CITIES IN THE SKY

(A Design Proposal for an Earth Orbiting Space Station)

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CITIES IN THE SKY

(A Design Proposal for a Manned Earth Orbiting Space Station)

1. ABSTRACT

More so than most design efforts, a manned spacecraft must be an efficient integration of many subsystems and yet function as an autonomous life support habitat. This document is a brief exposé of major determinants affecting extra-terrestrial habitability, subsequently leading to a design proposal for an earth orbiting space station.

Owing to the essential integration and mutual dependencies of subsystems, a scheme for the entire station is conceived. Particular emphasis is devoted toward habitability (especially under confined isolation conditions) and serves as a principal generator of the resultant design solution.

Information contained within this thesis is presented in the following manner:

1. Predecessor Concepts
   - significant past and proposed manned programs
2. Programmatic Issues
   - discussion of design elements
3. Digest of Information
   - concentration of design decisions
4. Design Proposal
   - presentation of physical resolution

2. CONTENTS

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5. INTRODUCTION

5.1. Program Description

5.1.1. Purpose

The principal intent of this document is to establish elements of habitability; then, from interpretation decisions, project a design resolution.

5.1.2. Scope

First, to establish a brief historical perspection of precusor manned space efforts.

Next, to identify the basic requirements and considerations of an earth orbit space station.

Finally, with an emphasis on habitability and existing technology, present a design solution.

5.2. Significant Predecessor Concepts

Included in this section are the significant predecessor concepts affecting manned missions in space. Analogous submersible and ground chambers comprise the first portion, with Earth orbit, Lunar and planetary missions being discussed next.

5.2.1. Analogs

In an attempt to comprehend the dynamics of small social groups exposed to the stresses of extended isolation and confinement, S.B. Sells developed the following criteria and subsequent elevation process.

Criteria of social group:[1]

1. A formal organization with prescribed responsibility patterns for the entire crew;
2. Crew composition characterized by an elite corps of highly selected, trained, and educated volunteer specialists, all extremely ego-involved in the program and the mission;
3. Low organizational autonomy as a result of the NASA organizational and operation system and the affiliation of crew members with military and civilian career services;
4. Low formally prescribed status distance among crew members; and
5. High task demand and mutual dependence, under high levels of isolation, confinement, limitation of mobility and privacy, and environmental threat.

Objectives and goals, value system, personnel composition, organization, technology, physical environment, and temporal characteristics are the seven major categories of his fifty-six system characteristics. Each of these characteristics was then evaluated in terms of its similarity to long term manned space missions. Results of this ranking demonstrated that submersibles most closely resembled the stress conditions of space stations and situations of shipwreck and disaster were least comparable. Table 5.1 shows the ranking results. Another comparison approach evaluates spacecraft, submersibles, and chambers against a sampling of operational conditions. The results indicate that spacecraft, submersibles, and chambers are similar under the conditions of confinement, social isolation, deprivation, and close quarters. While both submersibles and ground chambers are judged

TABLE 5.1

COMPARATIVE SPACE MISSION ANALOGS[2]

	Similarity Rank	Similarity Score
Submarines	1	79
Exploration parties	2	68
Naval ships	3	61
Bomber crews	4	60
Remote duty stations	5	59
POW situations	6	39
Professional athletic teams	7	37
Mental hospital wards	8	23
Prison society	9	20
Industrial work groups	10	16
Shipwrecks and disasters	11	11

against spacecraft, they each provide a separate means for evaluating operational effectiveness. The submersible can best handle crew habitability factors (food, clothing, accomodations), crew skill mix, command atructure, and selected spacecraft subsystems checkout and maintenance during a real mission. The chamber, on the other hand, is most effective in evaluating thermal variation, radiation and life tests under simulated environmental condition.

TABLE 5.2

SPACECRAFT/SUBMERSIBLE/CHAMBER SIMILARITIES[3]

	Spacecraft	Submersible	Chamber
Confinement	x	x	x
Social Isolation	x	x	x
Deprivation	x	x	x
Close Quarters	x	x	x
Meaningful Mission	x	x	
Sustained Motivation	x	x	
Hostile Environment	x	x	
Operational Stress	x	x	
Remote Operations	x	x	
Abort Difficulty	x	x	
Require Real Navigation	x	x	
Scientific Crew	x	x	
Data Transmission Difficulties	x	x	
On-Board Maintenance Provisions	x	x	
Complete Biological Isolation	x	x	
Command Structure	x	x	

5.2.1.1. Submersibles

The validity of submersibles as spacecraft analogs indicates a need for further investigation in this area. Two programs, Tektite and the Gulf Stream Drift Mission, were conducted and their objectives in part, were to explore the habitability provisions for the purpose of obtaining space station design criteria.

5.2.1.1.1. Tektite

Supported by government agencies (the Navy, Department of Interior, NASA, and College of the Virgin Islands) and industry (General Electric Co.), the Tektite project was conceived as a multi-disciplinary study. Initiated in 1968, it integrated marine science, human behavior and small group dynamics, physiological and biomedical research, and engineering and architectural design (or habitability) evaluation. The program was conducted in an underwater habitat (see Figure 5.1) anchored forty-seven feet below the surface of Great Lameshur Bay on St. John Island in the Virgin Islands. It included forty-eight aquanauts on ten separate missions in varying durations from fourteen to sixty days.

Tektite, as in space operations, provided the crews with real missions, which would be difficult or impossible under any other circumstance. That is to say, they did not perform merely as subjects of an isolation experiment. The conditions of the isolation did closely compare with space station guidelines. The aquanauts could not return to the surface without undergoing twenty and one-half hours of decompression, whereas rescue capability for a distressed space station requires a minimum of twenty-four hours.

Operating conditions of the Tektite project which are inconsistant with space missions are depicted in Table 5.3.

TABLE 5.3

TEKTITE AND SPACECRAFT OPERATING DIFFERENCES[4]

1. The habitat operated at one gravity.

2. Internal atmospheric pressure was two and one-half atmospheres (oxygen partial pressure: 158 mm Hg, balance nitrogen).

3. The habitat was not ecologically "closed," the breathing air and potable water were supplied from the surface and there was a constant water interface in one of the changers.

4. Unlike astronauts, the aquanauts made daily and far ranging journeys from the habitat; they were free to leave the confines of the habitat at will. Moreover, wherein aquanauts were eager to pursue their scientific interests in the extrahabitat environment, the opposite is probably true for astronauts; diving was not analogous to extravehicular activity.

5. Supplies from the surface were replenished on a daily basis or as requested.

Som preliminary findings discussed in an aquanaut debriefing following a sixty day mission are represented in Table 5.4. Conclusions of the Tektite program (see Figure 5.5) present viable criteria which can be directly applied to spacecraft design. They are shown in Table 5.5.

5.2.1.1.2. Gulf Stream Drift Mission

The Gruman Aerospace Corporation conducted a study on the

TABLE 5.4

PRELIMINARY TEKTITE FINDINGS[5]

1. Four men successfully performed scientific mission tasks for sixty days in a hostile environment.

2. Settling-in period longer than expected.

3. Living in habitat for several days prior to mission is needed.

4. Sociometric analyses showed distinct trends.

5. Interpersonal interaction and attraction changed with time. Shift in diving partners.

6. Intracrew hostilities were submerged or channeled to outside personnel.

7. Impression period to about mid-run. Complicated by ear infection. Typical of long term isolation studies.

8. Living space was adequate but working space was not.

9. Aquanauts felt strong need to escape into water--but habitat was always home and security.

10. Dinner meal--sometimes three hours long--was great source of relaxation and group interaction.

11. The act of food preparation including creative art of cooking was a source of recreation for at least one crew member. The others enjoyed his meals.

12. To maximize scientific data return, need small operational crew for command and control, equipment maintenance, routine duties.

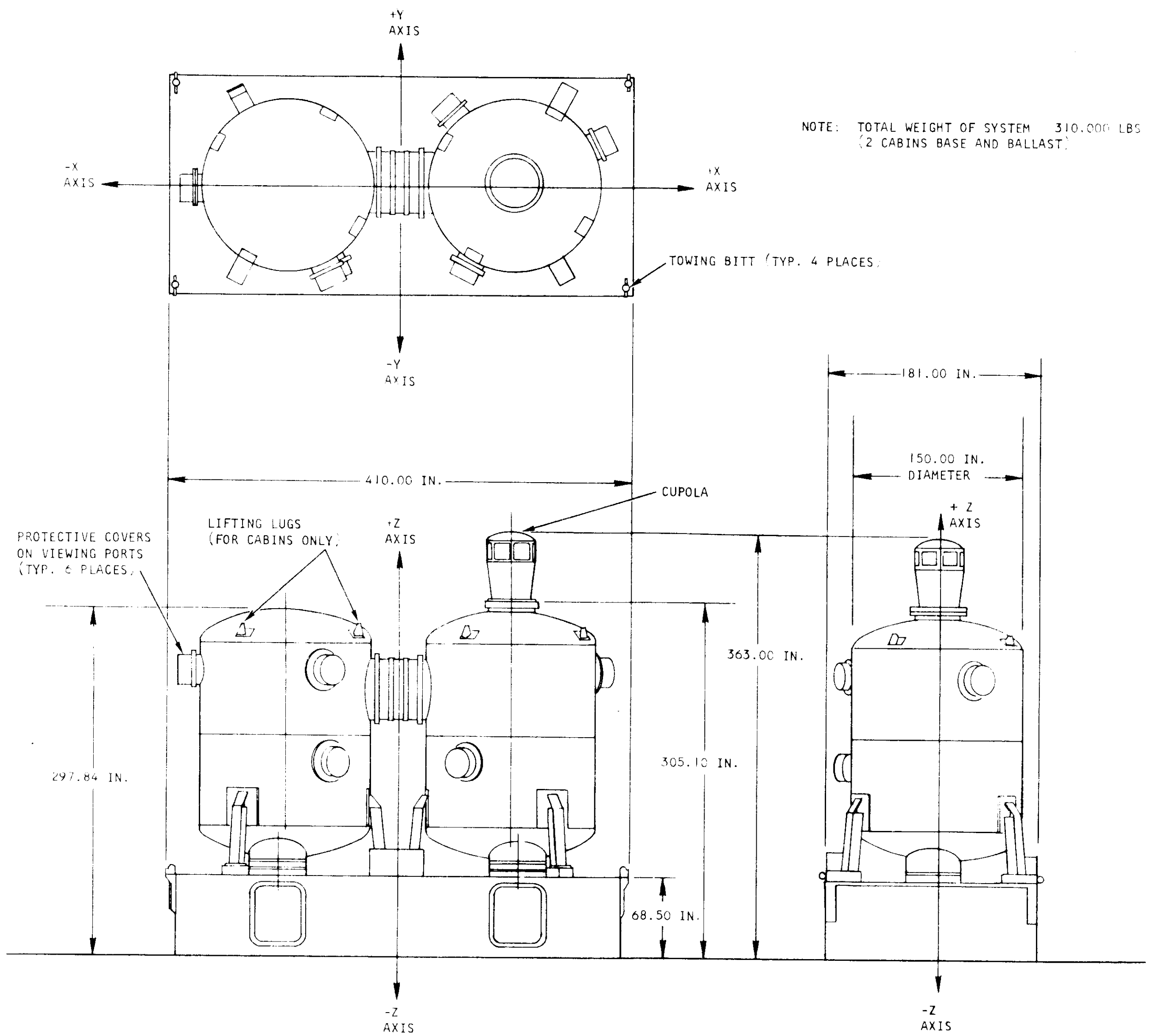


FIGURE 5.1

TEKTITE II HABITAT

TABLE 5.5

TEKTITE CONCLUSIONS[6]

1. On missions where a heterogeneous mixture of backgrounds is expected, crewmen should possess broad interests and should be eager to acquire new knowledge. Where the new leader's professional background is congruent with major mission goals, greater productivity seems to result.

2. Adequacy of laboratory or work facilities are at least as important to the habitability of remote stations as are off duty or "living" provisions.

3. It is highly important to thoroughly acquaint potential scientist-users with the capabilities of remote facilities prior to the beginning of their missions.

4. Two-way video communications more thoroughly integrate operational and support mission elements, leading to enhanced rapport, improved morale and increased productivity.

5. Scientific crewmen show high productivity and innovativeness when not constrained by rigid timelines, but are free to structure their own missions within broad constraints.

6. Leisure provisions become important even to highly work-oriented, busy crewmen.

7. It appears that valid instruments for predicting overall success of particular crewmen and groups can be developed.

8. The results of this program indicate that multiple-use spaces in isolated habitats can create a wide variety of physical and attitudinal problems for the residents. In particular, compartments utilized by the inhabitants for research must be designed with particular care. (See 2 above.)

feasibility of undersea facilities as space mission analogs. The program reinforced submersibles as reasonable comparisons of space missions, since they were both manned by scientific and engineering crews motivated by a scientific purpose to work under operational hazards. This study was a thirty day mission conducted in 1969 by Gruman's Ocean Systems Department. It was labeled the Gulf Stream Drift Mission (GSDM) and employed the use of the Ben Franklin submersible (see Figure 5.2). Part of the Mission's goals were to satisfy a NASA study investigating man related activities compatible with long duration space station missions.

Much like the Tekite project, the GSDM operated under conditions of (1) confinement in a closed ecosystem, (2) isolation from normal family and social contacts, (3) difficulty of escape or return, (4) hazardous environment external to the vehicle and a reduction in variety of stimuli.

The Ben Franklin submersible proved useful in observing human reactions during long term confinement since its size provided approximately the same free volume as allotted for proposed space station concepts. Some constraints of the submersible and experiment methods were comparable with space missions. The power available for data collection was limited to skilowatts and the envirnoment, scheduling, human engineering, and composition of the crew were all predetermined and could not be varied by the investigator.

The following are selected conclusions from the GSDM.

TABLE 5.6

CONCLUSIONS FROM THE GULF STREAM DRIFT MISSION[7]

1. As time progressed, all of the crewmen tended to eat more and more meals alone, thus reflecting a need for privacy and avoidance of conflict.

2. Analysis of the results of the Group Confinement Inventory revealed pertinent information including the following:
- The crewmen became more negative about their environment as time progressed
- Annoyance with partners increased steadily throughout the mission

3. Kinds of frustrations reported by the crewmen were characteristic of clinical interpretations of their personalities and predictions of their responses to environmental stresses.

4. Individual reports of important events generally reflected work assignments and personalities of the crewmen.

5. Sleep analysis indicated:
- Quality of sleep was not cyclic
- Quality of sleep for most of the men fluctuated and did not improve with time
- Quality of sleep for one man would be clearly related to work-rest schedules or circadian rhythm
- Amount of time spent in the bunk remained remarkably constant for each of the crewmen.

6. When questioned during the mission the men reported the consideration for others was one of the most important requirements for crewmen.

7. Subjective reports of performance varied, but for two of the six men, performance apparently was worse on days following fitful or poor sleep than it was on days following a "good" sleep.

8. Group recreation was rare; the men found that reading and listening to music were excellent forms of relaxation.

9. The available data indicate that additional training would have been useful; the men often felt that they had inadequate information and this was a source of annoyance.

10. Although four of the six crewmen lost weight, none suffered detectable physical deconditioning as a result of thirty days in confinement with limited activity.

11. The food was disliked and was a frequent topic of conversation; improvements in this area are important.

12. Certain aspects of the internal environment of the submarine, and provided equipment, were serious sources of annoyance and generalized psychological stress.

13. Conflicts with the personnel of the surface command were serious enough to underscore the need for selections of crewmen for the command post vehicles to be based on integrated compatibility with the subsurface crew.

14. The logs, the psychologists, topside command and the human-engineering limitations of the Ben Franklin were targets for the release of the crews frustrations.

15. People isolated from society should have targets other than their immediate fellowmen against whom they may vent their aggressions. To the extent to which it can be managed these aggressions should be directed to targets that do not affect mission accomplishment.

16. Communication with the outside was important for the well-being of the crew of the Ben Franklin; news from "home" should be unscheduled because men respond negatively when news is inexplicably lacking.

From the findings of the GSDM, a guideline for future spacecraft design was formulated. The issues appear, at first, rather minimal when compared with the complexities of the space station project development and design. Further analysis of the guideline indicates that the everydays of normal life gain orders of importance in confined environments. The following is the guideline developed from GSDM:

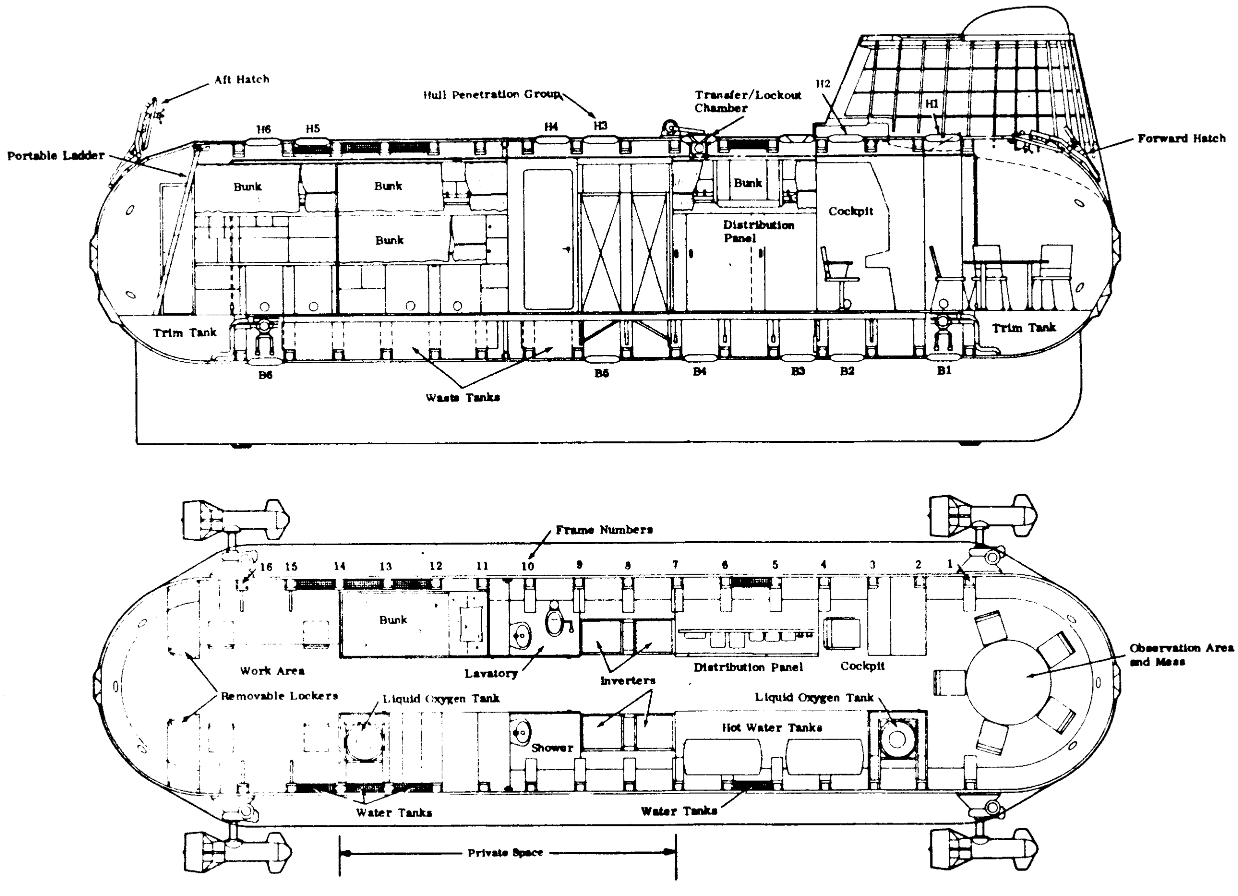


FIGURE 5.2

INBOARD PROFILE OF THE BEN FRANKLIN SUBMERSIBLE

TABLE 5.7

SPACECRAFT HABITABILITY GUIDELINES BASED ON GSDM FINDINGS

1. A separate area with soundproofing, adequate lighting and comfortable chairs is needed for reading and writing.

2. Sleeping quarters should be noise insulated to minimize work area noise.

3. Food preparation devices and techniques should be simple

4. Environmental monitoring should be automatic to free the crew for more useful activity

5. Clothing and bedding for space vehicles should be evaluated at off-design conditions to determine their adequacy

6. Illumination levels should be adequate for the task to be performed

7. The crew's use of the vehicle, crew activity, crew timeliness crew living and working areas detailed consideration and integration.

5.2.1.2. Ground Chambers

An alternate means of simulating the conditions of space is through ground chambers. This section does not describe the complex, computer supported, cockpit simulators of the Mercury, Gemini, and Apollo porgrams. Instead, the environmental simulators, primarily concerned with habitability, are discussed. They are the Manned Environmental Systems Analysis (MESA), the Ninety-Day Manned Test, and Man/Systems Simulator.

5.2.1.2.1. Manned Environmental Systems Analysis (MESA)

In 1964 at Boeing in Seattle, a study on isolation and confinement was performed for NASA headquarters. The thirty day experiment took place in a pressure chamber twenty-two feet long, ten feet wide, and eight feet high (1760 cubic feet) and included four engineers and a Navy M.D. The chamber was separated into three areas, living, sleeping, and operations.

Findings of major study areas are:

TABLE 5.8

MAJOR STUDY AREA FINDINGS OF THE MESA [8]

1. Medical evaluation: result all values were in the range of normal variation and no significant changes from pre-test baselines were found.

2. Psychological evaluation: no serious performance deficiencies were found/irritability and hostility levels were high, but not abnormal for a group in confinement.

3. Concluded: that the thirty day confinement was not particularly stressful or difficult for the five man crew. Human factors consideration (difficulty of use and maintenance of equipment) and habitability (crowding of chamber) led to irritations and interpersonal friction as well. Habitability considerations appear even more important for systems involving crowded confined environments.

5.2.1.2.2. Ninety Day Manned Test

A crew of four men inhabited a twelve foot diameter, forty feet long space station simulator for a period of three months. The chamber was equipped with a regenerative life support system simulating the conditions in space. A major objective was evaluating the men's ability to operate and maintain this hardware.

Complaints normally centered on deficiencies in (1) communications and recreational audio fidelity, (2) hygenic and urine collection inadequacies, (3) lack of attention to surface design details of interior decor, (4) insufficient attention to personal storage allocations, and (5) the limited volume in crew quarters when occupied by all four crewmen simultaneously.

5.2.1.2.3. Man/Systems Simulator

The Man/Systems Simulator is located at the NASA Marshall Space Flight Center and works as a flexible laboratory. It supports a crew of six for thirty days without resupply and tests future manned space systems and spacecraft concepts. The simulator is a cylinder fourteen feet in diameter and forty-eight feet long and provides atmospheric and temperature control, carbon dioxide removal, and water and waste management capabilities.

The testing of habitability factors is the principal function of this simulator and employs a four part measurement technique for purposes of evaluation. The technique includes:

1. habitability sensors used to monitor equipment usage (extent and frequency of use), traffic flow and various physical environment parameters.

2. crew test and questionnaires completed premission, during

mission, and post mission to determine normative personality features and realtime subjective reactions to the environment.

3. stateroom console test to identify crewman performance as a function of mission duration.

4. continual observation of habitat usage, sleep/work patterns, and social behavior.

5.2.2. Earth Orbit

Included in this section are brief descriptions of proposed manned, earth orbit missions. The Manned Orbiting Laboratory (MOL) is presented first with the Soviet Union's Salyut and United States' Skylab Missions being discussed next. Concepts of space stations and space bases conclude the earth orbit portion of significant predecessor concepts.

5.2.2.1. Manned Orbiting Laboratory

The proposed objectives of the MOL program were (1) to investigate man's behavior and capabilities during prolonged space flight eventually leading to a decision over a gravity condition, (2) the testing of subsystems; and (3) the conducting of scientific experiments. The MOL project was scrapped, but much of the program has been absorbed by Skylab.

Design concepts for the Manned Orbiting Laboratory were presented in three packages the minimum MOL, the small MOL and the large MOL.

The minimum MOL accomodates a two man crew in a modified Apollo spacecraft for periods up to 100 days.

The small MOL is a Saturn 1 or 1B stage supplied by four to six men and incorporates a shuttle or ferry vehicle.

A Saturn V launched laboratory with a twelve to twenty-four man crew makes up the large MOL.

Modified Gemini and Apollo capsules along with advanced logistics and lifting body concepts were reviewed as possible re-entry systems.

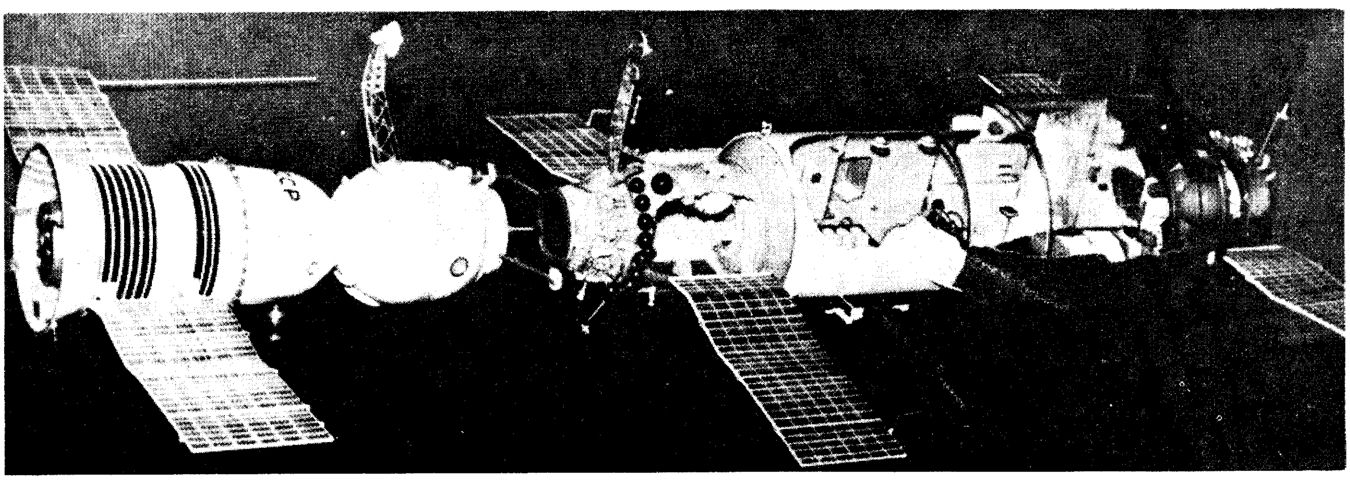


FIGURE 5.3

DOCKED SOYUZ AND SALUTE SPACE STATION

5.2.2.2. Salyut

For twenty-three days, three cosmonauts manned the Soviet space station, Salyut. Salyut, itself, is the laboratory end of the station and was connected to a Soyuz supply craft. Overall dimensions of the combined vehicles measured about sixty-five feet by a minimum diameter of thirteen feet.

The Salyut station was divided into several compartments. A docking unit located on the station's axis ajoined a short cylinder, about six feet in diameter, which contained astrophysical apparatus. Two adjacent cylinders, nine feet and twelve feet respectively, contained the working compartment.

The basic Salyut mission objectives were: (1) check out and test design of units and on-board systems and equipment; (2) try out methods of station orientation and navigation, some automatic; (3) study geological/geographical objects on Earth, atmospheric formations, snow and ice cover, with the aim of developing methods for using this information in the solution of economic problems; (4) to study physical chemical processes and phenomena in the atmosphere and outer space in various regimes of the electromagnetic spectrum; and (5) to continue biomedical studies, to determine the possibility of performing various tasks by cosmonauts in space stations and to study factors of spaceflight on the human system.

The Salyut station did not induce artificial gravity and from all indications the cosmonauts suffered no ill effects. Adjustment to re-entry forces and earth gravity data is unavailable since, after deorbit the Soyuz spacecraft experienced rapid depressurization and the cosmonauts were killed before reaching the ground.

5.2.2.3. Skylab

In early 1973, the United States will launch a 10,000 cubic foot space station called Skylab. The earth orbiting Skylab consists of an Orbital Workshop (OWS), Airlock and Multiple Docking Adapter, and an Apollo Telescope Mount. The OWS, the habitable portion, is twenty-two feet in diameter and contains a wardroom, sleeping compartment, a waste management facility and two work/experiment areas. Three crews of three astronauts each will live in the OWS for twenty-eight and fifty-six day missions.

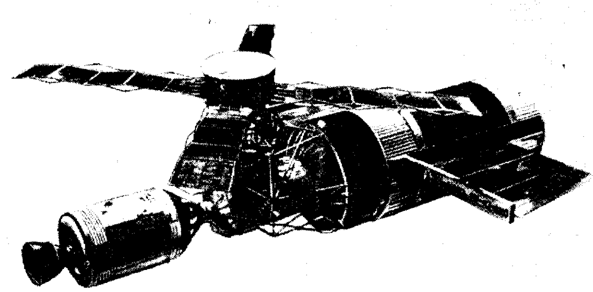


FIGURE 5.4

SKYLAB

M487, Habitability and Crew Quarters, is the Skylab experiment which will evaluate man/environment interactions. It will assess the following areas:

TABLE 5.9

SKYLAB ASSESSMENT AREAS

1. Personal Hygiene--includes body waste management, personal cleanliness and hygiene.

2. Food and Water--includes food handling, e.g., storage, preparation, palatability, and cleanup and water provisions (e.g., dispensing, activation/deactivation of water subsystem).

3. Clothing--examines mobility and functional capabilities of garment handling (e.g., donning, doffing, storage, disposal and comfort).

4. Architecture--assesses configuration location, operation, etc., of the crew quarters, work and recreational areas, storage, equipment, experiments and passageways in terms of adequacy, appeal and useability.

5. Astronaut aids--includes restraint devices (fixed and portable aids) and various mobility techniques (e.g., free soaring).

6. Off-duty Activities--includes preferences, handling, and adequacy of passive and active recreational and passive entertainment provisions.

7. Environment--includes crewman measurements and observations of environmental parameters (e.g., pressure, humidity, light level, acoustics).

8. Communications--includes maintenance, connector locations, and db levels of intravehicular communications subsystem.

9. Housekeeping--includes time requirements, techniques, and frequency of maintaining a clean and habitable OWS.

Along with the habitability, bio-medical, behavioral, and work effectiveness experiments, the Skylab program will test earth resource sensing equipment. Oceanography, water management, agriculture, forestry, geology and geography will be among the many study areas. Another field of concentration will be astronomy. With its obvious advantages over earth based observations, the Apollo Telescope Mount will study the sun and its affects on man.

5.2.2.4. Space Stations

Earth-orbiting space station proposals by North American Rockwell, McDonnell Douglas, and Marshall Space Flight Center are discussed in this section. All concepts are generated by a NASA 1980 Space Station goal and based on a twelve-man crew, ten year life, and Advanced Logistics System (ALS), or space shuttle. The North American Rockwell and McDonnell Douglas proposals are results of the second phase studies conducted during the period September 1969 to August 1970.

5.2.2.4.1. The North American Rockwell Proposal

The station developed by North American Rockwell (NAR) is composed of a thirty-three foot diameter, four deck core module attached to a solar power boom. The core module is separated into two pressure volumes, two decks each, and each deck has a height of six feet, ten inches, exclusive of a false ceiling situated five inches below a four inch deep structural ceiling. Two utility trunks thirty-one feet in length, ten feet wide, and one foot deep and separated by six feet two inches, support electronic and mechanical functions.

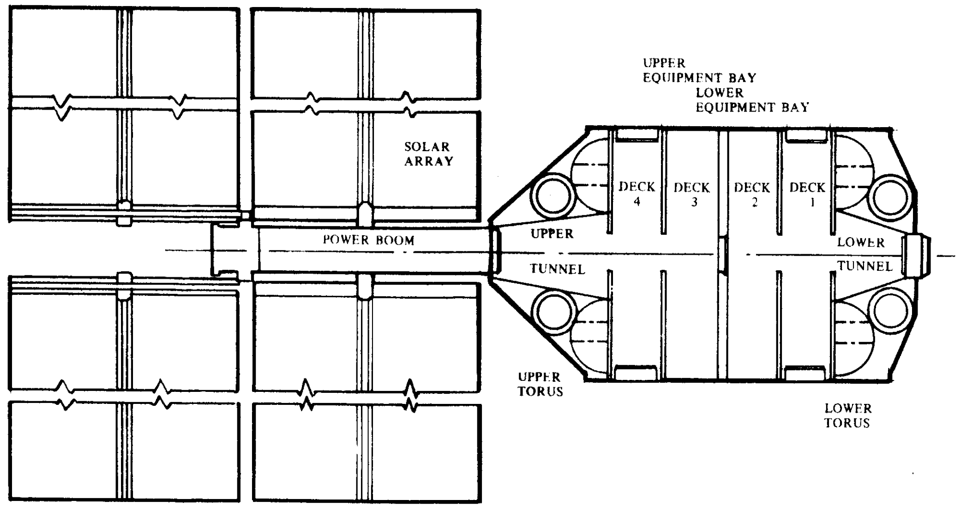


FIGURE 5.5

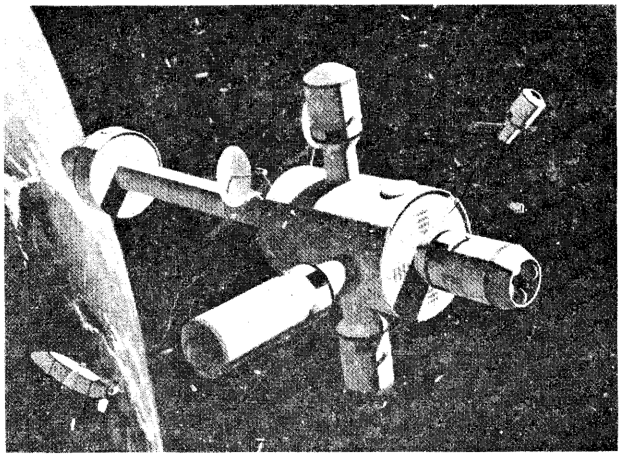
NORTH AMERICAN ROCKWELL SPACE STATION PROPOSAL

5.2.2.4.2. The McDonnell Douglas Proposal

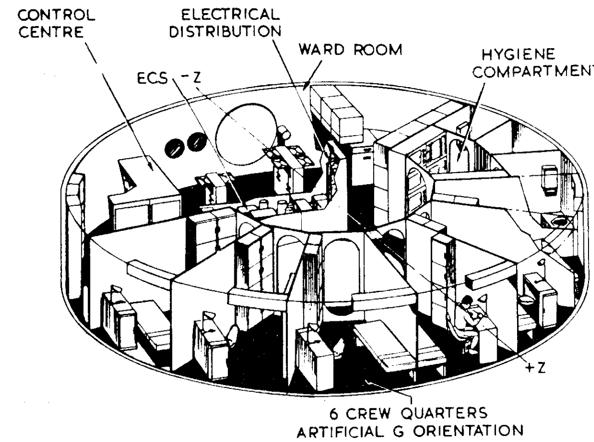
The McDonnell Douglas Corporation (MDAC) presented baseline and expanded capability concepts. The baseline design is a vertical assembly of two thirty-three foot diameter common modules with a combined length of fifty feet. As in the NAR station, the common modules contain two decks, which, in case of environmental failure, can support the full twelve man crew. A ten foot diameter pressurized tunnel extends the length of the core module.

It performs as necessary refuge in the event of emergency, means of inter deck equipment and personnel transportation, and serves as a structural tie for the entire assembly. Utility supply is routed along this tunnel and access to either common module is made through inter volume locks or the tunnel.

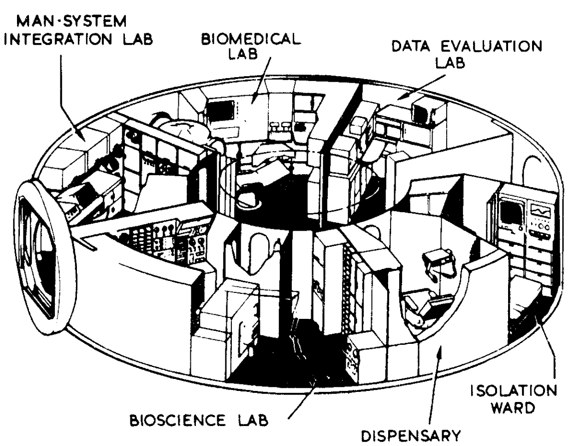
The expanded capability concept incorporates an additional



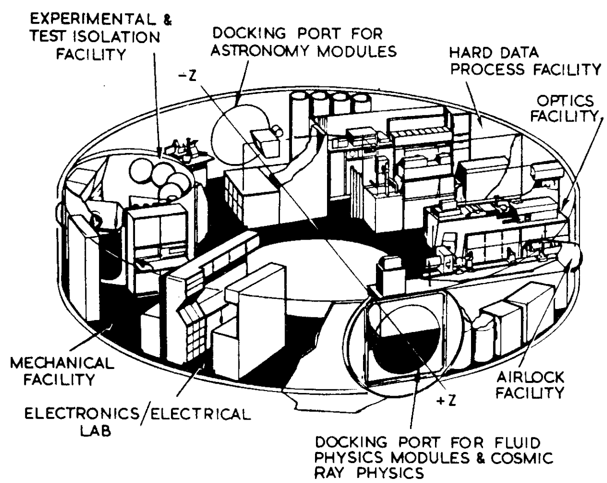
MDAL EXPANDED CAPABILITY
SPACE STATION



CREW FACILITIES AND OPERATIONS
DECKS 1 AND 3



EXPERIMENT
DECK 2



GENERAL PURPOSE LABORATORY
DECK 4

FIGURE 5.6

MDAC EXPANDED STATION PROPOSAL

two-deck common module. This module provides the station with artificial gravity simulation, acting independent of any other hardware.

The following space station concept comparison demonstrates the capability difference between the baseline and expanded proposals.

TABLE 5.10

MDAC BASELINE AND EXPANDED PROPOSAL COMPARISONS

Characteristic	Baseline	Expanded
Habitable volume (cu. ft.)	29,200	53,400
Weight (lb.)	157,050	176,960
Discretionary payload (lb.)	37,950	18,040
Common module decks	4	6
Docking ports	7	8
Power for experiments (kwe)	10	20.8
Experiment decks	2	4
Height at launch (ft.)	327.5	331
Crew support capability	12	18
Artificial gravity capacity	Limited	Unlimited

5.2.2.4.3. Marshall Space Flight Center/A Modularized Space Station

Marshall Space Flight Center developed a modular concept compatible with the Earth Orbit Shuttle cargo bay. Design parameters of the cargo bay at this time were dimensions of sixty feet in length and a fifteen feet diameter, and weight of 25,000 pounds. Since a module fifteen by sixty feet would be heavier than the established limit a fourteen by twenty—nine foot, 25,000 pound module was adopted.

Seventeen modules, involving five design elements, are required for the twelve man space station build up. The Electrical Power Boom (EPB) is the first design element and can be pressurized to allow shirt-sleeve work by the crew. The Solar Power Element (SPE) contains four arrays, totaling 10,000 square feet surface area, and delivers twenty-five kilowatt of power. The station's core is the Central Assembly Element (CAE). Each has six docking ports, and three coupled end to end form the central corridor.

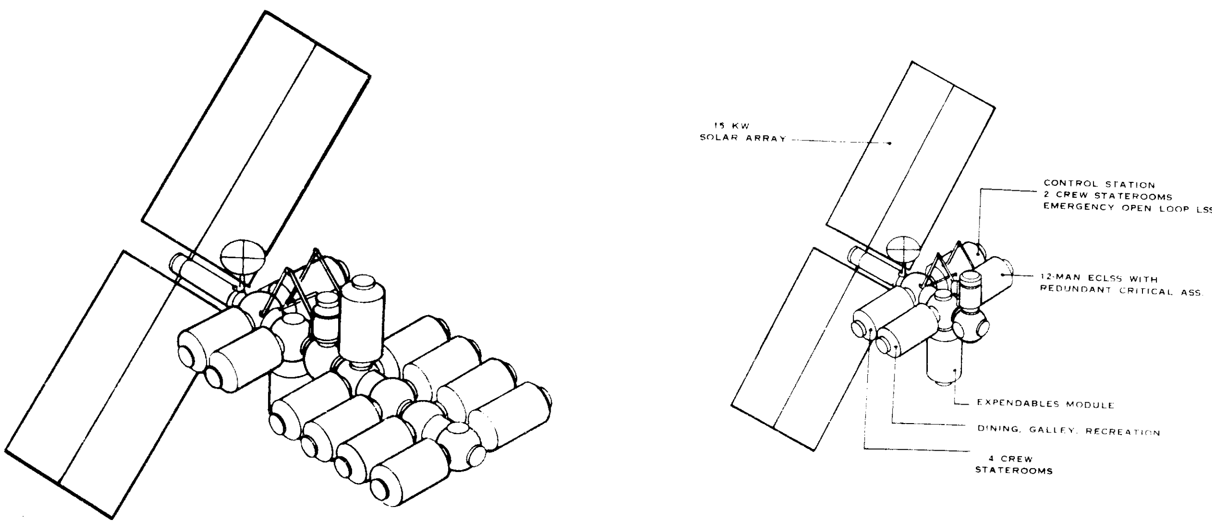
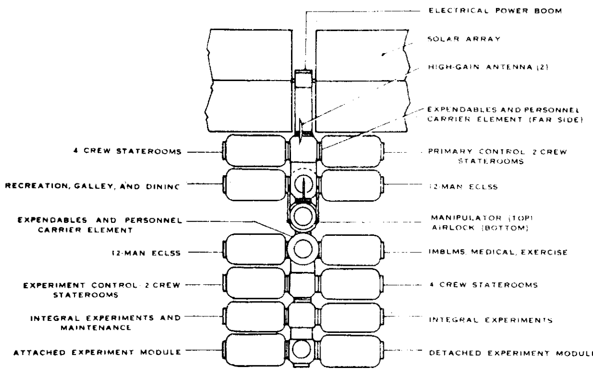


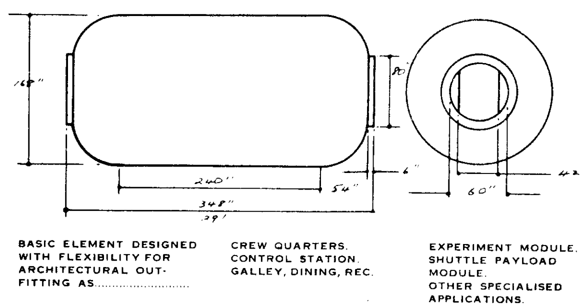
FIGURE 5.7

MARSHALL'S MODULAR SPACE STATION PROPOSAL

Fourteen BSE's or Basic Structural Elements are necessary for full assembly and makeup crew quarters, control station, dining and recreation rooms, laboratories, etc.

The Airlock/Manipulator Element (AME) is a pressure container with manipulator arms and the final design element.





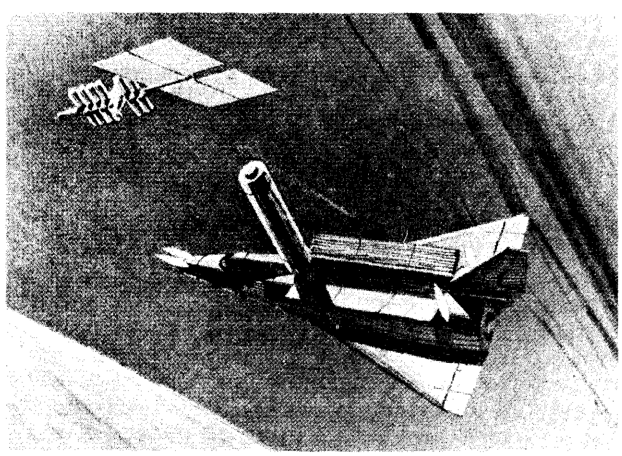


FIGURE 5.8

MODULAR SPACE STATION ELEMENTS

TABLE 5.11

MODULAR SPACE STATION BUILD-UP[9]

Launch	Module	Weight (lb.)	(kg)
1.	Airlock and Manipulator	12,500	5,700
2.	CAE (Central Assembly Element)	13,900	6,300
3.	SPE (Solar Power Element)	10,900	4,900
4.	BSE (control station and rooms)	13,500	6,100
5.	BSE (rooms)	16,500	7,500
6.	BSE (ECLSS)	15,200	6,900
7.	BSE (dining and recreation)	14,000	6,300
8.	BSE (expendable storage)	18,400	8,300
Totals for a six-man station:		114,900	52,000
9.	CAE	13,900	6,300
10.	BSE (medical, exercise)	11,400	5,100
11.	BSE (ECLSS)	15,400	7,000
12.	BSE (crew rooms)	16,500	7,500
13.	BSE (experiment control and rooms)	13,500	6,100
14.	CAE	11,700	5,300
15.	BSE (experiment laboratory)	14,500	6,600
16.	BSE (experiment laboratory)	14,500	6,600
17.	BSE (expendable storage)	18,400	8,300
Totals for a twelve-man station:		244,700	110,800

5.2.2.5. Space Base

Advanced planning has developed concepts for a Space Base, which, principally, is a large scale space station. North American Rockwell and McDonnell Douglas have proposed schemes growing to incorporate crews greater than sixty men.

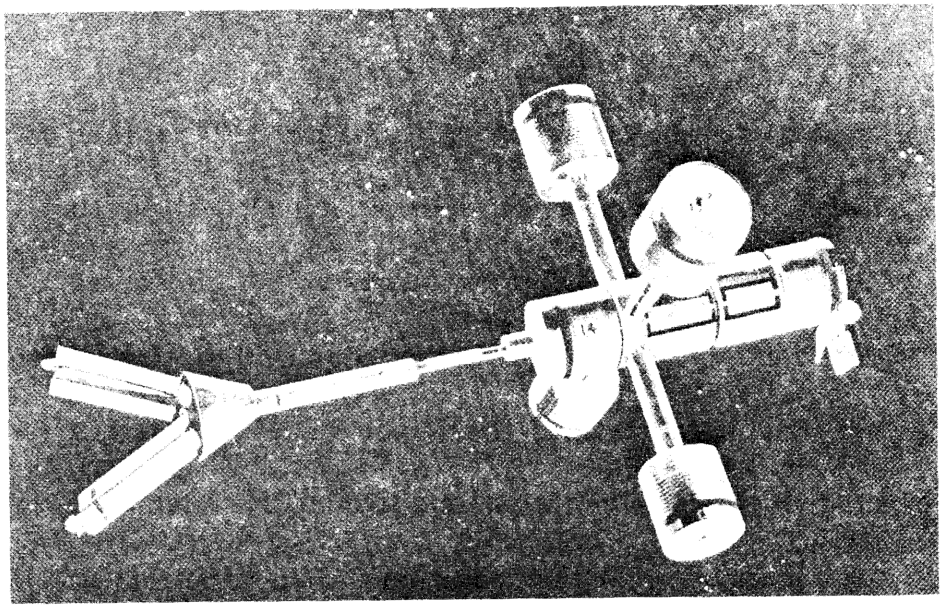
5.2.2.5.1. North American Rockwell

NAR combines both zero and artificial gravities in a proposed Base configuration. The rotating portion measures 234 feet between modules and 234 feet along the zero gravity axis.

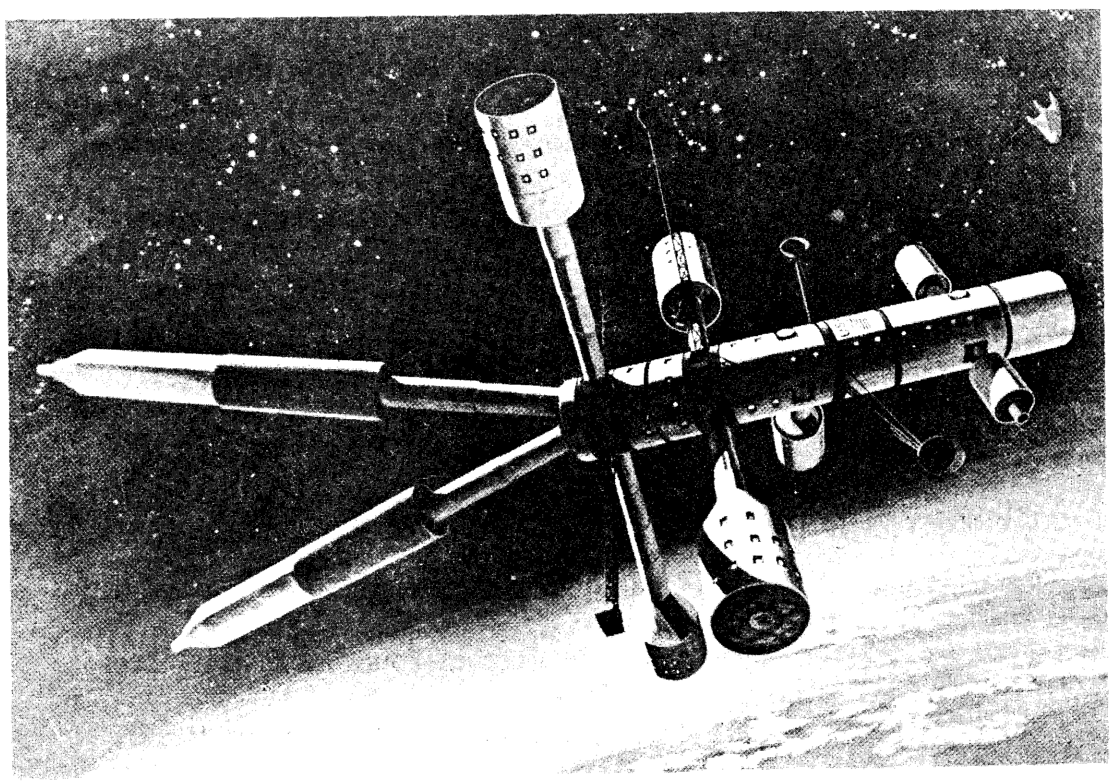
The nominal base is comprised of a basic unit, a four deck common module with equal division between Space Operation and Scientific Investigations (SOSI) and crew quarters. A two deck rotation system connected to a four deck hub assembly, along with two nuclear power modules complete the space base configuration.

An eight deck Space Operation and Scientific Investigation module is booster launched with two additional SOSI modules and hub unit following the second launch. When docked, the combination can support an initial crew of twelve men. A third launch orbits two nuclear reactors which are attached to a shuttle delivered, extendible boom. Earth Survey sensors are positioned on the second shuttle launch. The fourth launch of two, four-deck SOSI modules and their docking to the rotor booms completes the Initial Base. This configuration supports a thirty-six man crew, with four modules in zero gravity and the other two in an artificial gravity mode.

A sixty-man Nominal Base is established when two combined SOSI/crew quarter modules are positioned on the remaining artificial gravity booms. With the addition of a second four deck SOSI/crew quarters module to each of the four existing modules on artificial booms the full utilization Growth Based is created. The resulting 164 man capacity requires a total of seven booster launches and twelve shuttle flights.



NORTH AMERICAN ROCKWELL



McDONNELL DOUGLAS AIRCRAFT CORPORATION

FIGURE 5.9

TWO 60 MAN SPACE BASE CONCEPTS

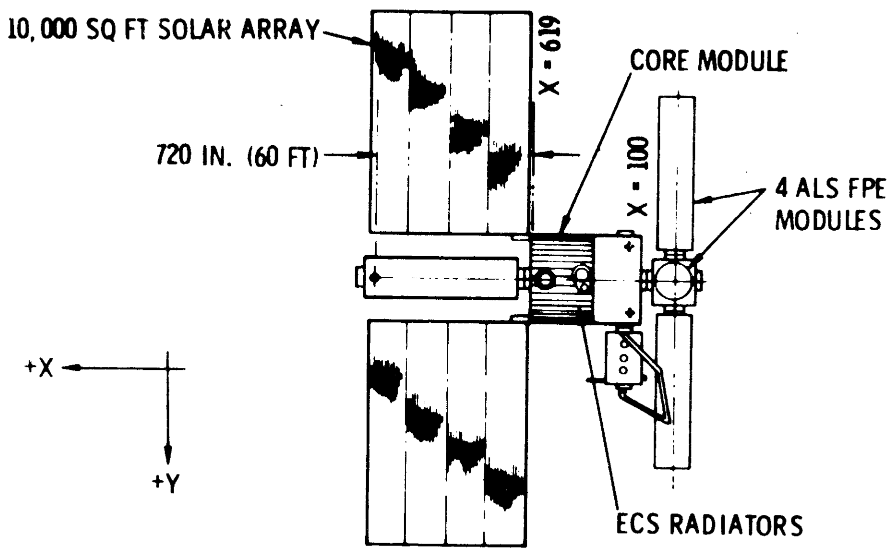


FIGURE 5.10

LUNAR ORBIT STATION CONFIGURATION

5.2.3. Lunar and Planetary

Presented in this section are two lunar orbit and three planetary exploration concepts. The lunar orbit proposals, products of NASA's Integrated Program Plan, are generated by both NASA and North American Rockwell. Proposed conceptual schemes of Mars Twilight Encounter, Triple Planet Encounter and Manned Mars Mission are also described.

5.2.3.1. Lunar

5.2.3.1.1 Lunar Orbit Station (LOS)/NASA

As currently envisioned, the LOS will be derived from a twelve man Earth Orbit Space Station and composed of a core module containing living facilities, internal experiment laboratories and subsystem areas.

The LOS will circle the moon in a polar orbit sixty nautical miles above the surface and support a number of scientific activities conducted there.

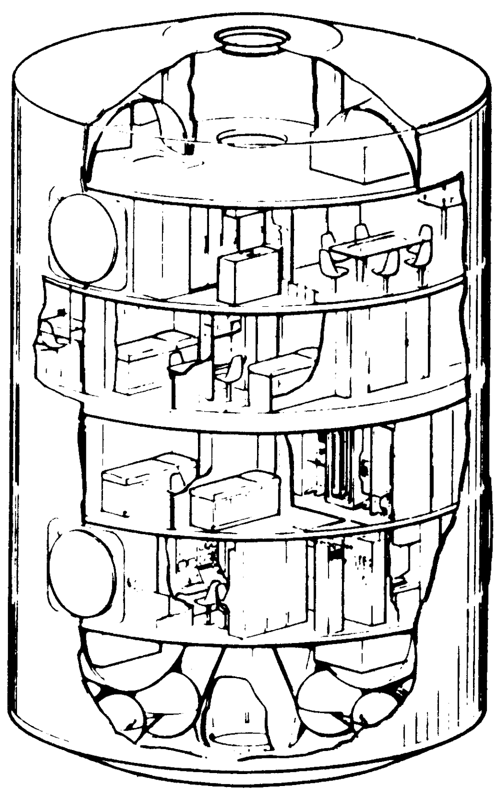


FIGURE 5.11

LUNAR ORBIT STATION INTERIOR

The selected core module is a thirty-three foot diameter by forty-six foot long cylinder containing four decks in two pressure volumes.

The Lunar Orbit Station is dependent on the following:[10]

1. INT-21 booster for insertion of the LOS, Space Tugs and Nuclear Shuttles into earth orbit.

2. Space Tug for transport of men, supplies and equipment from the EOSS to the LOS while the LOS is in earth orbit; for the transport of men, supplies and equipment between the LOS in lunar orbit and the lunar surface; and, as a vehicle which can be used for contingency transfer of men from the LOS in lunar orbit to the EOSS.

3. Nuclear Shuttle (NS) for transporting the LOS and Lunar Landing Tugs from earth orbit to lunar orbit; and for transporting men, equipment and supplies to and from earth orbit and lunar orbit.

4. Advanced Logistics System (ALS) for the transport of NS fuel, LLT fuel, crewmen, scientific equipment, and consumables to earth orbit from the earth surface; for the deorbiting of the spent S-II stage; and for the return of equipment from earth orbit to the earth surface.

5.2.3.1.2. Orbiting Lunar Station (OLS)/North American Rockwell (NAR)

The intent of the NAR study was to include the functions, operations, and performance requirements as well as a configuration for an Orbiting Lunar Station.

The principal assumptions and guidelines were similar to those used in NASA's proposed LOS with the exception of the conceptual design definition. NAR outlined two designs: an OLS that was unconstrained by precursor space station concept definitions, and a derivative of an earth orbital Modular Space Station. The Modular Space Station proposal was perhaps the most significant subobjective of the NAR study.

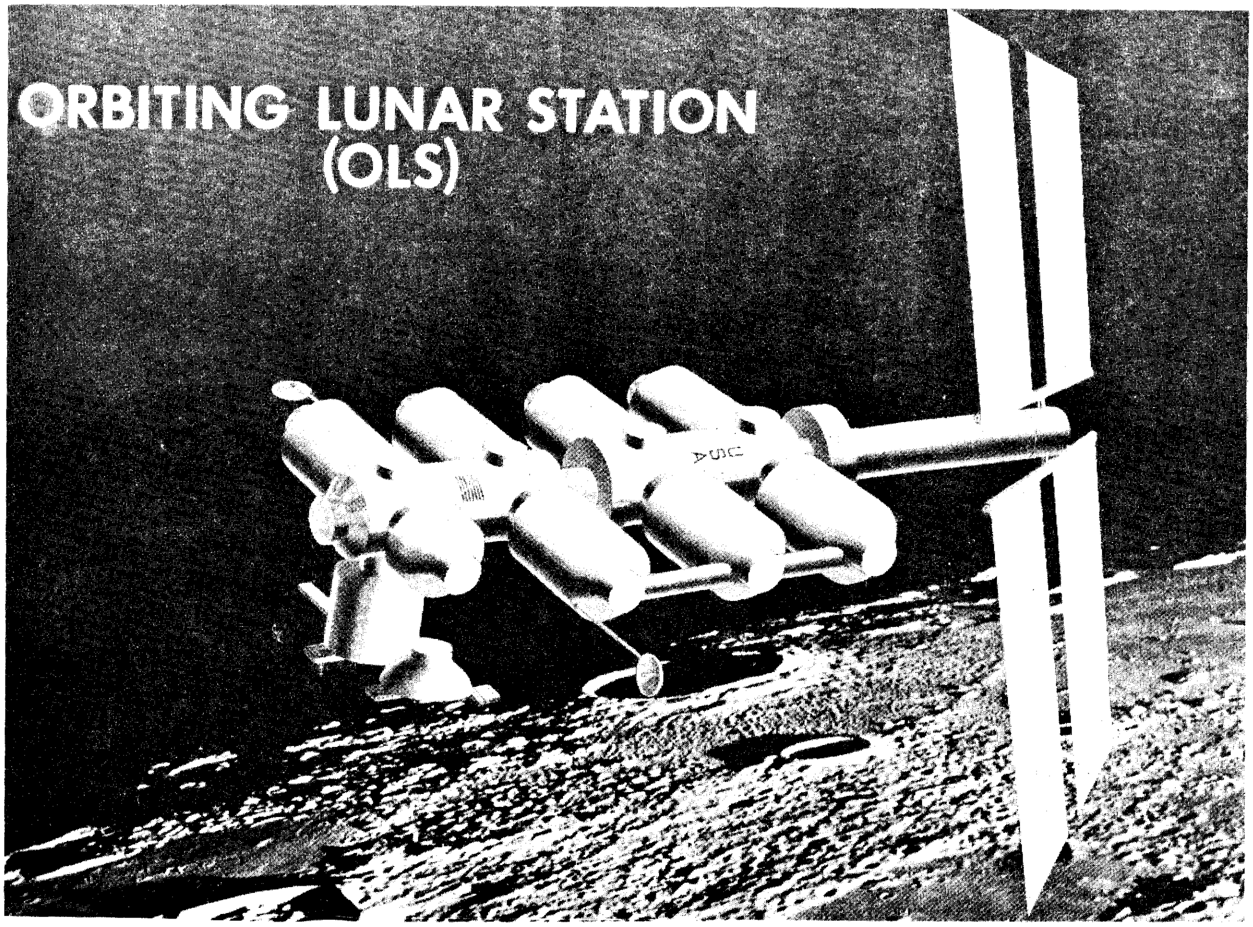


FIGURE 5.12

ORBITING LUNAR STATION

Characteristics of the OLS configuration are listed below.[11]

1. The core module is twenty-seven feet in diameter with an overall length of 60.83 feet. The internal arrangement consists of four transverse circular decks with toroidal end pressure bulkheads and two separate pressure volumes. Un pressurized volumes are provided in the upper and lower torus regions for cryogenic storage.

2. A four-element rollout solar array of 10,000 square feet is accommodated on a cylindrical power module. When mated at launch, the overall length of the power and core modules is 94.25 feet.

3. Four passive docking ports are located on the cylindrical portion of the core module plus two active neuter docking cones at each end. Passive side docking ports are employed to eliminate the need for large boost fairings. At anytime after boost to earth orbit, these passive ports can be modified by the addition of active/active docking adapters. Four of these are defined as necessary to satisfy OLS operational docking requirements.

4. An experiment module fifteen feet in diameter and twenty-two feet long (EOS compatible) is docked at the +Z axis port of the experiments deck to physically accommodate those science experiments requiring an unrestricted field of view while body mounted to the OLS. The experiment module also incorporates a separate compartment which functions as an airlock and subsatellite servicing hangar.

Specified as a dependent program element of both lunar orbit station proposals is the Space Tug or orbit-to-orbit shuttle. Pictured (below) is a Lockheed concept demonstrating satellite retrival and repair. The tug would also facilitate space assembly of major components and ferry satellites to and from orbit.

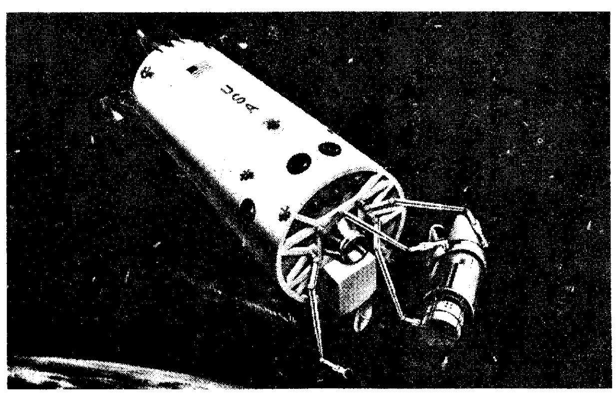


FIGURE 5.13

SPACE TUG

5.2.3.2. Planetary

5.2.3.2.1 Mars Twilight Encounter and Triple Planet Encounter

In a 1967 NASA publication, A Study of Spacecraft Design and Operations for Manned Planetary Encounter Missions, proposed Mars Twilight Encounter and Triple Planet Encounter missions are outlined. The Mars Twilight Encounter program includes four probes in addition to the flyby mission module. These are (1) a Mars Orbiter Probe containing cameras and scientific equipment, (2) an Aero Drag Probe, used for atmospheric data collection, (3) a Soft Lander Probe, an instrument package remaining as a scientific station, and (4) a Mars Surface Sample Retriever Probe, an instrument package which returns to the Mission Module.

5.2.3.2.2. Triple Planet Encounter

Briefly described, the Triple Planet Encounter involves a Venus flyby with deployment of sixteen experiment probes, a Mars encounter, encorporating two surface sample retrievers, and on the return leg a second Venus flyby with ten probes deployed.

5.2.3.2.3. Manned Mars Exploration Requirements and Consideration

The two previous planetary proposals indicate 1967 thinking. Subsequent events have altered program goals and the Manned Mars Mission developed by NASA's Advanced Studies Office is evidence of most recent developments.

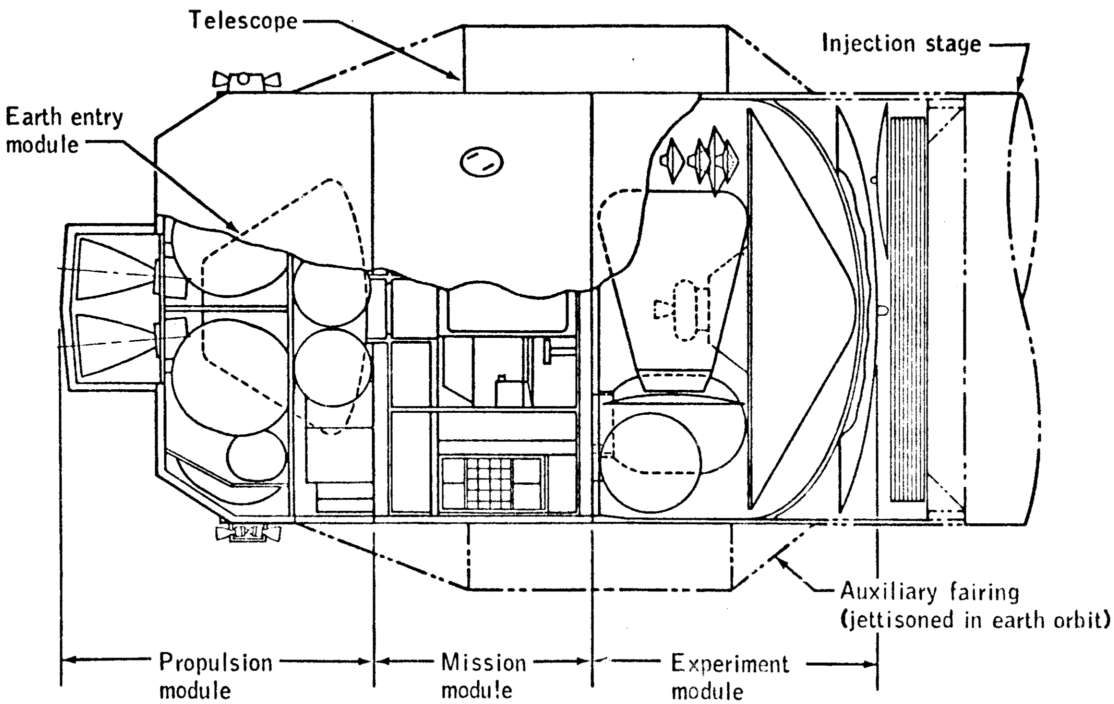


FIGURE 5.14

MARS TWILIGHT ENCOUNTER MISSION

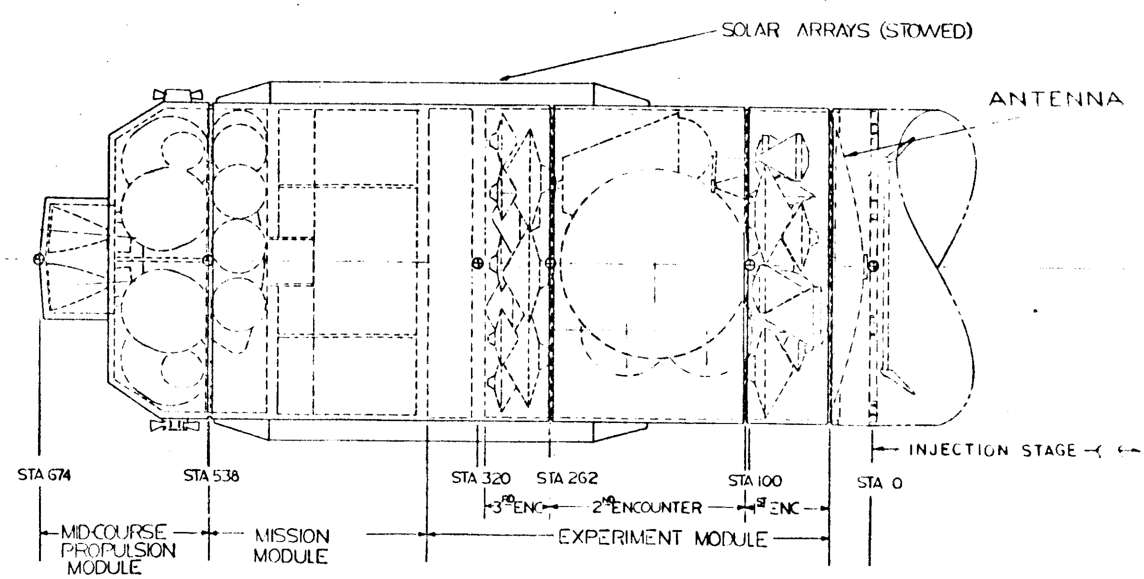
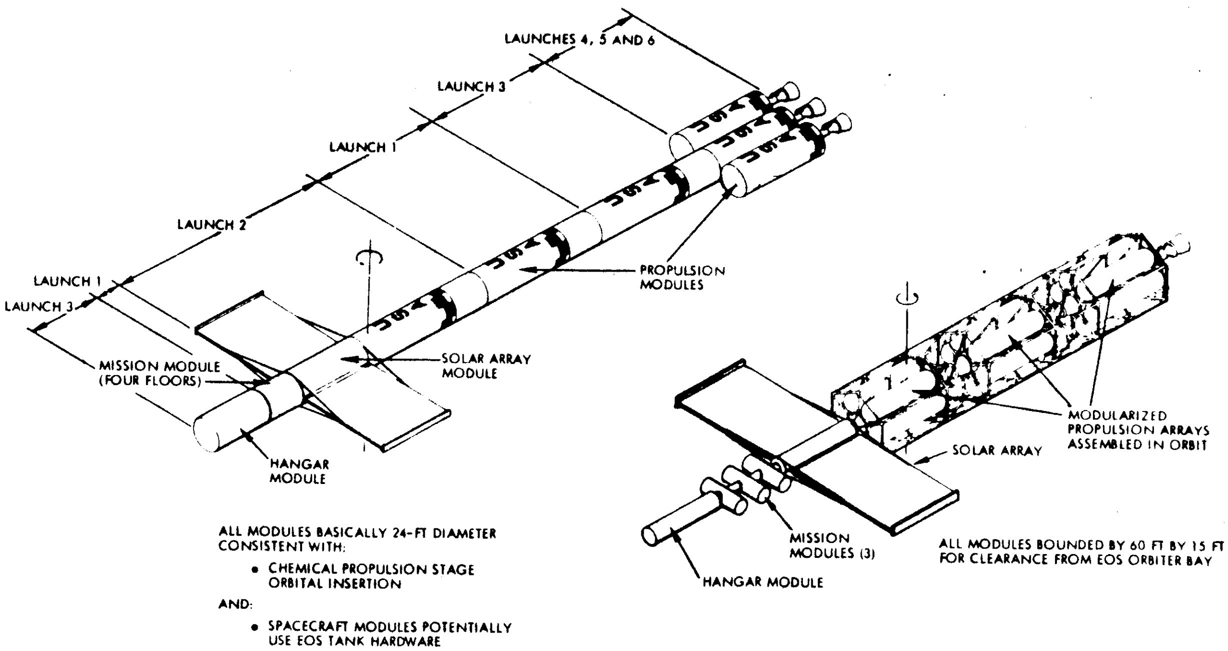


FIGURE 5.15
TRIPLE PLANET ENCOUNTER MISSION MODULE



a. Compatible With CPS and EOS Hardware

b. Compatible With EOS Orbiter Bay

FIGURE 5.16

MODULE SIZE ALTERNATIVE/MANNED MARS MISSION

It consists of (1) a Mars Excursion Module (MEM), (2) payload hanger for the MEM and probe, (3) a mission module designed for a crew of five men, (4) a solar array module, and (5) a propulsion array of six chemical propulsion stages.

Taking place in earth orbit the assembly of the spacecraft requires the support of the ALS shuttle, chemical propulsion stage, and space tug.

5.3. The Advanced Logistics System (ALS)

The ALS, sometimes called Earth Orbit Shuttle (EOS), is concieved as two stage fully reusable transportation system composed of a first-stage booster and a second-stage orbiter. The primary function of the ALS is in the resupply of space station and space base expendables, rotation of crew, and the placement and retrival and support of satellites.

The vertical assembly of the Booster and piggy-back Orbiter is launched to an altitude of 200,000 feet where they separate. The Orbiter heads for its programed rendezvous and the Booster is piloted back to the launch area.

Primarily differing in the wing configuration, there have been several earth orbiter proposals. A North American Rockwell scheme shows short "blade" wings while alternate concepts exhibit swept wing designs.

The ALS cargo bay is fifteen feet in diameter by sixty feet

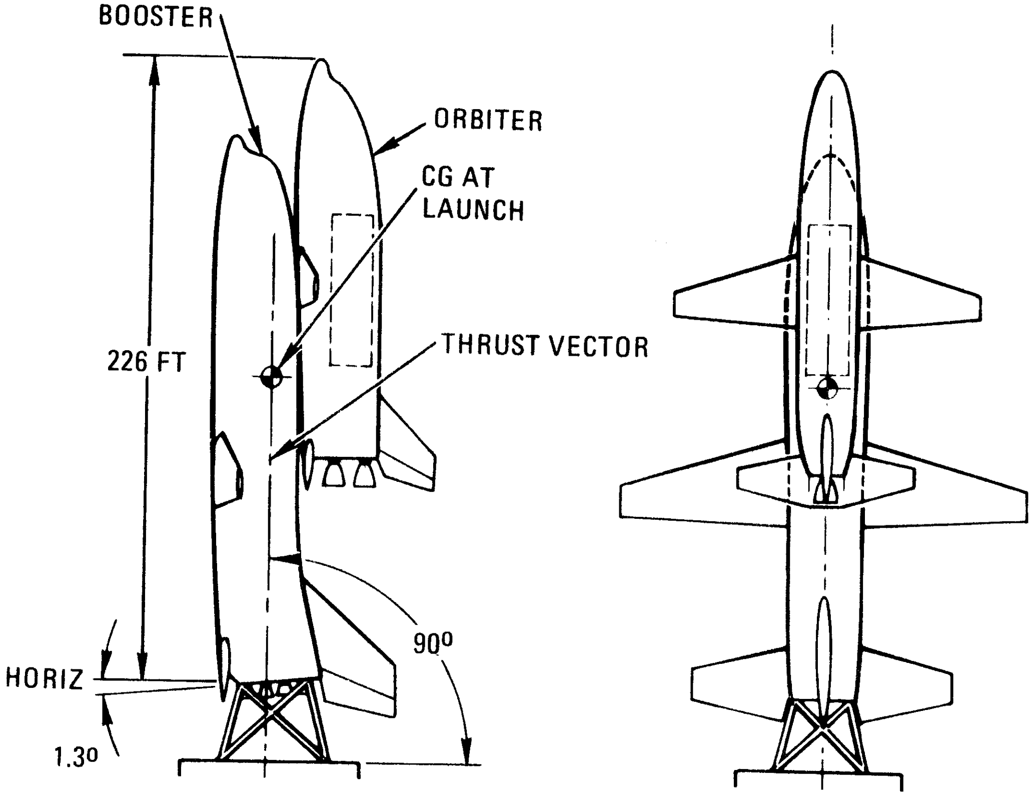
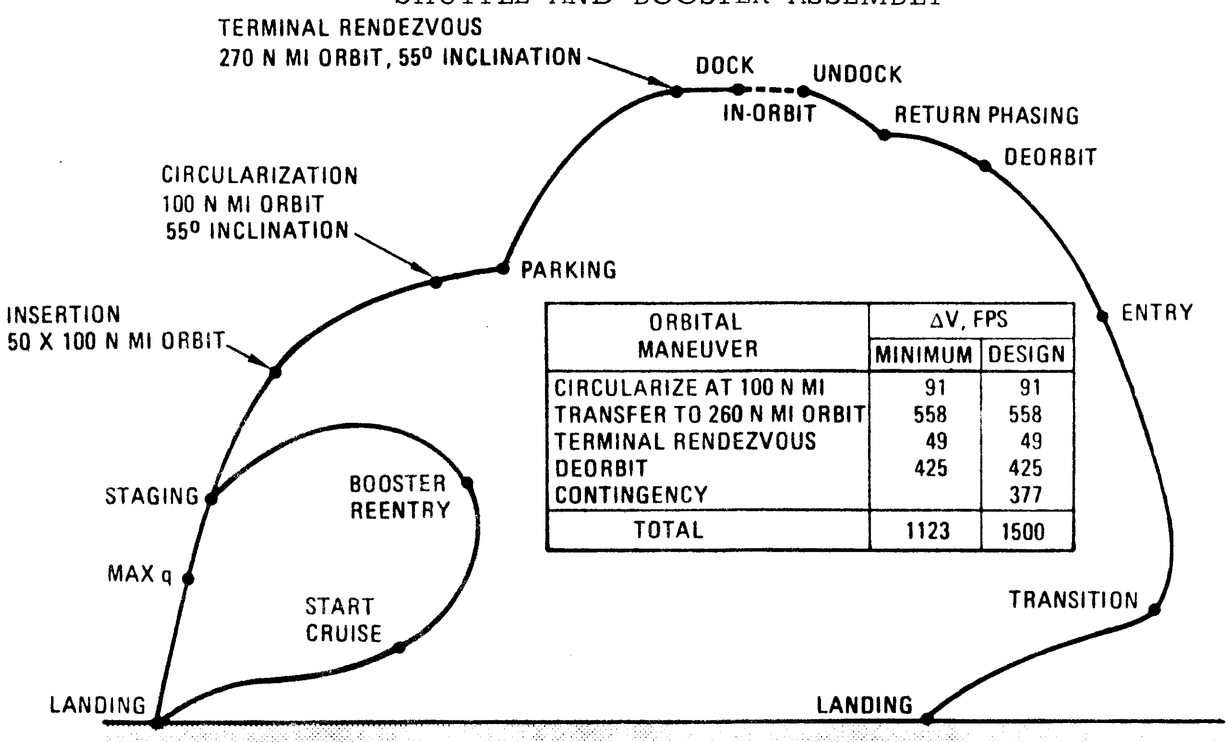


FIGURE 5.17

SHUTTLE AND BOOSTER ASSEMBLY



ORBITAL MANEUVER	ΔV, FPS	
	MINIMUM	DESIGN
CIRCULARIZE AT 100 N MI	91	91
TRANSFER TO 260 N MI ORBIT	558	558
TERMINAL RENDEZVOUS	49	49
DEORBIT	425	425
CONTINGENCY		377
TOTAL	1123	1500

FIGURE 5.18

ADVANCED LOGISTIC VEHICLE ORBIT-REENTRY SEQUENCE

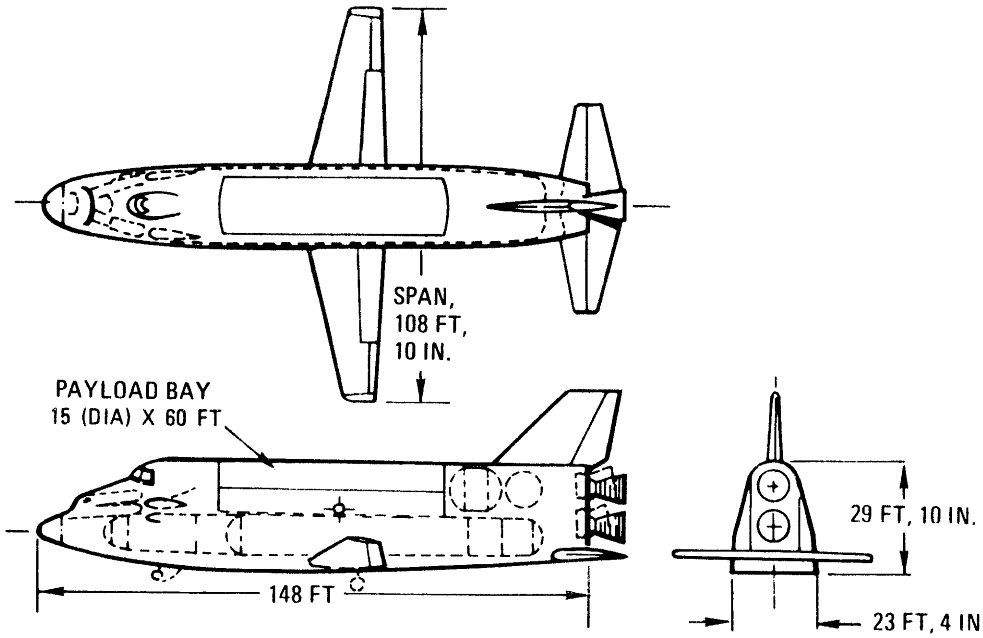


FIGURE 5.19

EARTH ORBIT SHUTTLE PROPOSAL

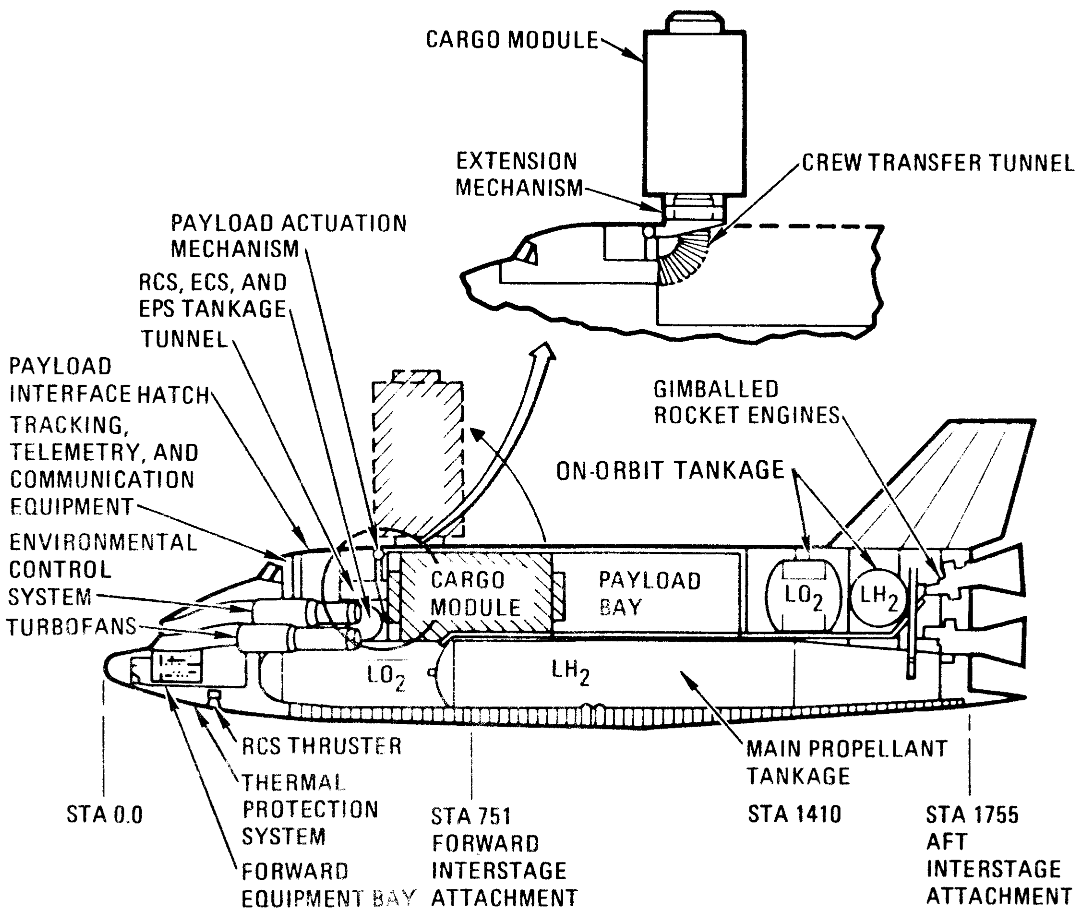


FIGURE 5.20

SHUTTLE CARGO TRANSFER

long and is sized to carry a nominal payload of 40,000 pounds ± 10,000 pounds, although the upper limit on payload weight is 65,000 pounds. The following chart demonstrates anticipated logistic requirements for up and down cargo transfer using proposed space station and space base concepts.

TABLE 5.12

CARGO-TRANSFER FOR PROPOSED SPACE STATION AND SPACE BASE CONCEPTS[12]

Requirements	Weight (lb./mo.)
Up Cargo	
Space Station	
Subsystems	5,389
Experiments	5,811
Total	11,200
Space Base (60-man)	
Subsystems	18,982
Experiments	14,445
Total	33,427
Down Cargo	
Space Station	
Subsystems	1,745
Experiments	6,123
Total	7,868
Space Base (60-man)	
Subsystems	3,228
Experiments	11,309
Total	14,537

Demonstrated in a comparison between cargo size and mission criteria, an increase in shuttle vehicles and flight frequency facilitates the requirements of a large space base.

TABLE 5.13

PROGRAM ELEMENT AND ALS SUPPORT[13]

Program Element (Crew)	Number ALS Required			Flight Frequency (days)		
	20,000 lb	30,000 lb	40,000 lb	20,000 lb	30,000 lb	40,000 lb
Station (12)	4	3	3	30	44	54
Base (36)	4	3	3	16	23	25
Base (60)	5	4	4	10	15	18
Base (164)	10	9	6	4	5	7

The assumptions enabling the above table are: (1) mission time/vehicle is seven days, (2) ground turnaround time is fourteen days, (3) the vehicle lifetime is 100 flights, and (4) that there is one standby rescue and spare vehicle.

Because of the reuseability of the shuttle costs per pound are projected to be reduced by a factor of ten, meaning that the existing $1,000/lb. could be chopped to $100/lb.

6. MISSION ENVELOPE

The determination of orbital parameters is dependent upon the following conditions:

1. Constraints imposed by the launch system (the advanced logistics vehicle) restrict the orbital inclinations to 28.5°-55' at 200 to 300 nautical miles, and 90°-97' at 200 nautical miles for polar or sun-synchronous missions.

2. Experiments and preferred operational environments restrict the orbit to 45° to 75° inclination at 270 nautical miles.

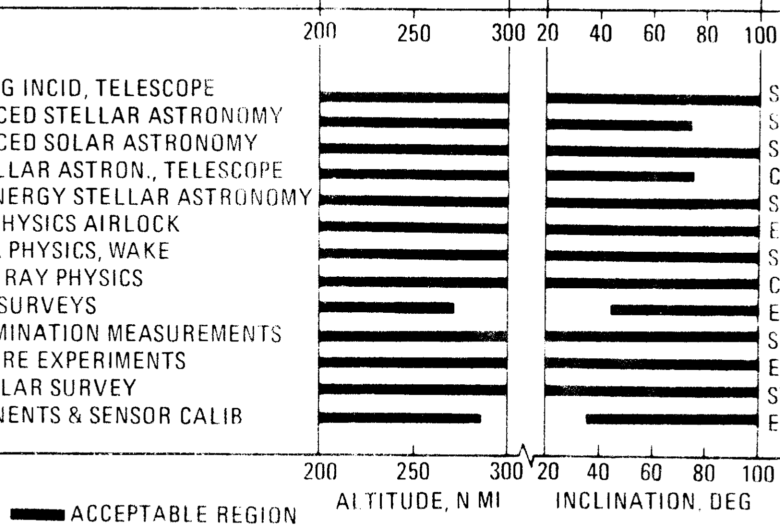
A compromise between preferred logistics and lower altitude drag characteristics placed the minimum orbit at 240 nautical miles. An inclination of 55° was selected from the above defined envelope, as to gain maximum potential of 82 per cent of the earth's land surface.

Proper space station attitude is achieved by satisfying the demands of earth and astronomical observation solar array orientation and communication alignment. Therefore the longitudinal or rotating X axis is aligned normal to the ground track and the Z axis is constant with the local vertical. Secondary and tertiary attitude modes should be established according to experiment requirements.

TABLE 6.1

ORBIT REQUIREMENTS OF SELECTED EXPERIMENTS[1]

TITLE	PREFERRED POINTING DIRECTION
GRAZING INCID, TELESCOPE	STELLAR
ADVANCED STELLAR ASTRONOMY	STELLAR
ADVANCED SOLAR ASTRONOMY	SOLAR
UV STELLAR ASTRON., TELESCOPE	CELESTIAL SPHERE
HIGH ENERGY STELLAR ASTRONOMY	STELLAR
SPACE PHYSICS AIRLOCK	EARTH, CELESTIAL SPHERE
PLASMA PHYSICS, WAKE	SUBSATELLITE
COSMIC RAY PHYSICS	CELESTIAL SPHERE
EARTH SURVEYS	EARTH NADIR +45°
CONTAMINATION MEASUREMENTS	SOLAR, STATION
EXPOSURE EXPERIMENTS	EARTH, ZENITH
IR STELLAR SURVEY	STELLAR
COMPONENTS & SENSOR CALIB	EARTH, DEEP SPACE



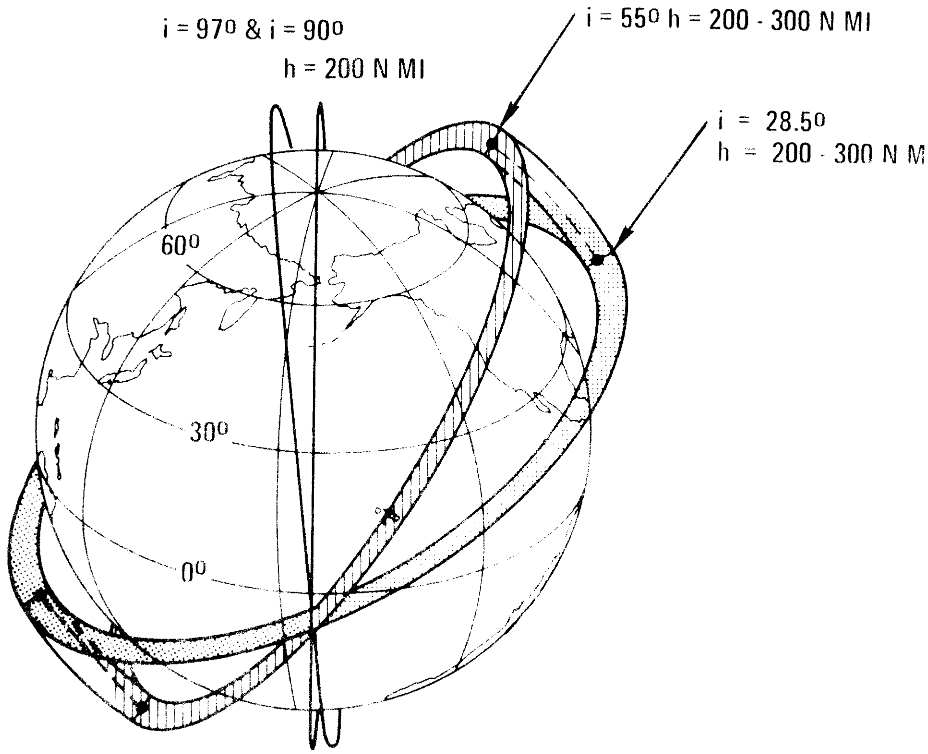


FIGURE 6.1

SPACE STATION ENVELOPE

7. CREW FACTORS

Former manned space missions accomodated life support, begrudgingly. Subsystem requirements and logistic parameters were the significant determinants of spacecraft design, as human dimensions and tolerances engineered the astronauts into proper position with respect to equipment. For fixed routine short duration missions, this austere approach provided maximum data return. Long duration missions, on the other hand, demand crew factor considerations beyond human engineering and will, for the most part, determine the success of the mission.

The issues of crew safety, crew operations, atmospheric make up, and habitability comprise crew factors and are discussed in the following sections.

7.1. Crew Safety

Design elements promoting crew safety are reliability, emergency provisions, gravity gradient, and communications.

7.1.1. Reliability

Facilitating reliability are two major items, design implementation techniques and rescue paths.

Design implementation techniques control failure tolerances and safety factors by requiring design specifications in excess of intended usage. Pressure containers and valves should have conservative parameters using a 4.0 safety factor. Hazardous fluid containers, lines, and components should be doubly contained and allow venting to space. The power output should accommodate excessive loads and the equipment should be able to handle additional duty cycles. Adequate shielding against micrometeorids and radiation should provide protection throughout extended duration missions.

Technology selection is based on a component's previous testing. Space tested hardware, which has proved itself reliable on predecessor programs, is most desirable. Equipment exposed to test facilities and rigorous flight simulation must comply with established performance standards. And items not having experienced space or simulator testing require a history of ground testing to insure performance capabilities.

Adherence to outlined activity schedules, such as systems and experimental operating procedures, should enhance reliability. Use of the Information Management System (see Spacecraft Design) will provide immediate access to these procedures as well as monitor subsystems and indicate scheduled maintenance.

Since support systems are critical for space survival necessary insurance against failure must be provided. Redundancy, a means to increase hardware reliability, will supply on-line parallel support to essential components; in case a component should fail, a substitute automatically supports its function. In addition to automatic switching a backup mode for manual switching should also be included.

Even with redundant systems, the hardware has an effective life span. Long duration missions will require provisions for equipment repair and substitution. Modularization of components will facilitate replacement of fatigued parts and add yet another level of redundancy. Besides a backup mode for critical systems, independent environmental volumes each with life support and station controls will further insure crew safety.

7.1.2. Emergency Provisions

Emergency mission procedures dictate design criteria facilitating escape routes. There should be dual means of egress from all modules and, in the case of inhabited modules, there should be rapid shirt-sleeve escape provisions. Alternate air-locks for extravehicular activity (EVA) and intravehicular activity (IVA) is required, since one might become inoperable.

In addition to transporting crew and cargo from earth to orbit, the ALS can serve as a rescue vehicle. The shuttle takes two hours to launch from standby status and can rondezvous with any low altitude manned spacecraft within twenty-four hours.

Dependent upon penalties incurred, provisions for "on-board" escape vehicles should be made. These could be anything from an

EVA suit with portable life support system to a "life raft" pressurized container accommodating several crew members.

7.1.3. Gravity Considerations

Safety factors encouraging implementation of artificial gravity deal with mobility, orientation, medical requirements and g-state transition.

Mobility in agravic situations could prove bothersome. A restraint mechanism is required for static positioning and hand holds are necessary for locomotion. Surroundings which forgive miscalculated thrusts would help eliminate possible damage to astronaut or equipment. Introduction of artificial gravity would accommodate a more terrestrial means of mobility along with providing "floor-ceiling" references for orientation.

It's possible that injuries occurring in space might require surgery. Dependent upon the extent of injury, simple surgery in orbit, would definitely prove feasible over a special rescue mission and exposure to re-entry gravity loads. Artificial gravity is, for all practical purposes a requirement for space surgery.

To date, very little is known about long term exposure to zero gravity. Skylab, planning two fifty-six day missions, will provide further data, but there is only speculation on results. Missions lasting several years will require a gravity decision, as not to jeopardize crew safety. Re-entry into earth's atmosphere produces loads several times that of earth's normal one 'g' (this factor varies with mission and type of re-entry vehicle). How a person will handle these forces after extended zero gravity exposure is unknown. A program consistent with crew safety should incorporate some periods and/or levels of artificial gravity over long duration missions, since the alternative (only zero gravity) provides a greater risk to crew safety.

The subject is given further attention under section eight, Gravity Condition.

7.1.14. Communications

Past missions involved literally thousands of people performing ground support tasks for short periods of time (two weeks). In future flights of longer duration, dependency on ground support will decrease and spacecraft will become more autonomous. This, to some extent, will reduce continuous communication demands, but for reasons of safety this procedure should be maintained (possibly by a limited or scheduled program).

7.2. Crew Operations

7.2.1. Crew Composition

In order to provide adequate manpower distribution and supply required crew skills, an early space station will require a twelve man crew.

During high routine experiment operations, station support will require approximately twenty-five man hours per day. Another twenty man hours/day are needed in aerospace medicine experiments. All other experiments use about fifty-five man hours/day.

Work loads increase during logistics supply periods. Man hours/day for station operations rise to forty, an additional ten man hours/day are necessary for experiment support, seventy man hours/day go for routine experiment support, while ninety man hours/day are required for experiment operations.

Twenty-seven crew skills are required over a ten year station life. The skills derived from a listing of functional program elements (FPE's) are determinants of crew selection. Not all skills run concurrently yet some will be necessary for the duration (ten year station life), such as commander, electrical engineer, dietician, etc. The skills per man, generally, never exceed three.

The following two tables represent which of the twenty-seven skill types are required for various program modes.

7.2.2. Crew Shift and Time Scale

A nominal work day of ten hours/man provides 120 man hours per day for the support and operation of both station and experiments. With eighty man hours/day devoted to function program element (FPE) operation and information distribution, task integration of crew work-loads is possible. Eleven of twelve members assigned full or part-time will accounts for the FPE operations. This operational profile

TABLE 7.1

SKILL TYPES AND PROGRAM MODES[1]

No.	Skill Type	A	B	C	D	E	F	G	H	I	J
		Program Mode									
1.	Spacecraft commander	x	x	x	x	x	x	x	x	x	x
2.	Spacecraft controller	x	x	x	x	x	x	x	x	x	x
3.	Spacecraft systems eng.	x	x	x	x	x	x	x	x	x	x
4.	Agriculturalist										x
5.	Aero-mechanical eng.	x	x	x	x	x	x	x	x	x	x
6.	Astronomer						x	x	x	x	x
7.	Behavioural scientist	x	x	x	x	x		x	x	x	x
8.	Biology lab. technician		x	x	x	x	x	x	x		
9.	Chemist			x	x	x	x	x	x	x	x
10.	Cook-dietician	x	x	x	x	x	x	x	x	x	x
11.	Electrical engineer	x	x	x	x	x	x	x	x	x	x
12.	Electrical technician	x	x	x	x	x	x	x	x	x	x
13.	Electronic technician	x	x	x	x	x	x	x	x	x	x
14.	Geologist										x
15.	High energy equip. tech.			x	x	x	x	x	x	x	x
16.	Medical doctor	x	x	x	x	x					
17.	Medical technician	x	x	x	x	x					
18.	Metallurgist	x	x	x	x	x	x				
19.	Meteorologist			x	x	x	x	x	x		
20.	Microbiologist										x
21.	Oceanographer										x
22.	Optical technician		x	x	x	x	x	x	x	x	x

TABLE 7.1--Continued

No.	Skill Type	A	B	C	D	E	F	G	H	I	J
		Program Mode									
23.	Photographic technician		x	x	x	x	x	x	x	x	x
24.	Physicist		x	x	x	x	x	x	x	x	x
25.	Plant biologist					x	x	x	x	x	
26.	Test engineer	x	x	x	x	x	x	x	x	x	x
27.	Zoologist				x	x	x	x	x		

Disciplines

Astronomy
Biology
Earth surveys
Engineering
operations
Space physics
Space processing

TABLE 7.2

CREW MEMBER AND SKILLS FOR PROGRAM MODE[2]

	Crew Title	Skills	Hours/Day/Skill
1.	Spacecraft Commander	Spacecraft commander	10
2.	Spacecraft Controller	Spacecraft controller	5
		Electronic technician	5
3.	Spacecraft Systems Engineer	Spacecraft systems engineer	6
		Aero/mech engineer	2
		Test engineer	2
4.	Dietician	Dietician	5
		Biolab technician	3
		Plant biology	2
5.	Medical Engineer	Behavioral sciences	1
		Biolab technician	5
		Chemistry	2
		Microbiology	2

TABLE 7.2--Continued

	Crew Title	Skills	Hours/Day/Skill
6.	Geoscientist	Geologist	10
7.	Biologist	Plant biology	2
		Zoology	8
8.	Physicist	Physicist	10
9.	Experiment Engineer	Electrical engineer	2
		High-energy technician	8
10.	Experiment Engineer	Astronomy technician	5
		Electronic technician	1
		High-energy technician	1
		Photo technician	3
11.	Experiment Engineer	Electromech technician	7
		High-energy technician	3
12.	Experiment Engineer	Microbiology	3
		Optical technician	3
		Photo technician	4

permits a twenty-four hour day for crew activities and work loads.

Generally speaking, a crew members' typical day uses ten hours for work, divided into averages which utilize maximum attention. The remaining fourteen hours assigns eight hours (at least four hours consecutively) for sleep, one hour for personal hygiene periods of forty-five, forty-five and fifty minutes for meals, and because of psychological and physiological factors, two and one-half hours for recreation, exercise, and general crew choice activities.

The aquanauts of the Tektite program, by comparison, spent a little over eight hours of their time sleeping, five hours in leisure activities and another eight hours working. The remaining time being spent on self-maintenance and miscellaneous tasks. Excluding socializing and coffee breaks, many persons working normal office routines spent about six hours a day in productive work.

The average of five proposed space missions show time assignments not inconsistant with the proposed station schedule. Approximately nine and one-half to ten hours for work, a little over seven hours for sleep, two to two and one-half hours off duty time and a contingency of two hours. The work days in one week on all missions were seven.

In cases of isolation recent studies have noticed that the most important time is during meals. Deprived of earthly temptations, confined experimenters have replaced the natural stimulus of sexual satisfaction with a desire to enjoy the delights of eating. This could prove an important factor in establishing an acceptable diet.

The Tektite program discovered that aquanauts took advantage of spontaneous conditions to reprogram their research. This evidence along with the increasing difficulty of effectively planning long duration mission indicates that a flexible profile should be adopted for space station operations.

7.2.3. Crew Structure

Following similar decision making crew structure distributions the space station will have one person making on-board operational decisions, a spacecraft commander. There will also be a spacecraft controller and systems engineer, to provide an intermediate level of responsibility.

7.2.4. Leisure Time

Provisions for leisure time activity of crew members should be based on individual preference with respect to confined environment behavior.

An inventory including (1) astronauts, (2) tactical fighter pilots, (3) aerospace research pilot students (ARPS) and aerospace engineers of present off duty time, depicted preference similarities. Job related activities, reading, physical exercise, and listening to music were close to the top, in every group's evaluation.

The same groups ranked anticipated preference of equipment used in leisure time on a spacecraft. The results were not as homogenous as the prior survey, but the general favorites were viewpoints, physical exercise, records or tape player and books.

The correlated preferences among the groups is presented in the following table.

TABLE 7.3

CORRELATED PREFERENCES AMONG ASTRONAUTS, TACTICAL FIGHTERS, ARPS, AND AEROSPACE ENGINEERS

	Present Off-Duty Activities			Equipment Usage in Spacecraft		
	Tact	Arps	Aero Eng.	Tact	Arps	Aero Eng.
Astronauts	.86	.95	.64	.93	.93	.96
Tactical Ftrs.		.86	.72		.89	.91
ARPS			.68			.92

A point worth noting is that men in confinement refrain from games or contests involving individual competition. Also, there is an increased appreciation for leisure time, with privacy gaining additional importance in isolated habitats.

Tektite concluded that the incorporation of (1) on-board two-way video, (2) good quality sound reproduction equipment, (3) individual choice items, (4) broad leisure reading materials, (5) view-ports, and (6) physical exercise equipment would provide a more habitable environment. These elements should be considered for future long duration space missions.

7.3. Atmospheric Make-up

Atmospheric composition is primarily governed by medical considerations with crew safety being another major determinant.

Since there is physiological degradation after long term exposure to pure oxygen, a two gas atmosphere should be incorporated.

Considered gas combinations are helium-oxygen ($He-O_2$) and nitrogen-oxygen (N_2O_2). In a comparison of comfort zones between the two candidate gas mixtures, the $He-O_2$ composition demonstrated consistantly higher comfort temperature zones, as represented in the following table.

TABLE 7.4

ONE G CREW COMFORT TEMPERATURE RANGES FOR $He-O_2$ & N_2-O_2 ATMOSPHERES[3]

Atmosphere	5 psia (3.5 psia O_2)	7 psia (3.5 psia O_2)
$He-O_2$	92^oF upper limit 82^oF average 73^oF lower limit	94^oF upper limit 85^oF average 76^oF lower limit
N_2-O_2	83^oF upper limit 77^oF average 71^oF lower limit	84^oF upper limit 78^oF average 73^oF lower limit

Modified to represent approximate zero g conditions, using 50 ft./minute gas velocity and a metabolic rated 460 BTU/hour the following table was drafted.

TABLE 7.5

ZERO G CREW COMFORT TEMPERATURE RANGES FOR $He-O_2$ & N_2-O_2 ATMOSPHERES[4]

Clo Factor	5 Psia	7 Psia	10 Psia
$He-O_2$			
0 Clo	76° - 80°F	78° - 81°F	79° - 83°F
0.5 Clo	72° - 75°F	75° - 78°F	77° - 80°F
1.0 Clo	68° - 71°F	72° - 75°F	74° - 78°F
N_2-O_2			
0 Clo	75° - 79°F	76° - 80°F	77° - 81°F
0.5 Clo	68° - 71°F	69° - 72°F	70° - 73°F
1.0 Clo	61° - 64°F	61° - 65°F	62° - 66°F

The determination of a helium-oxygen atmosphere requires further investigation into the effects of the mixture during hard exercise and the effects over extended $He-O_2$ exposure. Lack of sufficient $He-O_2$ testing, as compared with the earth-like N_2-O_2 atmosphere, makes the latter combination the most reasonable for early space stations.

Life support requirements limit the minimum partial pressure of oxygen to 3-3.5 $lbs/in.^2$. To provide protection against flash fire a minimum pressure of 7$lb/in.^2$ partial pressure of Nitrogen is required. The minimum total of 10 $lbs/in.^2$ is not inconsistant with some high areas on earth. The selection of a 14.2 $lbs/in.^2$ pressure, however, is consistent with normal earth atmospheric pressure and should be employed for general station use.

The relative humidity level should exceed 10%, since most physical harm, such as irritated mucous membrane, occurs below this level.

A relationship between the crew size and amount of necessary pressurized volume (see Table 7.1) shows a twelve-man space station requiring 50,000 ft.^{3}. The sizing of atmospheric support equipment coupled with safety factors (independent pressure volumes) should use 50,000 ft.^{3} as a nominal figure.

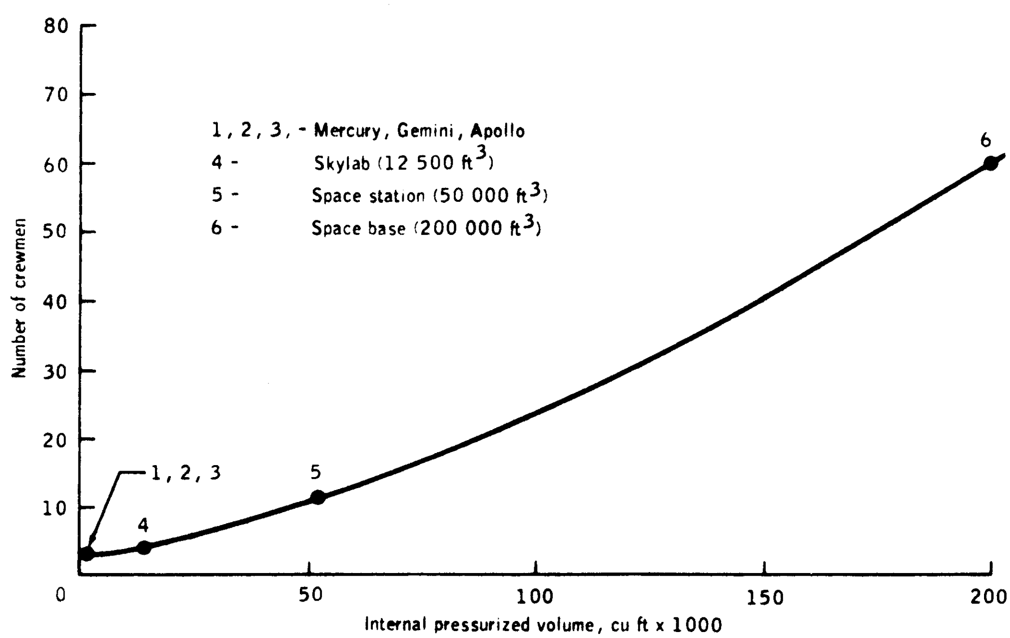


FIGURE 7.1

PRESSURIZED VOLUME/CREW SIZE CORRELATION

The penalties of excessive extravehicular activity (EVA) cost, weight, and volume override a two gas suit. Therefore a pure oxygen low pressure, 5-10 lbs./in.^{2} suit is recommended. With breathing exercises and short duration activity there should be no problem with EVA.

7.4. Habitability

With respect to spacecraft design, habitability provides possibly the greatest challenge to decision making. Engineering concepts are responses to defined problems and can be performance rated. Habitability on the other hand, is more subjective and not solely predicated on any imperical data base. NASA along with a host of other researchers, have established athropometric and tolerance criteria for the man in space. And attempting to apply principles of order and logic, MSC has created a habitability technology handbook.

The machines which accomodated early space explorers provided little more than a cockpit as habitable area. Table 7.7 displays selected predecessor and proposed programs with mission duration and inhabitable volumetric data.

The cubic footage figures reflect allowances and not capabilities or use. These capabilities and uses make up habitability which is defined as:

> That equilibrium state resulting from interactions of components of a man-machine environment complex which permit man to maintain psychological homeostasis, adequate performance, and acceptable social relationships.
>
> T. M. Fraser

TABLE 7.7

PROGRAM/VOLUME COMPARISON

Year	Program	No. of Crewmen	Mission Duration Maximum	Habitability volume, cubic feet	Volume man/ cubic feet
1963	Project Mercury	1	1.5 days	47	47
1963	Gemini Program	2	14.0 days	80	40
1968	Apollo Program	3	14 + days	225	75
1978	Skylab Program	3	28 to 56 days	500	4,167
1980+	Space station	12	2 yr. nominal[a]	50,000	4,167
1985+	Space base	50 to 100	10 yr.[a]	200,000	2000-4000

[a]Duration for hardware, not crew.

and

> A global and relative concept applied to any spatial envelope in which man must function. A system is habitable if man can function as a man within its environmental confines.
>
> J. F. Kubis

also

> A space is habitable if its design accomodates the individual requirements and functions of the people who are to use it.
>
> R. Barnes

Major elements composing habitability are:

Design factors

1. Mobility provisions: special requirements for individual mobility and restraint including cargo/equipment handling.
2. Garments and auxiliary equipment: includes garment selection, laundry system, and storage requirements.
3. Food management: deals with the weight, packaging, and storage of food along with ambient storage, food preparation and serving and cleanup.
4. Housekeeping: concerned with the handling, transfer processing, and utilization/disposal of waste.
5. Medical and emergency provisions, recreation, and physical conditioning comprised the remaining design factors of habitability.

Habitability Factors

1. Personal hygiene: manages urine, feces, and vomitus collection in addition to providing for personal care and

grooming.

2. Architecture and environment: deals with use/area selection, time use, architectural design criteria, and specific environment elements, such as lighting, acoustics, etc.

7.4.2.1. Mobility Provisions

Fundamentally, mobility in space is gravity dependent. Zero gravity situations should provide restraint devices, ranging from magnetic shoes to mechanical tethers. For the most part, the tethers employing one point connection wire guides are limited to very select uses and prove restrictive in most other cases. Handholds, toe slots, and a protection from equipment and wall projections should be considered. A provision for rearrangable handholds will accommodate future changes in interior arrangement.

In situations of artificially imposed gravity, the percentage of one "g" is the controlling design determinant. To date, only the 1/6 g of the moon can be used as true representation gravity levels below earth's one g. At this level mobility is no real problem provided other rotational effects of artificial gravity have been considered. As an extra measure of safety handholds, toe slots, and surface conditions forgiving miscalculated locomotion, should also be included in a gravity condition space station. In addition, belts, straps, Velcro pads, attach fittings, handles and rails should be provided were necessary to aid crew mobility.

7.4.2.2. Garments and Auxiliary Equipment

The garments should be selected to perform under the conditions of normal duty, special duty, leisure, sleeping and exercising. The garments should be reuseable, as opposed to being disposable, since the planned three to six month missions would cause excessive volume and weight penalties in disposable clothing. See Figure 7.2.

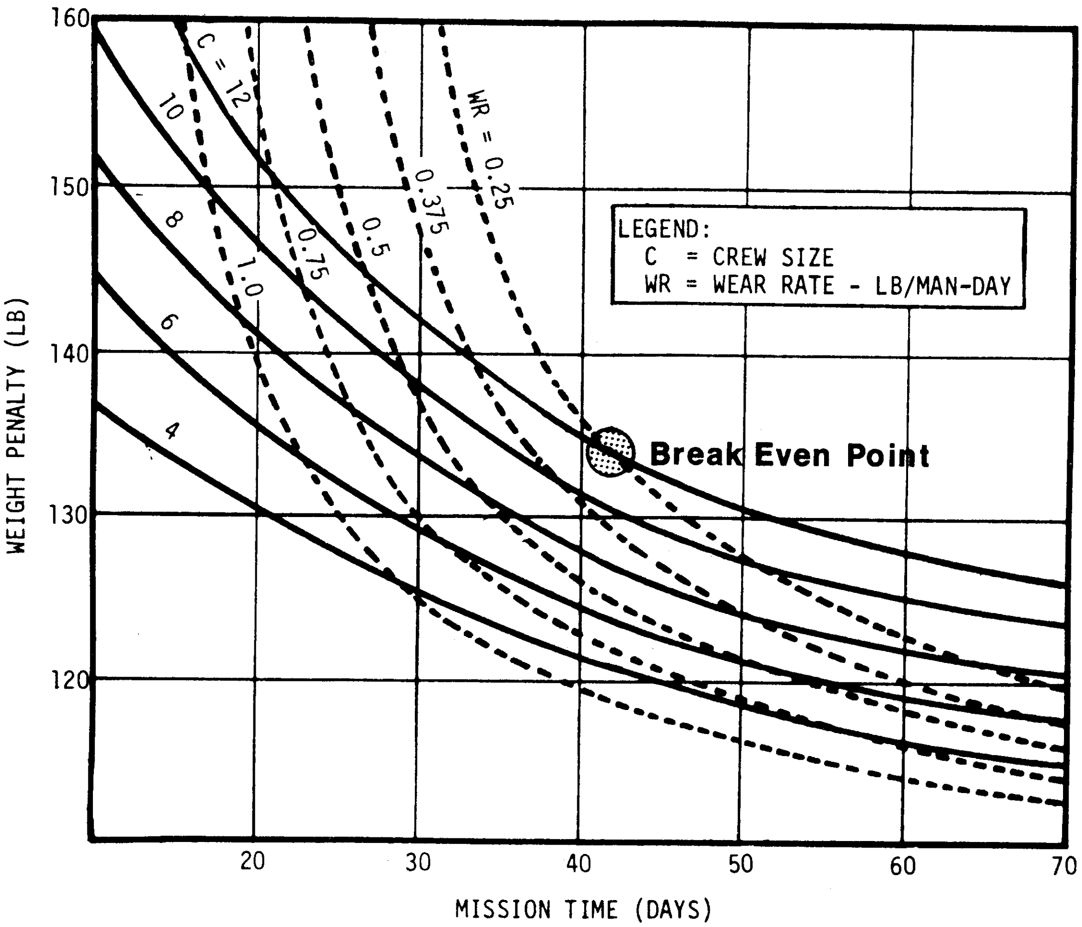


FIGURE 7.2

DISPOSABLE GARMENT EVALUATION[5]

The decision of using reuseable garments presents a need for laundry facilities. From NASA criteria for laundry load size, a twelve man crew, using water solvent, would require a twenty pound laundry system.

An oscillatory water instead of rotary water and rotary hydrocarbon solvent system should be incorporated, since the oscillatory water concept is the lightest, smallest (cubic feet) and only one which works in zero g.

The automatic concept also provides spin dry and heat cycles, integrated into the system eliminating a separate dryer.

Vacuum packaging reduces volume of the garments and auxillary equipment by at least twenty percent, sometimes more, dependent upon the item. This, in addition to modularized packaging and storage, should sufficiently aid garment management.

Items which comprise a crewman's wardrobe are twelve shirts two trousers, two jackets, twelve briefs, twelve socks, one head gear and one pair of shoes totaling ten pounds. The vacuum packed volume occupies 552 cubic inches and the orbit folded, 746 cubic inches.

Garments, when possible and particularly where the situation demands, should be made from fire retardant materials.

Resupply of the space station can fulfill special intermittent garment requirements when necessary.

7.4.2.3. Food Management

As the duration of space missions increases, a concern for expendables also increases the weight and volume of food goods should be carefully analysed.

Required waterless food for one man day is 1.5 pounds. This combines with 5.5 pounds of potable water (food content and drinking water) required for the same period.

Knowing the resupply period of the space station to be at most three months and selecting as an overall average 50/50 food mix ratio, it's possible to determine weight and volume of the necessary food from Figures 7.3 and 7.4.

Required capacities are:

1.	262 lbs. food/man	3,144 lbs. food/12 man crew
2.	7.1 cubic feet/man	85.2 cubic feet/12 man crew
3.	364 lbs. water/man	4,368 lbs. water/12 man crew
4.	62.4 lbs./cubic feet weight	71.6 cubic feet/12 man crew

Packaging techniques for containing dry, shelf stable, frozen, and perishable foods are important to note since they add significantly to food weight and volume totals.

Candidate container concepts are, can (steel or tin) box or bag (cardboard; polyethylene) and cylinder (rigid polyethylene). The cylinder was selected since it represented nominal volume and weight characteristics, although in actuallity, foods would be contained in accordance with their individual requirements.

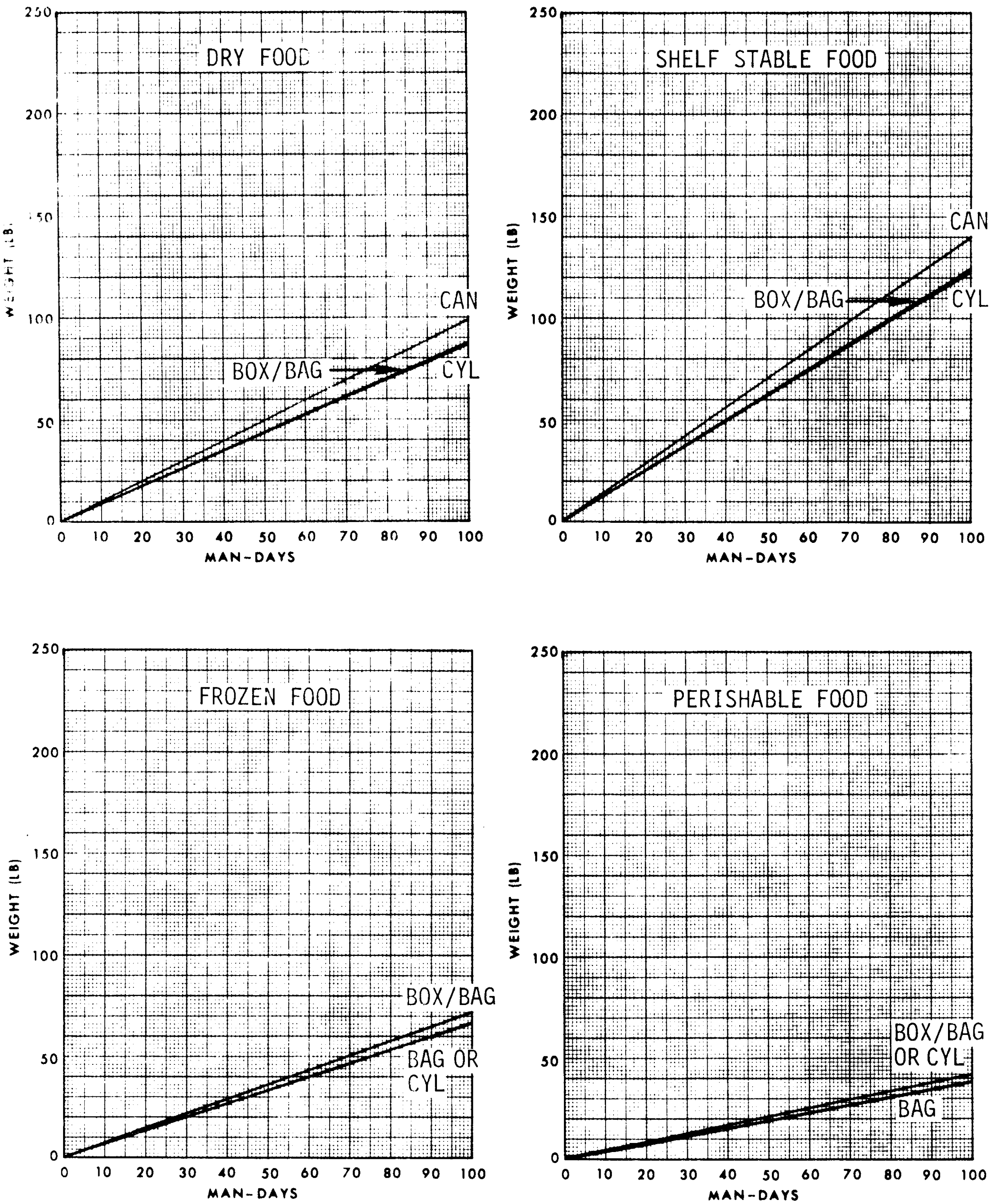


FIGURE 7.3

FOOD WEIGHT FOR PACKAGING CONCEPTS[6]

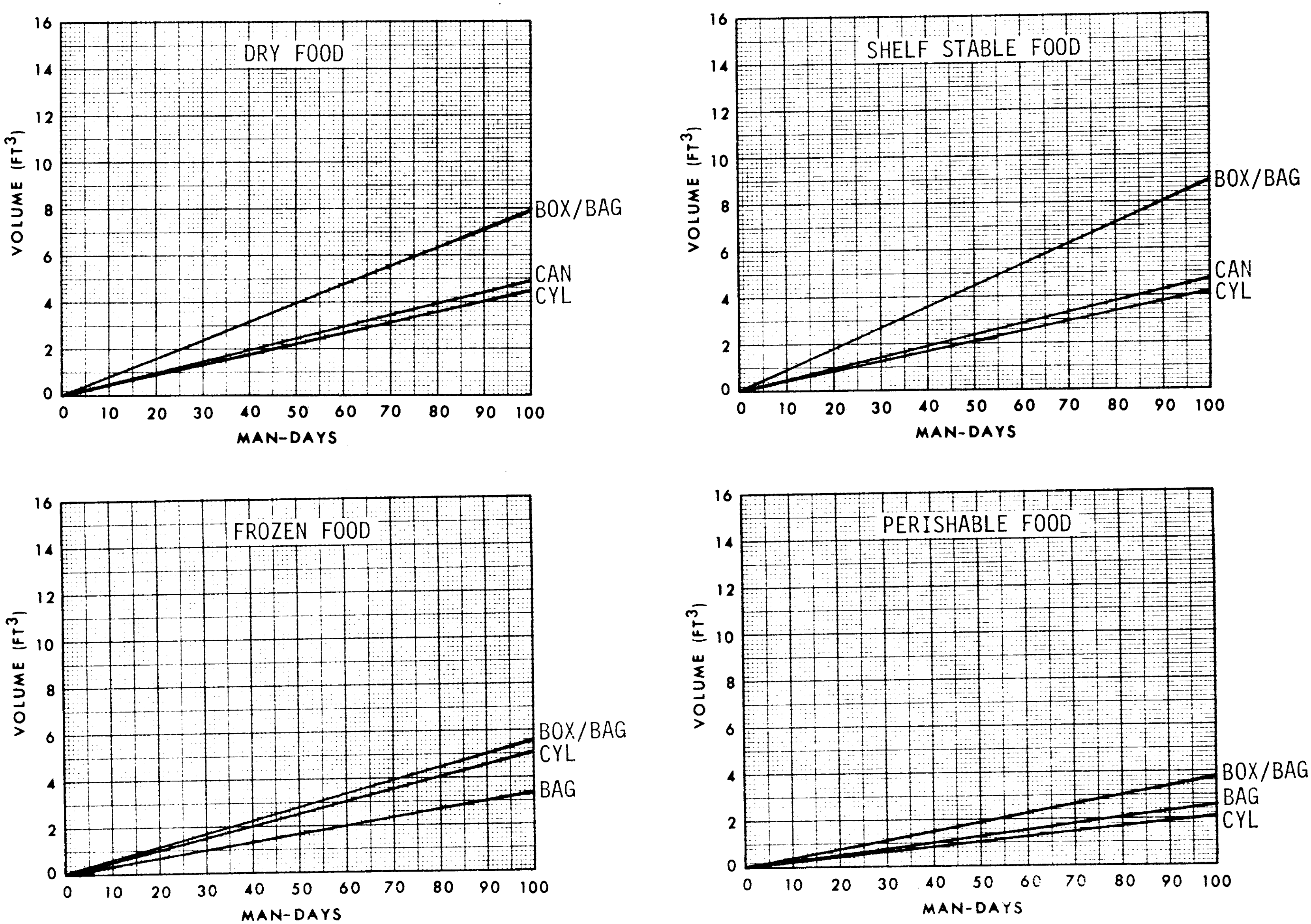


FIGURE 7.4

CONTAINER VOLUMES OF PACKAGED FOOD[7]

For a twelve-man crew, ninety days resupplied, packaged food weights are:

Food Type	Wt./Crew Member	Total/12 man crew
Dry Food	78 lbs.	
Shelf Staple	111	
Frozen	60	
Perishable	39	
	288 lbs. x 12 man crew =	3456 lbs.

In order to provide adequate storage space the container volume must be calculated. Figures 7.4a, b, c, and d show volume characteristics for the cylinder type packaging.

Food Type	Vol./Crew Member	Total/12 man crew
Dry Food	4 cubic feet	
Shelf Staple	3.8	
Frozen	4.5	
Perishable	1.9	
	14.2 cubic feet x 12 man crew =	170.4 cubic feet

Provisions for food storage are partly handled by refrigerated and frozen food lockers. The perishable food volume is just under twenty-three cubic feet and can easily be accommodated by a thirty cubic foot refrigerator and the eleven cubic feet remaining in a sixty-five cubic foot freezer (fifty-four cubic feet for frozen food storage).

With a thirty cubic foot refrigerated food locker capacity, the installed volume is approximately eighty cubic feet and weighs

425 pounds. The sixty-five cubic feet capacity forzen food locker, installed, requires 135 cubic feet and weighs 750 pounds.

The ambient storage space for a 50/50 mix ratio is 7.9 cubic feet per man day or 94.8 cubic feet for a three month, twelve man crew. Flexible storage space should be investigated. This concept could provide the minimum volume for fluxuating storage demands.

Individual food trays which electrically heat portions of a meal will partially support food preparation, while self servicing facilitates bussing and clean-up. The required volume for twelve installed food trays in seven cubic feet and they weigh forty-eight pounds.

The waste container for food preparation measures 10"x10"x30", the 'dish' washer-dryer for a twelve man crew measures 16"x20"x30", and the sink measures 24"x24"x40". These devices coupled with a vacuum system should adequately handle clean-up.

7.4.2.4. Housekeeping

Principally, housekeeping is concerned with handling, transferring, processing and utilization/disposal of waste. Waste handling originates with collection and should consider the following: [8]

1. Waste receptacles should be provided at the source of waste materials. The type of container within each receptacle should be characteristic of the state and attributes of the wastes generated in that area.

2. Waste collection should be accomplished at the waste source and deposited in the receptacle designated for the particular

waste attributes.

3. The waste pick-up task will begin at the receptacles and will include all actions required to secure the wastes in their containers, remove containers from waste receptacles, install new containers and prepare the wastes for transfer to their designated storage areas.

Methods of collection vary with the gravity condition. Zero g situations should include a vacuum system to remove air borne particulate solids. An imposed artificial gravity can treat waste collection much the same as it is on earth.

Various waste containers should be designed for their particular use, such as solids, gases, solid/liquid mixtures, and liquid gas mixtures. They should also provide for non-toxic, toxic, hot, cold, and radioactive waste conditions.

Waste transfer should involve efficient distribution and sorting from pickup points to ultimate destination.

Careful waste processing must consider the microbial control for the general treatment of contaminated wastes, including (1) physical separation; (2) water electrolysis; (3) oxidation; (4) decomposition; (5) waste compaction; and (6) waste shredding.

Two means of waste disposal are (1) to remove and store in another vehicle or to jettison the waste directly into space. (2) The latter should be analysed in further detail, since waste dumping produces a thrust, may linger around the spacecraft, and adds to space contamination.

7.4.3. Habitability Factors

7.4.3.1. Personal Hygiene

Personal hygiene deals with urinal selection, feces and vomitus collection along with personal care and grooming.

The urinal selection is based on:[9]

amounts:	1.1 lb. per urination maximum, 0.88 lb/use nominal
frequency:	3 to 7 urinations per man-day, 5 nominal
quality:	pH; 4.5 to 8.0 specific gravity; 1.002 to 1.035, 1.01 nominal
constituents:	electrolytes, nitrogen compounds, vitamins, acids, organic compounds, harmones.

From three concepts for spacecraft urinals, the aperature urinal was selected as most desirable, since it is the least difficult to use and most consistant with earth-like situations. It can also be used in zero gravity.

The aperature urinal has a fixed weight of twenty-three pounds and fixed volume of 3.2 cubic feet. Figure 7.5 diagramatically shows the aperature urinal and its support hardware.

Requirements for feces collection and processing are:[10]

amount:	wet weight; 0.66 lb/use maximum, 0.33 nominal dry weight; 0.275 lb/use maximum, 0.08 nominal
frequency:	0 to 2 times per man-day, 1 nominal

characteristics:	H_2O content; 65 to 90%, 75% nominal pH; 6.9 to 7.7 specific gravity; 1.0 to 1.4, 1.2 nominal
constituents:	water, electrolytes, nitrogen compounds, organic compounds, vitamins, amino acids

The Dry John was chosen from a selection of five space toilets. It has a fixed weight of twenty-three pounds and a fixed volume of nine cubic feet.

Vomitus collection and processing should follow the following criteria:[11]

1. The minimum capacity to collect vomitus shall be as follows:[11]

   Wet: 0.056 cubic feet per man-day
   Dry: 17.6 ounces per man-day

2. The capacity for vomitus processing equipment shall be 0.056 cubic feet per occurrence.

3. Microbial and chemical activity shall be permanently eliminated.

The pictured disposable toilet adapters should facilitate vomitus collection.

A shower for whole body cleaning and a wet wiping system for local body cleaning should be incorporated for personal care and grooming. The shower's fixed weight is 332 lbs. and installed, occupies 110 cubic feet.

The use of wet wipes for personal hygiene provides an adequate means of local body cleaning. The wet wipe system, Figure 7.9, weighs twenty-seven pounds and takes up 3.5 cubic feet.

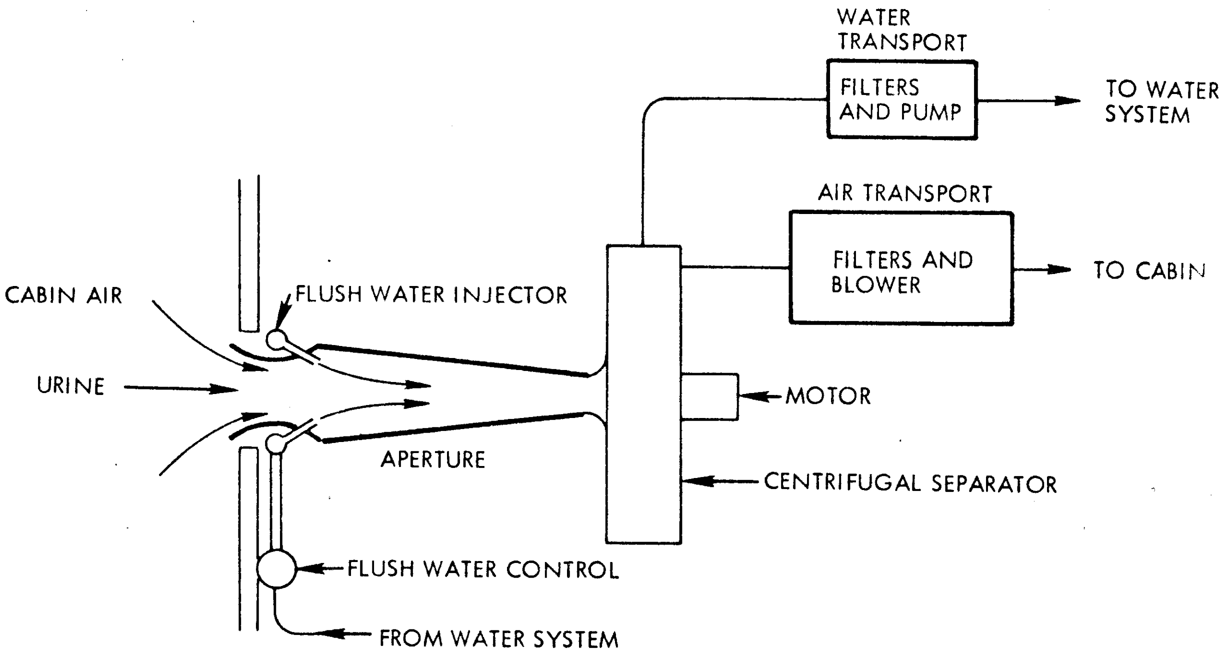


FIGURE 7.5

APERATURE URINAL[12]

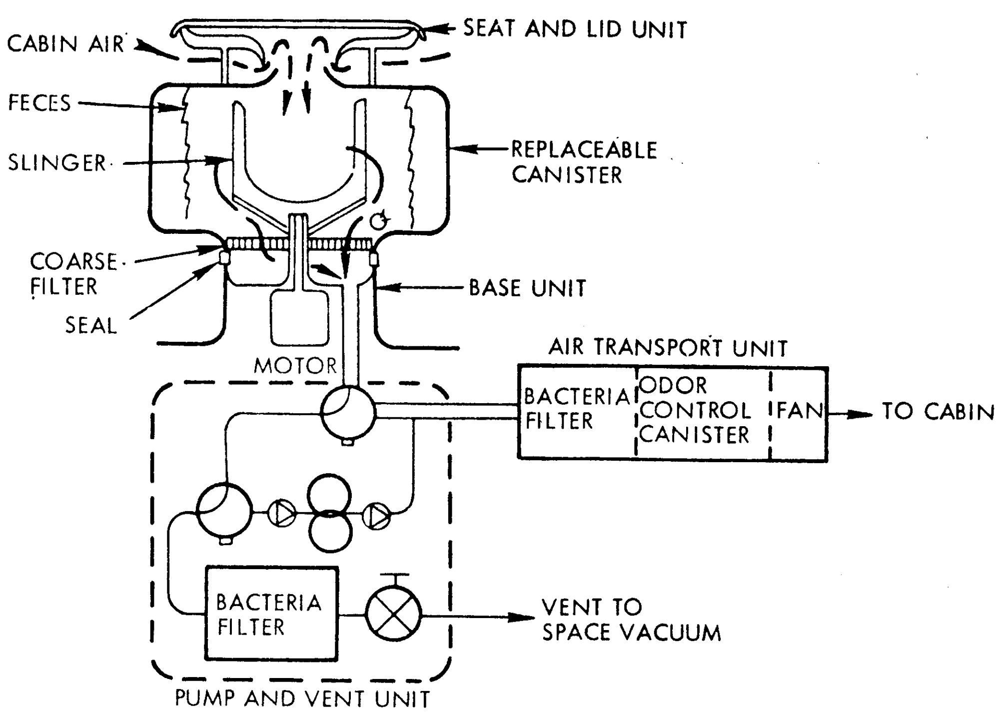


FIGURE 7.6

DRY JOHN[13]

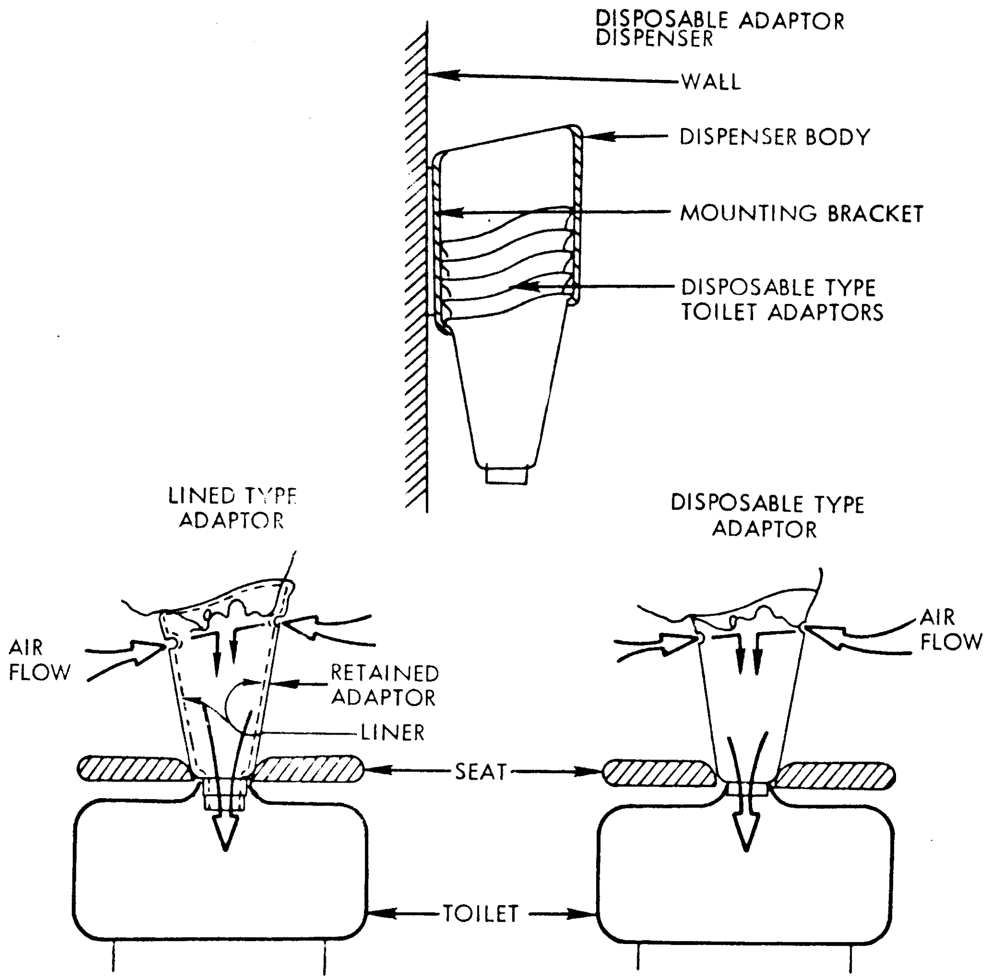


FIGURE 7.7

VOMITUS COLLECTION[14]

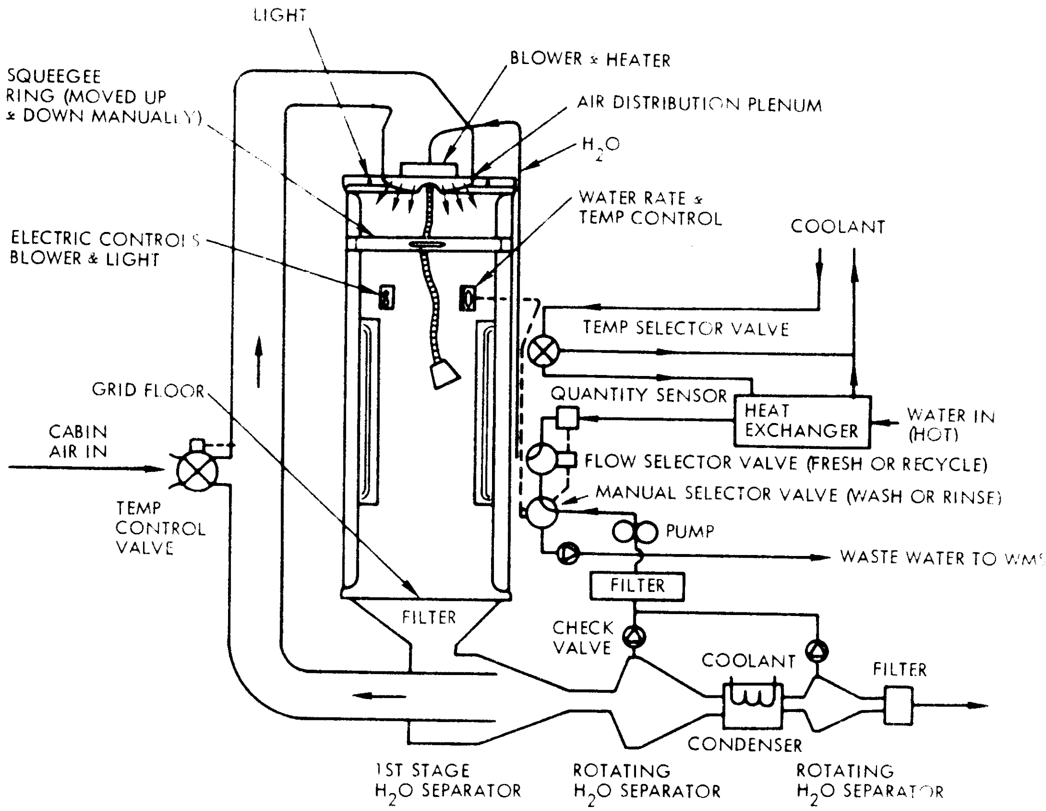


FIGURE 7.8

WHOLE BODY SHOWER[15]

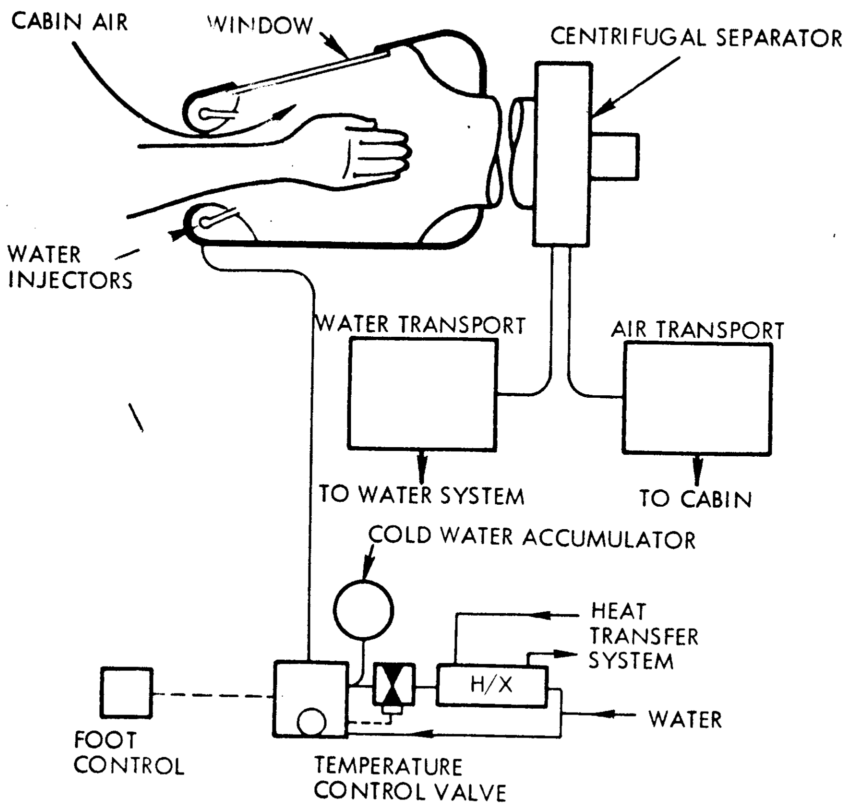


FIGURE 7.9

LOCAL BODY CLEANING[16]

Personal care including teeth cleaning, shaving and hair cutting, should also be provided for. Gravity condition will prove an important determinant of resulting personal care elements.

7.4.3.2. Change Factors and Crew Security

Several concerns, not as imperically generated as the prevously discussed issues, should be included with habitability. These are change factors and crew security.

Change Factors

The change factor is incorporated as a design consideration operating under the assumption that a change or alteration from an existing situation is a desirable or even essential element affecting the degree of relaxation. This does not as yet specify either the type of change (physical or mental) or the quantitative degree to which the change will occur. Only the fact that some change in the existing sequence of the routine should be altered. There is ample empirical evidence to support this point ranging in scale from the average coffee break where upon one changes physical position to the summer vacation where occurs the saying "a change of scenery will do you a world of good". In a sense, we advocate that simple phrase in this specific area, let it be a change in scene. The areas in which this change can be implemented are many and varied and can occur in any one of the following: color, spatial, geometry of area, materials, texture, sounds, graphics, etc.

Crew Security

Although this refers to the physical security of the crewman, it also considers the behavioral aspect of security in an area designated for rest and relaxation. We are describing a model condition in this analysis and it is the ideal requirement for complete rest if threats to existance are reduced to a minimum. One must feel safe to relax, safe from bodily harm, safe in the sense that his needs have been considered, and that anticipated fears or needs will, if they arise be accomodated with a high degree of certainty. This is particularly relevant in an area in which the crewmen will be in an unconcious state of sleep. Any contingency that might arise during this period must be considered in light of the fact that the delay time from sleep to awareness to decision making could be the critical period determining the life or death of the crewman. The knowledge that the facility will provide the maximum back-up for this type of situation provides the confidence necessary for complete relaxation and rest to occur.[17]

7.4.3.3. Architecture and Environment

Mission modeling helps in defining area allocations and subsequent assessment. Table 7.7 represents results of area as a function of the earth orbit shuttle, space station, and planetary missions. In addition to area/mission relationships the model can also include functions of usage frequency.

Specific environmental elements such as lighting, acoustics, temperature, color and volume, represent a piece by peice study of architectural and environmental concerns, however the value of these elements is in their union.

In addition to area/mission relationships, the model can also include functions of useage frequency as represented in Table 7.8.

Lighting

Lighting gains added importance due to the reliance upon vision in space situations. Adequate light is important for the safety and comfort of the crew as well as increasing output efficiency. Poor lighting, on the other hand, can have an adverse effect on performance in addition to causing eyestrain and fatigue.

Table 7.9 is a lamp source evaluation comparing functional requirements to a selection of light sources.

TABLE 7.7

CREW AREAS/MISSION MODELING[18]

Area	Mission Models		
	Logistics Spacecraft	Earth Orbital Space Station	Planetary Space Vehicle
Living Area			
Lounge	NR	D	D
Recreation	NR	R	R
Passageways	D	R	R
Study or Library	NR	R	D
Bedroom	D	R	R
Bathroom	D	R	R
Conference	NR	D	D
Food Preparation and Service			
Kitchen	D	R	R
Dining Room	D	R	R
Food Storage	R	R	R
Snack Bar	NR	D	D
Services			
Laundry	NR	R	R
Briefing Room	NR	D	D
Locker Room	NR	D	D
Theater	NR	D	D
Dispensary	NR	R	R
Chapel	NR	D	D
Barbershop	NR	R	R
Supply	NR	R	D
Maintenance	NR	R	R
Equipment	NR	R	R
Gym	NR	D	D
Power	NR	R	R
Work Areas			
Control Room	R	R	R
Airlocks	R	R	R
Inspection	NR	D	D
Photographic support	NR	R	D
Animal housing	NR	D	D
Docking	R	R	R

TABLE 7.7--Continued

Area	Mission Models		
	Logistics Spacecraft	Earth Orbital Space Station	Planetary Space Vehicle
Agricultural Study	NR	D	D
Computer	NR	R	D
Offices	NR	D	D
Laboratory	NR	R	D
Shops	NR	R	D
Communications	NR	D	D

Legend: R = required
NR = not required
D = desirable but not absolutely required

TABLE 7.8

FREQUENCY OF USAGE/MISSION MODELING[19]

Area	Hours per Day in Crew Areas					
	Logistics Spacecraft		Earth Orbital Space Station		Planetary Space Vehicle	
	Nom. Work-day	Off-Duty Day*	Nom. Work-day	Off-Duty Day	Nom. Work-day	Off-Duty Day
Living Areas						
Lounge			1	4	1	4
Recreation			1	3	1	3
Passageways	N		N	N	N	N
Study or library			0.5	2	0.5	2
Bedroom	8		9	9	9	9
Bathroom	1		1	1	1	1
Conference			N	0	N	0
Food Preparation and Serving						
Kitchen	2		1	1	1	1
Dining room	2		2	2	2	2
Food storage	N		N	N	N	N
Snack bar			N	N	N	N
Services						
Laundry			0	1	0	1
Briefing room	0.5		0.5	0	0.5	0
Locker room			N	N	N	N
Theater			0	N	0	N
Dispensary			N	N	N	N
Chapel			0	N	0	N
Barbershop			0	N	0	N
Supply			0	N	0	N
Maintenance			N	N	N	N
Equipment			N	N	N	N
Gym			0	1	0	1
Power			N	0	N	0
Work Areas						
Control room	10		8	0	8	0

TABLE 7.8--Continued

Area	Hours per Day in Crew Areas					
	Logistics Spacecraft		Earth Orbital Space Station		Planetary Space Vehicle	
	Nom. Work-day	Off-Duty Day*	Nom. Work-day	Off-Duty Day	Nom. Work-day	Off-Duty Day
Airlock	N		N	0	N	0
Inspection	N		N	0	N	0
Photographic support			N	N	N	N
Animal housing			N	0	N	0
Docking	N		N	0	N	0
Agricultural study			N	0	N	0
Computer			N	0	N	0
Offices			N	0	N	0
Laboratory			N	0	N	0
Shops			N	0	N	0
Communications			N	0	N	0

*It is assumed that no off-duty day will occur on Logistics Spacecraft.

Legend: N = nominal time period (less than two hours per day--time in area would depend on duties for that day).

TABLE 7.9

LIGHTING SOURCE EVALUATION[20]

	Incandescent - General Service	Incandescent - Halogen Cycle	Fluorescent - Standard Colors	Fluorescent - Deluxe Colors	Mercury Vapor - Deluxe White - HID	Metal Halide High Intensity Disch.	High Pressure Sodium - HID
Efficiency, lms/watt	5	4	1	2	2	1	1
Life, rated	5	4	1	1	1	3	3
Color							
Acceptable	1	1	2	1	2	2	4
Flattering	1	1	3	1	3	2	5
Color rendering	1	1	3	1	3	2	5
Optical Characteristics							
Point source	1	1	5	5	3	1	1
Large source, low brightness	5	5	1	1	3	5	5
Projection	1	1	5	5	3	1	1
Appearance							
Warm	1	1	1	1	4	4	1
Cool	5	5	1	1	1	1	5
Luminaire Characteristics							
Auxiliary equipment	1	1	5	5	3	2	2
Size	1	1	5	5	3	2	2
Weight	1	1	4	4	5	5	5
Lumen Depreciation	2	1	2	3	4	4	1
Costs							
Initial	1	1	2	3	4	5	5
Operating	5	5	1	2	2	3	4
Ruggedness	5	4	2	2	1	2	2
Effects of ambient conditioning	1	1	5	5	1	1	1

Rating Scale

1 – Optimum
2 – Acceptable
3 – Some Compromise
4 – Undesirable
5 – Unacceptable

Acoustics

Acoustical control is an essential determinant of limited volume habitats. High intensity sound can be damaging to the ear while, conversely, the absences of sound has proved to be exhausting. Proper acoustical management should promote the well being of the crew, as well as eliminate interference with communications or the performance of critical tasks.

In tasks requiring alertness over extended durations, work efficien has been observed to be reduced where noise is on the order of 100 dB. Intense noise, for the most part, is distracting rather than disabling, but extremely high noise levels can affect equilibrium and encourage disorientation, motion sickness and other ill-effects.

Pure tones over duration should also be avoided, since exposure can produce certain damage risks.

Auditory alarms are an essential element of system management and proper design including those in Table 7.10.

General acoustic performance requirements are listed below and proper design should reflect this criteria.[21]

1. The sound level of the auditory signal devices is sufficiently above the ambient noise levels to permit reception of the signal. Particular attention should be given to auditory signals indicating malfunction. Auditory warning signals must be easily detectable and must be quickly and accurately identifiable. They should not be of an intensity of frequency content to induce discomfort of panic response.

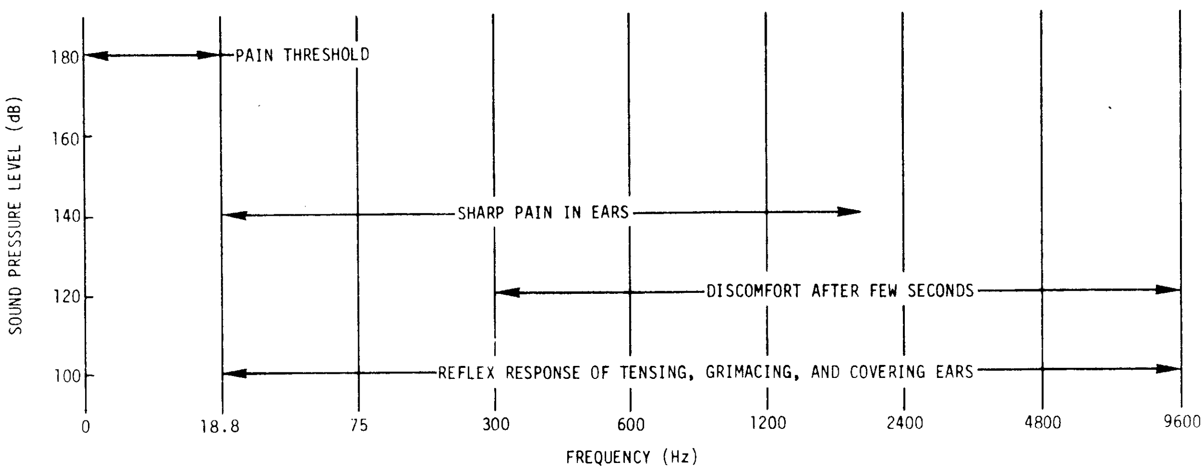


FIGURE 7.10

NOISE DISCOMFORT RANGE[22]

TABLE 7.10

DESIGN RECOMMENDATIONS FOR AUDITORY ALARM AND WARNING DEVICES[23]

Conditions	Design Recommendations
If distance to listener is great	Use high intensities and avoid high frequencies
If sound must bend around obstacles and pass through partitions	Use low frequencies (500Hz)
If background noise is present	Select alarm frequency in region noise masking is minimal
To demand attention	Modulate signal to give intermittent "beeps" or modulate frequency to make pitch rise and fall at rate of about 1-3 Hz
To acknowledge warning	Provide signal with manual shut-off so that it sounds continuously until action is taken.

TABLE 7.11

HEARING DAMAGE CONDITIONS[24]

Condition	SPL dB
Single blast pulses of low frequency	> 175
Sound cycles in range of maximum ear sensitivity	> 155

2. The auditory devices are sufficiently distinctive to permit discrimination between them under all ambient noise conditions.

3. The ambient noise level is sufficiently low in either the shirt-sleeve or pressure suit environments, to permit face-to-face verbal communications when required with an acceptable level of intelligibility, with half effort.

4. The signal-to-noise ratio and bandwidth for the intercommunication equipment is sufficiently high to permit an acceptable level of intelligibility.

5. The ambient noise level does not exceed intensity levels and durations which cause undue discomfort or could be expected to cause temporary or permanent damage.

Temperature

Thermal control provides the necessary comfort zone for habitable areas. This range is achieved by included self sufficient subsystems and, inherently, must shield the enclosed environment from the extremes outside.

Design criteria for thermal control is outlined in Table 7.12 with an accompanying tolerance and comfort zone chart. The remaining table represents activity/area relationships. Another chart displaying activity with respect to metabolic rates is presented in Table 7.13.

Color

Decisions of color selection are basically subjective in nature but there are factors of perception which should be considered. Room volume, function, and desired behavioral aspects can be

TABLE 7.12

ENVIRONMENTAL DESIGN CRITERIA/TEMPERATURE/GAS FLOW RATE/HUMIDITY [25]

Item	Limits	Remarks
Temperature, Air		
Minimum	60°F at 0.0 Clo 45°F at 1.0 Clo	Experimental data show low air temperatures are offset by high metabolic rates or radiation. Prevents uncomfortable cooling of any skin area.
Maximum	100°F	To avoid high skin temperature and prevent uncomfortable heating of any skin area
Temperature, Surface		
Minimum	55°F	To prevent overcooling or overheating of skin areas coming in contact with the surfaces
Maximum	105°F	
Gas Flow Rate		
Minimum	15 ft/min.	Equal to natural convection. This is required to avoid dead hot or cold gas pockets, dissipation of carbon dioxide and other waste gases, and avoids large changes in convective heat loss with body movement.
Maximum	100 ft/min.	Flow rates above this level are subjectively drafty and cause uncomfortable local skin temperatures.
Humidity		
Minimum	8mm Hg partial	Below this level, the mucus membranes begin to dry resulting in discomfort and increased possibility of respiratory infection.

TABLE 7.12--Continued

Item	Limits	Remarks
Maximum	95 percent R.H.	At this relative humidity level, liquid water is usually condensed on some surfaces. At high metabolic rates where sweating may occur, humidity will be limited by comfortable air or wall temperature.

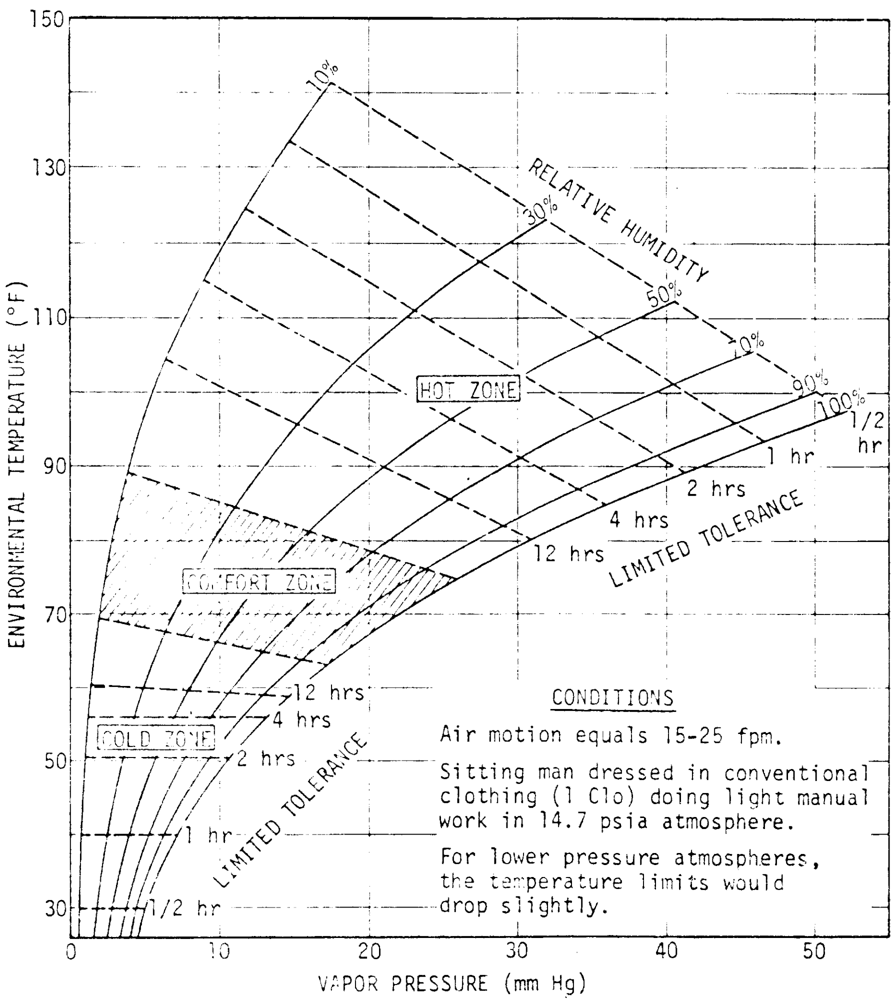


FIGURE 7.11

THERMAL COMFORT AND TOLERANCE ZONES[26]

TABLE 7.13

METABOLIC RATE FOR SPACE ACTIVITIES IN ZERO G[27]

Activity	Metabolic Rate	
	Range (Btu/hr)	Nominal (Btu/hr)
Assembling parts	800-1000	900
At lecture	400-800	600
Changing clothes	600-900	750
Cooking	600-1000	800
Eating	300-550	450
Electrical Assembly	800-1200	1000
Electronic repair	500-700	600
Exercising	1200-2200	1700
General office	500-900	700
Machining	550-750	650
Monitoring systems	350-650	500
Playing games (cards, chess, pool)	400-650	525
Sheet metal work	1000-1750	1375
Sitting at rest	300-500	400
Sleeping	250-350	300
Strenuous sports	1800-2800	2300
System checkout	500-1000	750
Transporting cargo	800-1600	1200
Typing	500-700	600
Walking	650-950	800
Washing	700-1300	1000
Watching/Listening, Entertainment	300-500	400
Welding	550-750	650
Writing	350-550	450

TABLE 7.14

AREA ACTIVITY RELATIONSHIPS[28]

Area \ Activity	Sleeping	Eating	Monitoring systems	Sitting at rest	At lecture	Typing	[illegible]	Assembling parts	Walking	Exercising	Transporting cargo	Changing clothes	Strenuous sports	General office	Welding	Sheet metal work	Electrical assembly	Machining	Electronic repair	System checkout	System operation	Writing	Playing games	Entertainment	Washing
Living Areas																									
Lounge				X					X													X			
Recreation				X					X													X	X	X	
Passageways									X		X														
Study or library				X																		X			
Bedroom	X								X			X													
Bathroom									X			X													
Classroom					X																	X			
Food Preparation and Serving																									
Kitchen							X		X																
Dining room		X		X					X																
Food storage									X		X														
Snack bar		X							X																
Services																									
Laundry			X						X		X														X
Briefing room					X				X													X			
Locker room									X		X														X
Theater				X					X															X	
Dispensary									X		X											X			
Chapel				X																					
Barbershop				X					X												X				
Supply									X		X														
Maintenance			X					X	X		X					X	X		X	X					
Equipment								X	X		X									X					
Gym									X	X			X												

TABLE 7.14--Continued

Activity / Area	Sleeping	Eating	Monitoring systems	Sitting at rest	At lecture	Typing	Cooking	Assembling parts	Walking	Exercising	Transporting cargo	Changing clothes	Strenuous sports	General office	Welding	Sheet metal work	Electrical assembly	Machining	Electronic repair	System checkout	System operation	Writing	Playing games	Entertainment	Washing
Power			X						X								X			X					
Work Areas																									
Control room			X						X												X	X			
Airlocks									X		X														
Inspection			X						X											X					
Photographic support									X		X											X			
Animal housing									X		X											X			
Dock									X		X														
Agricultural study									X		X											X			
Computer			X			X															X	X			
Offices						X			X					X								X			
Laboratory			X						X												X	X			X
Shops								X	X		X				X	X	X	X	X						
Communications			X																		X				

considered determinants of color selection. The effects of color on habitable areas can be assets with respect to desired effect as shown in Table 7.15. Color and its perceptual properties should be used to satisfy safety demands such as (1) accident prevention, (2) the marking of physical hazards, (3) the location of safety equipment and (4) the identification of fire and other protective equipment.

The following criteria for color coding should be used.[29]

Red shall be the basic color for identification of:

Fire protection equipment and apparatus
Danger
Stop.

Orange shall be used to designate exposed unguarded hazards, such as:

Inside of transmission guards for gears, pulleys, chains, etc.
Exposed parts (edges only) of pulleys, gears, rollers, cutting devices, power jaws, etc.
Safety starting buttons.

Yellow shall be the basic color designating caution, such as:

Waste containers for explosive or highly combustible materials
Caution signs
Piping systems containing dangerous materials.

Green shall be used as the basic color designation for safety and the location of first aid equipment.

Blue shall be the basic color for designation of caution limited to warning against the starting, the use of, or the movement of equipment under repair or being worked upon.

Purple shall be the basic color for designating radiation hazards, such as:

Rooms where such material is stored or handled
Disposal cans for radioactive material
Contaminated equipment

TABLE 7.15

COLOR AREA ASSESSMENT[30]

	Exciting	Stimulating	Cheering	Neutralizing	Retiring	Relaxing	Subduing	Depressing
Private								
Crew compartments			X	0		X	0	0
Public								
Dining room			X			X	0	0
Lounge			X			X		0
Recreation	X	X						0
Library	0	0		X		X	X	0
Study	0			X	X			0
Conference		X						0
Passageways				X			0	0
Chapel	0	0			X	X	X	0
Gym	X	X			0	0	0	0
Locker room			X		0	0	0	0
Theater		X					0	0
Briefing room		X					0	0
Service								
Galley			X					0
Snack bar			X	0				0
Bathroom		X	X	X		X		0
Dispensary			X			X		0
Laundry				X				0
Barbershop			X			X		0
Work								
Equipment				X				0
Maintenance				X				0
Power				X				0
Storage, food				X				0
Supply				X				0
Control room	0	0		X				0
Communications	0	0		X				0
Computer	0	0		X				0
Shop	0	0		X				0
Offices	0			X				0
Laboratories	0			X				0

TABLE 7.15--Continued

	Exciting	Stimulating	Cheering	Neutralizing	Retiring	Relaxing	Subduing	Depressing
Dock	0			X				0
Photographic support				X				0
Animal housing				X				0
Agricultural study area				X				0
Air locks	0			X				0

Legend: X = Desirable effect
0 = Undesirable effect

TABLE 7.16

EFFECT OF HUE[31]

Effect	Hue	Contrast
Exciting	Bright red Bright orange	High
Stimulating	Red Orange	Moderate
Cheering	Light orange Yellow Warm gray	Moderate
Neutralizing	Gray White/off-white	Low
Retiring	Cool gray Light green Light blue	Low
Relaxing	Blue Green	Low
Subduing	Purple	Moderate
Depressing	Black	Low

Signal lights which indicate when radiation-producing units are in operation.

Color coding standards for marking fluid lines and valves for military equipment are as follows:[32]

Red:	Fuel
Green, Gray:	Rocket oxidizer
Red, Gray:	Rocket fuel
Red, Gray, Red:	Water injection
Orange, Green:	Inerting
Yellow:	Lubrication
Blue, Yellow:	Hydraulic
Orange, Blue:	Pneumatic
Orange, Gray:	Instrument air
Blue:	Coolant
Green:	Breathing oxygen
Brown, Gray:	Air conditioning
Yellow, Orange:	Monopropellant
Brown:	Fire protection
Gray:	De-icing
Yellow, Green:	Rocket catalyst
Orange:	Compressed gas
Brown, Orange:	Electrical conduit
White:	All other

Volume

The allotment of habitable volume is dependent upon a variety of factors. The launch system assigns a maximum volume and weight. Necessary support subsystems, exponents, work stations, and maintenance criteria make logical high priority demands on this volume. Among other factors, habitability makes a bid for the remaining area.

In consideration of long duration missions it becomes essential that crew members work, sleep, eat and relax comfortably and efficiently.

The crews of early space stations will likely be comprised of highly qualified professionals exhibiting some degree of dominance. Interpersonal stress would only be encouraged by confining such a group in tight quarters. The division of volume, then becomes an essential design element. Table 7.17 shows a comparison between allotted area for different programs. Dimensional consistency is maintained for most programs through the items listed in Table 7.18.

Several elements particular to spacecraft area/use assignment are related to responsibility level and spatial need with respect to crew size and mission duration.

With a crew structure of spacecraft commander, line officers and working crew a spatial hierarchy of representative responsibility can be determined. Conditions of being confined in extrateriestrial space interfaced with the responsibilities of leadership can easily cause a situation of high stress. As means to temper the condition and suppress interpersonal conflict volumetric assignments should be proportioned to responsibility level.

Provided there is sufficient area the commander should be awarded private sleeping quarters, bath and office. The deputy commander and line officers should be provided with adjacent semi-private or private baths.

The spatial needs with respect to crew size and mission duration incorporate individual activity requirements along with total habitat area demands.

Individual activity requirements such as dining and sleeping should be sized according to direct increase ratio. That is to say, sleeping quarters for three crew members would be doubled in size to accomodate six men. Mission duration has little effect on the individual activity areas and there would be little change between 60 or 180 day missions.

Total habitat area demands will, on the other hand, significantly increase, due to mission duration. An increase in compartment specialization and reduced effectiveness in leisure time facilities is the reason for additional volume. Figure 7.12 illustrates the overall volumetric requirements as a function of crew size and mission duration.

The relationship between work area and living quarters is very dependent upon available volume. The special requirements of work area and the desired conditions of personal area validate a separation between the two activities. Moreover, this division provides a change of pace from the work area to the living area. As far as determining an individual's proximity between the two functions, responsibility for critical decision making and involvement emergency decisions should be considered.

Table 7.19 represents room height, area, and volume for habitable areas under both artificial gravity and zero g conditions.

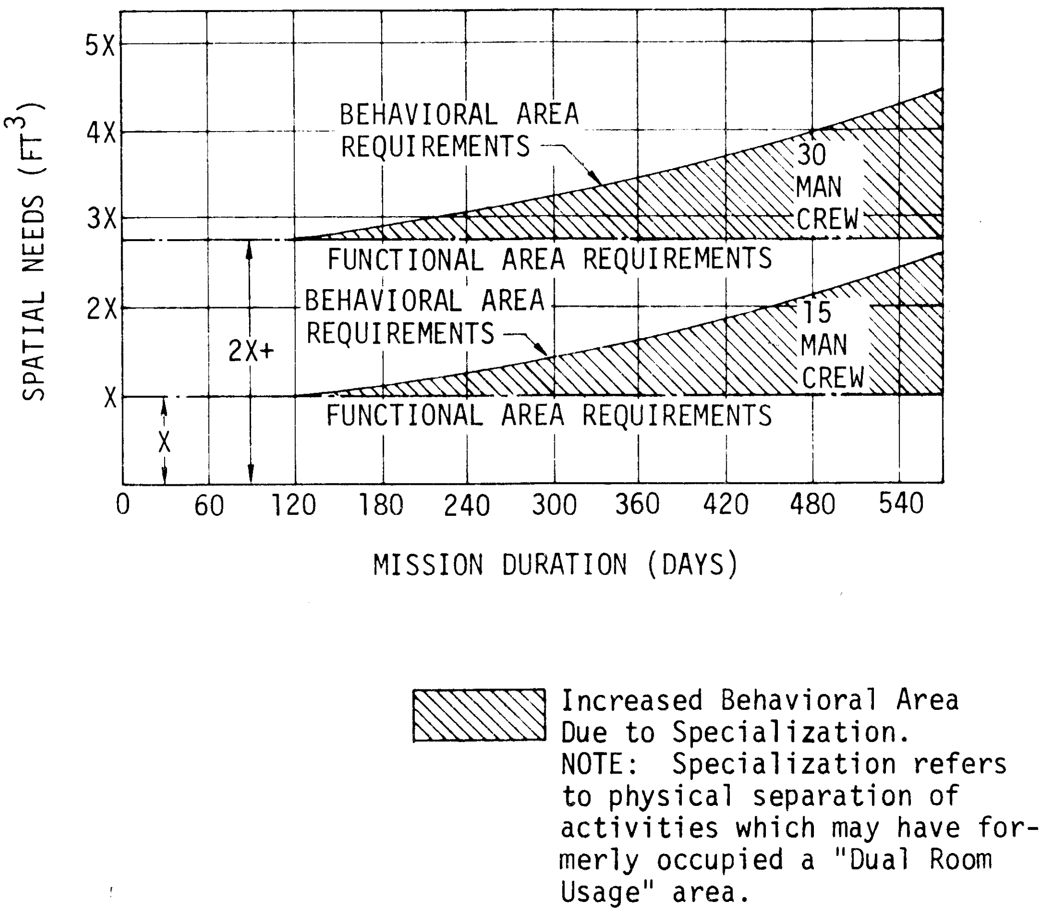


FIGURE 7.12

VOLUMETRIC REQUIREMENTS/CREW SIZE AND MISSION DURATION[33]

TABLE 7.17

AREA ALLOTMENT COMPARISONS

	Submarine		Surface Ship		Lunar Orbit Station	33 ft. Diameter Space Station			Planetary Missions				
	Crew	Officer	Crew	Officer		Minimum	Nominal	Preferred	6 Crewmen	9 Crewmen	12 Crewmen	24 Crewmen	
Crew Quarters	2.5	12	6	40	48	41	48	55	35	35	35	35	Square feet per man
Personal Hygiene					30	8	9	11	5	3	2	2	Square feet per man
Recreation					10	9	10	11	14	14	14	14	Square feet per man
Medical Treatment					6	5	6	7	11	12	9	6	Square feet per man
Galley					5	4	5	5	4	4	4	4	Square feet per man
Exercise					5	4	5	5	5	7	7	7	Square feet per man
Laundry					18	16	18	20					Total for Crew

TABLE 7.18

MOBILITY PROVISIONS

Items	Minimum (inch)	Comments
Passageways		
Ceiling Height	82	
Aisles/Corridors	30	
Hatch Diameters	60	Sized for equipment transfer
	32	Crew emergency use
Air Locks		
Length	84	
Diameter	48	For one-man occupancy
Diameter	60	For two-man occupancy
Tunnels		
Diameter	36	For lengths 7 ft. or less
Diameter	42	For lengths greater than 7 ft.
Compartment Entry		
Width	26	Single-man occupancy
Width	32	Multiman occupancy

TABLE 7.19

ROOM HEIGHT, AREA, VOLUMES[34]

Habitability Unit	Ceiling Height (ft)	Gross Area Per Man (ft^2)	Gross Volume Per Man Artificial Gravity (ft^3)	Zero Gravity (ft^3)
Bedroom-One man	6.5	50	325	220***
Bedroom-One man with bath	6.5	80	520	400***
Bedroom-Two men with bath	6.5	70	455	440***
Bedroom-One man with office and bath	6.5	133**	865	650
Dining room	7.0*	15	105	90
Lounge	7.0	16	112	90
Recreation	7.0	10	70	70
Library	7.0	10	70	70
Study	6.5	10	65	70
Conference	7.0	15	105	90
Passageway (2 way)	6.5	*	—	—
Chapel	6.5	15	98	90
Gym	7.0	10	70	70
Locker room	6.5	*	—	—
Theater	7.0	12	84	78
Briefing room	6.5	15	98	90
Galley	6.5	*	—	—
Snack bar	6.5	*	—	—
Bathroom-toilet, lav. and shower (single occupancy)	6.5	34	221	180
Dispensary-single patient occupancy	6.5	86	559	500
Laundry	6.5	*	—	—
Barbershop	6.5	43	380	280
Equipment]	*	—	—	—
Maintenance	*	—	—	—
Power	*	—	—	—
Food storage	6.5	*	—	—
Supply	6.5	*	—	—
Control	6.5	*	—	—
Communications	6.5	*	—	—

TABLE 7.19--Continued

Habitability Unit	Ceiling Height (ft)	Gross Area Per Man (ft^2)	Gross Volume Per Man: Artificial Gravity (ft^3)	Gross Volume Per Man: Zero Gravity (ft^3)
Computer	6.5	*	—	—
Shop	*	*	—	—
Offices	6.5	38**	247	247
Laboratories	*	—	—	—
Dock	*	—	—	—
Photographic support	*	—	—	—
Animal housing	*	—	—	—
Agriculture study area	*	—	—	—
Air locks	*	—	—	—

*Varies with mission parameters,
**31-60 man crew size
***Visual volumes of 247 $ft.^3$, minimum, may be shared

Note: The volumes listed are on a gross per man basis. They are derived by using the full dimensions from wall to wall and floor to ceiling and then dividing by the number of crewmen using the room at one time.

8. GRAVITY CONDITION

To date there is insufficient data to support any one stand on spacecraft gravity condition. Precursor programs suggest no serious problems with limited duration zero g exposure. Parenthetically, the Skylab program will evaluate longer zero gravity periods, with one twenty-seven day mission and two others, lasting fifty-eight days. This section presents issues related to gravity assessment and includes operational effects, physiological effects and dynamic stability criteria.

8.1. Operational Effects

Artificial gravity overcomes the disadvantages of weightlessness, but the rotation necessary to produce this gravity induces certain operational problems. On board installed systems such as (1) antennas (2) docking devices, (3) crew and cargo transfer, (4) guidance systems, observation, and (5) solar power collection all require attitude control and must be carefully designed into a rotating artificial gravity station. Yet still another consideration is extravehicular activity. In order for a crew member to engage in EVA the astronaut must exit at the hub or the station would have to despin (owing to the centrifugal force produced by spinning).

8.2. Physiological Effects

8.2.1. Sensory Perception.

Design resolution must consider man's narrow tolerance zone in terms of rotational parameters (that is, radius and rate of rotation). The upper limit on gravity level is assumed to be one g and the upper limit on angular velocity is four revolutions per minute (above this rate, vestibular disturbances may appear when the head is turned rapidly about an axis perpendicular to the axis of rotation). The minimum radius where the gravity gradient from head to foot is not enough to be disturbing, 15% maximum, is forty feet.

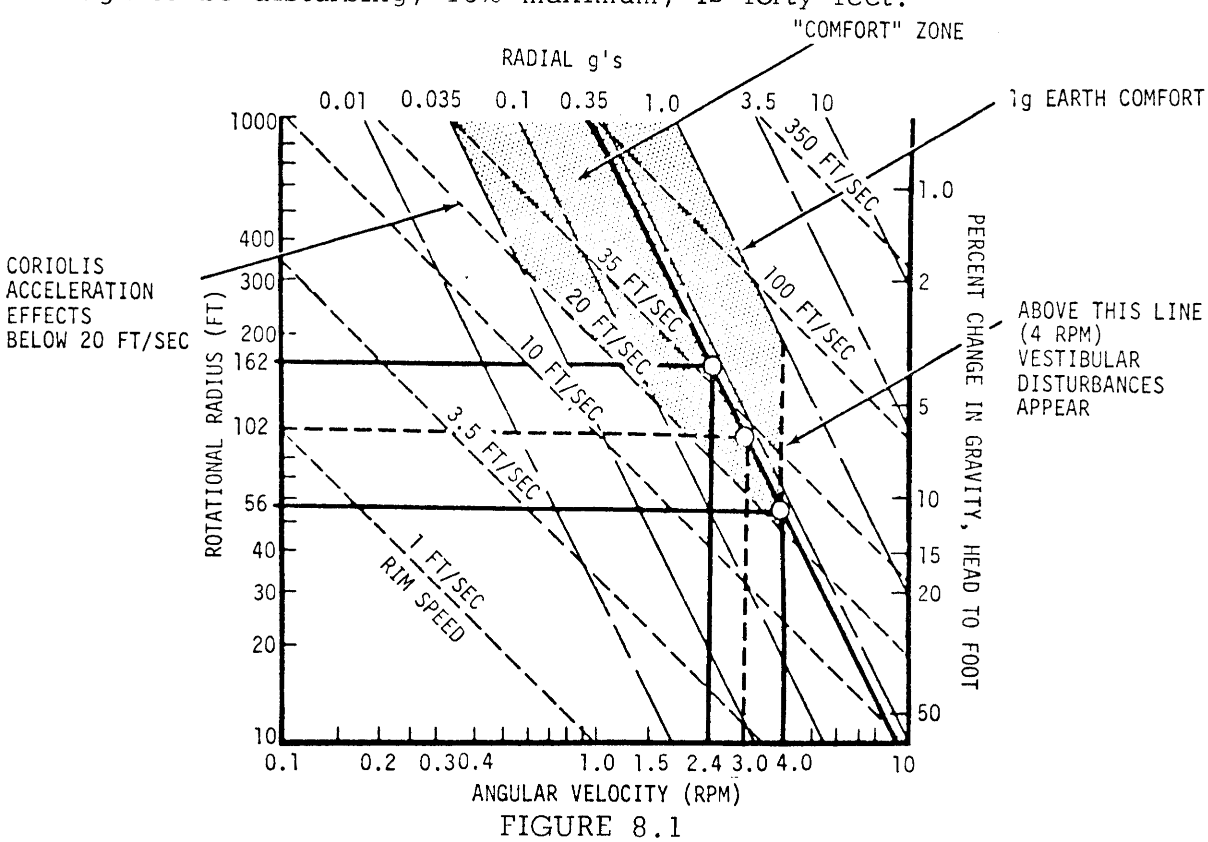


FIGURE 8.1

ROTATIONAL PARAMETERS AND COMFORT ZONE

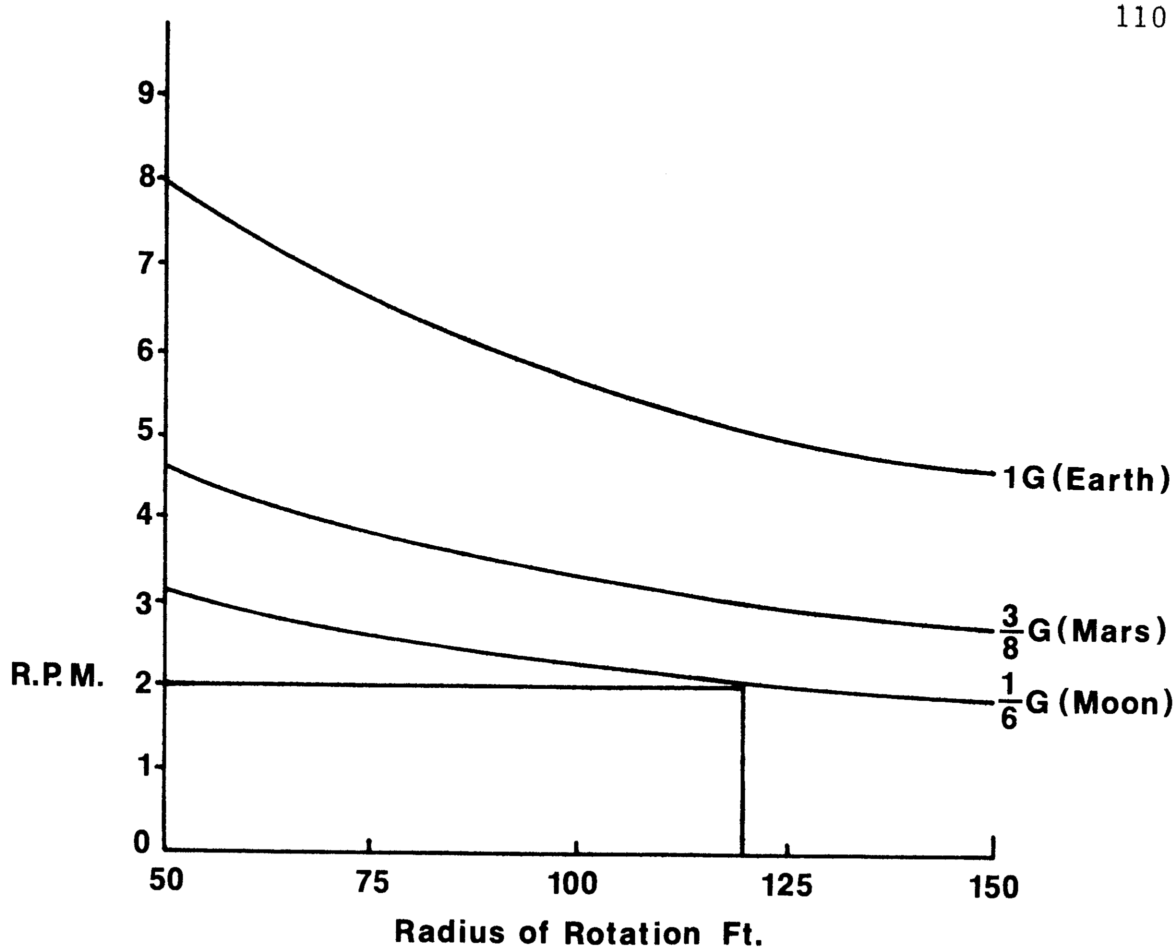


FIGURE 8.2

ARTIFICIAL GRAVITY AS A FUNCTION OF
RADIUS AND RATE OF ROTATION

8.2.3. Coriolis Acceleration

8.2.3.1. Radial Transfer.--In a rotating environment, a crewman will experience changing forces when moving in a radial direction towards or away from the hub (see Figure 8.3). When moving towards the hub, the crewman experiences a force acting upon him in the direction opposite to the rotational direction. Design of artificial gravity radial transfer aids will be dependent upon these conditions.

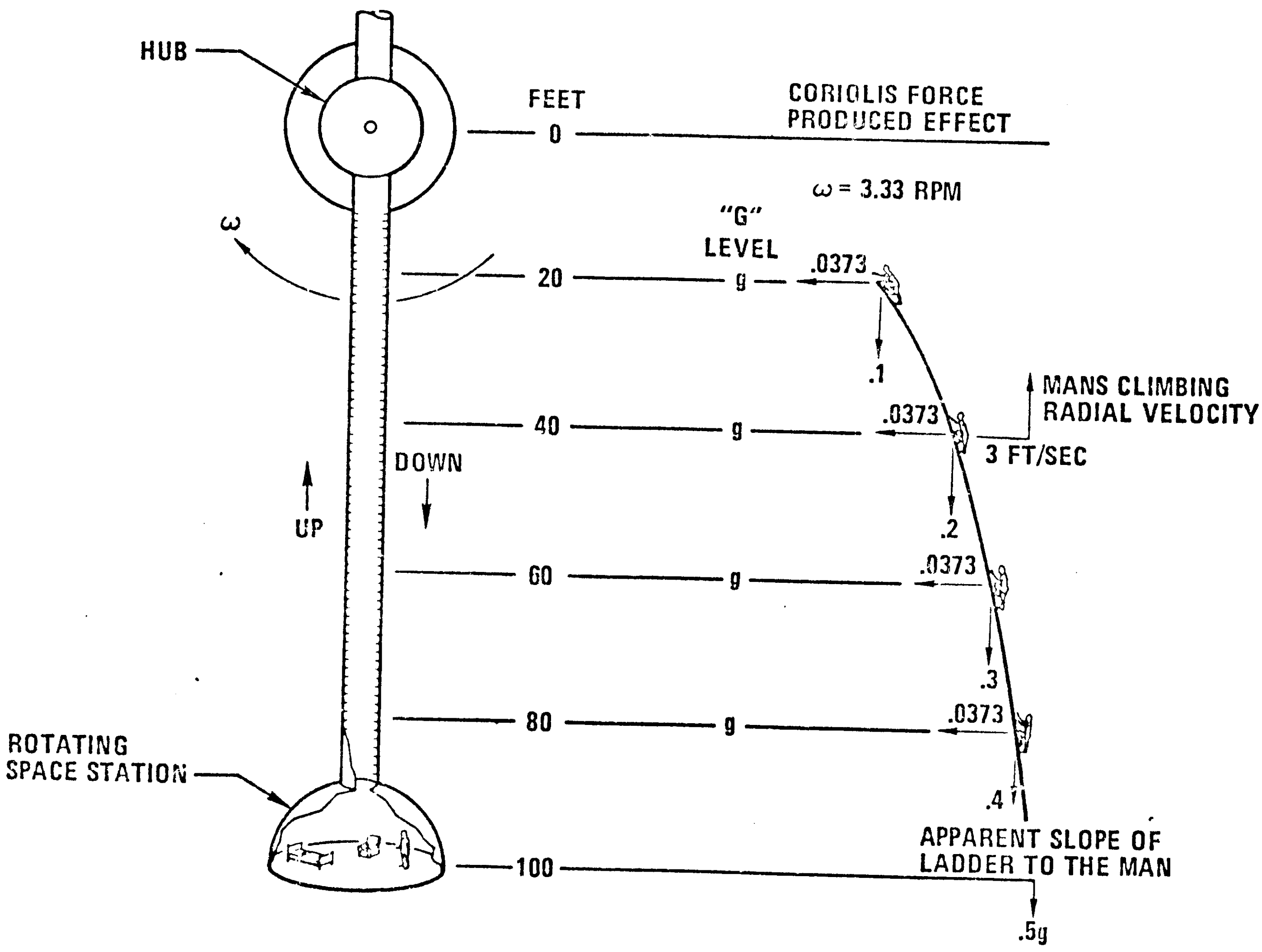


FIGURE 8.3

RADIAL TRANSFER IN A ROTATING STATION/CORIOLIS ACCELERATION

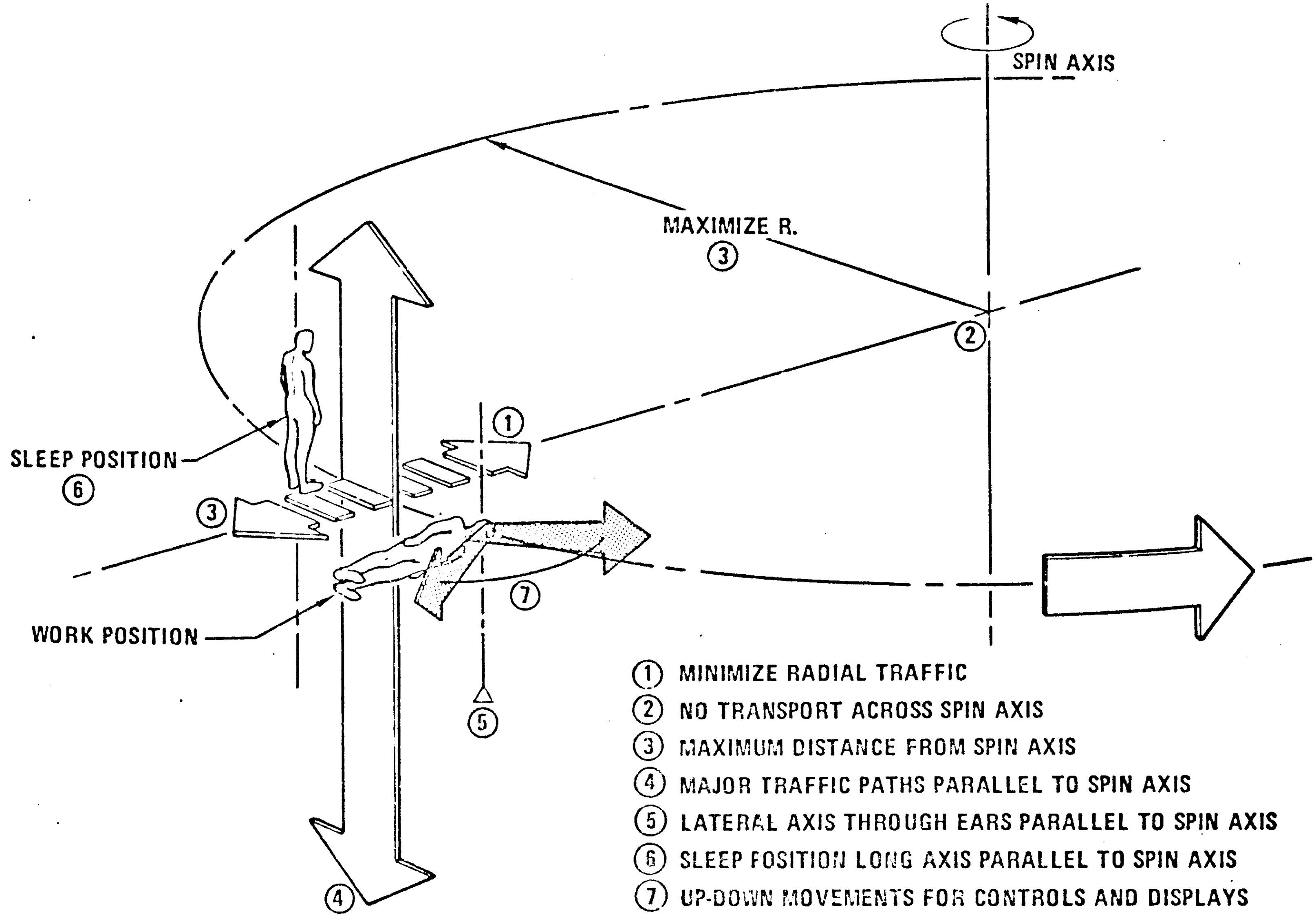


FIGURE 8.4

ORIENTATION PREFERENCES

8.2.3.2. Floor Walking.--As in radial transfer, when a mass such as a leg or arm is displaced radially, up or down (as the knee would be in normal walking), the same Coriolis wind effects take place. As the crewman walks perpendicular to the direction of rotation, his leg will feel a lateral force pushing it one way when he raises his foot, and an opposite force when he sets it down.

The magnitude of the Coriolis acceleration is directly proportional to the product of the artificial gravity rotational rate and the velocity of the crew numbers motion relative to the spacecraft in the plane of rotation.

1. Radial translation toward the center of spin forces the crewmen and cargo toward the leading edge of the spacecraft; the opposite is true as he descends.
2. Translation in a tangential direction results in Coriolis forces which increase or decrease his apparent weight.
3. Significant conflict among spatial senses (intersensory discordance) accompany radial and tangential translation and head movement not parallel to the rotation of the spacecraft.
4. Such conflict tends to provide illusions, spatial disorientation, and difficulty in locomotion, "motion" sickness, and general confusion and discomfort.

8.2.4. Static Lean

Static lean refers to the characteristic angle the crewman assumes to resolve apparent rim or floor inconsistencies. Crew members align their bodies along personal radii of rotation to offset sensed centrifugal acceleration. The crew member standing on a flat floor displaced from the perpendicular radius of rotation to the flat floor will naturally adopt a compensatory lean.

Sensory perception problems also occur with rotation and can be alleviated both by design and procedures. The hairs in the inner ear would sense fluid motion due to an effective change of rotation rate or direction and this sensing would be transmitted to the nervous system. If the eyes are focused on a fixed object, then this sensing produces a dominant rectifying message to the brain and restores a feeling of comfort. Quick head movement will produce a sensing of change of rotation and would destroy the visual anchor point. In the design of the arrangement of displays, necessity for quick head movements to view critical parameters should be avoided.

Additional considerations for determination of gravity condition are:

1. Changes in the mineral balance of bone tissue with a loss of calcium and resultant reduction in bone strength.

2. Orthostatic intolerance - The reflex contraction of venous muscles (that in one g normally prevents pooling of blood in the lower body) ceases to function. This is a progressive phenomenon.

3. A general cardiovascular deconditioning.

4. The effects of re-entry gravity loads after long term weightlessness.

5. Surgery procedures in an agravic situations.

6. Long term effects of eating and drinking in zero gravity.

7. The constraints of zero gravity waste management.

8. Conditions of weightless sleeping.

9. Problems associated with orientation in zero gravity.

10. Experiment requirements conducted under zero g conditions.

Adaptive changes which might occur due to long term exposure to artificial gravity are:

1. Learned alteration of responses to compensate for the rearrangement of sensory information.

2. Conditioned suppression of vestibular information.

3. Conditioned visual suppression of conflicting sensory information (the astronaut depends more than usual upon vision and is thus able to ignore conflicting inputs from other senses).

Design Considerations

1. Crew stations requiring seated or standing performance for more than a few seconds at a time should be oriented axially with respect to the rotating cluster; an astronaut at such a station would then face tangentially (toward the leading or trailing edge of the spacecraft).

2. Crew stations should be so laid out that head movements required for monitoring visual displays, the astronaut's own performance, etc. are made primarily within a plane parallel to the plane of rotation.

3. Bunks and the Lower Body Negative Pressure device should be oriented axially.

4. Translation within one floor should be accomplished in an axial direction to the greatest degree possible.

5. A ladder or specially designed elevator should be provided for radial translation, and should be centrally located with its rungs (if a ladder) oriented axially. Provision should be made for ascent on the trailing side of the ladder and descent on the leading side.

8.3. Dynamic Stability

The rotational effect which induces artificial gravity, provides additional benefits. If the principal axis of maximum moment of inertia is the same as the axis of rotation then the station will tend to be spin stabilized. Problems associated with the dynamics of spinning stations include, (1) elastic oscillations produced by crew motion and cargo shift, and (3) external torques resulting from docking impacts. Damping mechanism should be employed to prevent wobble produced by these disturbances.

9. SPACECRAFT DESIGN

9.1 Spacecraft Design Introduction

A space station, like any other spacecraft, is an integration of support subsystems. The subsystems of early stations should center emphasis on longevity of the unit, use of redundant elements and whenever possible the use of off-the-shelf items. A brief description of this hardware is discussed in this section.

9.2. Subsystems include:

1.	Electrical Power Subsystem	EPS
2.	Environmental Control and Life Support Subsystem	ECLSS
3.	Guidance and Control Subsystem	GCS
4.	Reaction Control Subsystem	RCS
5.	Information Management Subsystem	IMS
6.	Docking Subsystem	
7.	Structure Subsystem	
8.	Habitability Subsystem	

9.2.1. Electrical Power Subsystem

In order to determine the most feasible power system three candidate proposals were reviewed, the solar array, the nuclear reactor/Brayton cycle system, and the nuclear isotope/Brayton cycle system. The nuclear reactor/Brayton cycle candidate system was unacceptable because of excessive shielding weight penalties resulting from its inherently high radiation levels. The two remaining alternatives are comparatively evaluated in Table 9.1.

The advantages of the solar array system make it the obvious selection, especially for the initial station. Expanded area requirements of the array become a limiting factor as power demands increase with station growth. A design allowing conversion to the nuclean isotope/Brayton cycle system at some later stage should be incorporated.

The electrical power system utilizes 7,000 to 10,000 square feet of solar arrays, includes nickel-cadmium batteries for eclipse periods and peak loads, and also employs an emergency fuel cell back-up, using hydrogen and oxygen as energy source. This system provides a 416 volt ac source of power for an average of 25 kilowats of 115/200-volt, 400 Hp, 3 phase ac and fifty=six volt dc, including six kilowats for experiments.

9.2.2. Environmental Control and Life Support Subsystem

The ECLSS supplies the 14.7 psi oxygen/nitrogen atmosphere to all areas of the station. The oxygen is replenished through the electrolysis of water, while the nitrogen is maintained by ammonia decomposition. A Sabatier process performs two functions, (1) carbon

TABLE 9.1

ELECTRICAL POWER SUBSYSTEM ALTERNATIVES[1]

Considerations	Solar Array*	Nuclear Isotope Brayton Conversion Cycle
Experience	Extensive	R & D Stage
Availability	Accurately Predictable	Conditionally predictable No large scale Pu-238 extraction process existing Other Pu-238 uses outside of aerospace
Reliability	High	Long term isotope containment Requires back-up Brayton
Cost (includes development, test, operation, and back-ups)	Least	More
Heat Dissipation	Articulation	Extensive Radiatiors
Attitude Constraints	Solar Panel	Potentially None
Deployment and Retraction	Launch Thrusting maneuvers Hard particle radiation	Heat Source Deployment During Modular Replacement
Weight	10,000 lbs.	15,300 lbs.

dioxide is removed by reverse osmosis and decomposed for Sabatier oxygen recovery, then (2) supplied to the oxygen feed system. The reaction control system in turn, uses the methane byproduct of the Sabatier reactor. Each module incorporates two 180° radiators, which act as meteroid protection and radiate all station generated heat to space.

Most of the condensate and wash water is purified by the use of reverse osmosis, with the remainder cycled through the air evaporation unit and combined with urine and flushing water. The water, 99% pure, is then transfered to the station loop which produces 17.5 lb/day of methane and carbon dioxide for the reaction control subsystem and 13.0 lbs/day of water. For a given quantity of oxygen production the system offers the optimum recycling of water, eliminating the need for any replenishment from the shuttle

The required temperature control is any section of the station is maintained by atmospheric circulation at pre set values from fifteen to 100 ft/min. The level of humidity is maintained at 8-12 mm. of mercury partial pressure of water for the entire station. The station's contamination control assembly continuously monitors atmospheric constituents and removes toxic, corrosive or bacteriological contaminants prior to atmospheric resupply.

9.2.3. Guidance and Control Subsystem

Responsibility for stabilizing the station goes to the

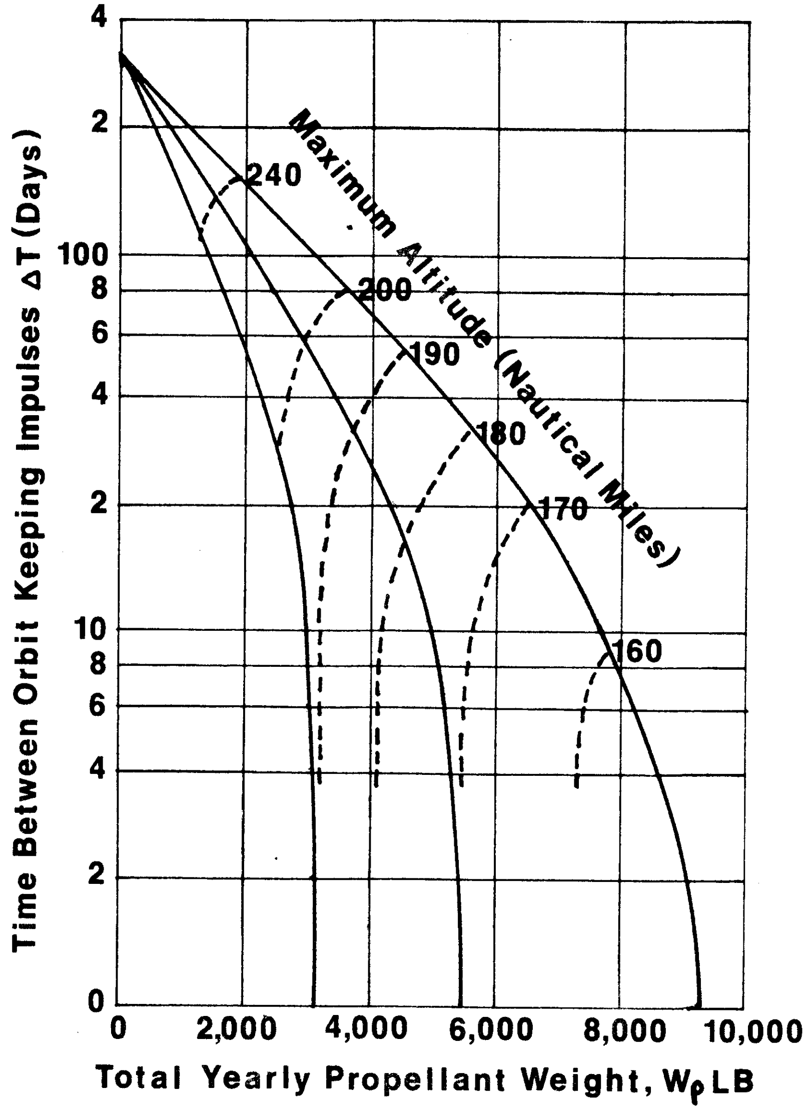


FIGURE 9.1

PROPULSION REQUIREMENTS FOR KEEPING ORBIT[2] guidance and control equipment which uses a six channel strapdown assembly for inertial reference, and control moment zero for nutation or wobble damping. Proper attitude is monitored by horizon sensors, horizon edge trackers, and star trackers and utilized the reaction control system for position adjustments. State vectors are kept in check through periodic use of sextant, telescope, and laser altimeter.

An essential factor in guidance and navigation is the desired autonomy of all program associated hardware from logistic vehicle rondezvous to the management of free flying experiment modules.

9.2.4. Reaction Control Subsystem

Closely linked with the GCS, the reaction control subsystem provides the forces required to control the space station. The 0.1 lb. thrust resistojets utilizing methane waste from the environment control subsystem trim the orbit and offset aerodynamic drag. Medium thrust bipropellant engines (twenty-five pounds) using gaseous hydrogen and oxygen produced by electrolysis, control the momentum vector and docking disturbances. Artificial gravity spin and despin are facilitated by 100 lb. thrust engines located at the opposite ends of the gravity arms.

9.2.5. Information Management Subsystem

The information management subsystem is responsible for (1) crew data management, (2) operations data management, command extension of station capabilities including environmental control and information system interfaces. Docking tolerances allow a margin of .5 ft/sec. impact velocity.

9.2.7. Structure Subsystem

Consistant with crew safety criteria, two independent pressureable volumes should be provided. Monocogue construction utilizing .145 inch thick 5052 aluminum alloy provides a cost effective concept with long term characteristics in the habitable pressure modules. Structural characteristics include three exterior frames which offer a clear module interior of 13 feet 8 inches in diameter and also provide rigid manipulator pickup sockets. Meteroid and radiation protection, are both integrated into an arrangement of pressure shell, insulation and radiators.

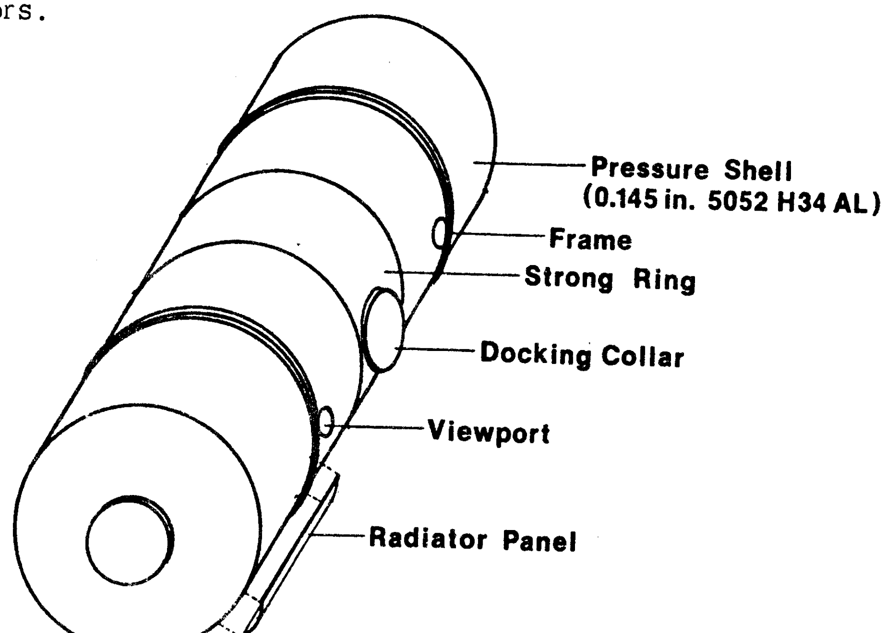


FIGURE 9.2

MODULE STRUCTURE

The structural assembly is augmented by an .03 inch aluminum meteriod bumper and a Kapton lined insulation is located inside the meteroid bumper acting as a secondary bumper. Figures 9.2 and 9.3 present the basic module structure.

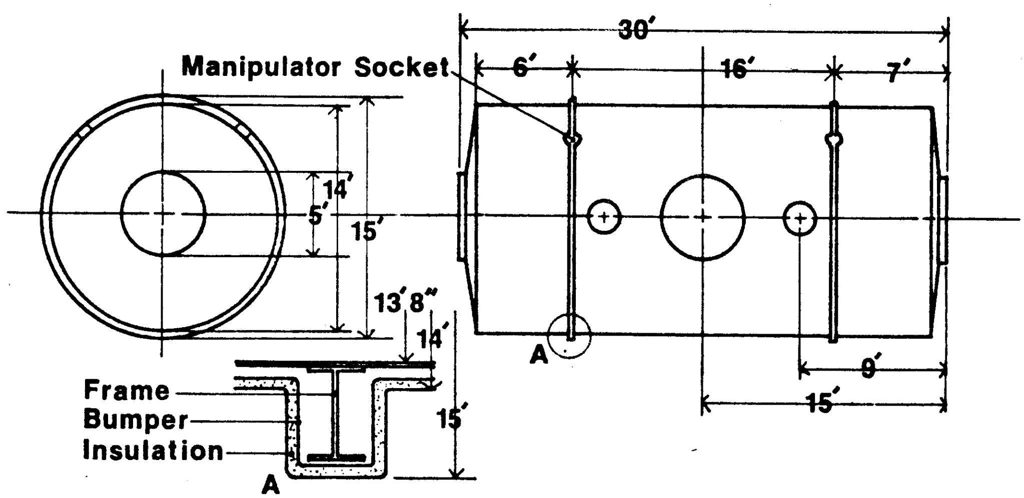


FIGURE 9.3

MODULE DIMENSIONS

9.2.8. Habitability

Extended duration space missions place such a dependency on the enclosed environment that habitability should be considered a subsystem, parallel with other subsystem components.

Habitability as a subsystem includes four environmental groupings: (1) personal, (2) functional, (3) mobility, and (4) recreation and control, experiment data management, (3) on-board check out, (4) mission operations scheduling, and (5) communications management.

Two directional antennae should accomodate communications and tracking. While semidirectional antennae provide communications with earth and serve as the primary link remote and detached modules. For full utilization and maximum capability, approach radar and antennae systems will possess a full compliment of power amplifiers, diplexers, and S-band converters.

Overall operational autonomy is maximized by fully integrating the communications, data processor, and console functions. Full computer integration also includes software storage in reference data, hard copy and information storage facilities.

9.2.6. Docking Subsystem

Docking presents certain difficulties with respect to the rotating artificial gravity station. The inclusion of a static docking element facilitates rondezvous techniques, as well as other required functions demanding specific attitude. Basic habitable modules will include five foot diameter docking collars, two located along the longitudinal axis and two diametrically opposed ports in the plane normal to the radius of rotation. In the case of incompatible docking mechanisms (Soviet and U.S.) an adaptor accommodating each should be used in the coupling. The docking system provides for a full and exercise equipment.

Personal equipment is the clothing, linen, grooming aids, food, emergency oxygen systems, and radiation dosimeters used by crew members.

Bunks, desks, chairs, and the like comprise the functional equipment. Also included in this equipment are private station to earth communication units.

The equipment which facilitates mobility includes crew and equipment restraint devices, transport aids, handling devices, and storage bays for redundant items.

The provision of adequate games, video tapes, motion pictures, reading material, taped music, ergometry devices, isotonic equipment, and medical and dental facilities make up recreation, exercise and crew care considerations. See section 7.4 Habitability for more detailed information.

9.3. Subsystem Component Replacement

Although there will still be redundant components for critical systems, emphasis should center on the continual monitoring of subsystems, operationally followed by fault isolation and component replacement. Responsibility for fault isolation, verification of fault development paths and distribution of checkout information lies in the on-board checkout subsystem. Maintenance loads are sizeably reduced by this concept since crew members are used only in the attendance of equipment and not in the check out process.

System design provides for component replacement in the pressurized volume with major subsystems still operable.

9.4. Integrated Subsystems

In addition to the solar arrays, the electrical power system (EPS) utilizes regenerative fuel cell assemblies which can supply emergency hydrogen, oxygen, or water to the environmental control system (ECLSS) or (RCS). Each assembly consists of (1) one fuel cell, (2) electrolysis unit, (3) nitrogen accumulator, (4) oxygen accumulator, and (5) half of a water storage tank.

The environmental control system uses a closed oxygen and water concept and produces the gaseous propelant used in the reaction control system.

Maximization of common hardware promotes subsystem integration. All the major subsystems utilize electro-chemical processes based on the reactions of hydrogen and oxygen, with similar working fluids, hardward maintenance checkout, and overall technologies. As a result of the integrated EPS, ECLSS, and RCS subsystems and shared development, reduced hardware through shared redundancy and reduced logistics through shared contingency consumables the over-all cost is substantially reduced.

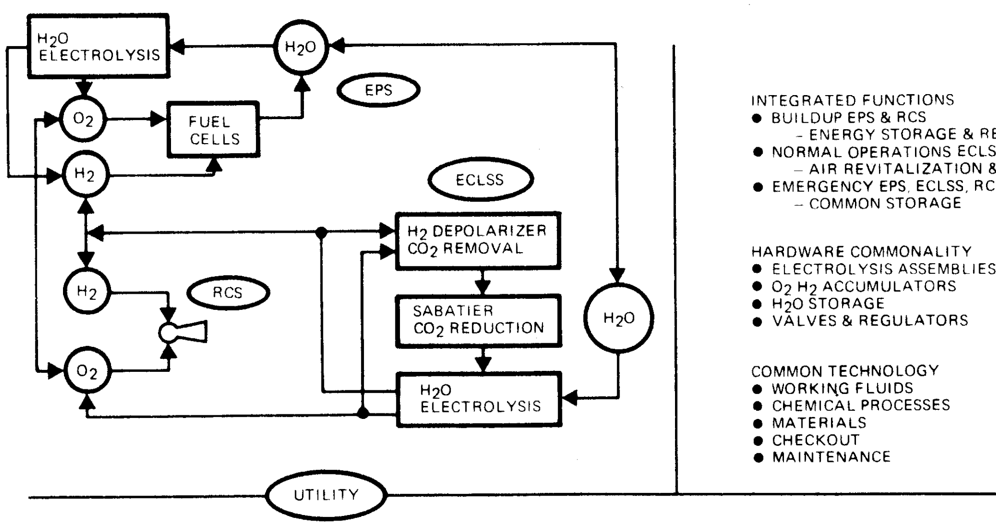


FIGURE 9.4

INTEGRATED SUBSYSTEMS EPS/ECLSS/RCS [3]

9.5. Subsystem Volume

TABLE 9.2

EXTERNAL AND INTERNAL VOLUMES FOR SUBSYSTEM EQUIPMENT[4]

Subsystem	External Volume ft.^{3}			Internal Volume ft.^{3}		
Crew Size	4	6	8	4	6	8
ECS						
Atmos. Regeneration	19	24	29			
CO_2 Removal	25	28	32			
Cabin Circulation	2.5	3.7	5	6	6	6
Coolant Loop	6	7.6	7	5	5	5
Water Supply	17.9	20.6	23.3	2	3	4
Solid Waste Mgt.	8	9	10	2	2	3
ECS Totals	78.4	92.9	106.3	15	16	18
EPS						
Batteries	12	12	12			
Power Conditioning	25	25	25			
Wiring	3	3	3	4	5	7
EPS Totals	40	40	40	4	5	6
COMMUNICATIONS						
RF Systems				10	10	10
Terminal Equipment				1	1	1
Audio & Premod.				2	3	4
TV				6	6	8
Data Management				6	7	7
Data Storage				10	11	12
Antennas						
Communications Totals				35	38	42
INSTRUMENTATION						
Measurement	1	1	1	2	2	2
Signal Conditioning				1	1	1
Displays & Control				15	17	20
Caution & Warning				1	1	1
Timing Equipment				2	2	2
Event Timer				2	2	2
Lighting				4	4	5
Instrumentation Totals	1	1	1	27	29	33

TABLE 9.2--Continued

Subsystem	Crew Size	External Volume ft.^{3} 4	6	8	Internal Volume ft.^{3} 4	6	8
GUIDANCE & CONTROL							
IMU					6	6	6
Electronics					17	17	17
Optics					3	3	3
CMG's		24	24	24			
Guidance & Control Totals		24	24	24	26	26	26
CREW SYSTEMS							
Food Management					28	37	44
Medical & Surgical					68	69	84
Personal Equip. & Hygiene					27	33	73
Exercise & Recreation					3	3	3
Pressure Suits & PLSS							
Crew Systems Total					152	181	252
CONSUMABLES							
Oxygen							
Nitrogen							
Food					408	612	816
Misc. Crew Systems					9	14	18
RCS Prop.		38	38	38			
Consumables Totals					417	626	834
Subsystems Totals					676	921	1212

10. MODULE SIZE AND FLOOR ARRANGEMENT

10.1. Module Size (See 9.2.7. Structure Subsystem)

10.1.1. Modularity Imposed by Launch System

Specifications of the Earth Orbit Shuttle require all modules to be compatible with the parameters of the cargo bay. This means that the pay load can not exceed the fifteen foot diameter by sixty feet long dimensions and must be within the 40,000 lb. ± 10,000 lbs. weight limitation although it is desirable to have all components consistent with shuttle criteria, various existing chemical propulsion stage (CPS) systems are available to orbit different size payloads.

10.1.2. Commonality

Advanced program planning in addition to the proposed shuttle concept has introduced expanded implications on module design. Envisioned manned programs of the 1980's include earth orbit space stations and bases, lunar orbit stations, lunar surface bases, planetary missions and space tug systems. The earth orbit shuttle along with the chemical propulsion stages are responsible for the configuration of these future missions; therefore the design of modules should be flexible enough to adapt to other missions besides an earth orbit station.

10.2. Floor Arrangement

Using the proposed fourteen foot diameter habitable module, the question is, which is the most efficient way to orient the floors and module itself? An assessment of floor arrangement can be determined from evaluation of static lean and Coriolis acceleration, volumetric efficiency, dynamic stability, number of required modules and growth potential.

10.2.1. Static Lean and Coriolis Acceleration

In an artificial gravity state, static lean (a crew member's sensed correction of centrifugal forces by alignment of the body along local radii of rotation) has significant impact on floor positioning. The maximum lean for either and/or longitudinal module orientation is within acceptable tolerances, however several mobility problems arise. The effective lean is modified by the Coriolis effect on artificial g acceleration. This results in an increased lean in the anti-spin direction and a decreased in lean in the program direction. Most critical is movement in the anti-spin direction. Most critical is movement in the anti-spin direction and backward lean. Static lean is sensitive to module length as an incriment of spin circumference.

10.2.2. Volumetric Efficiency

The ratio of usable floor area to total volume of a cylinder is the definition of volumetric efficiency. Useable floor area is allocated to major functions, such as command and control, laboratory facilities, sleeping quarter, etc., having adequate ceiling height for working. Tunnels, aisles and hatches, in general, major access routes are thought as usable floor area. This consideration makes the module diameter the critical element. In diameters less than fifteen feet the longitudinal floor installation proves more efficient than the axial. Therefore, habitable modules compatible with the shuttle bay, should orient floors longitudinally.

10.2.3. Dynamic Stability

An unstable spacecraft spins about an axis of intermediate inertia, while short period stability occurs when it is spun about an axis of minimum or maximum inertia. The initial station should be inherently stable yet possess damping devices to control wobble. The build up sequence of the station should respect the dynamics of spinning bodies and offer the minimum disturbance during docking procedures.

10.2.4. Number of Required Modules

The least number of modules required to make a stable station is a determinant of module orientation. An artificial gravity situation utilizing the longitudinal axis of the module in plane of rotation would best satisfy this requirement.

10.2.5. Growth Potential

Module and floor orientation should be aligned as to best accommodate future growth. This factor effects the relationship of traffic patterns to positioned docking, hatches and orientation of the floor to proposed addition.

11. CONFIGURATION

The determination of a space station configuration is largely dependent upon a wide spectrum of potential activity incorporating twenty-six functional program elements (FPE's). In lieu of dedicated experiment volume and operational constraints, the principal design objectives of the station are to create a safe, habitable environment for the crew. Extensive compartmentation will enhance the serviceability and maintenance of equipment, facilitate various degrees of flexibility and provide an adequate means of storage for 180 days of on-board consumables. The maximum utilization of accommodating potential (i.e., the competition for volume among major subsystems, crew equipment, crew habitation areas and experiment equipment) for a minimum size establish the structure configuration.

Figure 11.1 represents a selection of possible space station configurations.

11.1. Configuration Evaluation

Table 11.1 represents the evaluation of alternative space station configurations as a function of design criteria and relative priority. The scale of evaluation is composed of unacceptable (-2), poor (-1), fair (0), good (1), and excellent (2) terms. Each term is modified by a factor of importance, namely normative (1), limited (2), and critical (3) relative to station existance. Final analysis within the constraints of artificial gravity, a flat floor to radius alignment, and satisfactory traffic flow produced a limited selection of acceptable configurations. These include barbell, trimass, cruciform, heximass, toroidal, cube, and assembler.

11.2. Conclusions

The open class alternatives, barbell, cruciform, trimass, etc. help to minimize design, assembly and operational complexity, but require special devices to meet dual egress criteria. Hemihex is unacceptable because difficulty in maintaining satisfactory mass balance during buildup. The closed class inherently provides dual shirtsleeve egress, yet involves complex design and assembly procedures in addition to difficult growth pattern from initial station.

The cluster and hybrid classes produced no significant advantages and required complex assembly and build-up.

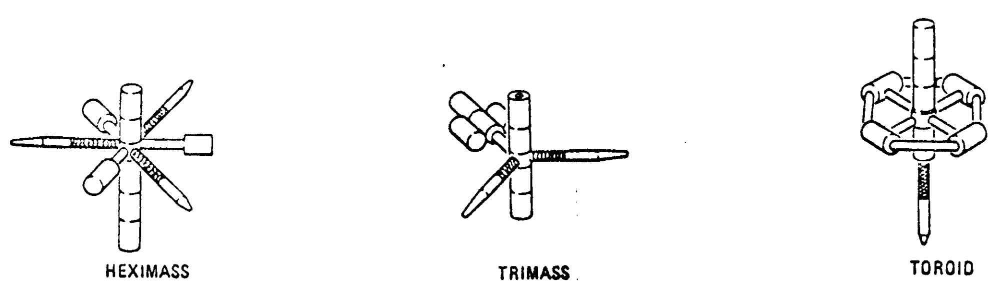
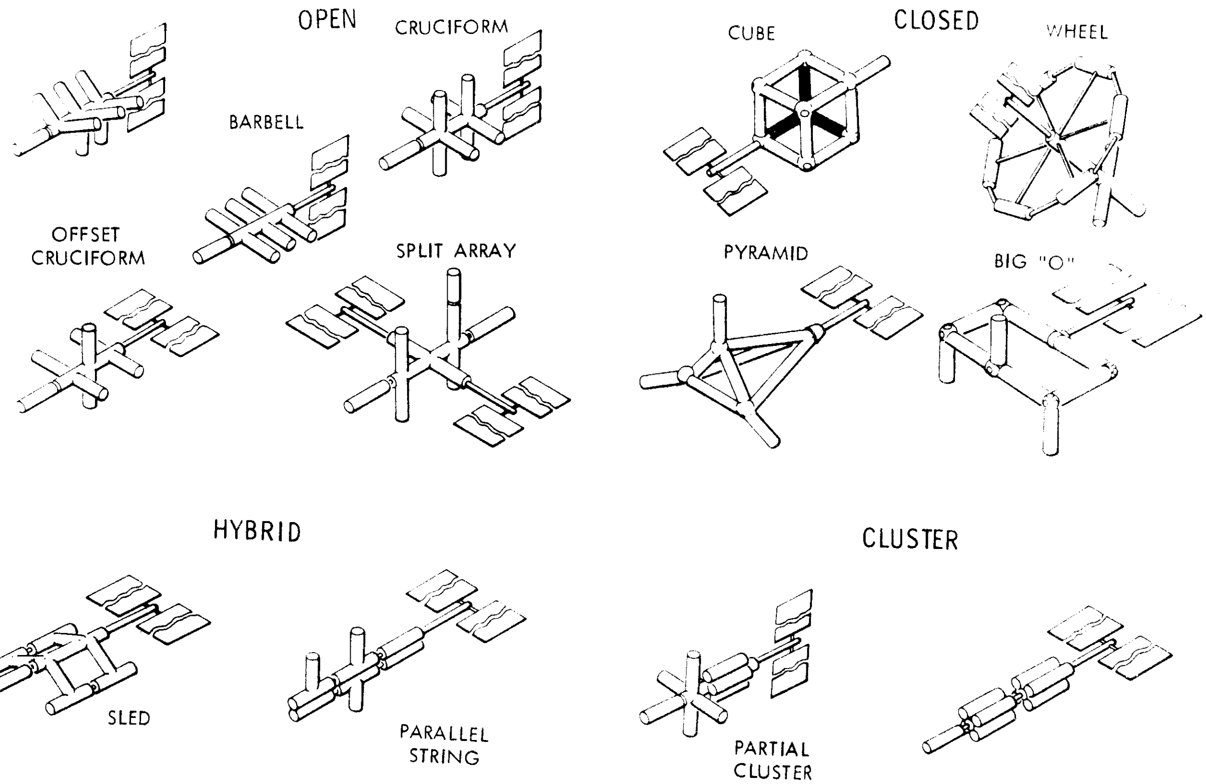


FIGURE 11.1

CONFIGURATION SCHEMES



ASSEMBLER

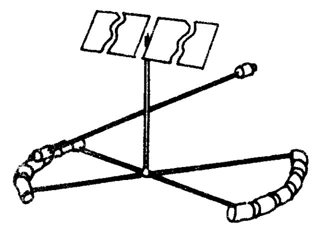


FIGURE 11.1

CONFIGURATION SCHEMES (cont.)

12. SCHEDULES AND COST

12.1. Schedules

The determination of funding levels in accordance with the phased development program is an essential factor for space station establishment. Estimations within the program satisfy flexibility requirements since realistic cost appraisal demands must be balanced against a technological schedule.

Figure 12.1 represents a comparison of program options based on cost experiment benefits and utility. The four level option provides the lowest peak annual funding with nominal experiment utility and benefits. Both two level options show highest achievement at higher peak annual funding.

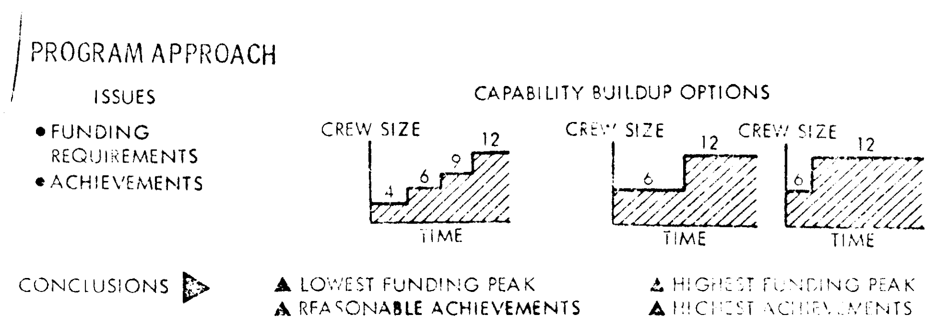


FIGURE 12.1

PHASED SCHEDULING [1]

TABLE 12.1

LOW BUDGET ALTERNATIVE/SCHEDULE[2]

HC/ADVANCED PROGRAM PLANNING OFFICE

5-28-70

	PROGRAMS & MISSIONS CY	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
EARTH ORBIT	INDEPENDENT EO SHUTTLE OPERATIONS	△—	—	—	—																		
	EO SHUTTLE SUPPORT (FLIGHTS/YEAR)	6	6	6	6																		
	12 MAN SPACE STATION																						
	SPACE BASE BUILDUP					△—	—	—	—	—													
	50 MAN BASE									—	—	—	—	—									
	100 MAN BASE											△—	—	—									
	TUG SUPPORT (FLIGHTS/YEAR) *													△—	—	—	—	—	—	—	—	—	—
						1	1	1	1	1	2	2	1	3.5	1	1	1	1	1	1	1	1	1
	INT-21 SUPPORT (FLIGHTS/YEAR) *					1.5*					3	3	1	2		.5						.5	
	EO SHUTTLE SUPPORT (FLIGHTS/YEAR)					8	10	9	10	9	23	20	19	27	26	24	25	26	25	25	26	25	26
	AUTOMATED SATELLITE DELIVERY	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	TUG SUPPORT (FLIGHTS/YEAR)					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	EO SHUTTLE SUPPORT (FLIGHTS/YEAR)	6	6	6	7	9	10	11	11	13	13	14	14	14	13	12	14	13	14	13	13	13	13
LUNAR	LUNAR ORBIT SPACE STATION					△—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	LUNAR SURFACE BASE					—	—	—	—	—	△—	—	—	—	—	—	—	—	—	—	—	—	—
	TUG (FLIGHTS/YEAR)					△	2	4	4	4	4	8	7	7	7	7	7	7	7	7	7	7	7
	NUCLEAR STAGE (FLIGHTS/YEAR)					1	5	5	5	5	7	8	8	8	8	9	8	8	8	8	8	8	8
	INT-21 SUPPORT (FLIGHTS/YEAR) *					2.5	2			1	3	2	1	1		2.5	2	1	1		1	.5	1
	EO SHUTTLE SUPPORT (FLIGHTS/YEAR)					6	55	48	49	46	63	72	74	75	77	75	72	75	73	77	75	72	75
PLANETARY	EARTH ORBIT ASSEMBLY															—	—	—	—				
	MARS MISSION																		△—	—	—	△	
	TUG SUPPORT (FLIGHTS/YEAR)															1	2	3	1	2			
	INT-21 SUPPORT (FLIGHTS/YEAR) *															3	4	4	1				
	EO SHUTTLE SUPPORT (FLIGHTS/YEAR)															4	29	29	17				

△ INITIAL OPERATIONAL CAPABILITY
— ACTIVITY IN PROGRESS
* 1/2 DENOTES SHARED TUG LAUNCH

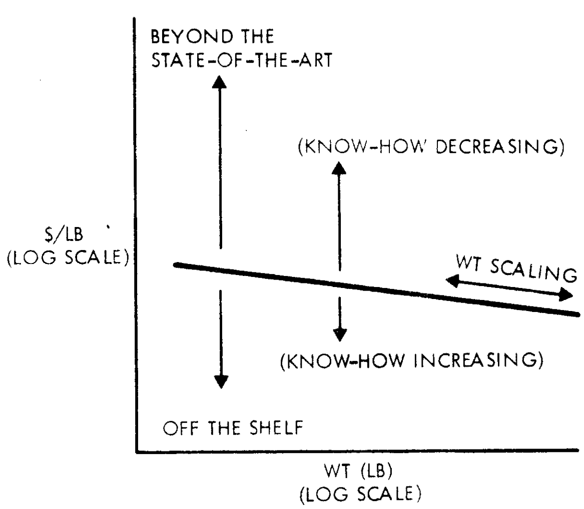
BASED ON NASA HEADQUARTERS LOW BUDGET GUIDELINE
BASED ON SPACE TASK GROUP OPTION II PHILOSOPHY AND SPACE SYSTEMS

A study by the Manned Spacecraft Center Advanced Program Planning Office reveals the following schedule composed in 1970. The schedule is a separate low budget alternative plan showing integrated manned programs.

12.2 Cost

An earth orbit space station is well within the existing state of technology. Full development of a several substations, in addition to, off-the-shelf components could satisfy existing program requirements. However, considerable attention should be given to the reality of the situation including scheduling and cost methodology.

Hardware weight estimates and subsystem technical descriptions are functions of developmental status, complexity of the item and its production and specification status. Figure 12.2 represents the results of this investigation.



KNOW-HOW RANKING	STATE-OF-THE-ART	PRODUCTION EXPERIENCE	SPECIFICATION STATUS
1	REQUIRES NO MOD	PRODUCED IN PROD. QUAN	SPEC FOR THE ITEM AS PRODUCED
2	MINOR MOD OF COMMERCIAL OR STD AEROSPACE ITEM	PRODUCED IN LIMITED QUANTITY	SPEC FOR ITEM AS PRODUCED
3	WITHIN STATE-OF-THE-ART BUT NO COMM COUNTER-PART EXISTS	PROTOTYPE PRODUCED	SPEC HAS BEEN PREPARED BUT UNDER REVIEW OR REVISION
4	ITEM SLIGHTLY BEYOND CURRENT STATE-OF-THE-ART SOME DEVEL REQUIRED	EXPERIMENTAL LAB FAB OF SIMILAR ITEM IN PROCESS	WORK ON A SPEC IN EARLY STAGE. ONLY GEN RQMTS IDENTIFIED
5	ITEM SUBSTANTIALLY BEYOND CURRENT STATE-OF-THE-ART MAJOR DEVEL REQUIRED	NO PRODUCTION OF ANY KIND	NO WORK ON SPEC STARTED

FIGURE 12.2

COST METHODOLOGY[3]

TABLE 12.2

DEVELOPMENT COST COMPARISON[4]

Experiment Operating Man-hours in Space

Approach	Hours	$/Man-Hour Ratio
12-Man Station (10 yr.)	280,800	1
6-Man Station (10 yr.)	109,200	2
7-Day Sortie (10 yr.)	20,000	4.5
3-Man Skylab (140 days)	2,352	60.4

Another factor affecting the program cost is the degree of commonality for subsystems within sortie payloads. The results of a commonality analysis are shown in Figure 12.3.

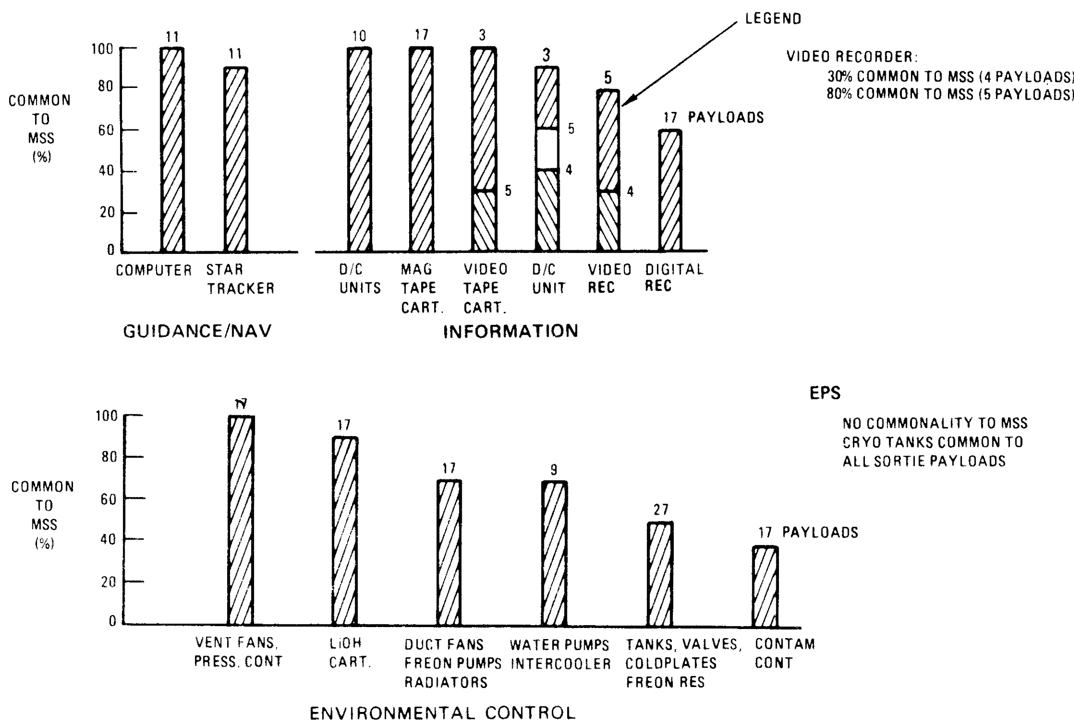


FIGURE 12.3

COMMONALITY RESULTS[5]

The cost analysis approach includes:

1. Development cost assuming that each individual payload was developed separately.

2. Development cost recognizing commonality between payloads and costs shared among payloads.

3. Dollar benefit based on commonality percentage to modular space station.

The cost analysis results indicate about 60% savings by the

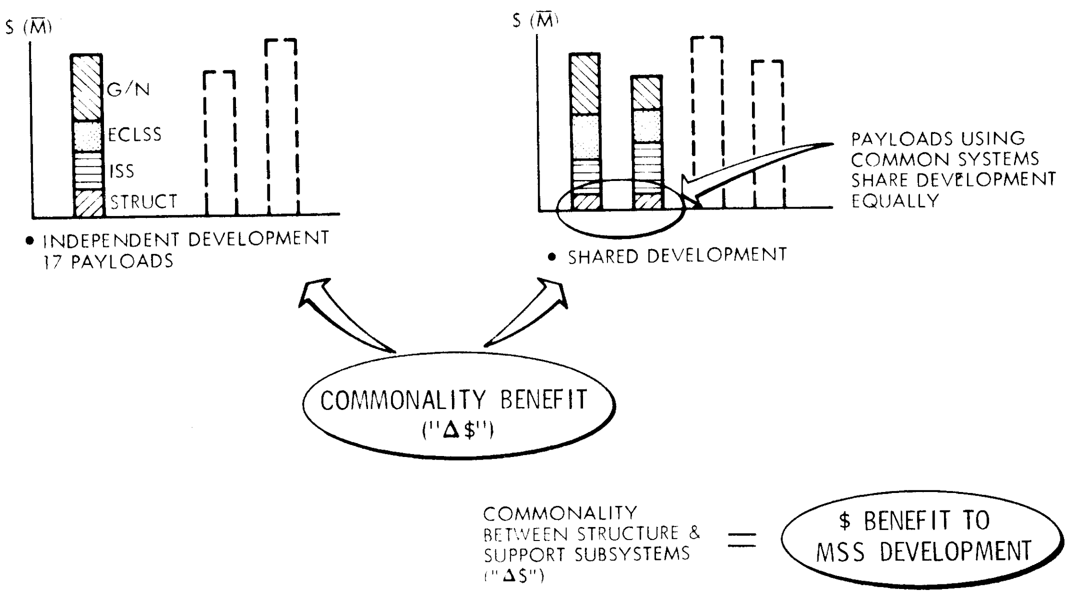


FIGURE 12.4

COMMONALITY BENEFITS[6]

TABLE 12.2

DEVELOPMENT COST COMPARISON[7]

Item	Independent Development (S)	Shared Development (S)	Savings to MSS (S)
Structure	770	140	28
ECLSS	370	120	27
EPS	120	25	--
G/C	305	235	5
Information	120	30	10
Crew/Hab.	115	20	7
Total	1,800	570	77

- 17 Sortie payloads
- Development costs only
- 1972 Dollars

use of shared costs among payloads. A 4% cost savings can be attributed to the initial station development cost. Additional intangible benefits result because of this cost approach and these are component reliability data, experiment procedures, operational experience and maintenance procedures.

The Advanced Logistics System (ALS) when fully utilized, both in weight and volume, represent the greatest cost-effectiveness. Figure 12.5 depicts program costs by:

1. Analysis with the Space Station bearing all ALS procurement and operating costs.

2. Analysis with the Space Station bearing only its portion of the ALS costs (i.e., sharing the procurement and operating costs with other manned space programs using the ALS).

3. Analysis of the cost effectiveness of various ALS payload concepts in terms of dollars per pound of payload to orbit.

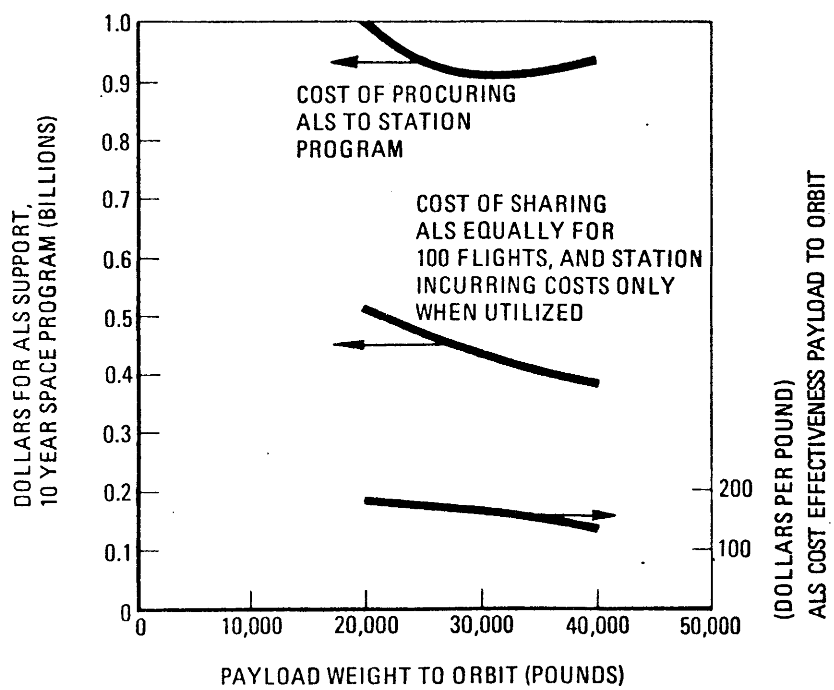


FIGURE 12.5

ALS COST EFFECTIVENESS[8]

13. DIGEST OF DESIGN CONSIDERATIONS

Mission Envelope

Owing to

1. Launch System
2. Experiment Demands
3. Atmospheric Drag

orbital parameters were established to be an inclination of 28.5^{o} to 55^{o} at an altitude between 240 and 270 miles.

Orbit selection of 55^{o} x 240-270 mi. in order to gain maximum potential of 82% of earth's land surface.

Crew Safety

1. Reliability
2. Emergency Provisions
3. Gravity Considerations
4. Communications

1. Reliability

Design Implementation

Safety Factor

Pressure Containers/Valves

Power Output

Shielding

Technology Selection

Space Tested

Flig:.. Simulated

Ground Tested

Redundancy

On-line Parallel Support

Back-up Mode

Automatic Switching

Replacement

Modular substitution

IMS Monitoring

2. Emergency Provisions

Escape Routes

Dual Egress

Alternate EVA/IVA Airlocks

Dual Pressure Volumes

ALS Rescue System

EVA Suit

"Life Raft"

3. Gravity Considerations (See Gravity Condition)

Artificial Gravity

Gravity Level .167 g (1/6)

Angular Velocity 6.3 ft./sec.

Radius 120 ft. (twice length of EOS cargo bay)

Physiological Effects

Head-foot Gradient less than 15% O.K.

Coriolis Acceleration O.K.

Static Lean less than 7% O.K.

Mineral Balance

Orthostatic Tolerance

Cardiovascular Condition

Re-entry Gravity Loads

4. Communications

Telemetry (instrument)

Ground Tracking

Audio/Video

Crew Operations

1. Crew Composition
2. Crew Shift and Time Scale
3. Crew Structure
4. Leisure Time

1. Crew Composition

High Routine Experiment Operations

Station Support	25 man hrs./day
Aerospace Medicine Experiments	20 man hrs./day
Other Experiments	55 man hrs./day

Logistic Supply Periods

Station Operations	40 man hrs./day
Experiment Support	10 man hrs./day
Routine Experiment Support	70 man hrs./day

Crew Skills

Skill types	27 man hrs./day

Crew Members	12 man hrs./day

2. Crew Shift and Time Scale

Typical Day

Work	10 hours/'day'
Sleep	8 hours/'day' (at least four hours consecutively)
Personal Hygiene	1 hour/'day'
Meals	45, 45, 50 min.
Off Duty	2 hrs. 40 min.

Work Load

Nominal Work Load	120 man hrs./day
FPE's	80 man hrs./day

3. Humidity

4. Crew Size/Volume

5. EVA Considerations

1. Gases

Composition

Medical Considerations	Physiological Degradation
Safety	Fire
Cost	2 gas more expensive than 1 gas system

Candidates

Helium-Oxygen	1 g	Higher temperature parameters 76^o—94^o and 74^o—78^o @ 1 Clo and 10 psia nominal temperature parameters 73^o—84^o and G2-66 @ 1 Clo and 10 psia
	Zero g	
Nitrogen-Oxygen	1 g	
	Zero g	
Selection		N_2-O_2

He-O_2 requires investigation

He-O_2 requires adjustment to earth atmosphere

N_2-O_2 earth-like

2. Partial Pressure	
Minimums	
Oxygen	3-3.5 psia/life support requirements
Nitrogen	7 psia/flash fire protection
Totals	14.7 psia/consistant with nominal earth pressure
3. Relative Humidity	Less than 10%
4. Crew Size/Volume	
12 Crewmen	50,000 cubic feet
5. EVA Considerations	
One gas	O_2/excessive 2 gas penalties
Low Pressure	5-10 psia/breathing exercises

Habitability

Design Factors

1. Mobility Provisions
2. Garments and Ancillary Equipment
3. Food Management
4. Housekeeping

Habitability Factors

5. Personal Hygiene
6. Architecture and Environment

Task Integration Devoted to FPE's	11/12 men full or part time
Added meal Importance	
Programmed Activity as Function of Mission Duration	
3. Crew Structure	
Hierarchy	
Commander	Life/Pilot Astronaut
Line Officers including Deputy Commander	Life/Pilot Astronaut
Working Crew	Scientist/Engineer Astronaut
4. Leisure Time	
Crew-type Similarities	Astro/Tact/Arps/Aero Eng.
Job Related Activities	
Reading	
Physical Exercise	
Music/Video	
Small Group Dynamic in Isolated Environment	Reduced Inter-personal competition

Atmospheric Make-up

1. Gases

2. Partial Pressure

1. Mobility Provisions

Gravity percent dependent

Magnetic shoes

Tethers

Belts/straps

Velcro pads

Fittings

Handles/rails

Toe Slots

2. Garment and Ancillary Equipment

Clothing-type Decision	Reusable in favor of disposable due to mission duration and weight penalties
Laundry System	
Size	20 lb. load
Type	Oscillatory--can be used in zero g (lightest and smallest by comparison)
Garment Supply	
Method	Vacuum packed/min. 20% volume saving
Items	12 shirts, 2 trousers, 2 jackets, 12 briefs, 12 socks, 1 head gear, 1 pair of shoes, special equipment

Resupply	3 mos./6-9 mo. duration
3. Food Management	
Required Food	
Waterless Food	1.5 lbs./man day
Potable Water	5.5 "
Food Mix Ratio	50/50 food/water
Resupply Period	3 months
Food (bulk)	
Weight	3,144 lbs/12-man crew
Volume	85 cubic feet/12 man-crew
Water	
Weight	4,368 lbs./12-man crew
Volume	71.6 cubic feet/12-man crew
Food (Packaged)	
Weight	3,456 lbs/12-man crew
Volume	170.4 cubic feet/12-man crew
Refrigerator	
Capacity (perishable)	30 cubic feet
Installed Volume	80 cubic feet
Installed Weight	425 lbs.
Freezer	
Capacity (perishable/frozen)	65 cubic feet

Installed Volume	135 cubic feet
Installed Weight	750 lbs.
Ambient Storage	
Per Man	7.9 cubic feet
Per 12-Men/3 months	94.8 cubic feet
Individual Food Trays	
Volume/12 Installed	7 feet
Weight Installed	48 lbs.
Waste Management	
Containers	2 cubic feet--2 lbs.
Dishwasher/Dryer	18 cubic feet--180 lbs.
Sink	13 cubic feet--60 lbs.

4. Housekeeping

Waste Handling	
Collection	Vacuum system/containers for gas/liquid/solid mixtures.
Condition	Toxic/non toxic/hot/cold/radioactive
Waste Transfer	Pick-up $\longrightarrow$ ultimate destination
Waste Processing	
Contaminated Waste	
Physical Separation	
Water Electrolysis	

Decomposition	
Waste Compaction	
Waste Shredding	
Food Processing	
Waste Utilization	Methane RCS
Waste Disposal	Another vehicle/jettison to space

5. Personal Hygiene

Aperature Urinal (installed)	
Weight	23 lbs.
Volume	3.2 cubic feet
Dry John	
Weight	23 lbs.
Volume	9 cubic feet
Vomitus Collection	
Shower (whole body)	
Weight	332 lbs.
Volume	110 cubic feet
Wet Wipes (local body)	
Weight	271 lbs.
Volume	3.5 cubic feet
Additional Determinants	
Change Factors	
Crew Security	
Stress Contingent	

TABLE 3.1

CORRELATED ARCHITECTURAL ELEMENTS

Inclusion (NR Not Required, D Desirable, R Required)	Color: Hue	Color: Contrast	Temp.: Air Flow Rate FPM	Temp.: Nominal BTUH	Acoustics in use noise generation: Noise Criteria Curves Nom.	Noise Criteria Curves Max.	Lighting: Level Min	Level Max	Level Desirable	Lighting: Source	Hrs. day in area: Off Duty Day	Hrs. day in area: Normal Wk Day	Volume: Gross Volume Per Man Zero Gravity	Gross Volume Per Man Artificial Gravity	Gross Area Per Man Ft.²	Ceiling Height Ft.		
D	3/6	2/3	50	450	20	35	10	30	20-30	1/3	4	1	40	112	16	7.0	Lounge	Living Area
R	1/2	1/2	70	450/700	30	55	10	30	20-30	1/3	3	1	70	70	10	7.0	Recreation	
R	4	3	[illegible]	400/750	20	30	1	20	5-20	2	2	2				6.5	Passageways	
R	4/6/7	2/3	50	450	20	30	10	30	20-30	2/3	.5	2	70/70	70/70	10/10	6.5/7.0	Study/Library	
R	3/6	2/3	50	300	20	30	3	30	10-30	1/3	9	9	220	325	50	6.5	Bedroom	
R	2/3/4/6	2/3	40-80	400	30	35	5	30	10-30	2/3	1	1	180	221	34	6.5	Bathroom	
D	2	2	[illegible]	500	35	40	20	70	50-70	4/6	2	0	90	105	15	7.0	Conference	
R	3	2	80	700	40	50	10	50	20-50	2/3	1	1				6.5	Galley	Food Prep. & Service
R	3/6	2/3	60	400	40	50	10	30	15-30	1/3	2	2	90	105	15	7.0	Diningroom	
R	4	3	80	750	10	20	5	10	5-10	2	2	2	170	170	1	6.5	Food Storage	
D	3	2	70	500	40	50	10	30	10-30	2/3	2	2				6.5	Snack Bar	
R	4	3	80	1000	40	50	15	30	20-30	2/3/5	0	1				6.5	Laundry	Services
D	2	2	60	500	35	40	20	70	50-70	3/6	.5	0	90	98	15	6.5	Briefing Room	
D	3	2	70	600	40	50	10	30	20-30	3	2	2				6.5	Locker Room	
D	2	2	60	450	35	50	2	25	5-20	1/3	0	2	78	84	12	7.0	Theater	
R	3/6	2/3	60	600	30	35	30	100	50-100	2/3	2	2	500	559	86	6.5	Dispensary	
D	5/6/7	2/3	60	400	30	35	2	20	5-20	2	0	2	90	98	15	6.5	Chapel	
R	3/6	2/3	60	600	30	40	15	30	20-30	4	0	2	280	280	43	6.5	Barbershop	
R	4	3	70	1000	40	55	5	20	15-20	2/3/5	0	2				6.5	Supply	
R	4	3	80	800/1600	50	70	30	100	50-100	2/3/5	2	2					Maintenance	
R	4	3	80	800/1600	30	50	10	20	10-20	2/3/5	2	2					Equipment	
D	1/2	1/2	80	800/1800	30	55	15	30	20-30	3/5/6	0	1	70	70	10	7.0	Gym	
R	4	3	80	800/1500	30	40	10	20	10-20	2/3/5	2	0					Power	
R	4	3	60	750	30	40	20	70	50-70	4/6	8	0				6.5	Control	Work Areas
R	4	3	60	850	10	35	1	10	5-70	1/3/5	2	0					Air Locks	
D											2	0					Inspection	
R	4	3	70	700	15	40	0	30	0-30	2	2	2					Photographic Support	
D	4	3	70	800	20	45	1	50	5-50	2/3/5	2	0					Animal Housing	
R	4	3	80	800/1500	35	55	10	30	10-30	2/3/5	2	0					Dock	
D	4	3	70	800	10	35	1	50	5-50	2/3/5	2	0					Agricultural Study	
R	4	3	60	700	20	40	20	70	50-70	3/6	2	0				6.5	Computer	
D	4	3	60	700	30	35	20	70	50-70	3/6	2	0				6.5	Offices	
R	4	3	70	1000	30	55	20	70	50-70	2/3/5	2	0					Laboratory	
R	4	3	80	1250	55	75	20	70	50-70	2/3/5	2	0					Shops	
D	4	3	60	800	20	35	20	70	50-70	4/6	2	0				6.5	Communication	

1. Exciting
2. Stimulating
3. Cheering
4. Neutralizing
5. Retiring
6. Relaxing
7. Subduing
8. Depressing

High 1
Mod 2
Low 3

Incandescent Gen. Service	1
Incandescent Halogen Cycle	2
Fluorescent Stand. Colors	3
Fluorescent Delux Colors	4
Mercury Vapor Delux White	5
Metal Halide High Intensity	6
High Pressure Sodium	7

— OPERATIONAL PHASES

- 6 Man Station
- 12 Man Station
- Growth Station

— TOTAL PAYLOAD, including expendables, spares, experiments and payload margin, will support a crew of 12 for 12 months.

— NOMINAL CREW ROTATION occurs at 3 months intervals.

— EARTH ORBIT SHUTTLE provides

4 flights/year	Logistics and Crew Rotation
4 additional flights/year	Experiment Delivery and Special Crews
	Unscheduled Maintenance
	Medical calls
	Refueling

— 10 YEAR LIFE FOR MODULE

GRAVITY ASSESSMENT CHECK LIST

	Zero G	Artificial Gravity (rotating)
Operational Effects		
Antenna attitude	X	
Dock procedures	X	
Crew and cargo transfer (supply vehicle)	X	
Guidance control	X	
Astronomy/earth observation	X	
Solar power collection	X	
Extravehicular activity	X	
Physiological Effects		
Gravity level		1/6 g (moon)
Angular velocity		2 rpm
Radius		120 ft.
Gravity gradient (head to foot)		3.5 %
Coriolis acceleration		O.K.
Static lean		O.K.
Sensory perception		O.K.
Mineral balance	?	O.K.
Orthostatic intolerance	?	O.K.
Cardiovascular deconditioning	?	O.K.
Additional Considerations		
Re-entry effects (long term weightlessness)	?	O.K.
Surgery	?	O.K.
Eating and drinking	special aids	earth like
Sleeping	restraint	earth like
Orientation	?	earth like
Experiment requirements	O.K.	O.K.
Bathing	pressure	
Dynamic stability	differential	O.K.
Spin stabilized	—	O.K.

14. DESIGN DESCRIPTION

14.1. Payload Alternatives

Comparison by Sortie/by Volume

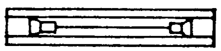
Requirements state that a 12-man station of 50,000 cubic feet should be completed within 11 sorties of the Earth Orbit Shuttle. The four payload packages outlined in Table 14.1, Payload Alternatives show that Scheme 1 (compact) can provide 85,986 cubic feet in 11 sorties whole scheme 4 (dispersed) can deliver a volume of 58,266 cubic feet in the same number of sorties. Scheme 2 was selected as a reasonable alternative delivering 76,746 cubic feet in 11 sorties which exceeds the required volume by over 150%.

14.2. Module Sizing/Floor Arrangement

In order to most efficiently utilize the earth orbit shuttle, each payload should be right at the maximum allowable weight and volume requirements. The proposed station design calls for two 30 foot by 14 foot diameter modules per sortie, thus fully occupying the 60 foot by 15 foot diameter cargo bay. Dependant upon particular use each particular use each module can weigh up to 30,000 pounds.

Additional factors determining module size are, that under

TABLE 14.1

1 Sortie	Payload	Habitable Volume Cu. Ft.	Artificial G Modules
1			
2		2,826	
3		9,240	2
4		9,240	4
5		9,240	6
6		9,240	8
MSS 7		9,240	10
NASA 8		9,240	12
	Initial Station	58,266	12
11	12-Man Station	85,986	18
14	Completed Rim	113,706	24

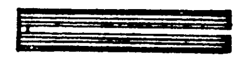
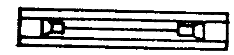
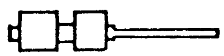
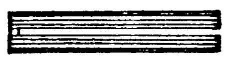
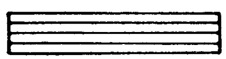
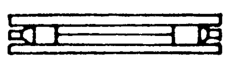
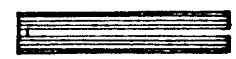
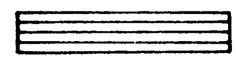
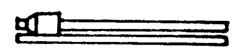
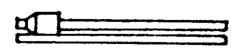
2 Sortie	Payload	Habitable Volume Cu. Ft.	Artificial G Modules
1			
2			
3		2,826	
4		9,240	2
5		9,240	4
6		9,240	6
7		9,240	8
8		9,240	10
	Initial Station	49,026	10
11	12-Man Station	76,746	16
15	Completed Rim	113,706	24

TABLE 14.1 (continued)

3 Sortie	Payload	Habitable Volume Cu. Ft.	Artificial G Modules
1			
2			
3			
4		2,826	
5		9,240	2
6		9,240	4
7		9,240	6
8		9,240	8
	Initial Station	39,786	8
	12-Man Station	67,506	14
16	Completed RIM	113,706	24

4 Sortie	Payload	Habitable Volume Cu. Ft.	Artificial G Modules
1			
2			
3			
4		1,413	
5		1,413	
6		9,240	2
7		9,240	4
8		9,240	6
	Initial Station	30,346	6
11	12-Man Station	58,266	12
17	Completed RIM	113,706	24

artificial gravity conditions, it is desirable to reduce static lean. Thus static lean, compromised by cargo bay and habitable volume dimensions results in a 30 foot long module. Still another determinant of module size is the requirement of balanced masses for a rotating station, hence two equally dimensioned modules. Mass differentials are compensated by the mass balancing subsystem.

TABLE 14.2

FLOOR ARRANGEMENT

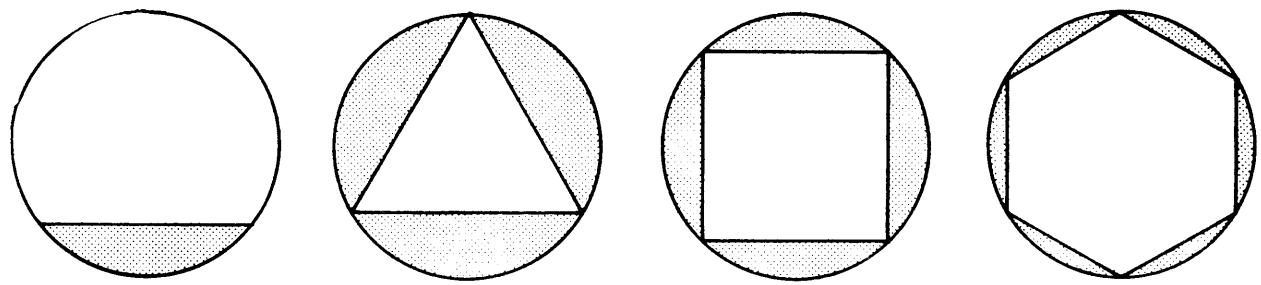
	Volumetric Efficiency	Static Lean	Number of Modules	Dynamic Stability	Rating	
Axial	Poor	3^{o}	2n	Stable	Sat.	Unsat.
Satisfactory		x		x	2	
Unsatisfactory	x		x			2
Longitudinal	Fair	6^{o}	n	Stable		
Satisfactory	x	x	x	x	4	
Unsatisfactory						0

From Table 14.2 it is shown that the gravity modules should have longitudinal floor arrangement, since they incur fewer penalties.

As indicated in Section 7.4.2. high priority is placed on viewports and their location should provide maximum utilization. There are four viewports, each two feet in diameter. They are located at

TABLE 14.3

PANEL SELECTION



		Plane	Factor	Index	Value	Triangle	Factor	Index	Value	Square	Factor	Index	Value	Polyhedron	Factor	Index	Value
1.	Sides	1 or 2	1	.2	.2	3	3	.3	.6	4	4	.2	.8	5+	5	.2	1.
2.	Tracks	2 or 4	2	.1	.2	3	3	.1	.3	4	4	.1	.4	5+	5	.1	.5
3.	(+)(-) volume	excellent	1	1	1	good	2	1	2	good	2	1	2	poor	3	1	3
4.	Floor area	13.6x	1	.5	.5	13.6-9.7x	2	.5	1	9.7x	3	.5	1.5	9.7x	4	.5	2
5.	Restrictions	none	1	1	1	upper torso	3	1	3	none	1	1	1	none	1	1	1
6.	Mech. vol.	o.k.	1	1	1	o.k.	1	1	1	o.k.	1	1	1	limited	2	1	2
7.	Apparent vol.	o.k.	1	.3	.3	reduced	2	.3	.6	o.k.	1	.3	.3	o.k.	1	.3	.3
8.	Fabrication	little advat'g	3	2	6	stable struct.	1	2	2	excellent	1	2	2	numerous side & joints	2	2	4
9.	Modularity	little	3	1	3	good (eq. lat.)	2	1	2	excellent	1	1	1	numerous	3	1	3
					13.2				12.5				9.0				16.8
	Ranking	Plane			3	Triangle			2	Square			1	Polyhedron			4

third points along the longitudinal axis and vertically, five feet from the floor. The five foot height provides view accessibility from either standing or sitting positions. In addition, the construction panel grid divides the viewport, offering two independent areas the opportunity to share the same window.

14.3. Grid Orientation and Sizing

Grid orientation aligns both parallel and normal to the spin plane. This is to control vestibular disturbances and sensory problems.

Grid Sizing - Convenient to shirt sleeve anthropometrics (passing, sitting, sleeping)

- Compatible with EVA suit dimensions
- Accomodates workable instrument package
- Facilitates mobility in 1/6 g with 7-1/2 foot nominal ceiling height, and options to 10 feet.

An important factor in a gravity condition decision is that, the volumetricly efficient zero gravity space station design could not effectively convert to a later imposed gravity situation. This is principally due to reduced passageway dimensions and use of all surfaces, without respect to gravity orientation. On the other hand, a station design based on an imposed gravity, is more flexible, since it can be readied to operate in both modes.

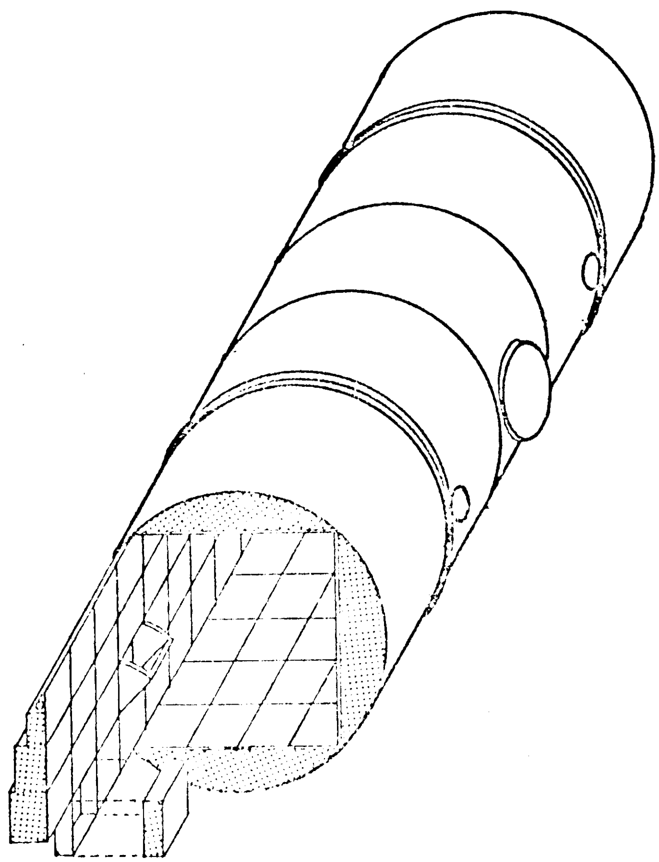


FIGURE 14.1

PANEL MAKE-UP

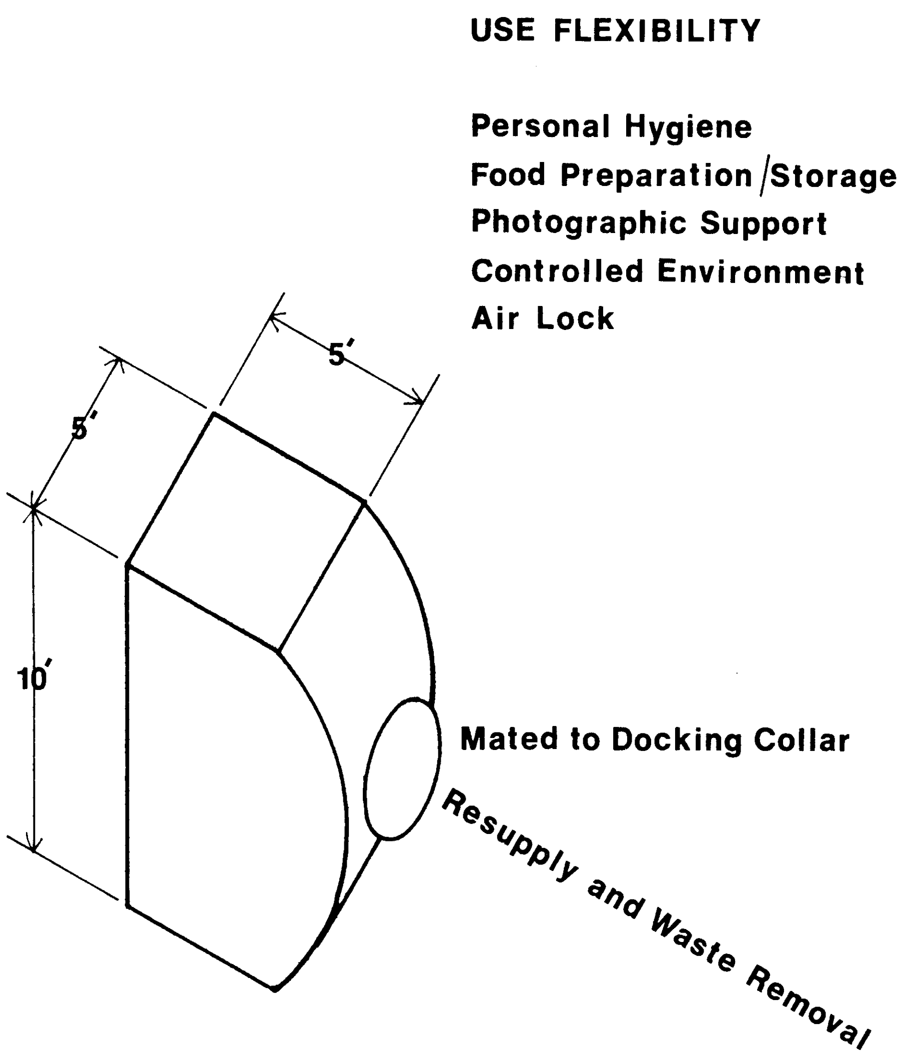
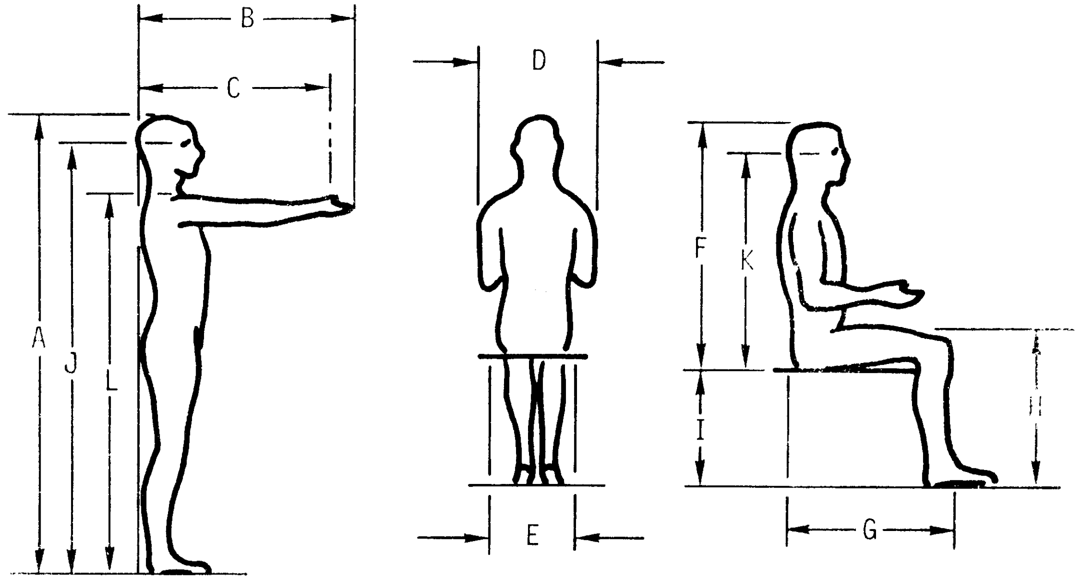


FIGURE 14.2

UTILITY PACKAGE

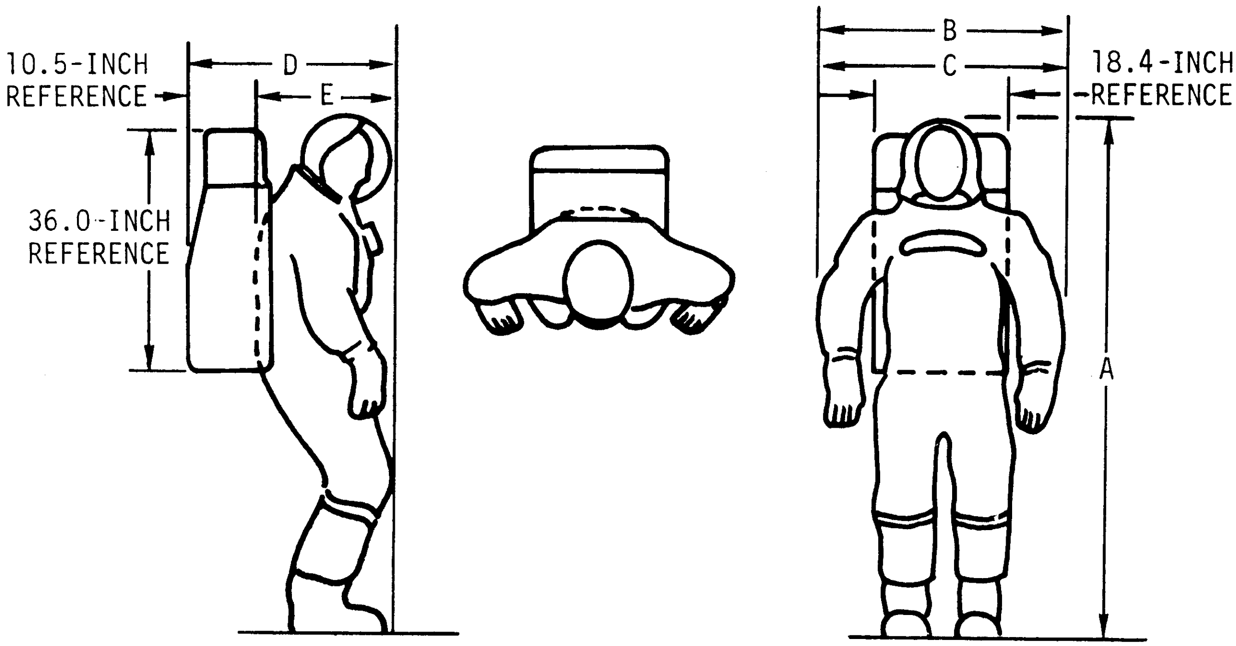


DIMENSION	PERCENTILE MAN	
	5%	95%
A - Standing Height	65.2*	73.1*
B - Maximum Reach	35.4	41.7
C - Functional Reach	29.7	35.0
D - Shoulder Breadth	16.5	19.4
E - Hip Breadth (Sitting)	12.7	15.4
F - Sitting Height	33.8	38.0
G - Buttock-Knee Length	21.9	25.4
H - Knee Height (Sitting)	20.1	23.3
I - Popliteal Height	15.7	18.2
J - Eye Height (Standing)	60.8	68.6
K - Eye Height (Sitting)	29.4	33.5
L - Shoulder Height	52.8	60.2
Weight (lb)	132.5	200.8

*Dimensions shown are in units of inches

FIGURE 14.3

CREWMAN ANTHROPOMETRIC DIMENSIONS[1]



DIMENSION*	PERCENTILE MAN	
	5%	95%
A - Height	67.5**	75.5**
B - Maximum Breadth at Elbows (Arms Relaxed)	—	29.4
C - Maximum Breadth at Elbows (Arms at Side)	—	26.4
D*** - Maximum Depth with Portable Life Support System (PLSS) and Backup Oxygen (OPS)	26.0	28.4
E*** - Maximum Depth without PLSS/OPS	15.5	17.9
Weight (lb), with PLSS/OPS	316.0	385.3
Weight (lb), without PLSS/OPS	190.3	259.6

Notes:

* Measurements made on A7L PGA, pressurized to 3.75 psig

** Dimensions shown are in units of inches

*** To obtain envelope dimensions, 2 inches have been added to maximum chest depth of suited/pressurized crewman for PLSS control box.

FIGURE 14.4

PRESSURE SUITED ANTROPOMETRIC DIMENSIONS[2]

14.4. Specific Elements

The umbilical tether performs several important tasks. It serves as a (1) structural tie, (2) electrical power line, (3) mass balancing tube, and (4) an emergency life support line.

The mass balancing system distributes the available water supply through umbilicals in order to control imbalance and crew movement.

In design scheme, module interdependency and replacement is compensated by flexible use design both operationally and in support hardware. Assuming an effective volume lifespan of ten years.

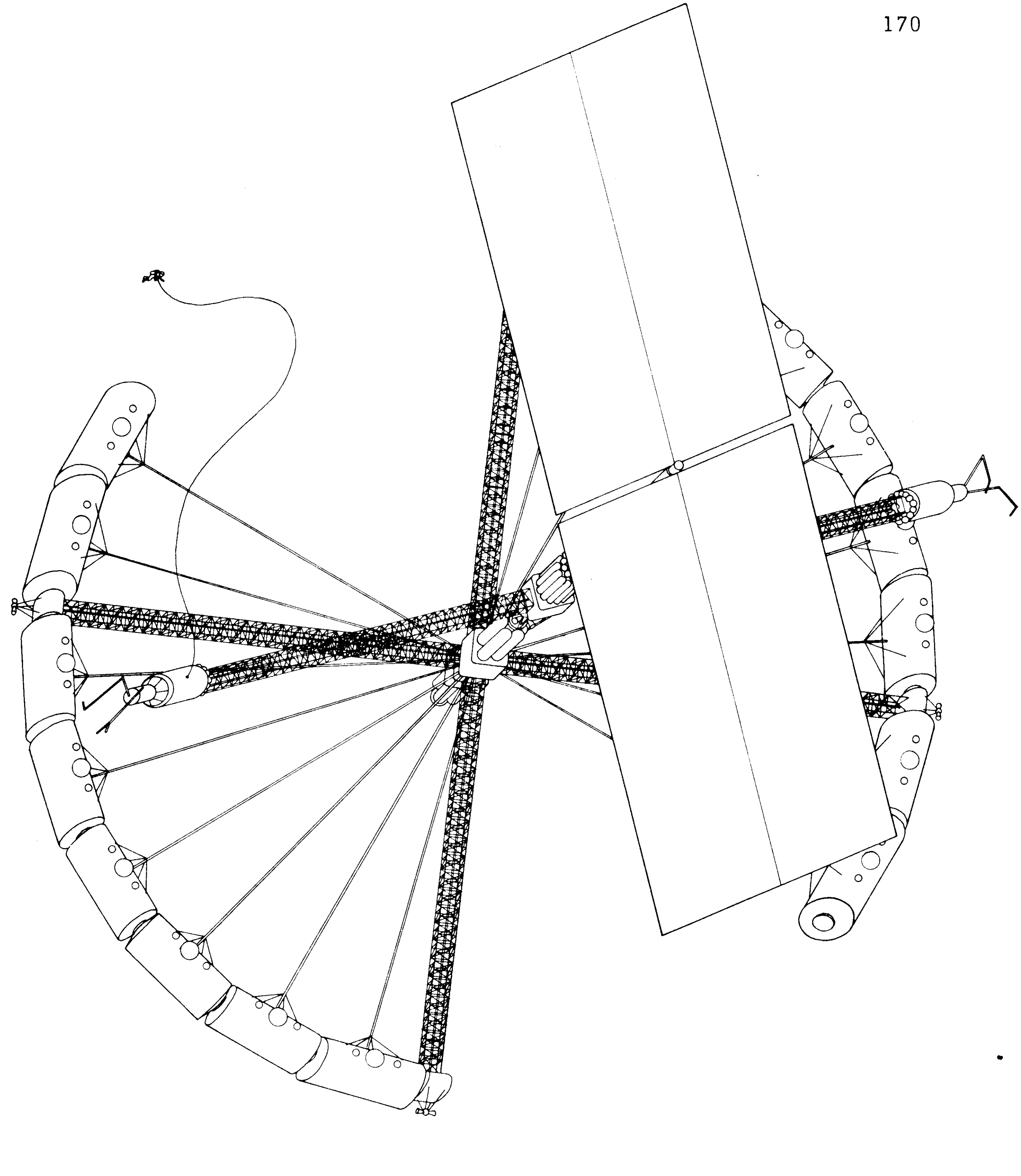
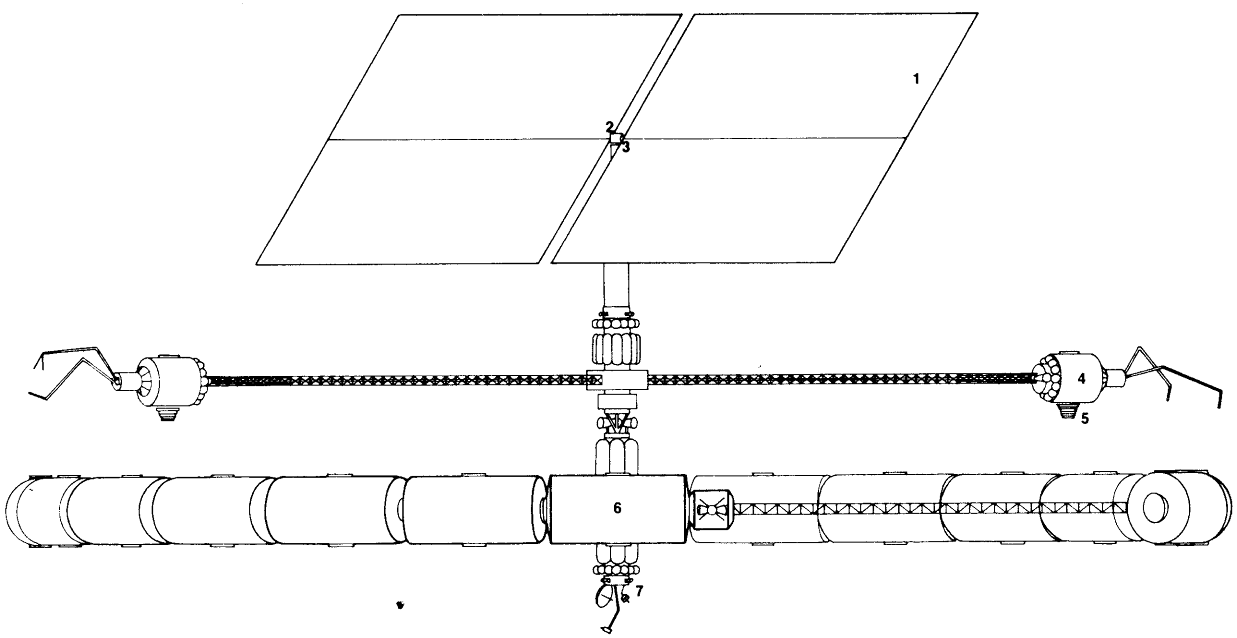


FIGURE 14.5

12 MAN SPACE STATION

Profile



1 Solar Array

2 Orientation Drive
3 Power Transfer

4 Slave Module
5 Telescopic Docking Collar

6 Gravity Modules

7 Instrument Package

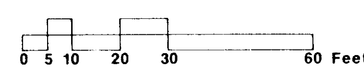


FIGURE 14.6

STATION CONFIGURATION

Configuration

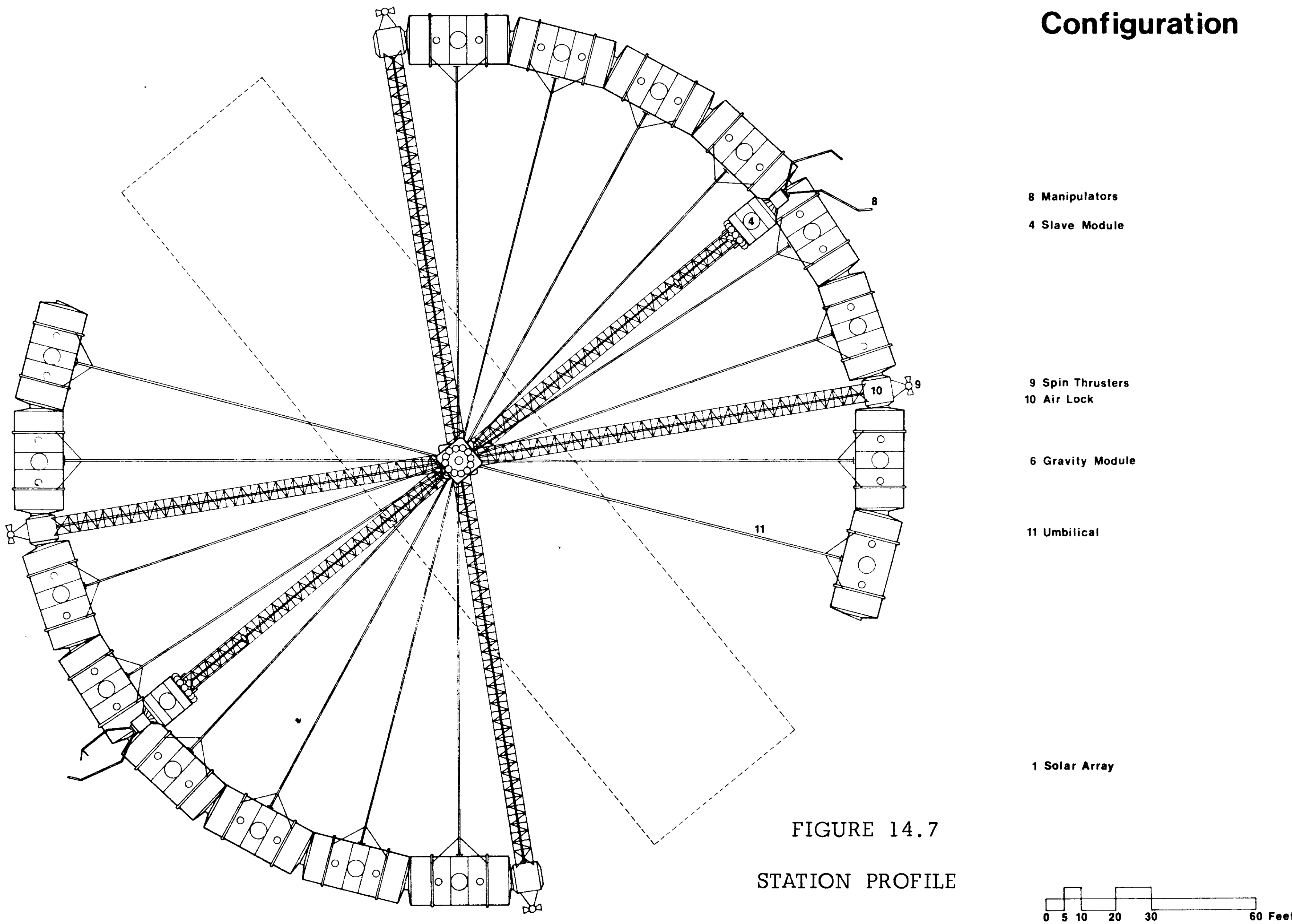
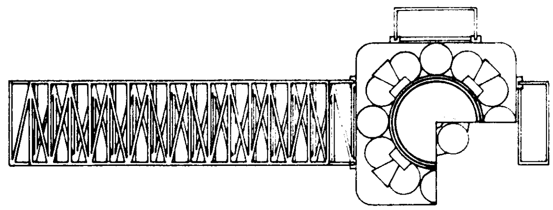
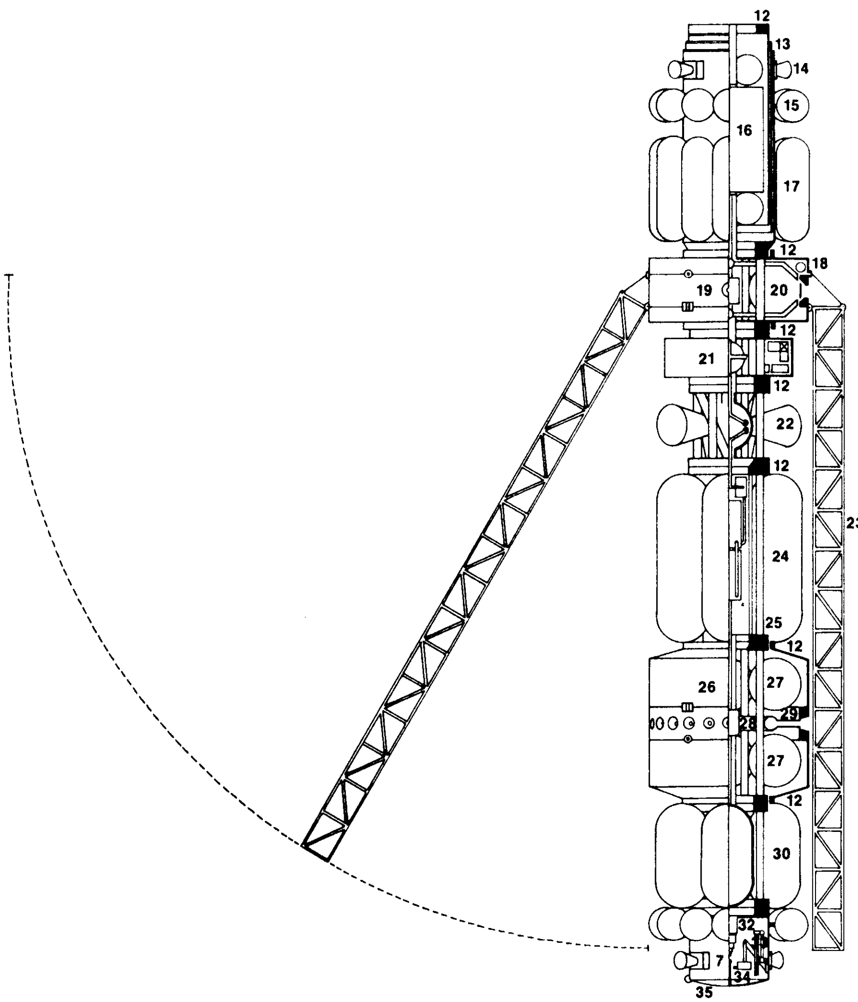


FIGURE 14.7

STATION PROFILE

Hub Assembly





12 Docking Collar
13 Telescopic Mount (Electrical Power System)
14 Attitude Control Thrusters (4)
15 Fuel (Attitude Control Thrusters) (12)
16 Batteries / Fuel Cells
17 Fuel (Main Propulsion System) (12)
18 Truss Positioner
19 Slave Arm Sub-Assembly
20 Emergency Life Support System (6)
21 Guidance and Control System
12 Docking Collar
22 Main Propulsion Engine (4)
23 Slave Arm Truss
24 Fuel (Main Propulsion System) (6)
25 Structural Framing
26 Gravity Arm Sub-Assembly
27 Emergency Life Support System (12)
28 Mass Balance Control
29 Umbilical Ring
30 Fuel (Main Propulsion System) (7)
31 Fuel (Attitude Control Thrusters) (12)
7 Attitude Hold Instrument Package
32 Refuel
33 Omni Antenna
34 T.V. Camera
35 Parabolic Antenna

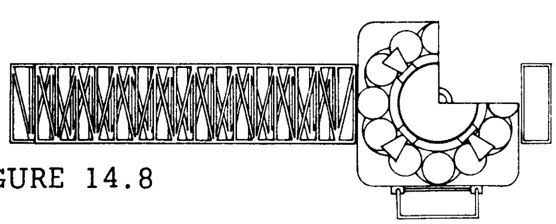
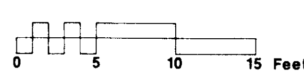


FIGURE 14.8

HUB ASSEMBLY



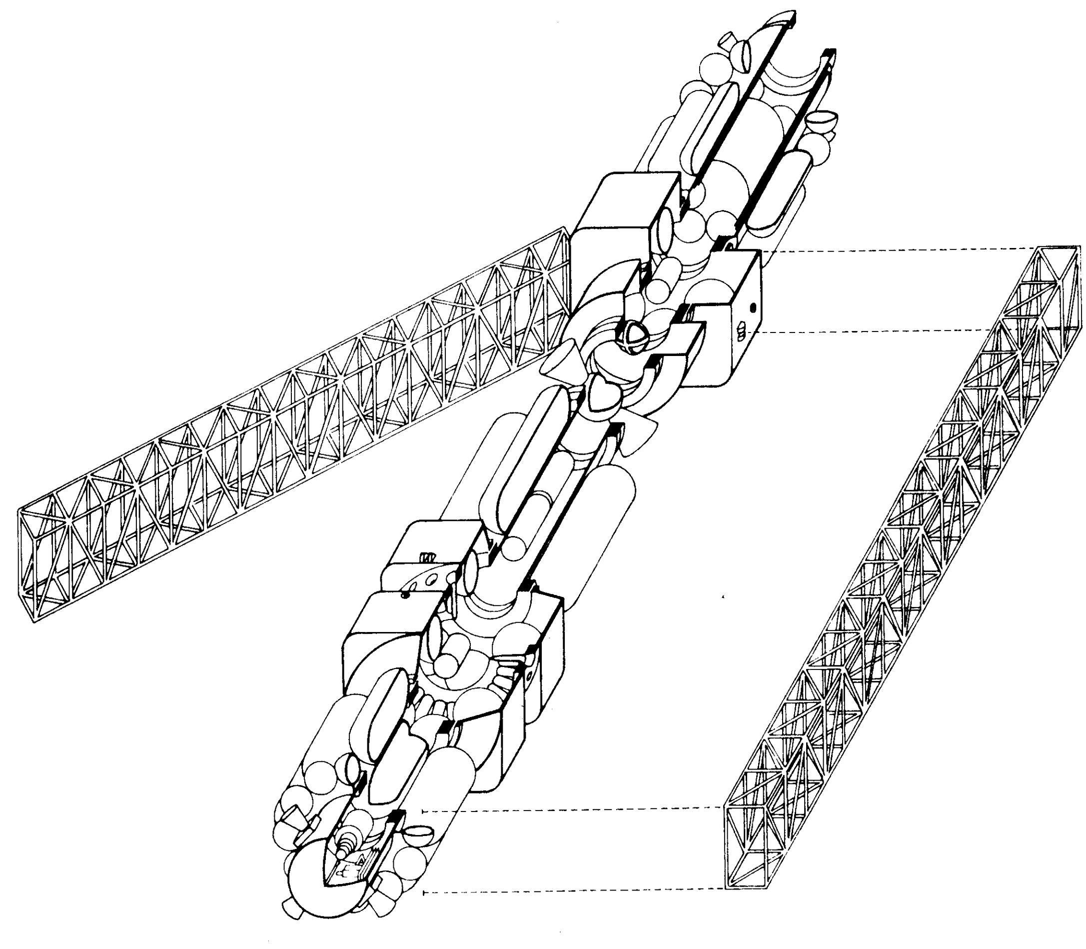
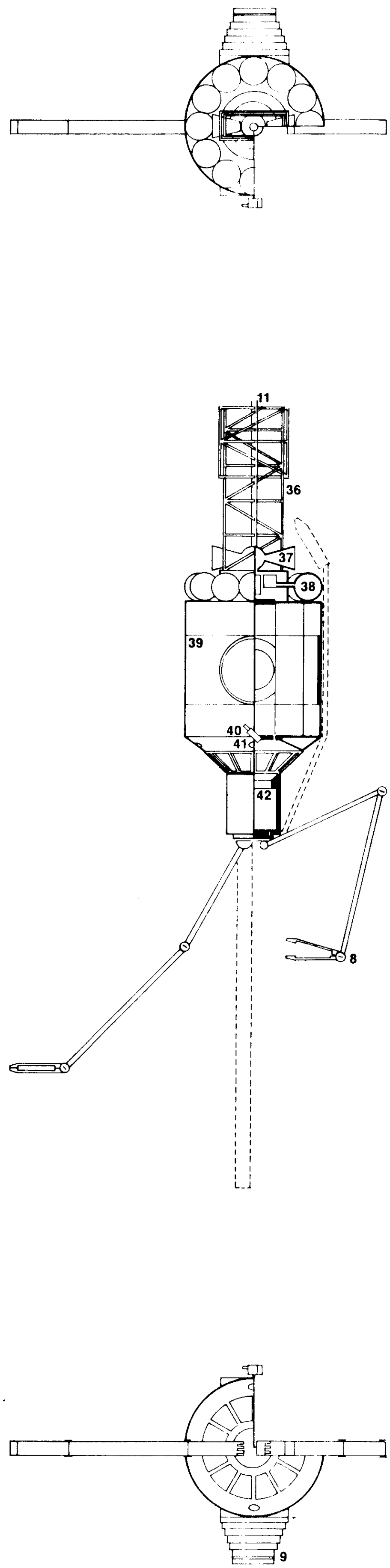


FIGURE 14.9

HUB ASSEMBLY (axonometric)

Slave Module



11 Umbilical

36 Telescopic Truss

37 Spin Thruster

38 Fuel (Spin Thruster) (12)

39 Docking Ring

40 T.V. Camera

41 Flood Lights

42 Manipulator Control

8 Manipulator Arm

FIGURE 14.10

SLAVE MODULE

9 Telescopic Docking Collar

0 5 10 15 Feet

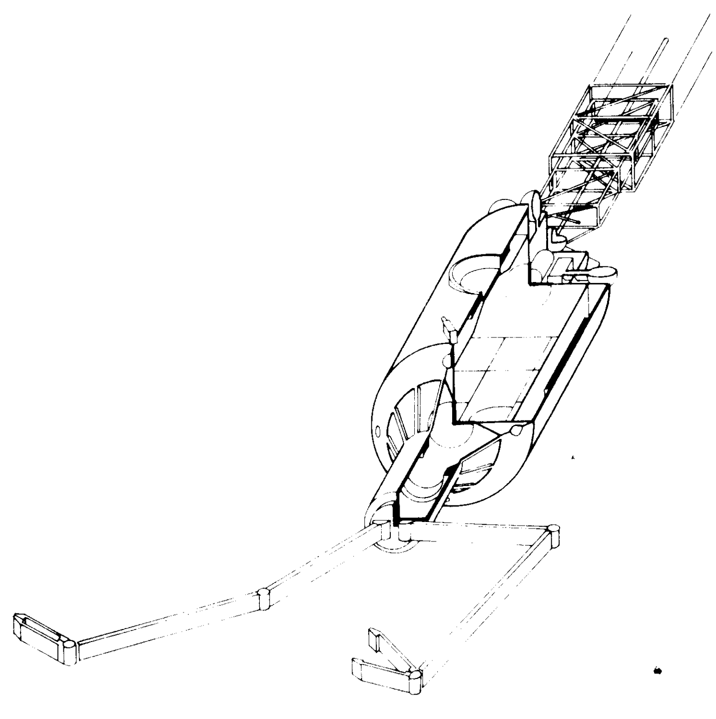
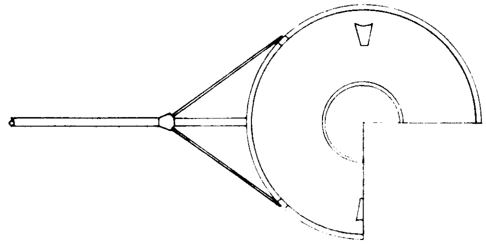
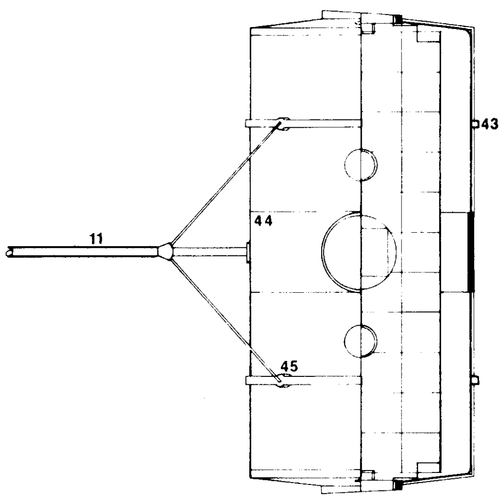


FIGURE 14.11

SLAVE MODULE (axonometric)





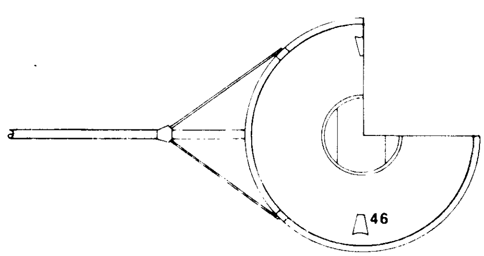
43 Structural Rib

44 Strong Ring
11 Umbilical

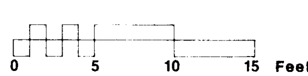
45 Manipulator Socket

FIGURE 14.12

GRAVITY MODULE



46 Trim Stabilizing Thruster



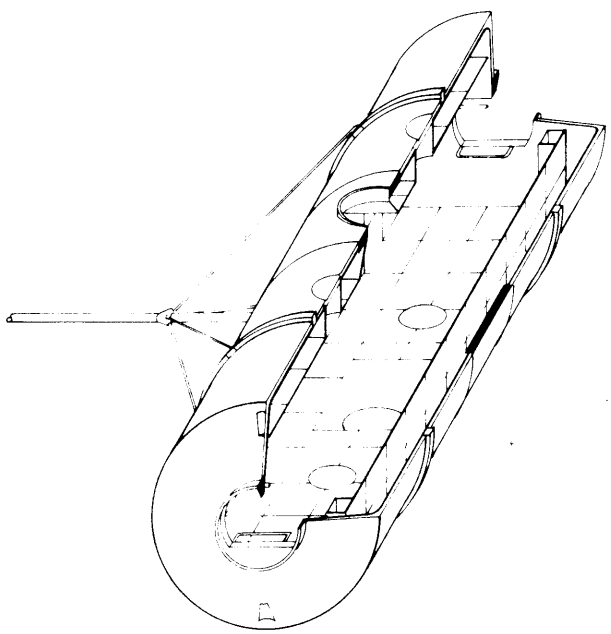
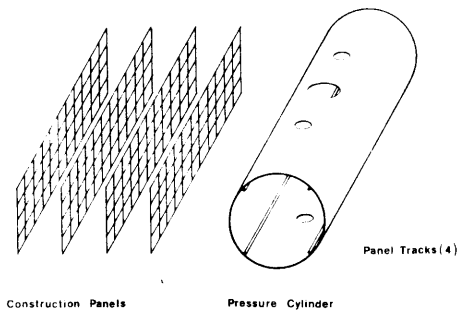
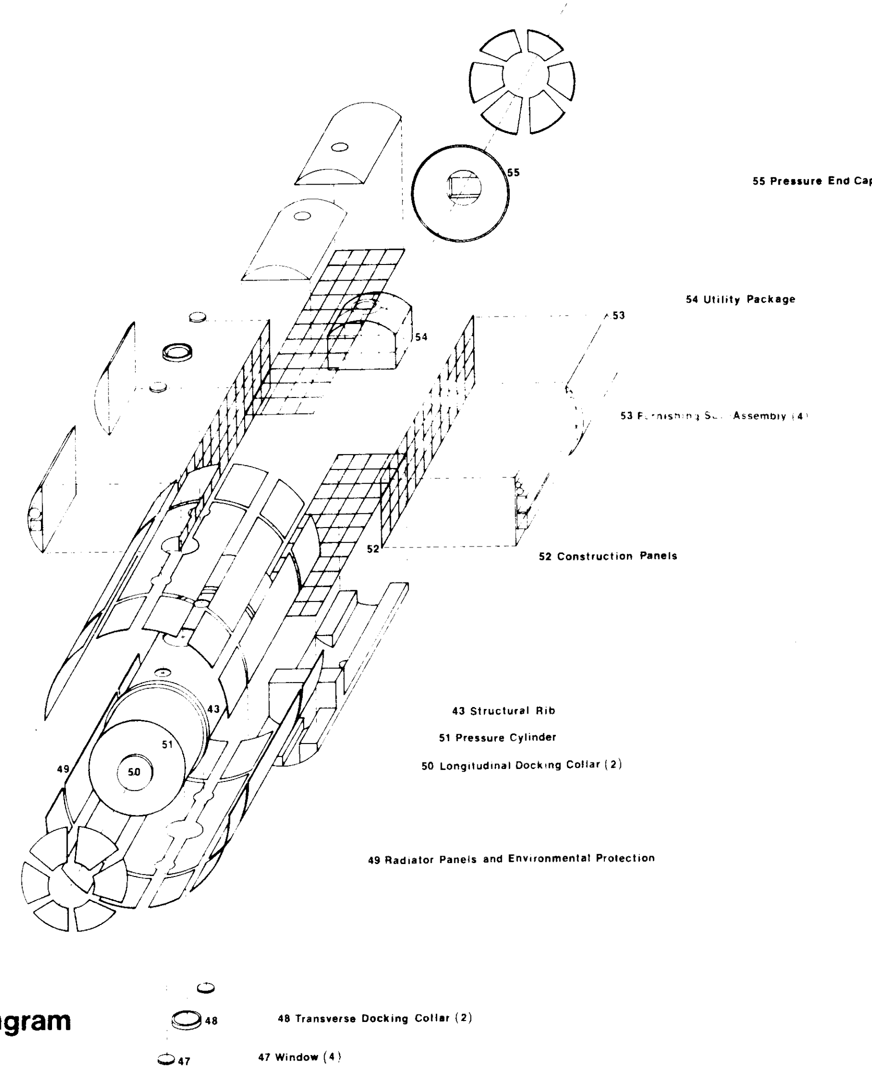


FIGURE 14.13

GRAVITY MODULE (axonometric)



Basic Elements



Assembly Diagram

FIGURE 14.15

GROUND FABRICATION (exploded axonometric)

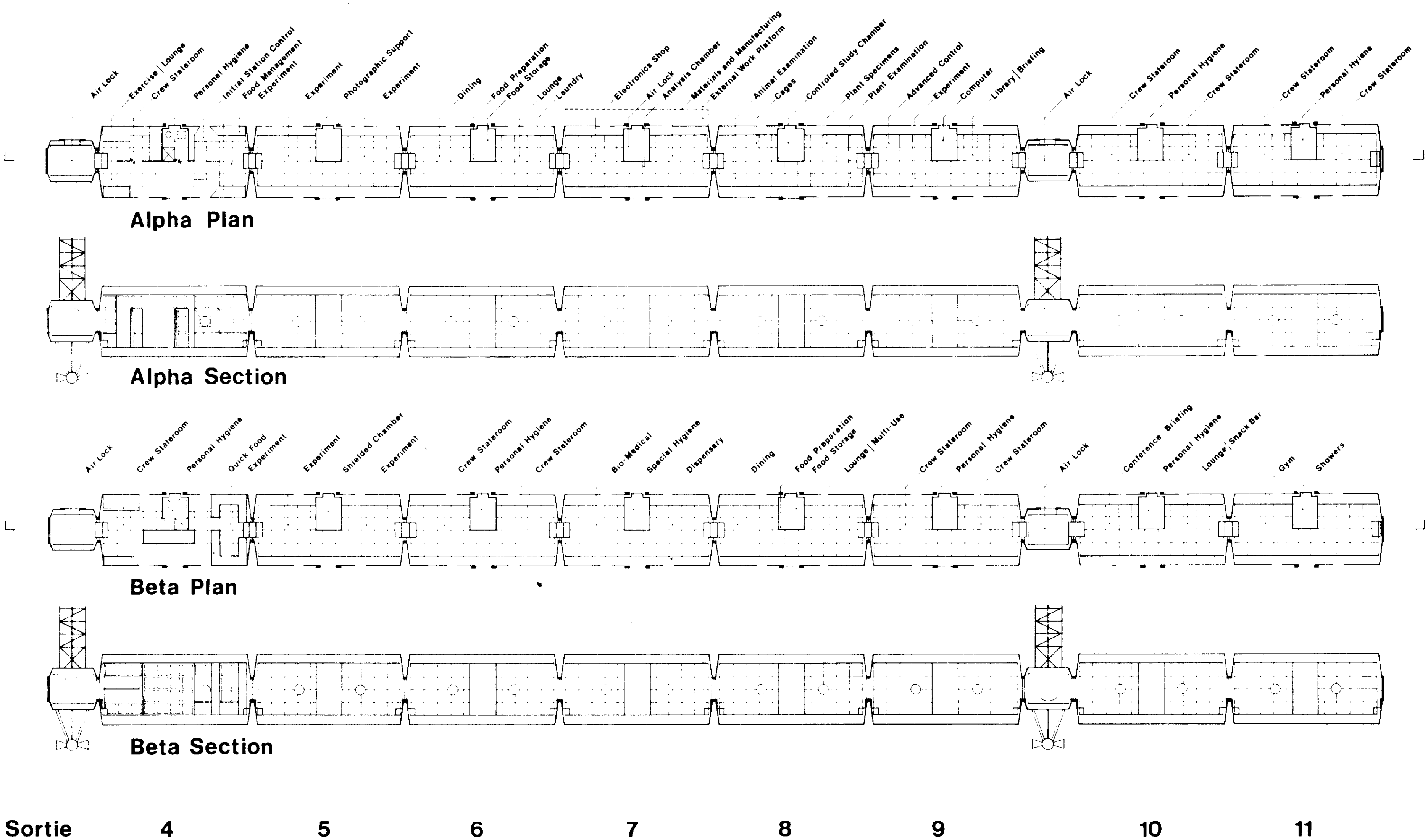


FIGURE 14.16

PLANS AND SECTIONS

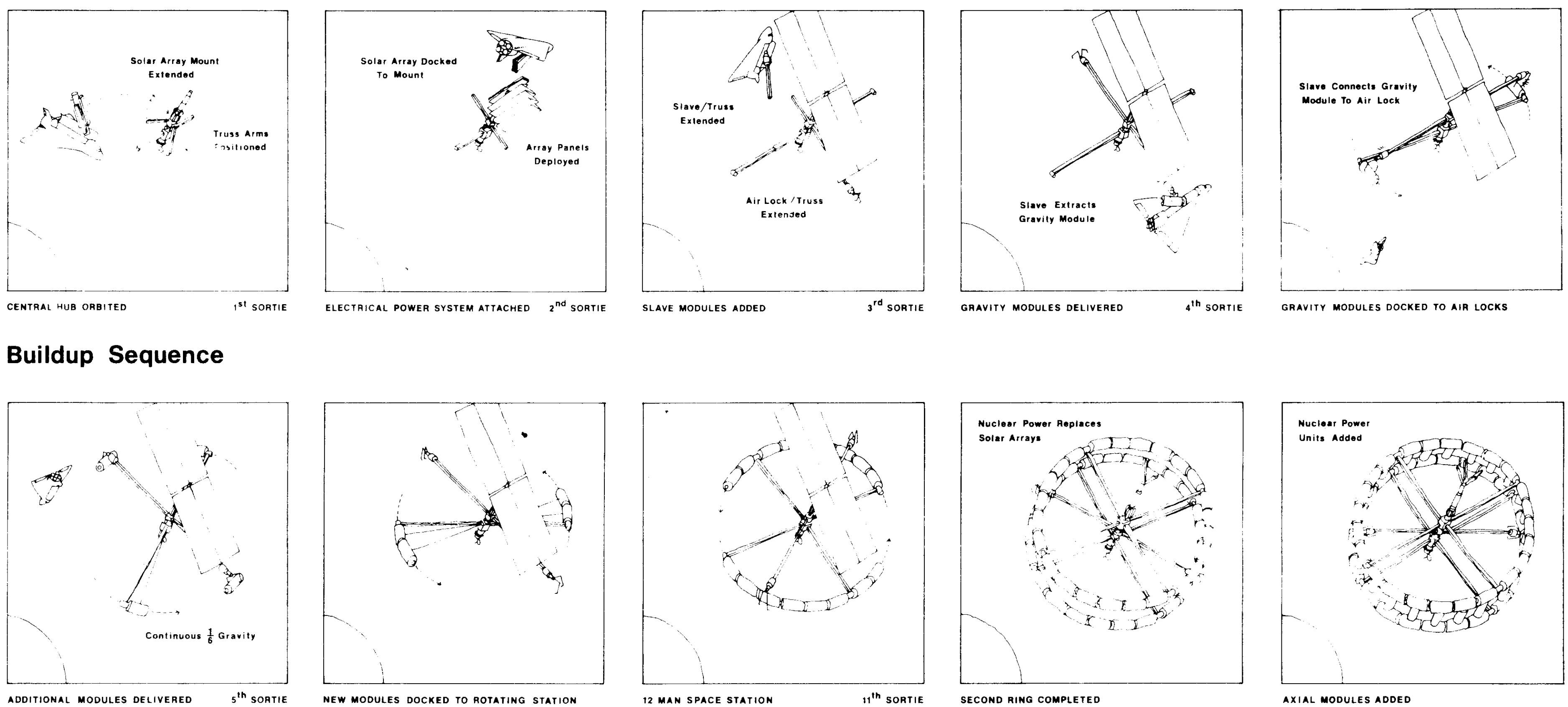


FIGURE 14.17

BUILDUP SEQUENCE

15. SUMMARY/DESIGN FEATURES

Simultaneous zero gravity and artificial gravity.

Continuous 1/6 gravity--even during resupply and buildup.

Attitude Control

a) Solar Array

b) Astronomical Observation

c) Earth Sensors

d) Directional Antennae

e) Docking

f) Refueling

g) Propulsion System (Inter-Orbit Maneuvering)

Assembler (Slave)

a) Performs station buildup, reducing active workload of Advanced Logistics System

b) Acts as zero-gravity laboratory

c) Emergency escape vehicle

d) Facilitates Extravehicular Activity

Mass Balancing System — equalizes mass differentials by controlled distribution of available source

Multi-purpose Umbilical

a) Structural tie for Gravity Modules

b) Electrical power supply line

c) Mass balancing tube

d) Emergency life support supply line

External Work Platform--outside work station under the influence of 1/6 gravity.

Growth Station--potential for unlimited incremental growth.

Simplified Ground Fabrication

a) Standarized Elements (Pressure Shell, Grid Panels, Utility Package)

b) Provides flexibility of hardware and furnishing upon initial installation

Utility Package--(gravity module) accomodates up/down cargo to individual module.

In-Orbit Flexibility--within module and between module hardware and furnishing rearrangement

Solar Array Replacement--when nuclear power source added, orientation is proper, with respect to habitable station.

16. GLOSSARY

16.1. Acronyms and Abbreviations

ALS	Advanced Logistic System
AME	Air/Lock Manipulator Element
ARPS	Aerospace Research Pilot Students
CAE	Central Assembly Element
CPS	Chemical Propulsion Stage
ECLSS	Environmental Control and Life Support System
EOS	Earth Orbit Shuttle
EPB	Electrical Power Boom
EPS	Electrical Power System
EVA	Extravehicular Activity
FPE	Functional Program Element
GCS	Guidance and Control System
GSDM	Gulf Stream Drift Mission
IMS	Information Management System
IVA	Intravehicular Activity
LOS	Lunar Orbit Station
MDAC	McDonnel Douglas Aircraft Corporation
MESA	Manned Environmental Systems Analysis

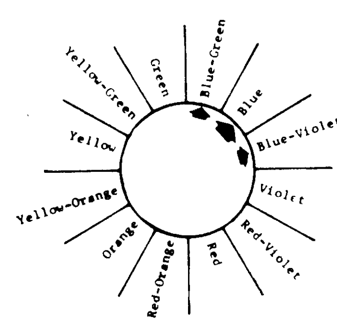
MEM	Mars Excursion Module
MOL	Manned Orbital Laboratory
MSFC	Marshall Space Flight Center
NAR	North American Rockwell
NASA	National Aeronautics and Space Administration
OLS	Orbiting Lunar Station
OWS	Orbital Workshop
RCS	Reaction Control System
SOSI	Space Operations and Scientific Investigation

16.2. Definitions

Absorption Coefficient.--The sound-absorption coefficient of a surface which is exposed to a sound field is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface.

Acoustic Impedance.--The complex ratio of the effective (rms) sound pressure over a surface to the effective volume velocity through it.

Analogous Color Scheme.--A scheme utilizing two or more hues next to each other on the spectrum, e.g., blue with blue-green or blue-violet.



Area per Man.--Area per man refers to the numerical figure arrived at by dividing the gross area of a space by the number of occupants the space is designed to hold.

Articulation Index.--A predictive measure of speech intelligibility. Formulation of the articulation index is based on the fraction of the total speech band-width to the listener's ear and the signal-to-noise ratio at the listener's ear.

Attenuation.--Attenuation is the term used to express the reduction in decibels of sound intensity at a designated point A as compared to sound intensity at point B which is acoustically farther from the source.

Brightness.--That which the eye actually sees and is the result of light being reflected or emitted by a surface directly into the eye. Measured in foot lamberts or candelas per square inch.

Candela.--Unit of luminous intensity of a light source in a specified direction. Defined as 1/60 the intensity of a square centimeter of a black body radiator operated at the freezing point of platinum (2047°K).

Characteristic Impedance (ρoC).--The ratio of the effective sound pressure at a given point to the effective particle velocity at that point in a free, plane, progressive wave.

Clo Factor.--The thermal resistance of clothing to the flow of heat from or to the body is expressed in Clo units. The Clo is a unit of insulation and is the amount of insulation necessary to maintain comfort and a mean skin temperature of 92°F in a room at 70°F with air movement not over 10 feet per minute, humidity not over 50 percent, with a metabolism of 50 calories per square meter per hour. On the assumption that 76 percent of the heta is lost through the clothing, a Clo may be defined in physical terms as the amount of insulation that will allow passage of one calorie per square meter per hour with a temperature gradient of 0.18°C between the two surfaces.

$$1 \text{ Clo} = \frac{0.18^{\circ}\text{C}}{\text{cal/m}^2\text{/hr}}$$

Color Temperature.--As applied to a light source, refers to the absolute temperature in degrees Kelvin of a theoretical black body or full radiator whose color appearance matches that of the source in question.

Conduction.--Conduction is a process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (solid, liquid, or gaseous) or between different mediums in direct physical contact. In conduction heat flow, the energy is transmitted by direct molecular communication without appreciable displacement of the molecules.

Contrast.--A measure of brightness of an object compared to its immediate surroundings.

Convection.--Convection is a process of energy transported by the combined action of heat conduction, energy storage, and mixing motion. The transfer of energy by convection from a surface whose temperature is above that of a surrounding fluid takes place in several steps. First, heat will flow by conduction from the surface to adjacent particles of fluid. The fluid particles will then move to a region of lower temperature in the fluid, due to the increase in temperature and internal energy of the fluid particles, where they will mix with, and transfer a part of their energy to, other particles. This is known as free convection as the change in density is the motivating force causing the mixing motion. When the mixing motion is induced by some external agency, such as a pump or blower, the process is called forced convection. An increase in humidity increases heat transfer to the body for a given temperature difference and air velocity, since water vapor has a heat absorptive capacity twice that of dry air.

Comfort Zone.--The area enclosed by the boundaries of the effective temperatures and relative humidity that induces a feeling of comfort to humans. All factors affecting the thermal condition of man are used in determining the comfort zone.

Decibel.--The decibel is a dimension used for expressing the ratio of two powers and is referred to a reference level of 0.0002 dynes per square centimeter. Mathematically, the number of decibels is 10 $\log_{10}$ of the power ratio. Since sound pressure is proportional to the square root of sound power, the number of decibels in sound pressure level ratios is expressed as 20 $\log_{10}$ of the ratio of the two sound pressures.

Dry-Bulb Temperature.--The terms temperature, air temperature, ambient air temperature, and dry-bulb temperature are all synonymous. They can be measured with a common thermometer.

Dynamic Range (of speech).--Difference, in decibels, between the pressure level at which overload occurs (according to some overload criterion) and the pressure level of the noise of the system.

Energy Density.--The average energy per unit volume in a medium due to the presence of a sound wave.

Evaporation.--The evaporative heat exchange mode is limited to sensible and insensible perspiration from the surface of the body. The evaporative heat loss is a function of volume flow rate, absolute humidity, temperature, and pressure of the atmosphere. If the air is saturated with water vapor at skin temperature, evaporation does not occur; in fact, if the vapor content is such that the air will be super-saturated when cooled to skin temperature, condensation will occur with rapid transfer of heat to the skin. If the human body is surrounded by saturated air at a higher temperature, it responds by producing an excess amount of perspiration, without losing any heat. A continuation of this condition may result in fever, discomfort, weakness, rapid heart action, difficulty in breathing, delirium, and collapse.

Footcandle.--The measure of illumination at any point that is a distance of one foot from a uniform point source of one candle power.

It is also equivalent to a density of one lumen uniformly distributed over an area of one square foot.

Foot Lambert.--The measure of brightness of a surface, when viewed from a particular direction, emitting, or reflecting one lumen per square foot.

Free-Field.--A field in which the effects of the boundaries are negligible over the region of interest.

Frequency.--The rate of repetition in cycles per second of the sound wave. Frequency is equal to the ratio of the speed of sound to the wave length of sound. It is normally expressed as Hertz (Hz).

$$\text{Approximate frequency} = \frac{\text{speed of sound}}{\text{wave length of sound}}$$

Gas Flow Rate.--This is the velocity at which the gas moves past an object and is expressed in feet per minute. Determining factors are the mass of gas, volume, and rate of gas change per unit of time.

Glare.--The sensation produced by brightness within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility.

Gross Area.--Gross area is the approximate area required to attain the minimum tabulated net area. Gross area is found by deducting only large ventilation trunks, access trunks and other similar items. No deduction should be made for normal access ladders or main passageways within the space. This area represents the entire wall to wall area.

Hearing Loss.--Hearing loss is the difference in decibels between the threshold of audibility for that ear and the normal threshold of audibility at the same frequency.

Hue.--The property that distinguishes one color from another; e.g. green from blue.

Dominant Hue.--The general overall color of the area, or the largest color application.

Subdominant hue.--The second largest color application.

Subordinate hue.--Those colors used to accent the dominant and subdominant hues.

Illumination.--Amount of light incident upon a surface measured in foot candles.

Intensity.--The quality which indicates the degree of color strength of hue. As a color is muted or softened by the addition of its own complement on the color wheel, its intensity diminishes.

Intensity.--The average rate at which sound energy is transmitted through a unit area perpendicular to the direction of wave propagation. A decibel scale of sound intensities is indicated in Figure 17.1.

Intensity Level.--Ten times the logarithm to the base 10 of the intensity under consideration to the reference intensity.

	160	Near Jet Engine
	130	Threshold of Painful Sounds; Limit of Ear's Endurance
	120	Threshold of feeling (varies with frequency)
	110	18' from Airplane Propeller Express Train passing at High Speed
	100	Loud Automobile Horn 23' away
	90	
	80	New York Subway
		Motor Trucks 15' to 50' away
	70	Stenographic Room
	60	Average Busy Street
Range of Speech Usually Heard in Conversation	50	Noisy Office or Department Store Moderate Restaurant Clatter
	40	Average Office
		Soft Radio Music in Apartment Average Residence
	30	
	20	Average Whisper 4' away
	10	Rustle of Leaves in Gentle Breeze
	0	Threshold of Audibility

FIGURE 16.1

DECIBEL SCALE OF SOUND INTENSITY

Lamp Source.--A generic term for an artificial source of light.

Light.--That part of the radiant energy spectrum which can be seen by the human eye. The electromagnetic spectrum includes radiant energy of many wavelengths, but only a narrow band, from about 400 to 700 millimicrons, is visible to the normal eye for vision.

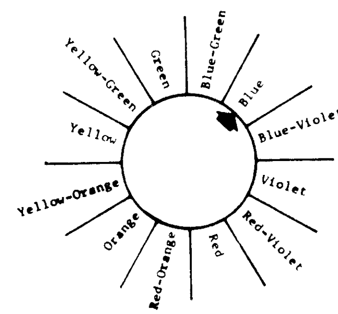
Lumen.--A unit to measure the intensity of luminous output of lamps and luminaires. Defined as the rate at which light falls on a one square foot area surface which is equally distant one foot from a source whose intensity is one candela.

Luminaire.--A complete lighting unit consisting of a lamp, or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the proper supply.

Metabolic Rate.--Metabolic rate is the thermal exchange between the human body and the environment. The rate of heat production, metabolism, is always positive in value and is expressed in Btu/hr.

Microbar.--A unit of pressure commonly used in acoustics. One microbar is equal to one dyne per square centimeter.

Minimum Desirable Volume.--That volume provided for a specific activity which man will perceive as adequate. A minimum desirable volume provides adequate space to support the dynamic envelope man describes in performing the activities related to that space, the volume in which man feels comfortable in regard to distance between himself and others, and the volume which man visually perceives as adequate during all activity conditions.



Monochromatic Color Scheme.-- A scheme utilizing one spectral hue, e.g., blue in varying values and intensities.

Noise.--Noise is any undesired sound. As used broadly in acoustics, this may include not only aircraft noise and industrial sounds, such as traffic and machinery, but also speech and musical sounds if they are undesired at any particular location.

Net Area.--Net area is defined as deck area that can actually be walked upon. Deck area occupied by trucks, hatches, fixed berths, lockers, installed furniture, etc., are excluded.

Phon.-- A unit of loudness level of any sound is defined as the sound pressure level of a 1000 Hz. tone that sounds as loud as the sound in question.

Preferred Frequency Speech Interference Level (PSIL).--The average in decibels of the sound pressure levels of a noise in the three octave bands of frequency centered at 500, 1000, and 2000 Hz.

Pressure.--This refers to the absolute total pressure of the environment and is expressed in pounds per square inch. The pressures considered for this study are 5, 10, and 14.7 psia with a constant partial pressure of oxygen at 3.01 to 3.45 psia.

Pure-tone vs Wide-band Noise.--A pure-tone is predominantly made up of pure frequency components such as propellor noise, compressor whine, and sirens. In wide-band noise the acoustical energy is spread throughout the spectrum. In most cases, especially within aerospace vehicles, the noise is a combination of pure-tone and wide-band noise. Since there are different criteria for each case, the designer must decide whether the noise is predominantly pure tone or wide band. A practical rule of thumb is that, if the OB SPL in a band is more than three dB above the adjacent bands, the noise is pure tone or has narrow-band components.

Quality.--The three factors which determine the quality of a color (hue, intensity, and value) can make a room look expansive or cramped, dark or light, and calm or exciting.

Radiation.--This is a process by which heat flows from a high temperature body to a body at a lower temperature when the bodies are physically separated with no barrier between them. Heat transfer by radiation becomes increasingly important as the temperature of an object increases. The intensity of the emissions depends on the temperature and nature of the surface.

Reflectance.--The ratio of the flux reflected by a surface or medium to the incident flux. In simplified terms it is the ratio of the brightness to the illumination.

Relative Humidity.--This is the ratio between absolute humidity and the saturation value at a given temperature expressed in percent. When a quantity of air holds all the water vapor it can, it is said to be saturated and the humidity is 100 percent.

Reverberation Chamber.--An enclosure in which all the surfaces have been made as sound reflective as possible.

Reverberation Time.--The time required for the average sound pressure level, originally in a steady state, to decrease 60 dB after the source is stopped.

Sound Power Level (PWL).--A computed quantity which expresses the acoustic power of a sound source relative to a reference power.

Sound Pressure Level (SPL).--Twenty times the logarithm (to base 10) of the ratio of a sound pressure to the reference pressure.

Sound Waves.--Sound waves can be described by any of several characteristics, such as the displacement of particles of the medium, the particle velocity, or the sound pressure measurements under certain conditions. The passage of a sound wave is accompanied by a flow of sound.

Speech Interference Level (SIL).--The speech interference level of a noise is the average in decibels of sound pressure levels of a noise in the three octabe bands of the frequency 600-1200, 1200-2400, and 2400-4800 Hz.

Specific Acoustic Impedance.--The complex ratio of the effective sound pressure at a point of an acoustic medium to the effective particle velocity at that point.

Spectrum.--Spectrum is the composition of the frequency distribution of a sound wave. In noise survey work, the spectrum of primary importance includes frequencies from 20 to 10,000 cycles per second. For the purpose of presenting damage risk, speech interference, and nuisance levels, the spectrum is broken down into eight octave bands.

Temporary Threshold Shift.--A shift in the threshold of audibility after exposure to even a moderate noise level.

Threshold of Audibility.--The threshold of audibility for a specified signal is the minimum effective sound pressure of the signal that is capable of evoking an auditory sensation in a specified fraction of the trials.

Transmission Loss.--Transmission loss is the ratio expressed in decibels of the sound energy incident on a structure to the sound energy which is transmitted through it. The term is applied both to build structures, such as walls and floors, as well as to air passages, such as mufflers and ducts.

Visual Acuity.--The ability to distinguish fine details. Quantitatively, the reciprocal of the angular size in minutes of the critical detail which is just large enough to be seen.

Visual Space.--Visual area is the amount of space visually perceived as usable. This space is related to physical objects in a room, e.g., furniture and partitions, and the placement of these objects relative to the observer's eye level (sitting and standing). For example, a seven foot long by three foot wide by five foot high bunk bed placed against the wall in a seven foot by seven foot by seven foot room appears to make the room look smaller. On the other hand, a single low bed seven feet long, three feet wide and eighteen inches high, placed against the wall in the same seven by seven room does not significantly reduce the visual area of the room.

	Area (ft^2)		
Room and Furnishings	Gross	Net	Visual
7 x 7 No furniture	49	49	49
7 x 7 Low Bed	49	28	49
7 x 7 Bunk Bed	49	28	28

Wet-Bulb Temperature.--This is the temperature obtained when the thermometer bulb is cooled by the rapid evaporation of water by air moving at a velocity of 900 feet per minute. Wet-bulb temperature varies with himidity and is the same as dry-bulb temperature when the humidity is 100 percent.

17. Appendix (Computer Graphics)

Essential to the realization of a space station is the sequence of growth. As a flexible means to analyse and display the buildup process, a computer graphics system was employed. Pictured in Figures 17.1 and 17.2 are selected results of this technique. Ideally, this process should be animated producing a simulation of station growth, thus overcoming some of the limitations of static drawings.

```
PROGRAM DRAW(INPUT,OUTPUT)
DIMENSION X(100),Y(100),Z(100),XR(100),YR(100),ZR(100)
3 CONTINUE
PRINT,*TYPE LOCATION OF OBSERVER*
READ,XO,YO,ZO
PRINT,*TYPE LOCATION OF VIEW POINT*
READ,XL,YL,ZL
PRINT,*TYPE NUMBER OF VERTICES*
READ,NPOINT
PRINT,*ARE YOU READY?*
READ,ANS
CALL G AHM(X,Y,Z)
C THE FØLLOWING CONSTANTS DEFINE VP,VL,AND TRANS.COORD
XM=0 $ YM=0 $ ZM=0
XO=XO-XL
YO=YO-YL
        ZO=ZO-ZL
        PDISTZ=SQRT(XO**2+YO**2+ZO**2)
        ALPHA=ATAN2(XO,YO)
        BETA=ATAN2(YO,SQRT(XO**2+ZO**2))
CALL OBSERV(X,Y,Z,XR,YR,ZR,NPØINT,ALPHA,BETA)
CALL PERSPE(XR,YR,ZR,NPOINT,PDISTZ)
XMAX=XR(1)
        YMAX=YR(1)
        XMIN=XR(1)
        YMIN=YR(1)
        DO 299 I=1,NPOINT
IF(XR(I).GT.XMAX)XMAX=XR(I)
IF(YR(I).GT.YMAX)YMAX=YR(I)
IF(XR(I).LT.XMIN)XMIN=XR(I)
IF(YR(I).LT.YMIN)YMIN=YR(I)
 299 CØNTINUE
     ZMAX=AMAX1((XMAX-XMIN),(YMAX-YMIN))
 IS=SCALE
 IF(IS .NE. 0) GØ TØ 451
 ZMAX=4999.9/ZMAX
XSCALE=ZMAX/1.5
YSCALE=ZMAX
PRINT,*PLTL*
DO 450 I=1,NPØINT
 XR(I)=XR(I)*XSCALE
YR(I)=YR(I)*YSCALE
CALL PLT(XR(I),YR(I))
 450 CONTINUE
GØ TO 4520
```

```
451 PRINT,*PLTL*
DØ 452 I=1,NPØINT
XR(I)=XR(I)*SCALE/1.5
 YR(I)=YR(I)*SCALE
CALL PLT(XR(I),YR(I))
ZMAX=SCALE
452 CONTINUE
4520 CØNTINUE
PRINT,*PLTL*
PRINT 460
370 CONTINUE
 PRINT 355
355 FORMAT(*TO DRAW ANØTHER BOX,TYPE 1*)
 PRINT 356
356 FØRMAT(*IF YOU WANT TO STØP,TYPE 0*)
READ,A
IF(A.EQ.1) GØ TØ 2
 GØ TØ 6
2 PRINT 470,ZMAX
470 FØRMAT(*S.F.= *,F15.2)
 PRINT 471
471 FØRMAT(*TØ RESCALE,TYPE: S.F.*)
READ,SCALE
 GØ TØ 3
 6 PRINT 460
460 FØRMAT(*PLTT*)
 END
SUBRØUTINE ØBSERV(X,Y,Z,XR,YR,ZR,NPØINT,ALPHA,BETA)
DIMENSIØN X(2),Y(2),Z(2),XR(2),YR(2),ZR(2)
SINAL=-SIN(ALPHA)
CØSAL=CØS(ALPHA)
SINBE=SIN(BETA) $ CØSBE=CØS(BETA)
C11=CØSAL $ C13=SINAL
C21=SINAL*SINBE $ C22=CØSBE
C23=-CØSAL*SINBE
C31=-SINAL*CØSBE
C32=SINBE $ C33=CØSAL*CØSBE
DØ 10 I=1,NPØINT
XI=X(I) $ YI=Y(I) $ ZI=Z(I)
XR(I)=XI*C11 + ZI*C13
YR(I)=XI*C21 + YI*C22 +ZI*C23
ZR(I)=XI*C31 + YI*C32 + ZI*C33
10 CONTINUE
RETURN $ END
SUBRØUTINE PERSPE(XR,YR,ZR,NPØINT,DIST)
DIMENSIØN XR(2),YR(2),ZR(2)
DØ 10 I=1,NPØINT
D=DIST/(DIST-ZR(I))
XR(I)=XR(I)*D
YR(I)=YR(I)*D
10 CØNTINUE
RETURN $ END
SUBRØUTINE PLT(X,Y)
I=X+4000
J=Y+4000
```

```
PRINT 100,I,J
100 FØRMAT(I4,I5)
RETURN $ END
SUBROUTINE ØRBITER(X,Y,Z)
DIMENSION X(2),Y(2),Z(2)
X(1)=X(14)=X(33)=250
Y(1)=Y(14)=Y(33)=500
Z(1)=Z(14)=Z(33)=500
X(2)=400
Y(2)=525
Z(2)=500
X(3)=X(11)=625
Y(3)=Y(11)=628
Z(3)=Z(11)=500
X(4)=X(36)=625
Y(4)=Y(36)=525
Z(4)=Z(36)=525
X(5)=X(8)=625
Y(5)=Y(8)=500
Z(5)=Z(8)=525
X(6)=625
Y(6)=500
Z(6)=550
X(7)=555
Y(7)=500
Z(7)=525
X(9)=X(35)=625
Y(9)=Y(35)=475.
Z(9)=Z(35)=525
X(10)=X(12)=625
Y(10)=Y(12)=372
Z(10)=Z(12)=500
X(13)=400
Y(13)=475
Z(13)=500
X(15)=X(37)=400
Y(15)=Y(37)=525
Z(15)=Z(37)=525
X(16)=X(20)=400
Y(16)=Y(20)=518
Z(16)=Z(20)=525
X(17)=X(23)=550
Y(17)=Y(23)=518
Z(17)=Z(23)=525
X(18)=X(26)=550
Y(18)=Y(26)=482
Z(18)=Z(26)=525
X(19)=X(31)=400
Y(19)=Y(31)=482
Z(19)=Z(31)=525
X(21)=X(29)=400
Y(21)=Y(29)=518
Z(21)=Z(29)=507
X(22)=X(24)=550
Y(22)=Y(24)=518
```

```
Z(22)=Z(24)=507
X(25)=X(27)=550
Y(25)=Y(27)=482
Z(25)=Z(27)=507
X(28)=X(30)=400
Y(28)=Y(30)=482
Z(28)=Z(30)=507
X(32)=X(34)=400
Y(32)=Y(34)=475
Z(32)=Z(34)=525
DO 10 I=1,37
IF(Z(I).EQ.550.)Z(I)=600
IF(Z(I).EQ.525.)Z(I)=550.
IF(Z(I).EQ.507.)Z(I)=514.
X(I)=(X(I)-500.)*.01
Y(I)=(Y(I)-500.)*.01
Z(I)=(Z(I)-500.)*.01
10 CONTINUE
RETURN
END
SUBROUTINE SOLAR(X,Y,Z)
DIMENSION X(2),Y(2),Z(2)
X(1)=X(6)=498
Y(1)=Y(6)=600
Z(1)=Z(6)=500
X(2)=498
Y(2)=675
Z(2)=500
X(3)=198
Y(3)=675
Z(3)=500
X(4)=198
Y(4)=525
Z(4)=500
X(5)=498
Y(5)=525
Z(5)=500
X(7)=X(14)=500
Y(7)=Y(14)=600
Z(7)=Z(14)=500
X(8)=X(13)=502
Y(8)=Y(13)=600
Z(8)=Z(13)=500
X(9)=502
Y(9)=675
Z(9)=500
X(10)=802
Y(10)=675
Z(10)=500
X(11)=802
Y(11)=525
Z(11)=500
X(12)=502
Y(12)=525
Z(12)=500
```

```
02200 X(15)=500
02210 Y(15)=425
02220 Z(15)=500
02230 X(16)=500
02240 Y(16)=413
02250 Z(16)=513
2260 PRINT,*PLTT*
2270 PRINT,*PLTL*
02280 X(17)=X(18)=496
02290 Y(17)=Y(20)=403
02300 Z(17)=Z(20)=516
02310 Y(18)=Y(19)=397
02320 Z(18)=Z(19)=510
02330 X(19)=X(20)=504
2335 DO 15 I=1,20
02340 X(I)=(X(I)-500)*.01
2351 Y(I)=(Y(I)-500)*.01
2352 Z(I)=(Z(I)-500)*.01
2353 15 CONTINUE
2354 RETURN $ END
2365 SUBROUTINE SLAVE(X,Y,Z)
02370 DIMENSION X(2),Y(2),Z(2)
02380 X(1)=X(20)=500
02390 Y(1)=Y(20)=450
02400 Z(1)=Z(20)=500
02410 X(2)=X(3)=X(4)=X(7)=X(8)=X(9)=X(16)=X(17)=X(18)=222
02420 X(19)=222
02430 Y(2)=Y(19)=500
02440 Z(2)=Z(19)=500
02450 X(5)=X(6)=X(10)=X(11)=X(12)=X(13)=X(14)=X(15)=178
02460 Y(3)=Y(9)=Y(10)=Y(12)=Y(13)=Y(15)=Y(16)=Y(17)=488
02470 Z(3)=Z(4)=Z(5)=Z(8)=Z(13)=Z(14)=Z(15)=Z(16)=488
02480 Y(4)=Y(5)=Y(6)=Y(7)=Y(8)=Y(11)=Y(14)=Y(18)=512
02490 Z(6)=Z(7)=Z(9)=Z(10)=Z(11)=Z(12)=Z(17)=Z(18)=512
02500 DO 10 I=1,20
02510 X(I)=(X(I)-500)*.01
02520 Y(I)=(Y(I)-500)*.01
02530 Z(I)=(Z(I)-500)*.01
02540 10 CONTINUE
02550 DO 15 I=1,20
02560 X(I+20)=-X(I)
02570 Y(I+20)=Y(I)
02580 Z(I+20)=Z(I)
02590 15 CONTINUE
02600 RETURN $ END
02610 SUBROUTINE G ARM(X,Y,Z)
02620 DIMENSION X(2),Y(2),Z(2)
02630 X(1)=X(20)=500
02640 Y(1)=Y(20)=450
02650 Z(1)=Z(20)=500
02660 X(2)=X(3)=X(4)=X(7)=X(8)=X(9)=X(16)=X(17)=X(18)=200
02670 X(19)=200
2675 DO 10 I=1,19
02680 Y(2)=Y(19)=450
02690 Z(2)=Z(19)=500
```

```
X(5)=X(6)=X(10)=X(11)=X(12)=X(13)=X(14)=X(15)=164
10 CONTINUE
Y(3)=Y(9)=Y(10)=Y(12)=Y(13)=Y(15)=Y(16)=Y(17)=432
Z(3)=Z(4)=Z(5)=Z(8)=Z(13)=Z(14)=Z(15)=Z(16)=462
Y(4)=Y(5)=Y(6)=Y(7)=Y(8)=Y(11)=Y(14)=Y(18)=468
Z(6)=Z(7)=Z(9)=Z(10)=Z(12)=Z(11)=Z(17)=Z(18)=538
DO 15 I=1,20
X(I)=(X(I)-500)*.01
Y(I)=(Y(I)-500)*.01
Z(I)=(Z(I)-500)*.01
15 CONTINUE
DO 20 I=1,20
X(I+20)=-X(I)
Y(I+20)=Y(I)
Z(I+20)=Z(I)
20 CONTINUE
RETURN $ END
READY.
```

Coordinates (x,y,z)

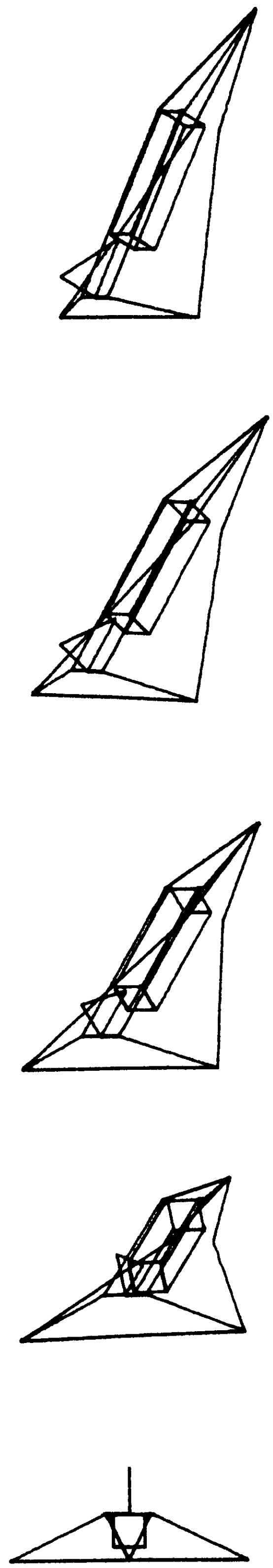
600, 1200, 600

600, 900, 600

600, 600, 600

600, 300, 600

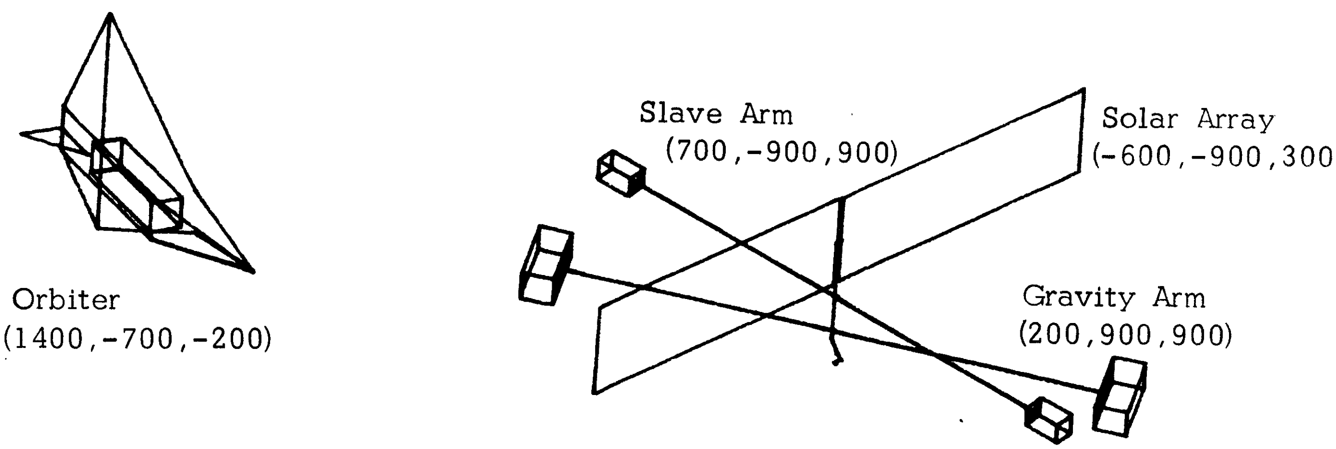
600, 0, 600



Scale Factor = 500

FIGURE 17.1

ORBITER ROTATION



Scale Factor = 500

FIGURE 17.2

INITIAL STATION AND ORBITER

18. FOOTNOTES

5. Introduction

[1]S. B. Sells, A Model for the Social System for the Multi-Man Extended Duration Space Ships, vol. 37, No. 11, November 1966.

[2]Stanley Deutsch, Ph.D./NASA, "The Habitability of Confined Spaces," in 1st National Symposium on Habitability, Vol. 3, May 1970, p. 14.

[3]Use of the Ben Franklin Submersible as a Space Station Analog, Advanced Systems Office, Marshall Space Flight Center, Vol. 1, May 1970.

[4]H. H. Watters and J. W. Miller, Ph.D., Tektite: Experience with an Underwater Analog of Future Space Operations, Marshall Space Flight Center.

[5]Ibid.

[6]Ibid.

[7]Use of the Ben Franklin Submersible as a Space Station Analog, Advanced Systems Office, Marshall Space Flight Center, Vol. 11, May, 1970.

[8]Stanley Deutsch, Ph. D./Nasa, "The Habitability of Confined Spaces," in 1st National Symposium on Habitability, Vol. 3, May 1970, pp. 14, 16, 17.

[9]Herman Hendrickx, "A Modularized Space Station," in Space Flight, Vol. 13, No. 9, Sept. 1971.

[10]Lunar Orbit Station, Advanced Missions Program Office, Manned Spacecraft Center, NASA, April 1970.

[11]Orbiting Lunar Station, Phase A, Feasibility and Definition Study, Space Division, North American Rockwell, April 1971.

[12]Executive Summary, Space Station Program, Phase B Definition, Space Division, North American Rockwell, July 1970, p. 96.

[13]Ibid., p. 97.

6. Mission Envelope

[1]Executive Summary, Space Station Program Phase B Definitions, Space Division, North American Rockwell, July 1970, p. 90.

7. Crew Factors

[1]David Baker, "Space Station Situation Report 1: The North American Rockwell Proposal," in Space Flight, Vol. 13, No. 9, September 1971, p. 331.

[2]Executive Summary Space Station Program Phase B Definition, Space Division, North American Rockwell, July 1970, p. 63.

[3]Habitability Data Handbook, Vol. 2, Architecture and Environment, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, 3-63.

[4]Ibid., p. 3-64.

[5]Habitability Data Handbook, Vol. 5, Garments and Ancillary Equipment, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, p. 3-21.

[6]Habitability Data Handbook, Vol. 4, Food Management, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, p. 3-5.

[7]Ibid., p. 3-14.

[8]Habitability Data Handbook, Vol. 3, Housekeeping, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, p. 3-1.

[9]Habitability Data Handbook, Vol. 6, Personal Hygiene, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, p. 3-55.

[10]*Ibid.*, pp. 3-55.

[11]*Ibid.*, pp. 3-68.

[12]*Ibid.*, pp. 3-10.

[13]*Ibid.*, pp. 3-28.

[14]*Ibid.*, pp. 3-69.

[15]*Ibid.*, pp. 4-20.

[16]*Ibid.*, pp. 4-23.

[17]Raymond Loewy and William Snaith, *General Habitability Standards Statement, Crew, Individual Compartments*, pp. 3, 4.

[18]*Habitability Data Handbook, Volume 2, Architecture and Environment*, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, pp. 1-8.

[19]*Ibid.*, pp. 1-7.

[20]*Ibid.*, pp. 3-13.

[21]*Ibid.*, pp. 3-51.

[22]*Ibid.*, pp. 3-50.

[23]*Ibid.*, pp. 3-34.

[24]*Ibid.*, pp. 3-50.

[25]*Ibid.*, pp. 3-60.

[26]*Ibid.*, pp. 3-61.

[27]*Ibid.*, pp. 3-67.

[28]*Ibid.*, pp. 3-68.

[29]*Ibid.*, pp. 3-79.

[30]*Ibid.*, pp. 3-76.

[31]*Ibid.*, pp. 3-77.

[32]*Ibid.*, pp. 3-79.

[33]*Ibid.*, pp. 3-90

[34]*Ibid.*, pp. 3-89

9. Spacecraft Design

[1]Morris Jenkins, *Manned Mars Exploration Requirements and Considerations*, Engineering and Development Directorate, Manned Spacecraft Center, NASA, February, 1971, pp. 4-20.

[2]Joseph F. Shea and Michael I. Yargmovych, The Manned Orbital Laboratory, NASA, Fig. 4.

[3]Modular Space Station, Phase B Extension, Space Division, North American Rockwell, April 1971.

[4]*A Study of Spacecraft Design and Operations for Planetary Encounter Missions*, Vol. II, Advanced Spacecraft Technology Division, Manned Spacecraft Center, NASA, 1967, p. 86.

12. Schedules and Cost

[1]*Modular Space Station, Phase B Extension*, Space Division, North American Rockwell, April 1971.

[2]*Integrated Program Plan Reference Schedule, Low Budget Alternative*, Advanced Program Planning Office, Manned Spacecraft Center, NASA, May 28, 1970.

[3]*Modular Space Station, Phase B Extension*, Space Division, North American Rockwell, April, 1971.

[4]*Ibid.*

[5]*Ibid.*

[6]*Ibid.*

[7]*Ibid.*

[8]*Executive Summary Space Station Program, Phase B Definition*, Space Division, North American Rockwell, July 1970, p. 98.

14. Design Description

[1] *Habitability Data Handbook, Volume 1, Mobility and Restraint*, Spacecraft Design Division, Manned Spacecraft Center, NASA, July 31, 1971, pp. 1-4.

[2] *Ibid.*, pp. 1-5.

19. REFERENCES

Advanced Missions Program Office, Lunar Orbit Station, Project Description Document, Manned Spacecraft Center, National Aeronautics and Space Administration, April, 1970.

Advanced Missions Program Office, Lunar Surface Base, Manned Spacecraft Center, National Aeronautics and Space Administration, June 15, 1970.

Advanced Program Planning Office, Integrated Program Plan Reference Schedule, Low Budget Alternative, Manned Spacecraft Center, National Aeronautics and Space Administration, May 28, 1970.

Advanced Systems Office, Use of the Ben Franklin Submersible as a Space Station Analog.

a) Volume I Summary Technical Report OSR-70-4
b) Volume II Psychology and Physiology OSR-70-5
c) Volume III Habitability OSR-70-6

produced by Marshall Space Fight. Center for the National Aeronautics and Space Administration, May, 1970.

Baker, David, "Space Station Situation Report 1: The North American Rockwell Proposal," Space Flight, Vol. 13, No. 9, September, 1971.

Barker, David, "Skylab," Space Flight, Vol. 13, No. 9, September, 1971.

Barker, David, "Space Station Situation Report 2: The McDonnell Douglas Proposal," Space Flight, Vol. 13, No. 9, September, 1971.

Barnes, R. "Habitability Requirements for Multi-Man Long Duration Missions," unpublished NASA Report, September, 1969.

Berry, Charles A., M.D. Director of Life Sciences/NASA, Biomedical Findings on American Astronauts in Space Missions, Man's Adoption to Weightlessness September, 1969.

Henderickx, Herman, "A Modularized Space Station," Space Flight, Vol. 13, No. 9, Sept. 1971.

Hill, Arthur, "NASA Budget Request Centers on Shuttle," Houston Chronicle, Jan. 24, 1972.

Hitchcock, Robert E./Univ. of Florida, Interior Design of an Intermediate Earth Orbiting Space Station, A Preliminary Study prepared for Habitability Technology Laboratory, Manned Spacecraft Center, National Aeronautics and Space Administration, May, 1970.

Jenkins, Morris, Manned Mars Exploration Requirements and Considerations. Advanced Studies Office, Engineering and Development Directorate, Manned Spacecraft Center, National Aeronautics and Space Administration, February 1971.

Johnson, William B. Factors Affecting the Interior Design of Crew Compartments for Long Duration Space Flight, Manned Spacecraft Center, National Aeronautics and Space Administration, MSC Internal Note, Sept. 1967.

Kepner, William E., "The Saga of Explorer 1: Man's Pioneer Attempts to Reach Space," Aerospace Historian, Vol. 18, No. 3, September 1971.

Kubris, J. F. Habitability: "General Principles and Applications to Space Vehicles," paper presented at the Second International Symposium on Basic Environmental Problems of Man in Space, Paris, 1965.

Kurzhals, Perter R., "Nutation Dampers for Manned Spacecraft," Fith Aerospace Mechanisms Symposium, Langley Research Center, National Aeronautics and Space Administration.

Lilly, John C., "The Effect of Sensory Deprivation on Consciousness," Environmental Effects on Consciousness, edited by Karl E. Schaefer, Macmillan Company, New York, 1962.

Loewy, Raymond and Snaith, William, Habitability Study, prepared for Martin Marietta Corp., February 1968.

Louviere, Allen J., "Engineering Aspects of Habitability: Space Flight Considerations," 1st National Symposium on Habitability Vol. II, May 1970.

Brown, John, Ph.D. "Sensory and Perceptual Problems in Space Flight," Physiological Problems in Space Exploration. Charles C. Thomas, publisher, 1964.

Deutsch, Stanley, Ph.D./NASA, "The Habitability of Confined Spaces," 1st National Symposium on Habitability, Vol. 3, May, 1970.

Fielder, Dennis E., Integrated Program Plan Reference Schedule, High Budget Baseline, Manned Spacecraft Center, National Aeronautics and Space Administration, May 19, 1970.

Fraser, T. M., The Intangibles of Habitability During Long Duration Space Missions, Washington, D.C., National Aeronautics and Space Administration, June, 1968.

Gatland, Kenneth W., "Salyut," Space Flight, Vol. 13, No. 9, September 1971.

Gerathewohl, Siegfried J. "Effects of Gravity-Free State," Environmental Effects on Consciousness, edited by Karl E. Schaefer, Macmillan Company, New York 1962.

Graybiel, Aston, "Orientation in Space, with Particular Reference to Vistibular Functions," Environmental Effects on Consciousness, edited by Karl E. Schaefer, Macmillan Company, New York, 1962.

Habitability Technology, Habitability Data Handbook,
Vol. 1 Mobility and Restraint
Vol. 2 Architecture and Environment
Vol. 3 Housekeeping
Vol. 4 Food Management
Vol. 5 Garments and Ancillary Equipment
Vol. 6 Personal Hygiene
Spacecraft Design Division, Manned Spacecraft Center, National Aeronautics and Space Administration July 31, 1971.

Hardy, James D. Ph.D , "Weightlessness and Sub-Gravity Problems," Physiological Problems in Space Exploration, Charles C. Thomas, Publisher, 1964.

Haymes, Robert C./Rice University, Introduction to Space Science, John Wiley and Sons, Inc., 1971.

Haythorn, William W., "A 'Needs' by 'Source of Satisfaction' Analysis of Environmental Habitability," 1st National Symposium on Habitability, Vol. 11, May 1970.

Manned Spacecraft Center, Intermediate Workshop Study, Modular Approach, National Aeronatuics and Space Administration, October, 1968.

Manned Spacecraft Center, Shuttle Fact Sheet, NASA, 1972.

Marshall, Tyler, "NASA Tells Conference: Space Station will be both Factory and Laboratory," Product Engineering, September 28, 1970.

Marshall Space Flight Center, Skylab and Beyond Press Briefing, June 29 and 30, 1970.

Nowlis, David P., Ph.D., H. H. Watters, and E. C. Wortz, Habitability Assessment Program.

Nowlis, David P., Ph.D., H. H. Watters, and E. C. Wortz, Tektite II Habitability Research Program, Airesearch Manufacturing Company, Marshall Space Flight Center, National Aeronautics and Space Administration, January 14, 1972.

Planetary Missions Office, A Study of Spacecraft Design and Operations for Manned Planetary Encounter Missions, Advanced Spacecraft Technology Division, Manned Spacecraft Center, NASA, Vol. II, 1967.

Program Administration, Executive Summary, Space Station Program, Phase B Definition, Space Division, North American Rockwell, July, 1970.

Richmond, Roger R., Interior Design of an Intermediate, Zero Gravity Earth Orbiting Space Station, Manned Spacecraft Center Internal Note, Sept., 1968.

Science and Applications Directorate, Skylab A, EREP Users Handbook, Science Requirements and Operations Branch, Manned Spacecraft Center, March, 1971.

Sells, S. B. A Model for the Social System for the Multi-Man Extended Duration Space Ships, Vol. 37, No. 11, November, 1966.

Schwartz, Seymour I. "A Framework for Environmental Decision Making," Department of Industrial and Systems Engineering, University of Southern California, 1st National Symposium on Habitability, May, 1970.

Sharpe, Mitchell R., Living in Space, Doubleday and Company, Inc. 1959.

Shea, Joseph F. and Michael I. Yargmovych, The Manned Orbital Laboratory, National Aeronautics and Space Administration.

Spacecraft Design Division, Shuttle Orbiter Nose Design Considerations, Manned Spacecraft Center, November 12, 1971.

Space Division, Orbiting Lunar Station, Phase A. Feasibility and Definition Study, North American Rockwell, Advanced Program Engineering, April 1971.

Space Division, Modular Space Station, Phase B Extension, North American Rockwell, November 4, 1971.

Watters, H. H., NASA, Marshall Space Flight Center and J. W. Miller, Ph.D., National Oceanic and Atmospheric Administration, Tektite: Experience with an Underwater Analog of Future Space Operations.

Watters, H. H. and Jeri W. Brown, Marshall Space Flight Center, The Application of Space Habitability Technology to Earth Environments, working papers.

Additional information was acquired by discussions with the following individuals:

Baillie, Richard F., Advanced Missions Program Office, Manned Spacecraft Center, NASA; prepared Lunar Orbit Station document.

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