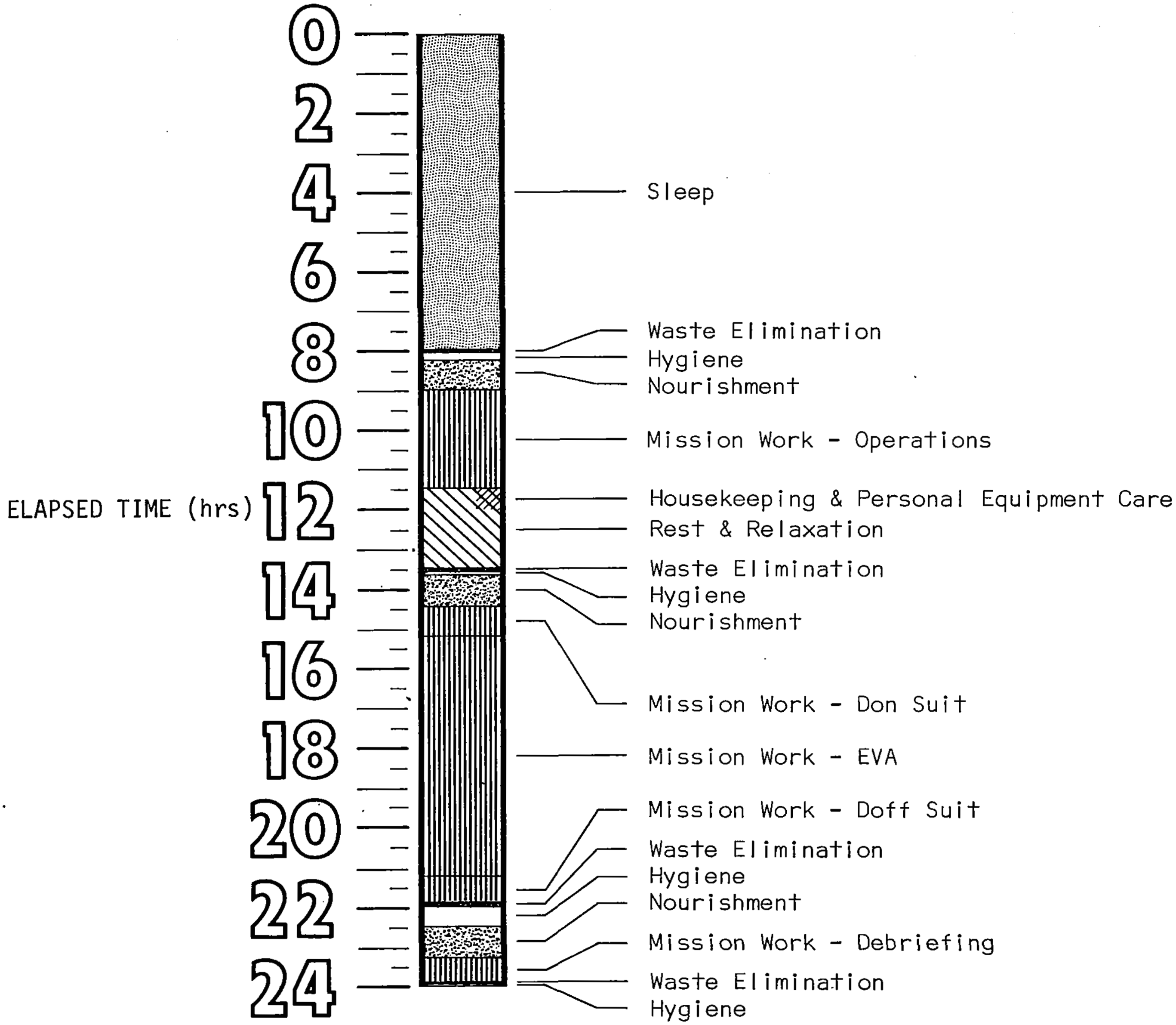
Only one rest and relaxation period is indicated on the timeline. Actually the astronauts will rest whenever they desire to during the day. Periods of relaxation are assumed immediately prior to and after actual sleep and during nourishment periods.

The timeline shows three separate periods of mission work. One period is prior to EVA where preparation and plans are made for the surface operations The second work period includes the six hour EVA with a period of suit donning prior to, and suit doffing after, the EVA. The third period consists of a debriefing exercise wherein data from the EVA are recorded and communicated to mission control.

An important aspect of the timeline was the scheduling of activities. A minimum of four hours was selected to separate any two meals. Actually the meal separation times are four and one half, eight, and nine hours. Four periods of waste elimination and conducting personal hygiene are provided. Actually no restrictions are imposed on waste elimination. The astronaut can relieve himself whenever he desires. The periods are included to facilitate packaging of the modules in the shelter.

One period of housekeeping and personal equipment care is included which will occur every three days and will be performed during the early portion of the rest and relaxation activity. The activities required to clean and service separate areas and personal equipment will be conducted daily as the areas and equipment are used; however, a period of general cleaning, checkout, and minor repair is scheduled for the period occurring every three days.

TIME LINE


ELAPSED TIME (hrs)
0
2
4
6
8
10
12
14
16
18
20
22
24
Sleep
Waste Elimination
Hygiene
Nourishment
Mission Work - Operations
Housekeeping & Personal Equipment Care
Rest & Relaxation
Waste Elimination
Hygiene
Nourishment
Mission Work - Don Suit
Mission Work - EVA
Mission Work - Doff Suit
Waste Elimination
Hygiene
Nourishment
Mission Work - Debriefing
Waste Elimination
Hygiene

5.2 ACTIVITY ANALYSIS

One consideration in allocating available space to individual modules is the amount of time spent in activities associated with the module. The activity analysis presents the percentage of total time spent in each module activity.

A comparison of those allocations with those recommended for LESA, NASA guidelines for ELS, actual ELS, and Lunex II is presented below.

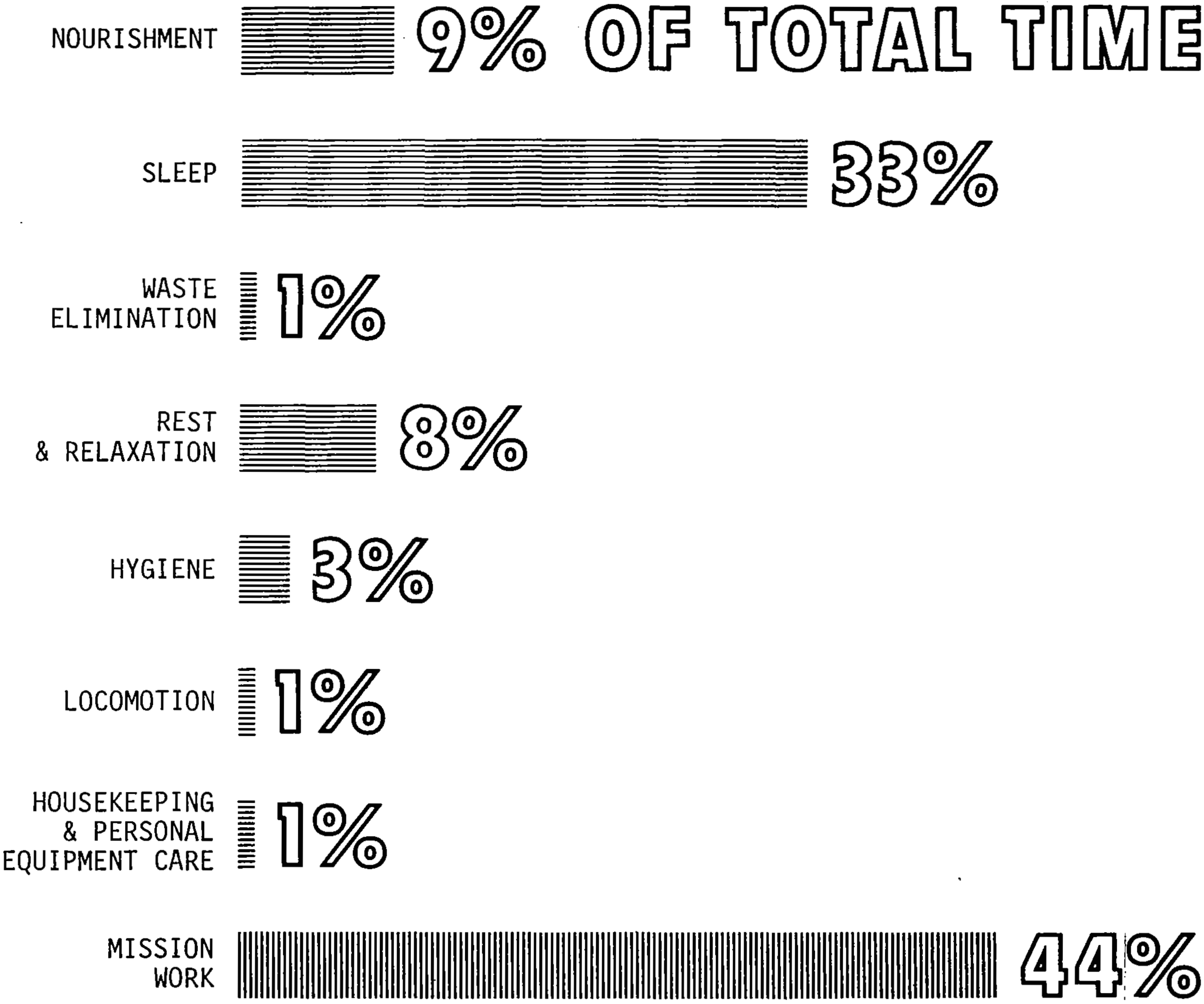
	Present Study	LESA	NASA Guidelines ELS	ELS Modification	Lunex II
Sleep	33%	32%	42%[2]	37.5%	35%
Mission Work					
EVA	25%	24%	19%	19%	3.8%
ISA[1]	19%	22%	25%	19%	36%
Unscheduled	0	7%	0	0	0
TOTAL	44%	53%	44%	38%	39.8%
Exercise	0	1%	0	0	0
Personal Activities					
Locomotion	1%				
Waste Elimination	1%				
Rest & Relax	8%				7%
Personal Hygiene	3%				1.5%
TOTAL	13%	7.5%	10%[3]	17.8%	8.5%
Eating	9%	6%		.7%	12.5%
Housekeeping	1%	.5%	4%	6%	4.7%

[1] includes don/doff

[2] includes R & R

[3] includes eating

ACTIVITY ANALYSIS



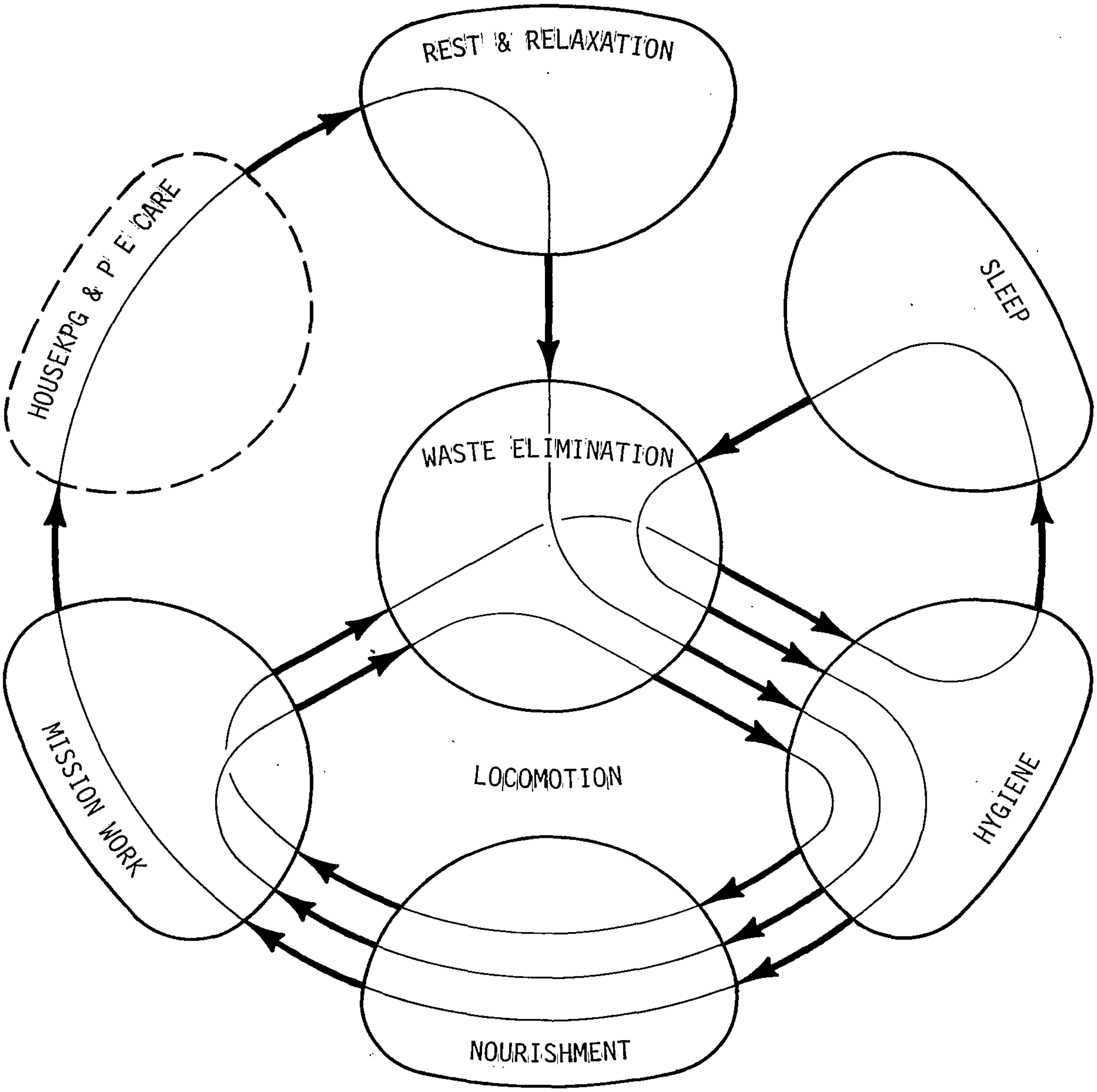
As indicated by these comparisons time allocated for sleep and mission work across the studies was fairly comparable. The present study equals the NASA ELS guidelines and is second only to LESA in total time for mission work. In the present study no time is allocated for exercise since it is assumed that exertion during EVA will be sufficient. The time allocated for personal activities in the present study is well above LESA and Lunex II. The allocation for housekeeping in the present study is much less than the NASA guidelines, ELS, and Lunex II. Time allocated for eating in ELS is extremely small while time for personal activities in that study seems excessive.

5.3 FLOW ANALYSIS

The flow map indicates the direction and frequency of interfaces among the various modules. No assumptions are made that these modules comprise separate physical areas, however, the map indicates locomotion requirements if one separate area was assigned to each module. The map indicates a total of 17 trips when housekeeping is included. The extent of the trips is reduced as modules are shared in a common area.

As shown on the map the astronaut performs waste elimination activities after sleep, rest and relaxation, and mission work. From waste elimination, he always procedes to hygiene. From hygiene he goes to sleep or to nourishment. After nourishment he always performs work and he performs planned rest and relaxation after work or, every third day, after housekeeping.

FLOW MAP


REST & RELAXATION
HOUSEKPG & P E CARE
SLEEP
WASTE ELIMINATION
MISSION WORK
LOCOMOTION
HYGIENE
NOURISHMENT

5.4 CONCEPTS FOR MODULE AREA SHARING

Alternate concepts for area sharing could range from a single compartment used to house all functions at one extreme to a separate compartment for each function at the other. The sharing concepts evaluated in this study did not include either extreme since it was assumed that the airlock would always be separate from the living/working area and since the use of completely dedicated areas for each function was not practical.

Concept A	Single working/living compartment and airlock (Lunex II, Early Lunar Shelter, Stay Time Extension Module)
Concept B	Same as concept A except that a separate area for waste elimination is provided.
Concept C	Dedicated areas for airlock, waste elimination, and personal hygiene with all other functions shared in a single compartment
Concept D	One area shared between sleep, personal equipment care, and rest and relaxation; one area shared between mission activities and nourishment; separate areas for airlock, waste elimination, and hygiene.
Concept E	One sleep compartment shared with nourishment and rest and relaxation; one sleep compartment shared with mission activities and rest and relaxation; separate areas for airlock, waste elimination, and hygiene.
Concept F	Same as concept E except that a separate area is provided for all rest and relaxation.

A tradeoff of these concepts on applicable habitability requirements was performed and the results of this analysis are presented in the Sharing Concept Tradeoff Table. In this table requirements are listed for each of the three classes: safety, performance, and comfort. These requirements were developed from each of the habitability criteria. The numbers entered in the table are weighted ratings of the degree to which a specific concept satisfies a given requirement. The ratings used in the analysis were:

1 - Poor   2 - Inadequate   3 - Minimal Effect   4 - Good   5 - Excellent

When a rating was established for a concept on a requirement, that rating was weighted as follows - a weighting of three times the rating was used for all requirements under safety, a weighting of two for performance requirements, and a weighting of one for comfort requirements.

REQUIREMENTS	CONCEPTS					
	A	B	C	D	E	F
SAFETY						
Emergency Egress	15	12	9	6	6	6
Ease of Locomotion	12	12	9	6	12	6
Ease of Communication	12	12	9	6	6	6
PERFORMANCE						
Space Required	10	8	6	6	4	2
Flexibility	8	8	6	4	8	6
Area Preparation	4	4	4	4	8	8
Growth Potential	8	8	6	8	8	8
Packaging	6	6	6	8	6	4
Multiple Use	8	8	4	8	8	6
Deployment	4	6	6	8	8	8
Housekeeping	8	6	6	2	4	4
Lighting Control	2	2	4	10	10	10
Temperature Control	2	2	4	8	8	8
Noise Control	2	2	4	8	8	8
Use of Space	4	4	6	8	8	10
COMFORT						
Privacy	1	2	2	4	4	4
Confinement	1	1	3	4	4	4
Varied Visual Stimulation	1	2	3	4	4	4
TOTAL	108	105	97	112 *	124	112

* most effective concept in terms of the requirements

5.5 DESIGN INTEGRATION

The final step is to apply the analytical techniques to develop representative shelter design concepts. Descriptions of three concepts are provided to illustrate the activities which comprise the habitability systems development approach and are not to be construed as design recommendations.

The integration of modules into a floor plan is done in several steps:

- Choose a sharing module concept
- Choose function
- Assign the function module configuration to the sharing concept.

The sharing module chosen is the recommended concept (See, Concepts for Module Area Sharing), Concept E, one sleep compartment shared with nourishment and rest and relaxation; one sleep compartment shared with mission activities and rest and relaxation; separate areas for airlock, waste elimination, and hygiene. This sharing concept is used for all three shelter concepts to illustrate the design possibilities by choosing different function module configurations.

The perimeter and outside shape of the shelter is formed from within, through choice and juxtaposition of the function modules. There are three concepts for the shelter: (1) square, (2) circular, and (3) rectangular. Juxtaposition possibilities of the chosen function modules are reduced by the sharing concept and the direction and frequency of interfaces among the various modules. Sharing Concept E has five major modules:

A. Nourishment, sleep, rest
B. Mission work, sleep, rest
C. Hygiene
D. Waste
E. Airlock

Modules C and D should be together and A and B next to them; module E should be close to modules B and C.

5.6 DESCRIPTION OF CONCEPTS

SLEEP

The sleeping configuration used in concepts 1 and 3 is the recommended sleep module configuration. Sleep configuration 2,3 has a separating wall with the crewmen's heads at opposite ends. Concept 2 used 0,3 which is a separating wall with the crewmen's heads at the same end.

HYGIENE

The hygiene wall is next to the waste elimination module in all concepts. The configuration is the fourth configuration concept. The shower unit is in a separate, but nearby, location. Concepts 1 and 3 use the curtain wall, fold-out shower unit. Concept 2 uses a separate, permanent shower stall.

REST AND RELAXATION

Rest and relaxation modules are shared with the sleep modules. Also, one is shared with mission work, and the other is shared with nourishment. The configuration chosen for concept 1 and 3 is 2,3, which corresponds with the sleep configuration having a separating wall with the crewmen's heads at opposite ends. Configuration 2,2 is used for concept 2. It also corresponds with concept 2's sleep configuration, which has a separating wall with the crewmen's heads at the same end.

A table for reading and writing is provided in the same manner as the nourishment and mission work modules. The table is pulled down from the wall and exposes the storage of rest and relaxation equipment: reading material, ear phones for music, games, etc. Although each crewman has his own table (same location as the nourishment and mission work tables), both crewmen can sit at one table for games, etc.

NOURISHMENT

Concepts 1, 2, and 3 use the total wall nourishment design--a pull-down dining table which exposes the stored food containers, preparation equipment, utensils, heaters, etc. The nourishment module is shared with one sleep and one rest and relaxation module which makes it possible to utilize the cushions from the sleep and rest and relaxation modules. The recommended configuration 1,1, where the crewmen sit across from each other with storage and necessary equipment to one side of the table, is used in Concept 1 and 3. Concept 2 uses configuration 1,3, in which crewmen sit next to one another with the storage and necessary equipment directly across the table.

MISSION WORK AREA

The mission work area is a mirror image of the nourishment area design.

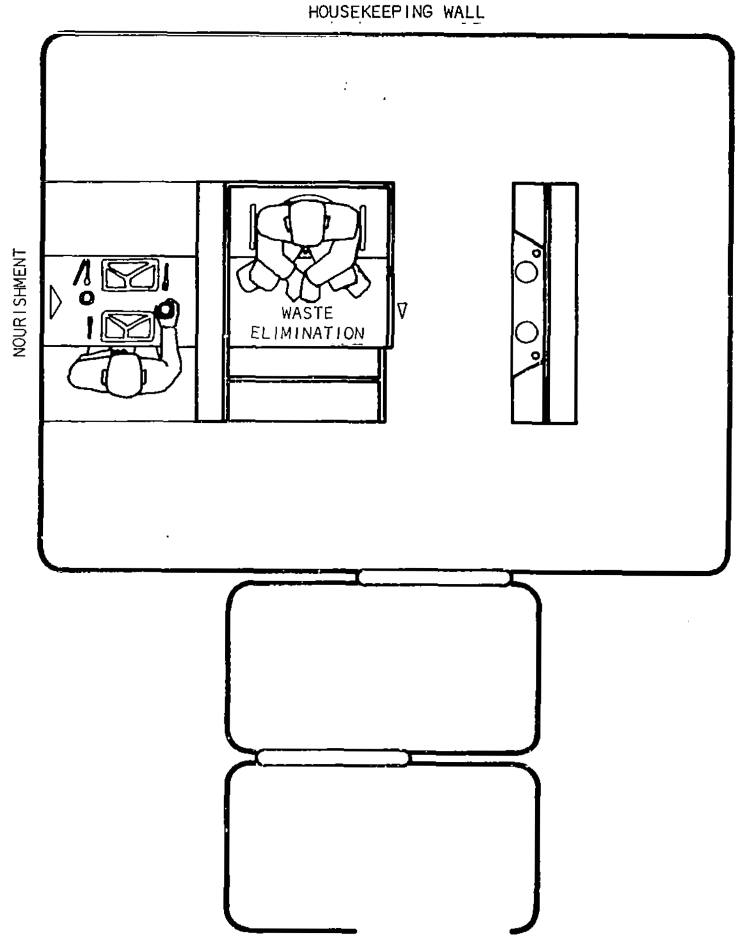
WASTE ELIMINATION MODULE

The waste elimination module is next to the hygiene module in all concepts. The configuration chosen is 0,3, which has the storage area directly in front of seated crewmen.

HOUSEKEEPING AND PERSONAL EQUIPMENT CARE

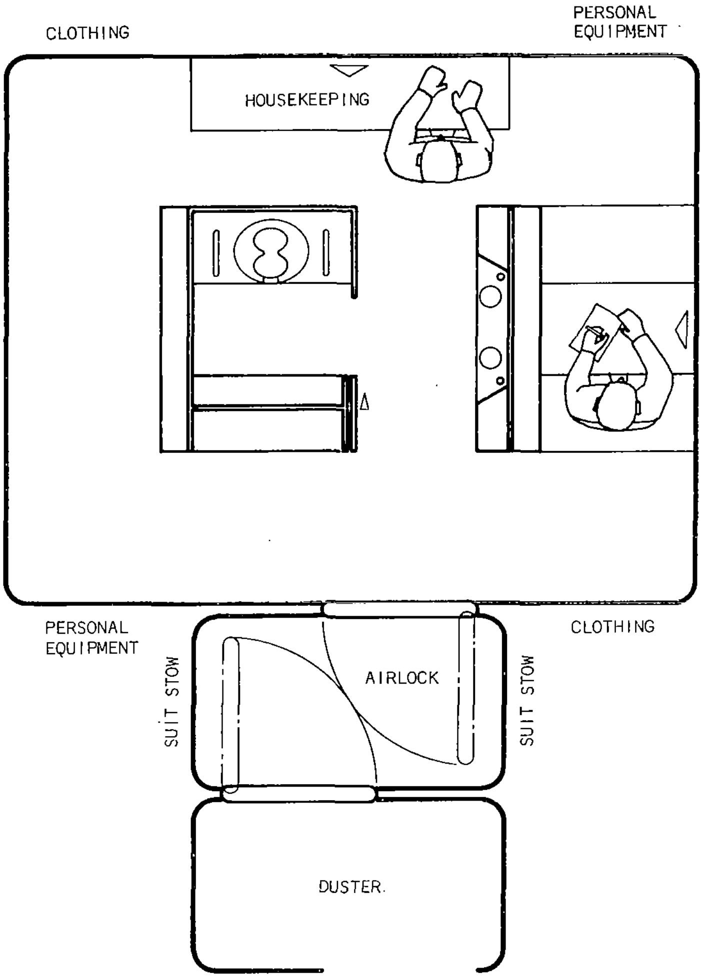
The equipment care module in concept 1 is the single wall design incorporating all of the necessary equipment. Concepts 2 and 3 have a similar design. The difference is that they have two smaller wall modules which house the equipment. The personal gear such as clothing is stowed next to the sleep modules.

CONCEPT 1



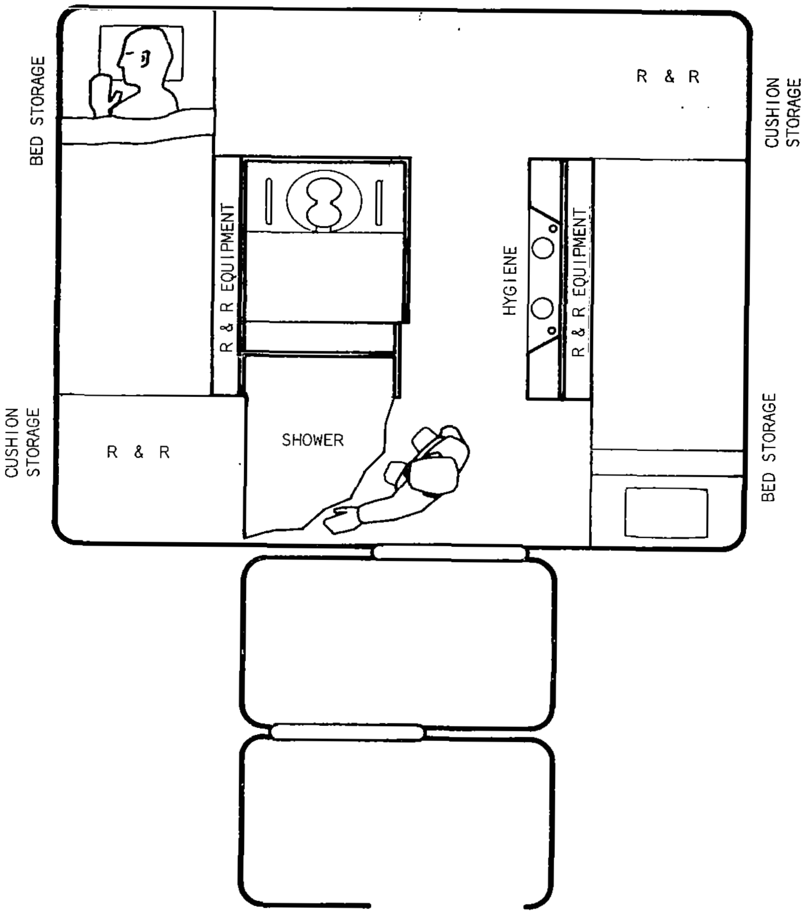
NOURISHMENT/WASTE ELIMINATION

CONCEPT 1



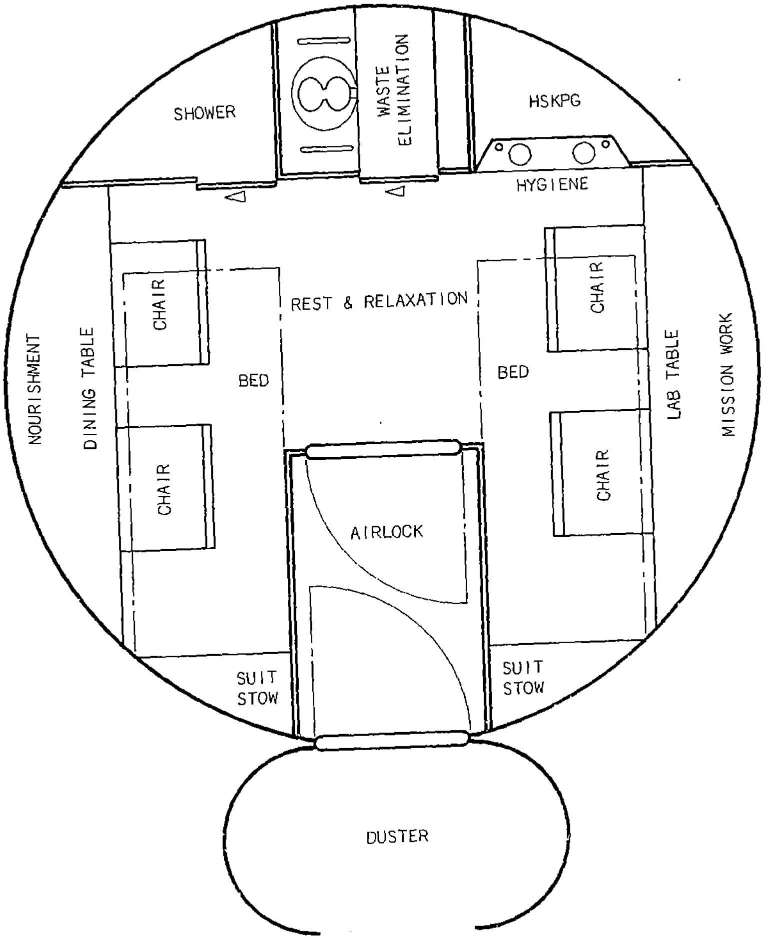
MISSION WORK/HOUSEKPG & P E CARE

CONCEPT 1

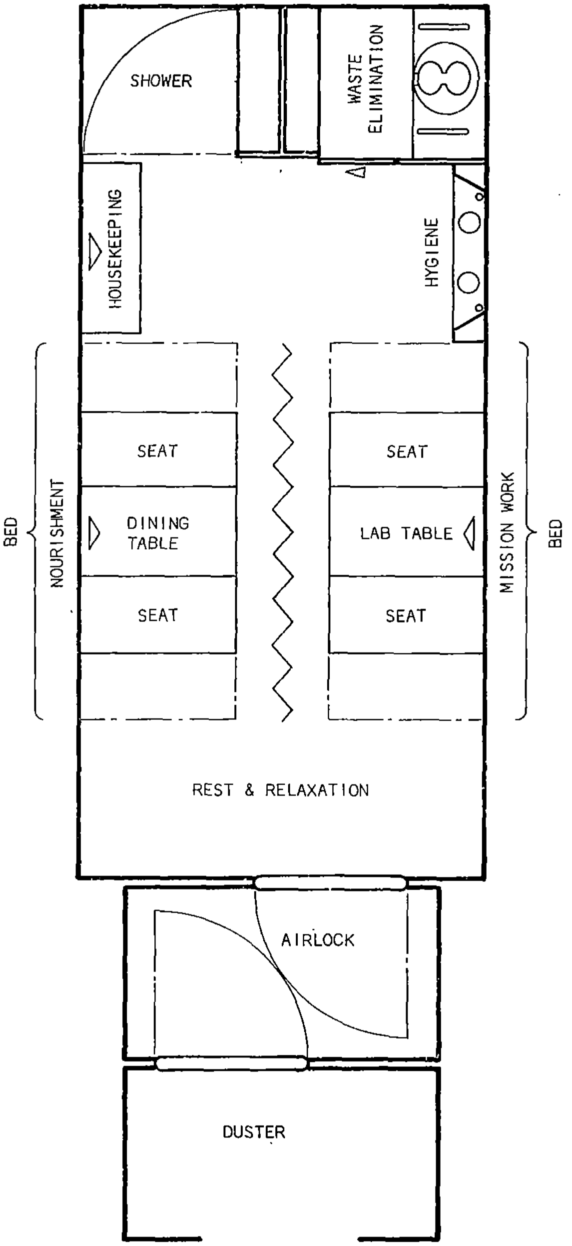


SLEEP/HYGIENE/REST & RELAXATION

CONCEPT 2


SHOWER
WASTE ELIMINATION
HSKPG
HYGIENE
REST & RELAXATION
NOURISHMENT
DINING TABLE
CHAIR
CHAIR
BED
BED
CHAIR
CHAIR
LAB TABLE
MISSION WORK
AIRLOCK
SUIT STOW
SUIT STOW
DUSTER

CONCEPT 3



SHOWER
WASTE ELIMINATION
HOUSEKEEPING
HYGIENE
SEAT
SEAT
DINING TABLE
LAB TABLE
SEAT
SEAT
BED
NOURISHMENT
MISSION WORK
BED
REST & RELAXATION
AIRLOCK
DUSTER

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