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Lunar Base Synthesis Study

FINAL REPORT

VOLUME III
Shelter Design

Space Division
North American Rockwell

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15 MAY 1971

APPROVED BY

J.M. MANSFIELD, PROGRAM MANAGER
LUNAR BASE SYNTHESIS

Space Division
North American Rockwell

FOREWORD

The Lunar Base Synthesis Study was conducted by the Space Division of North American Rockwell under Contract NAS8-26145 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Program Development Directorate of the George C. Marshall Space Flight Center.

This document is Volume III, Shelter Design, which constitutes part of the final report on the study. The following additional documents comprise the entire final report:

Volume I - Executive Summary

Volume II - Mission Analysis and Lunar Base Synthesis

Part 1 - Mission Analysis
Part 2 - Lunar Base Synthesis

Volume IV - Cost and Resource Estimates

ACKNOWLEDGMENTS

The Lunar Base Synthesis Study was conducted by the Space Division of North American Rockwell under Contract NAS8-26145 for the George C. Marshall Space Flight Center.

The Study Manager and Contracting Officer Representative (COR) for the National Aeronautics and Space Administration was James B. Brewer of the Program Development Directorate of the George C. Marshall Space Flight Center. Milton A. Page of the same Directorate was the Alternate COR. T. N. V. Karlstrom and R. D. Regan of the United States Geological Survey, Astrogeology Center, provided assistance to the National Aeronautics and Space Administration regarding geological exploration. The Program Manager for the National Aeronautics and Space Administration Headquarters was S. S. DiMaggio of the Manned Space Flight Lunar Exploration Office.

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INTRODUCTION

The objectives of the Lunar Base Synthesis Study were to define and analyze lunar exploration missions to establish the role of a semi-permanent lunar surface base (LSB) as an element of an integrated space program, and to prepare conceptual designs for two different lunar surface shelters. One shelter concept was to be optimized for the LSB mission requirements whereas the other represented a potential adaptation of a specified space station module.

The study was oriented towards a lunar surface base which would support a two to five-year program of scientific and exploration activities in the 1980's by a crew of up to 12 men at any location on the moon which might be selected. The principal program option involved considering the operation of the LSB concurrently with an operational Orbiting Lunar Station (OLS) or without the existence of the OLS. The space station module which was designated as the candidate for adaptation to an LSB shelter configuration was the Shuttle Launched Modular Space Station as defined by North American Rockwell, Space Division (NR/SD) under Contract NAS9-9953 for the Manned Spacecraft Center and documented in NR report, SD 70-546-1, January 1971.

The basic approach adopted for the study involved the identification of scientific and exploration activities appropriate to a single, semi-permanent base on the lunar surface from an examination of the consensus of previous studies of lunar scientific missions. A typical distribution of these activities on the lunar surface was derived from a detailed examination of several potentially desirable areas and operational/design requirements were defined to accomplish the various classes of activities. The activities were found to fall into two main categories: main base activities which included astronomy and deep drilling as well as the regular logistics and housekeeping functions and the selenological explorations at multiple sites in an expanded region around the base site.

The definition of a program encompassing these activities, the associated operational and design requirements, the logistics operational concepts, and the precursor surface and orbit missions comprised study tasks 1 and 2, Mission Analysis and Lunar Base Synthesis respectively.

A lunar surface base configuration which included a main shelter, major science elements, and surface mobility system elements was conceptually defined. The initial design considered the probable state-of-the-art and the operational and design requirements in arriving at a shelter configuration optimized for the spectrum of lunar surface missions. The subsystem options were identified and tradeoffs performed in arriving at the selected configuration. The potential emergency situations were considered and the implications delineated including a maintenance and repair philosophy. Maintenance, repair and housekeeping functions were described and typical tool requirements identified.

Following the definition of the optimized LSB shelter, a conceptual design of a lunar shelter derived from the specified space station module was developed. The degree of modification required, including specific additions for the lunar mission and environment, was identified.

These two conceptual designs and the definition of the characteristics of the mobility concept and its interfaces with the shelter comprised study task 3, Shelter Design.

Cost and resource estimates were prepared for the design and development of each of the shelter configurations and for the science, mobility, and power source elements of the LSB program. The shelter development costs were generated utilizing cost estimating relationships from other space programs. Cost estimates for the science mobility and power source elements were primarily derived by adjusting prior studies of these elements for the recommended concept modifications and the passage of time. These cost estimates together with program schedules and milestone data comprised study task 4, Cost and Resource Estimates.

The study was accomplished and documented in an 11-month period between 15 June 1970 and 15 May 1971. The study results are documented in four basic volumes: Volume I is an executive summary which briefly outlines the objectives, summarizes the results, conclusions, and recommendations; Volume II contains a comprehensive description of the analysis and synthesis results of tasks 1 and 2; Volume III presents the LSB configurations including the conceptual designs of the optimized and derivative shelters which resulted from study task 3; and Volume IV describes the cost estimates derived in task 4.

VOLUME III - SHELTER DESIGN

SUMMARY

Volume II has defined the LSB mission, its operations and the resulting requirements as they influence the design and location of a lunar surface base. This volume is concerned with the design of the base and its supporting facilities.

LSB design requirements imposed by the mission parameters resulting from astronomy, exploration sorties, deep drilling, logistic vehicle support, surface vehicle support and the need for extended EVA work are interpreted in this volume as to their inferences on the LSB design. Sensitive factors are identified and assessed specifically to define boundary conditions for the influenced parameter.

Module design trades were performed to define configuration drivers; i.e., boundary conditions for both size and weight as well as shape. Design options were identified and evaluated and from these a baseline was selected for the base synthesis. From these data, design criteria were identified applicable for any LSB modular concept.

An approach for expended mass conservation was devised which permitted reduction of the personnel support consumables to less than 10 pounds per man-day. The concept takes into account the effects of the long sorties, outposts, EVA and main base activities, including defining the effects of variations in time spent between these activities.

The subsystems were evaluated on the basis of a four-man module. Options were identified, defined, and trade data developed to permit a logical selection of the optimized design. It was found that by resupplying hydrazine and wet food, no cryogens need be resupplied.

Dust control received a particular emphasis because of the Apollo lunar mission experiences. A subcontract was let to Holmes and Narver to define the problem in detail, identify potential options and recommend a solution. A mission/system concept was defined and integrated into the LSB complex.

For electrical power, the wide spread distribution of the requirements led to selection of a modularized concept providing between 3.5 and 5 kw per module. The power level per module is too low to make reactors effective which resulted in the selection of an isotope organic rankine system as the primary source of power.

Communications from a frontside LSB is relatively straightforward since a continuous earth line-of-sight would permit even the surface-to-surface links to be handled by a S-band relay. A backside LSB, however, presents a serious problem in communications and a libration point satellite seems to be the best solution. The Data Management function was found to be very dependent on the selected operational concept and recommendations are included to minimize the problem.

An LSB baseline shelter complex was configured using eight 15-foot diameter by 30-foot modules. It provided a "circular" floor plan with three crew modules, a lab module, a drive-in warehouse, and a pressurized garage. It is responsible to all the safety criteria.

Part 2 of this Volume presents the Modular Space Station Derivative LSB. It presents the results of a comparative analysis of functional requirements and design alternatives. Shelter complex configurations were evaluated and an optimum selected, much like the baseline LSB. A subsequent function-by-function analysis resulted in the conclusion that a complex composed of an MSS Core Module, three Crew Modules, two Control Modules, and a Galley Module will satisfy the LSB requirement with only minor modifications and the addition of two drive-in/airlock modules.

Part 3 of this Volume defines the LSB support operations required and the resulting systems designs or design criteria. The mobility concept includes a prime mover, attachments and trailers. The base buildup operations and sequence was defined, including the requirement for soil movement and its influence on the support equipment.

A delivery concept was developed interfacing with the baseline logistics system derived in Volume II.

The safety analysis included the identification of potential hazards, a definition of the situation or conditions that could result from these hazards and the derivation of both operational and design options that could either preclude their occurrence or minimize the danger potential.

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PART 3 SUPPORT OPERATIONS AND SYSTEMS

ACRONYMS

IVA	Intra-Vehicular Activity, synonomous with shirtsleeve herein
EVA	Extra-Vehicular Activity, in a spacesuit
PLSS	Portable Life Support System, spacesuit backpack
APLSS	Advanced Portable Life Support System
EPS	Electrical Power Subsystem
A&CS	Atmospheric Management and Crew Services
ECLSS	Environmental Control and Life Support Subsystem
LSB	Lunar Surface Base, includes shelter and supporting elements
RAS	Requirement Analysis Sheets
RNS	Reusable Nuclear Shuttle
EOS	Earth Orbit Shuttle
EOSS	Earth Orbital Space Station
MSS	Modular Space Station
CIS	Chemical Inter-orbital Shuttle
JPL	Jet Propulsion Lab
TLI	Translunar Injection
LOI	Lunar Orbit Insertion
TEI	Trans-Earth Injection
EOI	Earth Orbit Insertion
OLS	Orbiting Lunar Station
JD	Julian Date
CS	Cislunar Shuttle
LFV	Lunar Flying Vehicle
MSFN	Manned Space Flight Network
PGA	Pressure Garment Assembly
EMU	Extravehicular Maneuvering Unit
SAS	Space Activity Suit
DRSS	Data Relay Satellite System
RAD	Radiation Absorbed Dose
USGS	United Stages Geological Survey
IITRI	Illinois Institute of Technology Research Institute

1.0 LSB DESIGN FACTORS

The objectives of the LSB are to facilitate exploration of the moon and its use in extra-terrestial research. The base must therefore provide the required manpower and facilities to make these activities possible. The influences on base design of the mission and system requirements which were defined in Volume II, are assessed in the following paragraphs. The factors are identified by Figure 1.0-1.

1.1 THE SORTIE MISSION INFERENCES

The surface exploration mobility concept derived to satisfy the extended sortie mission involves the use of five vehicles in an overland train concept as illustrated by Figure 1.1-1. This sortie mission concept imposes both direct and indirect requirements on the base.

<u>Sortie Requirements With Indirect Influence</u>

1. Each sortie involves four men being away from the base but supplied by it for up to 90 days.

2. The sortie train requires an average of 3.6 kw of electrical energy throughout the sortie.

3. The prime mover (two required for safety) has an autonomous operational capability for up to 36 hours of operation away from all other vehicles(or the base).

4. The sortie concept includes a mobile lunar shelter for crew quarters during the sortie.

<u>Sortie Requirements With Direct Influence</u>

1. The sortie vehicles will require about 168 hours of maintenance and repair work after each sortie, part of which involves the external systems and can best be done in a pressurized area.

2. A modularized mobile power source is indicated because the power requirements move with the men. The departure of four men from the base creates a significant drop in the power required there and moves it to the sortie train.

3. The data system must be able to handle up to 10^4 bits per second from a distance of up to 230 miles from the base.

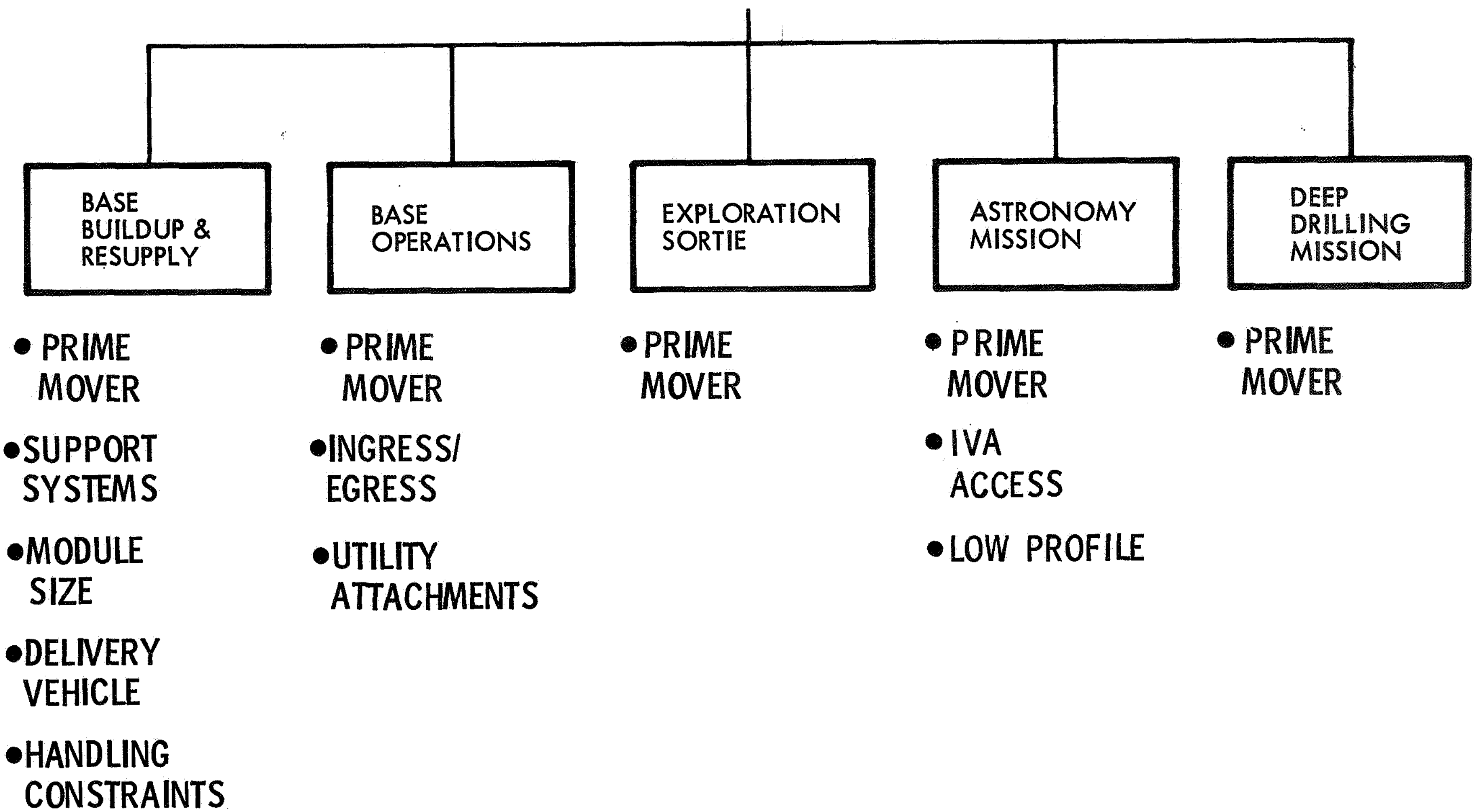


Figure 1.0-1. Base Configuration Considerations

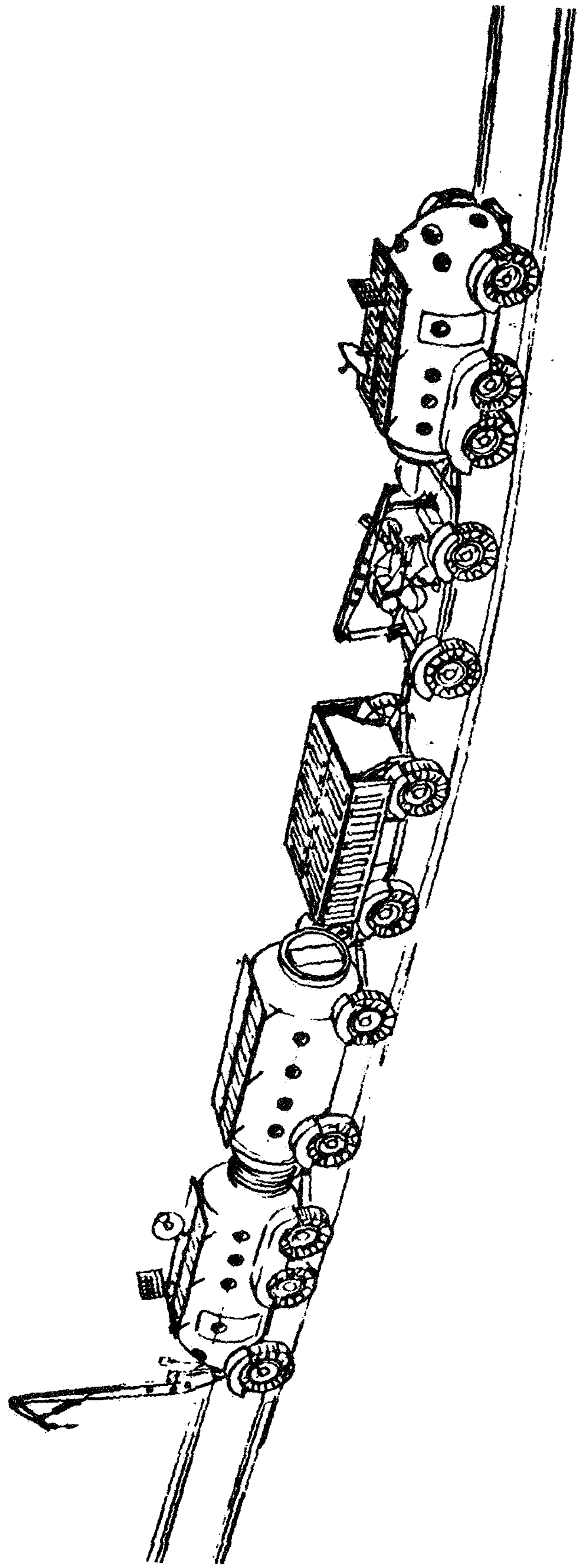


Figure 1.1-1. Sortie Concept

4. The extended sortie missions and the associated four-man team require about 10K pounds of diverse supplies every 180 days, which will occupy a volume of about 1,000 ft.^{3}. Warehousing must be provided for much of this.

5. The sortie personnel (4 men) will be at the base for about one-third of their lunar stay. Services must be provided to these men during the pre- and post-sortie activities.

1.2 ASTRONOMY MISSION INFERENCES

The astronomy mission includes seven separate autonomous scientific systems, with components varying in weight from a few pounds to many thousands of pounds. These impose requirements for specialized handling equipment and structures to house them. The area covered by the radio telescopes involves some 14 square miles, as indicated by Figure 1.2-1.

The installation time is expected to require four men for 100 working days. Most of this time is under EVA conditions and at distances of up to ten miles from the main shelter.

The preferred location for the astronomy activities is on the limb or backside near the equator.

The program is expected to require four men and take up to five years to meet the data objectives and obtain the full benefits of the investment.

The equipment will be dispersed over the 14-square mile area and the power requirements, a total of 4 kw average, will also be divided between several locations. This will necessitate transmission lines or several power units.

The data handling requirements are not definitive at this time. They are highly dependent on the available systems and the selected operational mode and can vary by several orders of magnitude. It has been estimated that the gross data derived from the seven systems can exceed 8.6×10^{10} bits per day.

1.3 DEEP DRILLING INFERENCES

The deep drilling mission involves drilling several holes approximately 1,000 feet into the lunar surface. The operation is expected to involve two men and take about 145 days per hole if they can work in shirtsleeve conditions within a pressurized module.

The drilling concept, therefore, involves a pressurizable module (Figure 1.3-1) which:

1. holds the assembled drill

2. can be easily erected and disassembled for moving

3. provides atmospheric control in conjunction with the prime mover

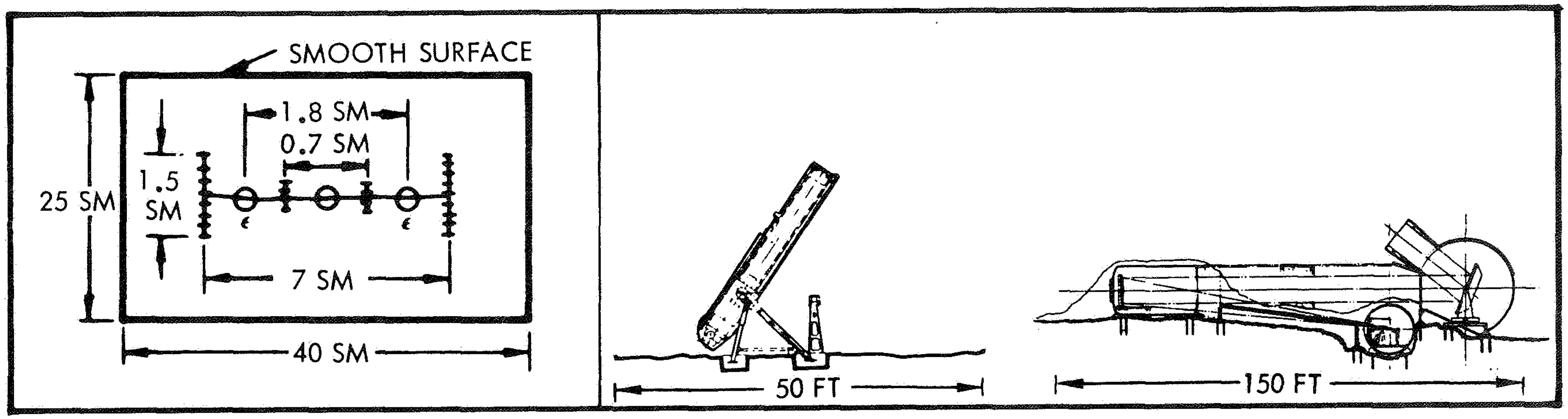


Figure 1.2-1. Astronomy Inferences

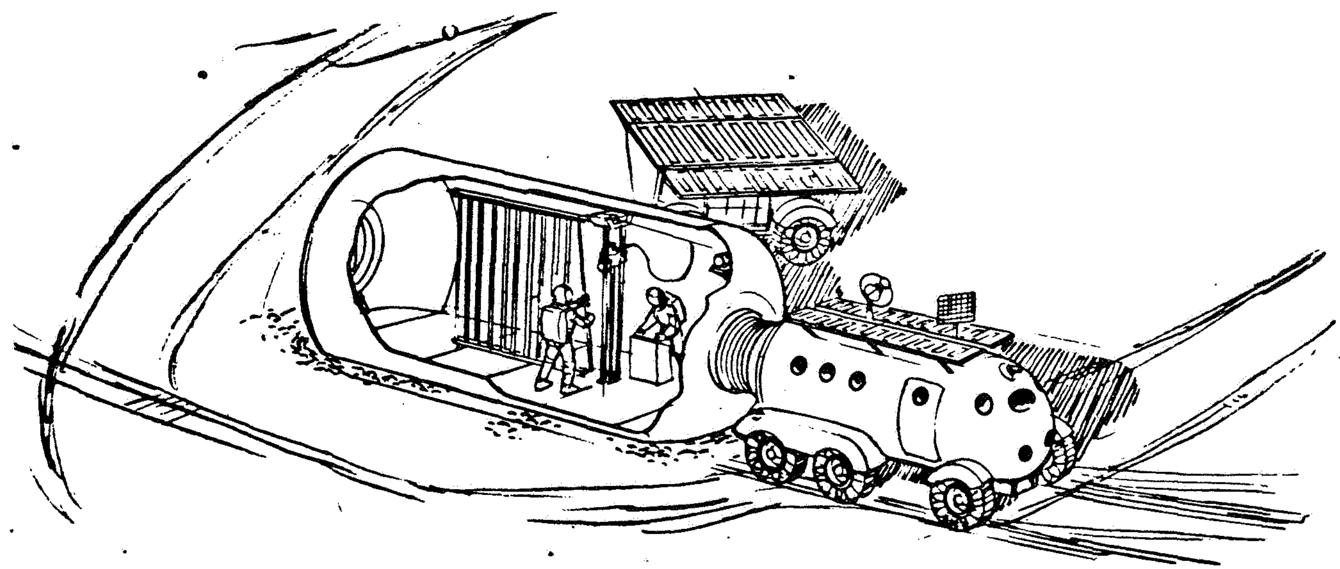


Figure 1.3-1. Deep Drilling Mission Inferences

4. provides for shirtsleeve transfer of crew from the prime mover into the drill housing.

Drilling is expected to be a daily operation early in the LSB era and is expected to be within commuting distance of the shelter complex, i.e., close enough to not significantly impact the available work time. Approximately one hour was alloted for commuting.

Shirtsleeve transfer from the shelter complex to the prime mover and from the prime mover to the drill module is highly desirable to minimize time lost from the working day. EVA transfers could approximately double the drill operations time.

Drilling operations require an average power level of 3.4 kw per 24-hour period, with some form of energy storage required to handle the peaks of up to 12 kw created by the actual drilling. The power source must be mobile so as to move with the drill.

The LSB shelter must provide the following support for the Drilling Mission:

1. Quarters and services for the two-man teams for approximately one year.

2. Maintenance facilities for the mission prime mover, the drill, and any support equipment. This is estimated to require 18 man-hours per month.

3. Warehousing for about 7,000 pounds of supplies and equipment every 140 days.

1.4 LOGISTIC VEHICLE SUPPORT INFERENCE

The logistics system options and modes are discussed in Volume II. For some modes the landing vehicle may spend a major portion of its operational cycle at the LSB site and service interfaces, therefore, required of the LSB.

The scope of these interfaces between the logistic vehicles and the LSB depends on the selected operational concept; however, the major functional requirements and their interfaces can be identified. Figure 1.4-1 presents a second level functional flow diagram depicting the operations of significance, the associated LSB functional requirements and/or their interfaces. Of these functions, the vehicle quiescent operations and the cargo transfer operations are of most significance to both the base concept and the surface mobility vehicle design or selection criteria.

Module Removal

Cargo or base shelter modules delivered to the lunar surface will be removed from the landing vehicle and moved to the shelter site. These are estimated to weigh up to 18,000 pounds and therefore require handling equipment of some form.

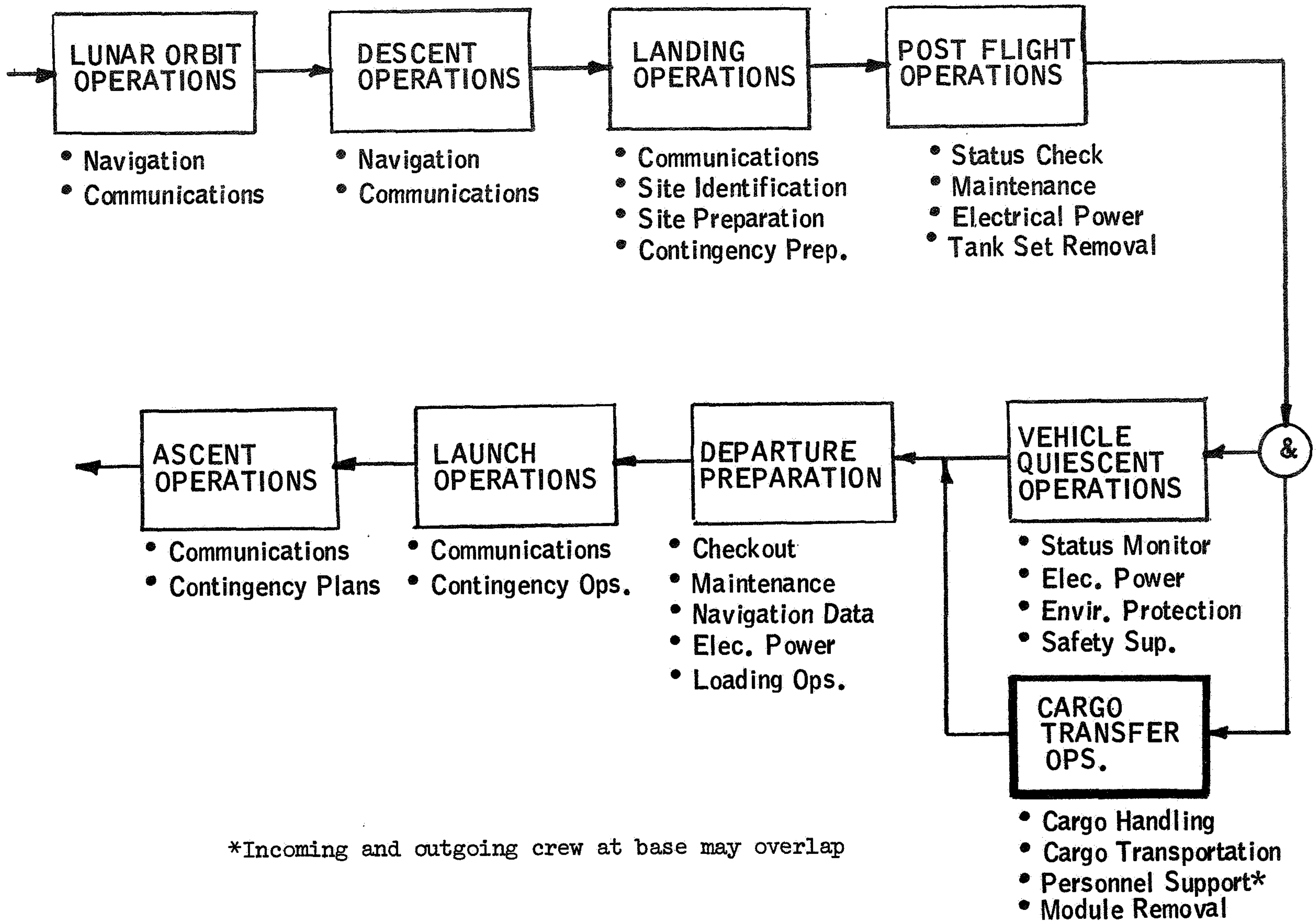


Figure 1.4-1. Logistic Vehicle Operations and Support Functions (Lunar Area Only)

The selected Tug concept will require removal of the expended tank set from the basic vehicle. These will weigh about 5,000 pounds and be fairly high above the lunar surface.

Environmental Compensation

If the logistic vehicle is to be reused, it may require added protection against the extended exposure to the lunar environment. To minimize loss of propellant, the external tank surface temperature should be maintained as low as possible and it appears that a reliquifaction facility to capture the boiloff and return it to the cryogenic state faction will be weight effective even though it is expected to require between 1 and 5 kw of electrical power. The power level required depends on the final insulation concept and the time within the day-night cycle.

A meteoroid bumper may be required to protect the vehicle from the secondary ejecta particles which are peculiar to the lunar surface.

Status Assurance

While the vehicle is on the surface for extended periods of time, its operational status must be assured and periodic maintenance and repair may be required. Facilities for transmitting status information to the base command center would be required, plus the electrical power to operate them. Additional power may also be required to power the logistic vehicle systems required to assess and assure operational status.

1.5 SURFACE VEHICLE INFERENCES

The requirement for and presence of surface vehicles lead to certain interface requirements on the LSB: (1) The base power must be able to recharge the local prime mover batteries; (2) The base must provide the mechanical interface to permit a shirtsleeve transfer, to eliminate the need for EVA transfer; (3) Facilities for at least 92 hours per month of vehicle maintenance is required. As indicated by Figure 1.5-1, the maintenance activities may be subdivided into internal and external maintenance and repair.

Internal maintenance is estimated to comprise the largest support activity; up to 16 maintenance hours per vehicle month is required to assure the operational status of the prime movers alone. The mobile shelter will also require internal maintenance. This may be accomplished through the same interface that provides the shirtsleeve transfer.

External maintenance is required for the prime mover and all trailers. The kinds of work projected for these vehicles can best be accomplished in a shirtsleeve environment. Although this requirement is limited to less than two hours per vehicle month, there are enough vehicles to bring this requirement up to over ten hours per month.

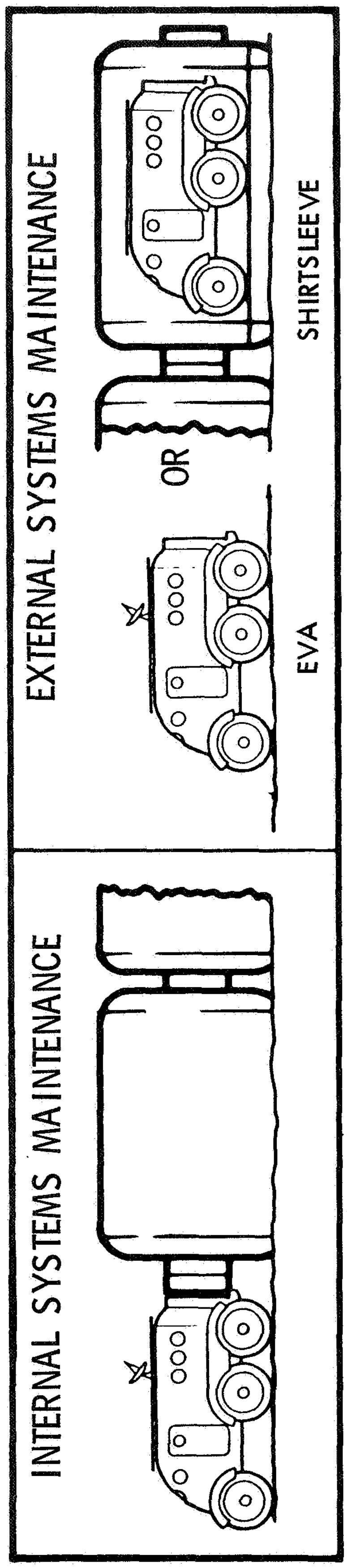


Figure 1.5-1. Vehicle Inferences

The two basic options illustrated in Figure 1.5-1 involve either the provision and use of a dedicated garage module or, performing the work under EVA conditions.

Some of the quantifiable factors associated with the garage concept include:

Garage and support equipment basic weight

Atmospheric losses due to leakage and residual loss after pumpdown

Garage systems maintenance time

The factors associated with the EVA maintenance concept include:

Special EVA tools and equipment

EVA work cost delta (increased time)

EVA systems maintenance

Airlock cycle costs

Cargo capabilities to supplant garage module function during initial buildup.

In addition, many other quantitative factors influence the choice, including the following:

Reliability/safety improved with garage

Design impact on mobility vehicle for EVA maintenance

Increased free volume for LSB and attendant redundancy with garage module

Capability for higher quality and more extensive work under shirtsleeve conditions

The quantitative factors have been assessed using factors derived for the subsystem and module characteristics, and the data are presented in the weight trade of Figure 1.5-2. Note that for very short programs the EVA concept is indicated to be weight effective, but for a 3 or 4-year program, the garage pays for itself. A comparison of electrical power costs indicate that they are approximately equal; the garage takes longer to pumpdown but the smaller crew airlock must be used about ten times more often.

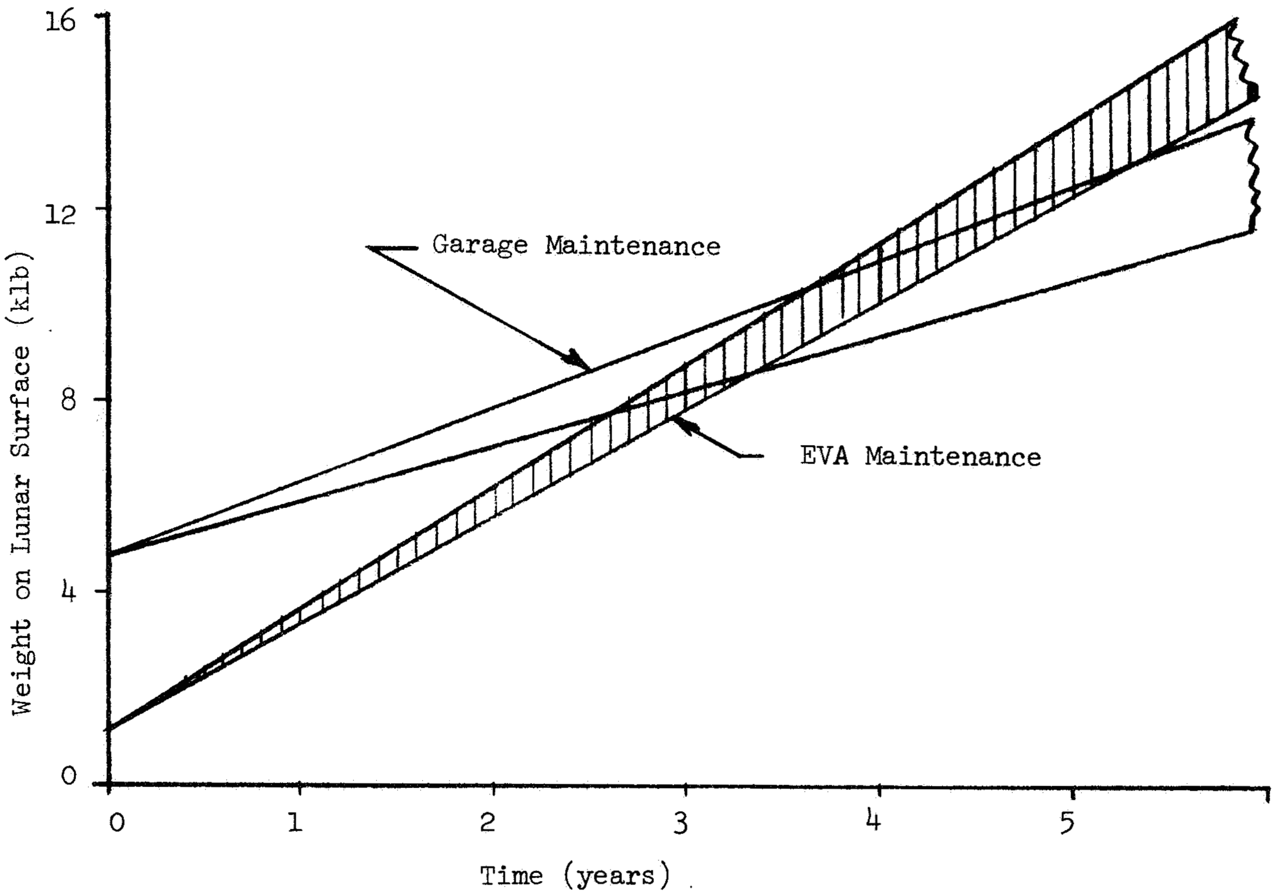


Figure 1.5-2. Garage Maintenance Vs. EVA Maintenance, External Systems Only

Spares support requirements are inferences on the supply system. Commercial operations indicate that the spares requirements for heavy equipment can achieve 8 percent of the vehicle weight each month where they are used continuously.

1.6 ENVIRONMENTAL INFLUENCES

The lunar environments and their effects have been described in Volume II and indicate that there are three environmental factors to be concerned with, temperature, meteoroids and solar radiation. The analysis indicated the most reasonable solution for protection against all of these factors is to bury (or cover) the shelter components with at least six inches of the lunar soil.

1.7 THE EVA REQUIREMENTS INFERENCES

The lunar exploration program requires a large amount of extra vehicular activity (EVA). The need to pass in and out of the shelter, outposts and enclosed vehicles imposes a requirement for some form of ingress/egress facilities. Three basic requirements have been identified in Figure 1.7-1.

1. Facilities to bring a large vehicle inside for shirtsleeve maintenance which involves volumes of over 3,000 $ft.^3$.

2. Facilities for a shirtsleeve transfer of crewmen from shelter to vehicles without EVA.

3. Airlock for at least four men at a time and facilities for removing lunar dust while performing the ingress operation.

1.8 MISSION SYSTEMS INTERFACE INFERENCES

The LSB mission is composed of many system elements as indicated by Figure 1.8-1. If each of these were designed independently the result would be a conglomerate of unrelated systems and subsystems. A base complex design must include the influences of the outposts, the vehicles and the EVA crewmen.

The EVA crewman expends up to one-half of his daily energy budget while outside the shelter. As a result, one-half of the O_2 is consumed and one-half of the resulting CO_2 could be outside the influence of the shelter subsystems and lost to the base complex. In the same way, it can be seen that the water budget, power and other functions could also be affected. Inadequate consideration of these interfaces could result in raising the personnel consumables requirements from about 9.5 pounds per man-day to over 20 pounds.

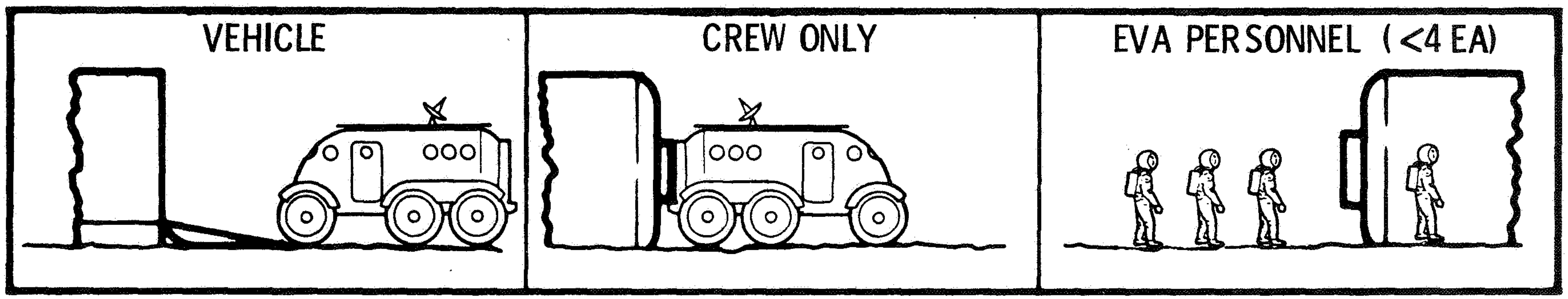


Figure 1.7-1. Ingress/Egress Considerations

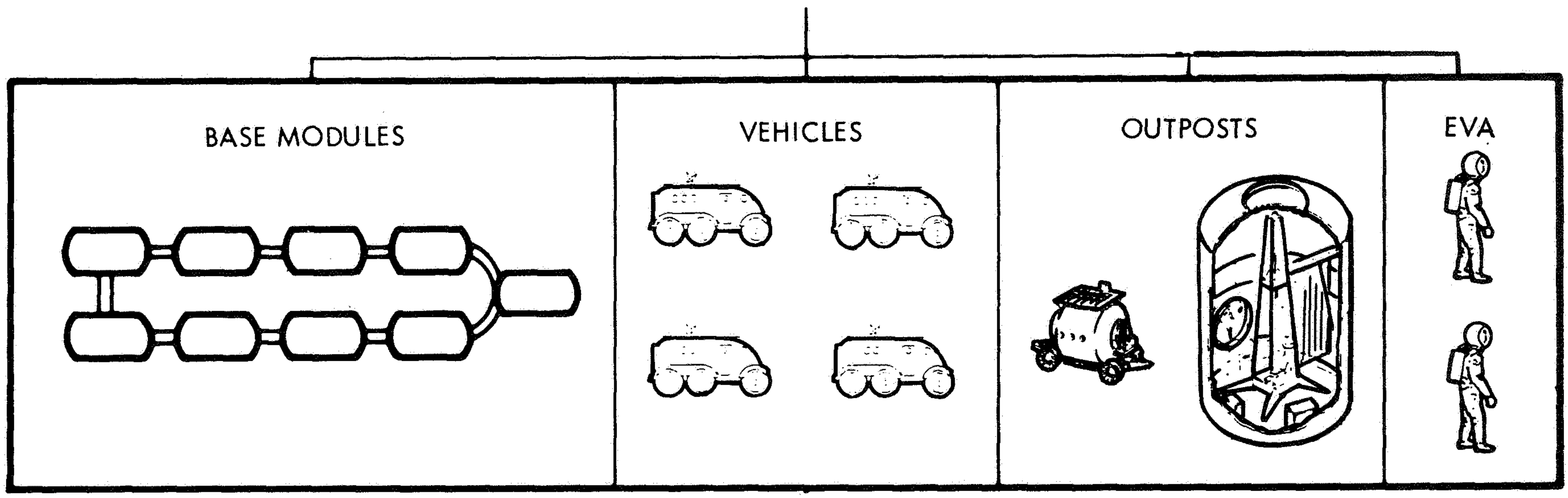


Figure 1.8-1. Subsystems & Mission System Interfaces

2.0 MODULE DESIGN TRADES

The LSB will be composed of a series of modules; the number, size, shape, orientation and construction of which were to be defined in the study. This section presents the basic module selection logic.

2.1 CONSTRUCTION CONSIDERATIONS

The construction of the basic building block modules for the shelter complex was determined on the basis of potential boundary conditions established by a logistic system and a weight optimized structure which would satisfy the functional requirements. The functional requirements for the module structure are defined in Table 2.1-1 and elaborated in the following.

1. Support the delivery loads of the basic module and installed equipment. These loads are estimated to be (based on Saturn V and others):

Load Condition	Acceleration (g's)	
	Lateral	Longitudinal
Boost	2.5	4.0
Lunar Landing	2.5	8.0

2. Contain a pressure of 10 psia ± 1.

3. Floors and doors support the operational loads associated with earth tests as well as on the moon.

4. Provide environmental isolation (since is is to be provided by soil, the shelter must support the soil and the deployment operations).

The internal pressure of the module was set at 10 ± 1 psia; however, the structural analysis indicated that launch loads were the predominant design factor. The pressure wall components were checked utilizing the minimum gauge equation:

$$t_i = (11.6 \times 10^6/E_i)\ (1.25 \times 10^{-4} D_i + 0.022) \text{ inches}$$

where E is modulus of elasticity and D is module diameter. It was found that pressure would not become a dominant factor until p = 14.1 psi for a ten-foot diameter module, 16.1 psi for a fifteen-foot module, and 20.1 psi for a twenty-foot module. Launch load bearing, therefore, becomes the dominant design criteria for the module design.

Table 2.1-1. Module Structural Design Considerations

Subsystem/ Primary Function	Functional Activity	Environmental Factors/Station Physical Constraints	Lunar Base Affected Parameters
Primary and Secondary Structure	Sustain handling, assembly, erection, gravity and functional loads Support a floor loading at least 40 pounds per square foot Internal/external pressures Leakage requirements System and subsystem interfaces Structural penetrations	Materials, conditions and properties Acceptable criteria (FS, MS, etc.) Minimum shop fabrication gauges Material thicknesses Local and general instability Station volume and exposed area Lifetime Acceptable leakage criteria Seals and lubricants space properties Emergency repair Aurthorized volumes and areas Lifetime of leaking fluids	Wall and floor thickness Bumper thickness Structural material Number and type of tool Number and type of crew Frequency of survey Frequency of repair Joint thickness Lubricants (weight of supplies and dispensers) Tools and procedures Frequency of inspection Frequency of repair
Thermal Protection	Thermal balance protection of crew and subsystems Reduce the worse case heat loss (lunar night) to less than 1 Btu/ft^2 of shelter area	Acceptable criteria Material properties Base volumes and areas Lifetime Internal/external arrangement	Struct. material properties and thickness Insul. properties and thickness Penetration effects Damage and repair Tools and procedures Freq. of inspection Frequency of repair
Radiation Protection	Rad. protection of crew and subsystems Reduce the probability of the worse case flare creating sickness to less than one chance in 10,000	Acceptable criteria Subsystems distribution and arrangement Emergency procedures for crew protection	Material properties Thickness Min. weight and distribution Shielding subsystem
Meteoroid Protection	Meteoroid protection of crew and subsyst. Reduce the probability of a penetration to less than one chance in 10,000 for the total program	Environmental characteristics Penetration mechanics Secondary ejecta Effects of related subsystems and struct, thermal and radiation protection, etc. Acceptable criteria Emerg. inspection, detection & repair Exposed volumes, areas Mission lifetime Terrain topography	Meteoroid bumper thickness Struct. wall thickness Insulation thickness Pressure wall thickness Struct. and bumper mat'l Fabrication technique Frequency of inspection Tools and procedures Frequency of repair Leakage effects Tanks and plumbing Heat radiators

Module design includes consideration of shape, as well as the constituent elements such as floors, walls, and bulkheads. The potential design options considered are identified by Figure 2.1-1; however, to simplify the the initial shape selection process, the wall, bulkhead, and floor factors were integrated into a strawman concept. Using a honeycomb floor design, various module/pressure bulkhead combinations were evaluated; the results are illustrated by Figure 2.1-2. The objective of this analysis was to determine the most weight efficient volume as a function of shape, given a fixed envelope (a cylinder) within which the module must fit. The example envelope selected was a 260-inch diameter by 260-inch cylinder. However, the parametric results are independent of baseline size. The structural load was based on a 10 psia internal pressure although this also exercises little influence on the results. Using the sphere as the baseline, the figure presents the weight/volume relationships for these various configurations. These data indicate that the modified toroidal shape is the most weight effective and the cylinder with ellipsoidal bulkhead design next. Other considerations including production complexity and effective use of the volumes led to selection of the cylinder with ellipsoidal bulkheads. This is used as a baseline configuration for the subsequent parametric analysis.

The construction concept options previously identified were evaluated on the basis of cylinder diameter where the ceiling height was fixed at eight feet with the ellipsoidal bulkhead baseline module used for reference. Figure 2.1-3 presents the estimated overall module weight for various module construction techniques as a function of its diameter. An internal pressure of 10 psia was again used and where the floor loading influenced the design, both 20 and 40 pounds per foot were considered. No protection was included for meteoroids, radiation, or temperature control. The weight is determined for the basic structure required to contain the pressure and support both static and dynamic loads. Figures 2.1-4 through 2.1-6 illustrate the basic shelter launch and delivery concept assumed for each module type to permit basic load estimates. Figure 2.1-7 illustrates two potential soft shelter designs after deployment, either of which will satisfy the design criteria after being properly emplaced. These may be of value for outposts and/or mobile shelters as required.

A review of the data from Figure 2.1-3 indicates that the nylon skin module would be lightest and the stackable rigid module the heaviest. If a three-man module were used as the baseline, the basic module weight (without any protection) would vary between 600 and 1700 pounds mass for these concepts. The 22-foot diameter module represents an upper probable limit for compatibility with projected launch and delivery systems. However, the weight trend per unit volume for all four design concepts increases with increasing diameters indicating that the smaller diameter modules are a more weight optimum design because of the shorter spans.

Assuming a cylindrical module with ellipsoidal bulkheads, the cylinder orientation was resolved on the basis of maximum usable floor area. A comparison of the two options reveals that when the length to diameter ratio reaches or exceeds 0.9 the floor should be parallel to the major axis and the module should be on its side. Two-story options are less desirable when deployment and loading factors are considered.

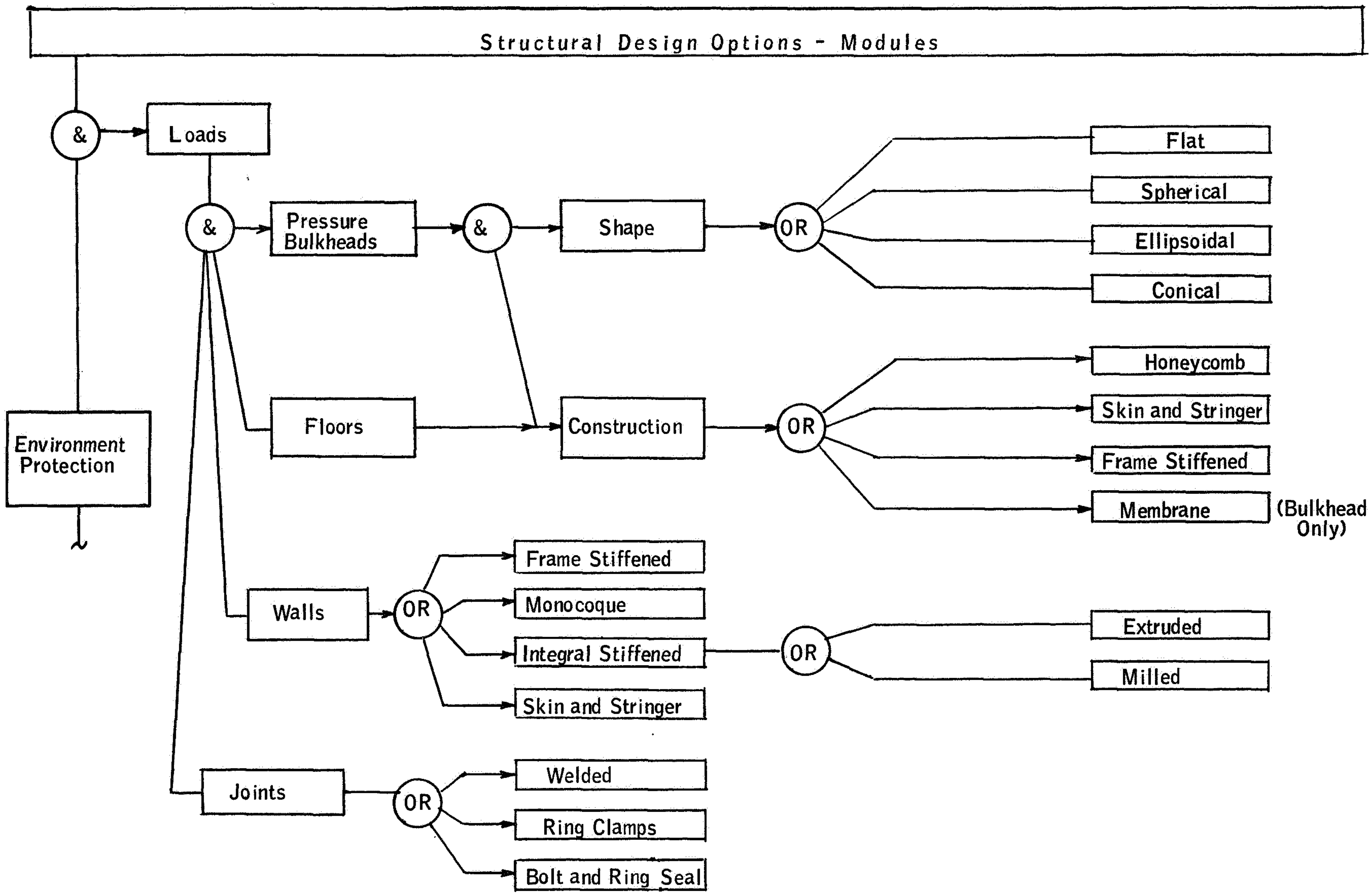


Figure 2.1-1. Structural Design Options - Modules

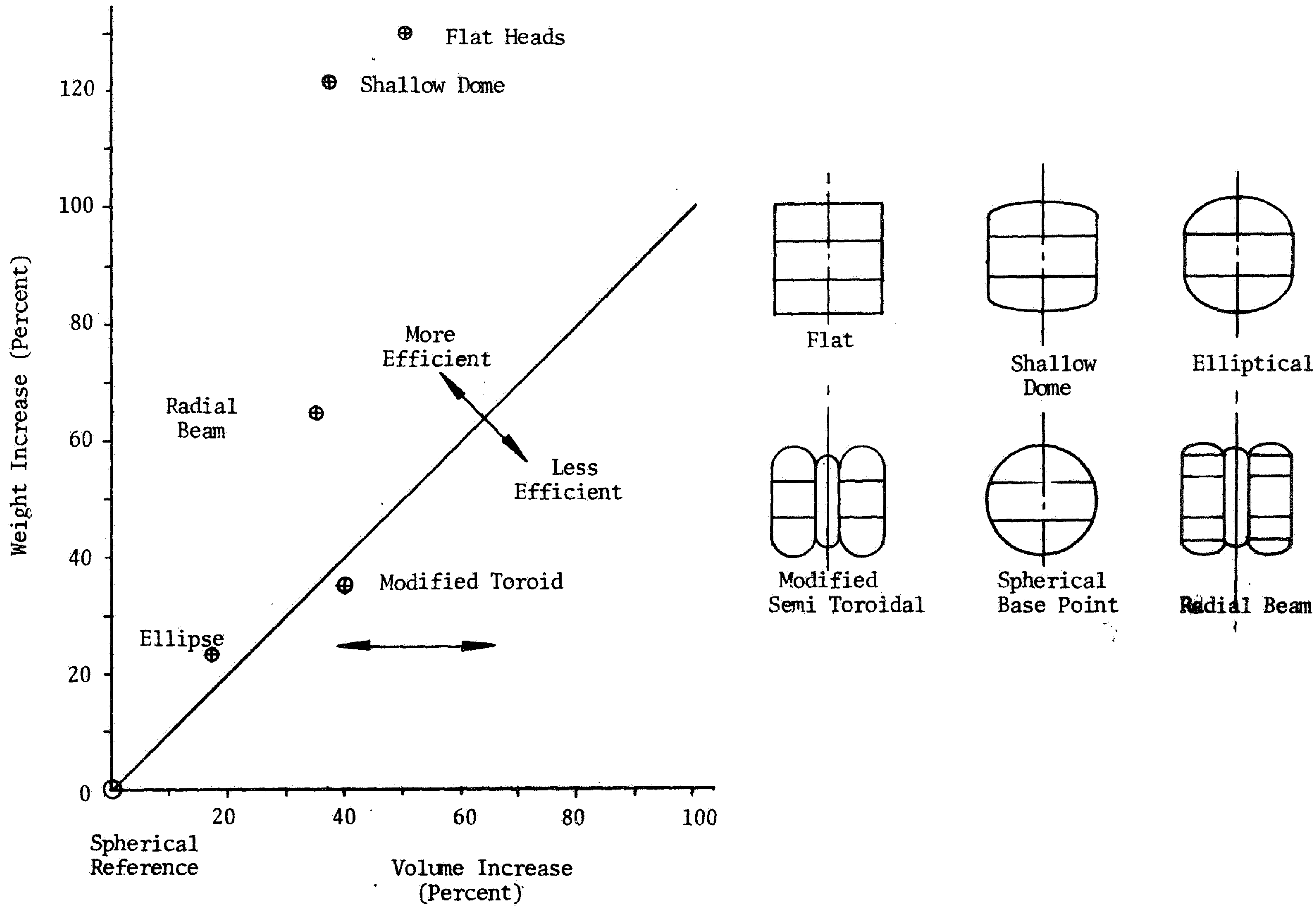


Figure 2.1-2. Shelter Module Design Trades - Shape Efficiency

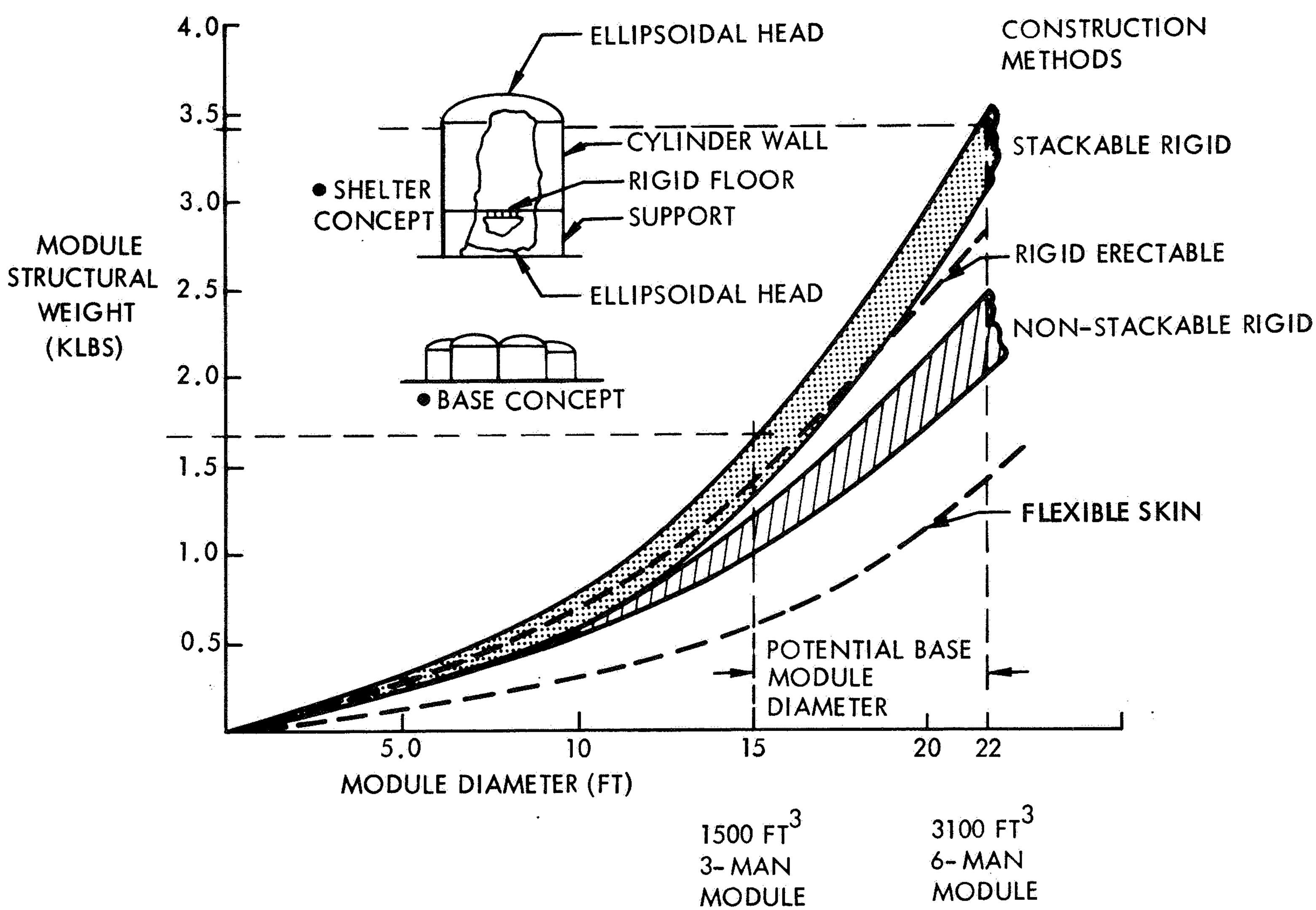


Figure 2.1-3. Shelter Module Design Trades - Construction

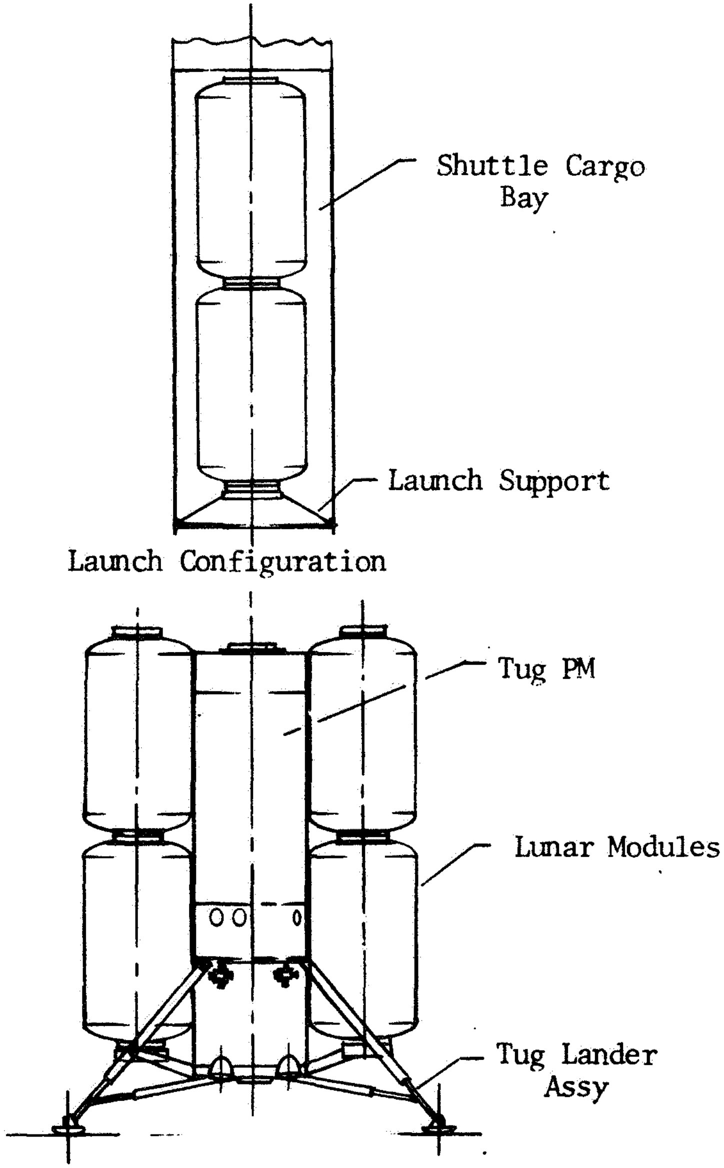


Figure 2.1-4. Rigid Module
Stacked Landing Concept

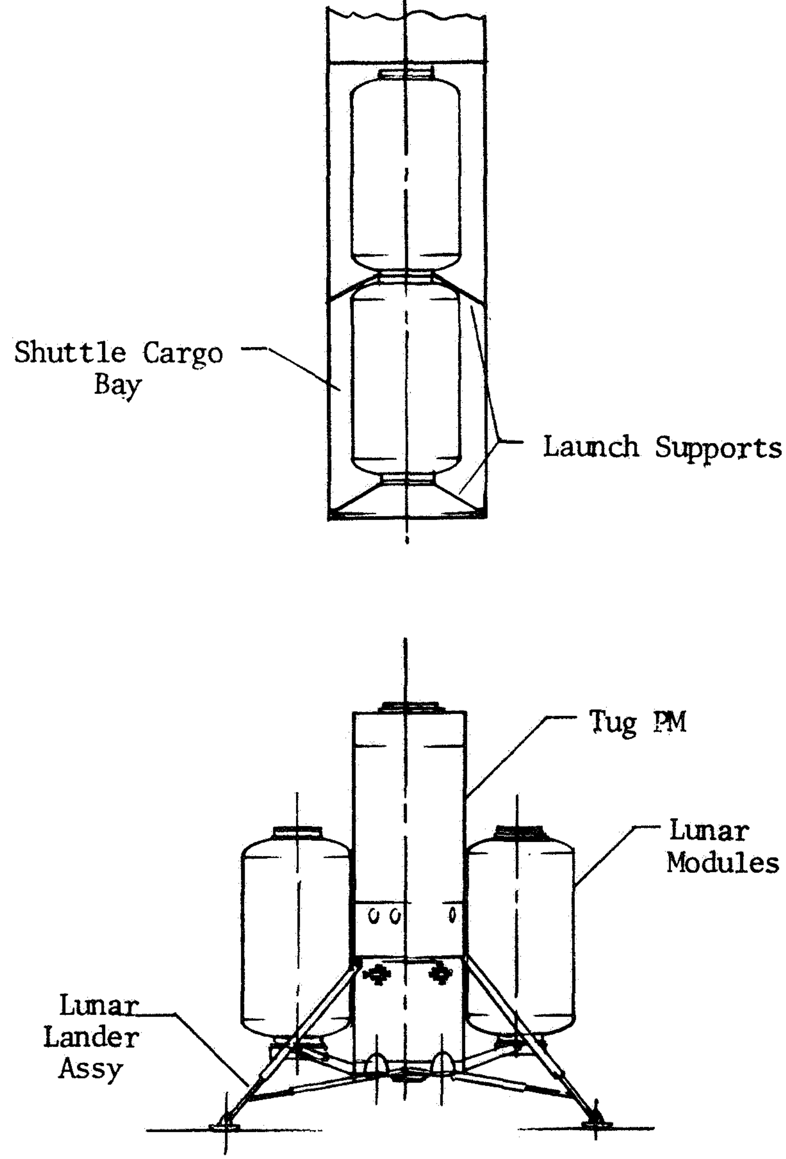


Figure 2.1-5. Rigid Module
Non-Stackable

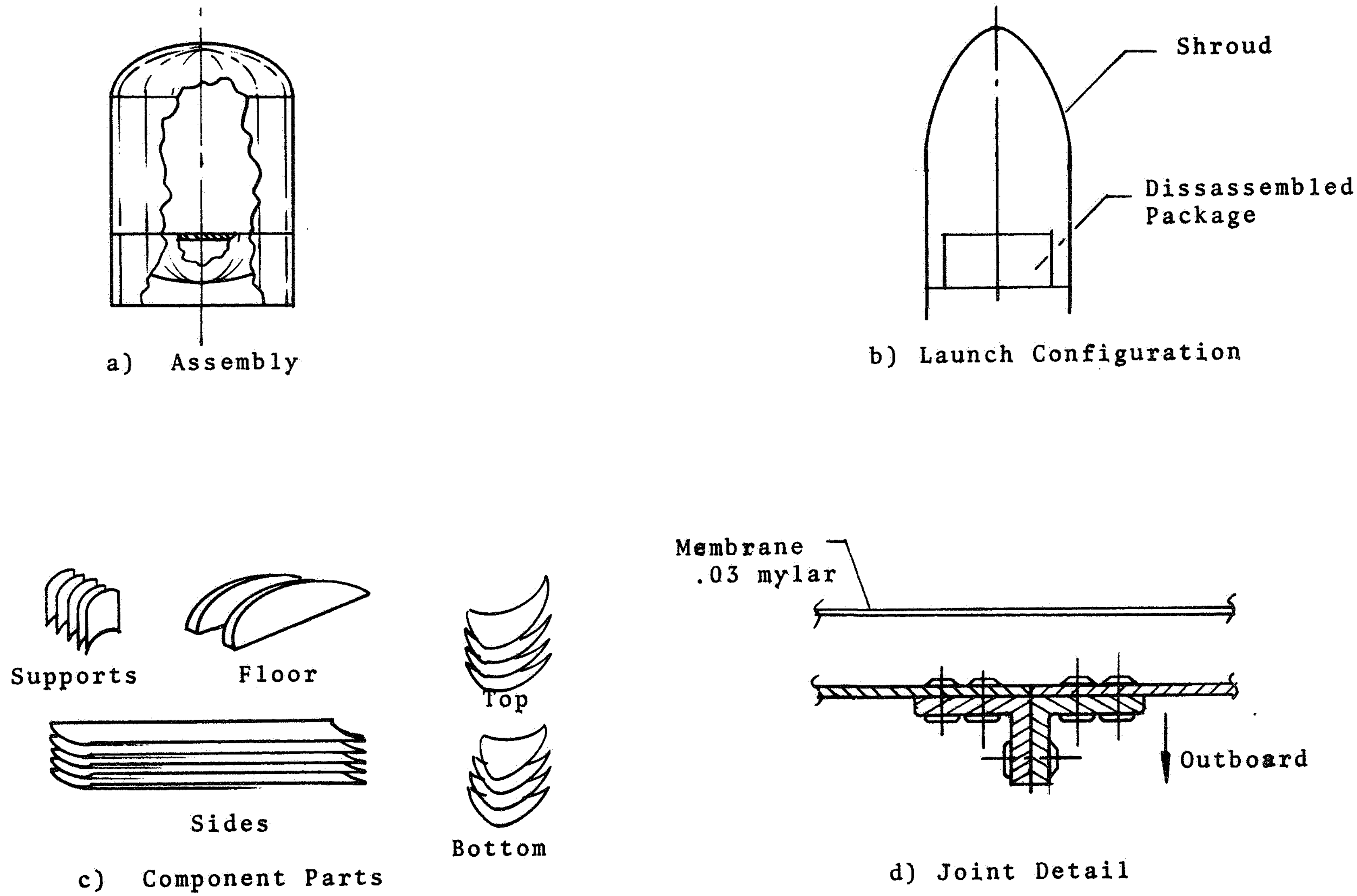


Figure 2.1-6. Rigid Module - Erectable Shelter

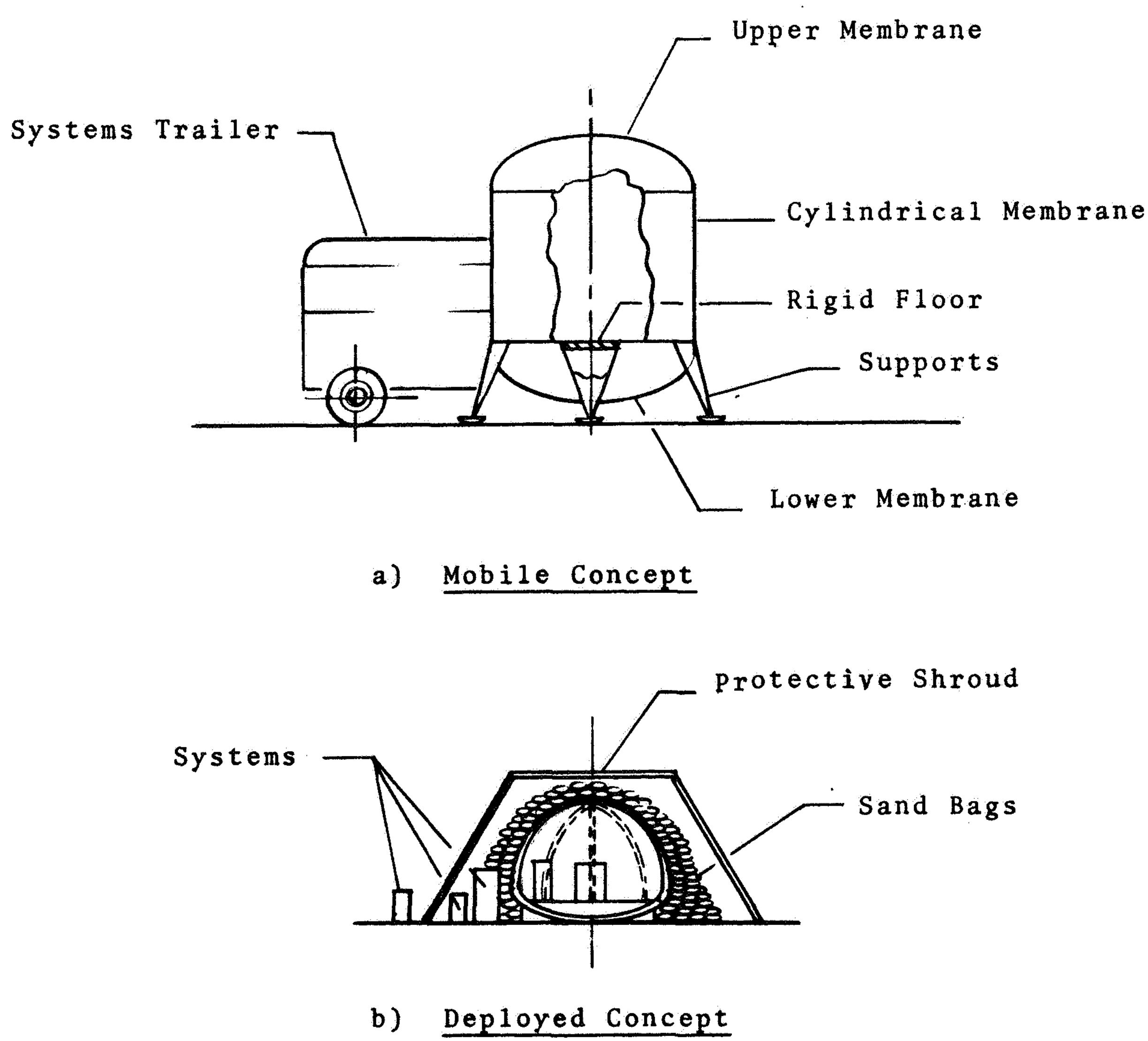


Figure 2.1-7. Potential Soft Erectable Shelter Concepts

2.2 BASELINE MODULE SIZE ANALYSIS

Considerations

The determination of an optimum module size (and shape) for the LSB considered the services required as well as the natural and operational environment. The services required were established by the habitability criteria. The natural environments impose the need for protection which can best be satisfied with six or more inches of soil. The operational environment, particularly the delivery and installation phases, therefore, include placement of the modules and the protective soil. Figure 2.2-1 identifies the operational environment factors which influence the module sizing. These factors are discussed in detail in subsequent sections.

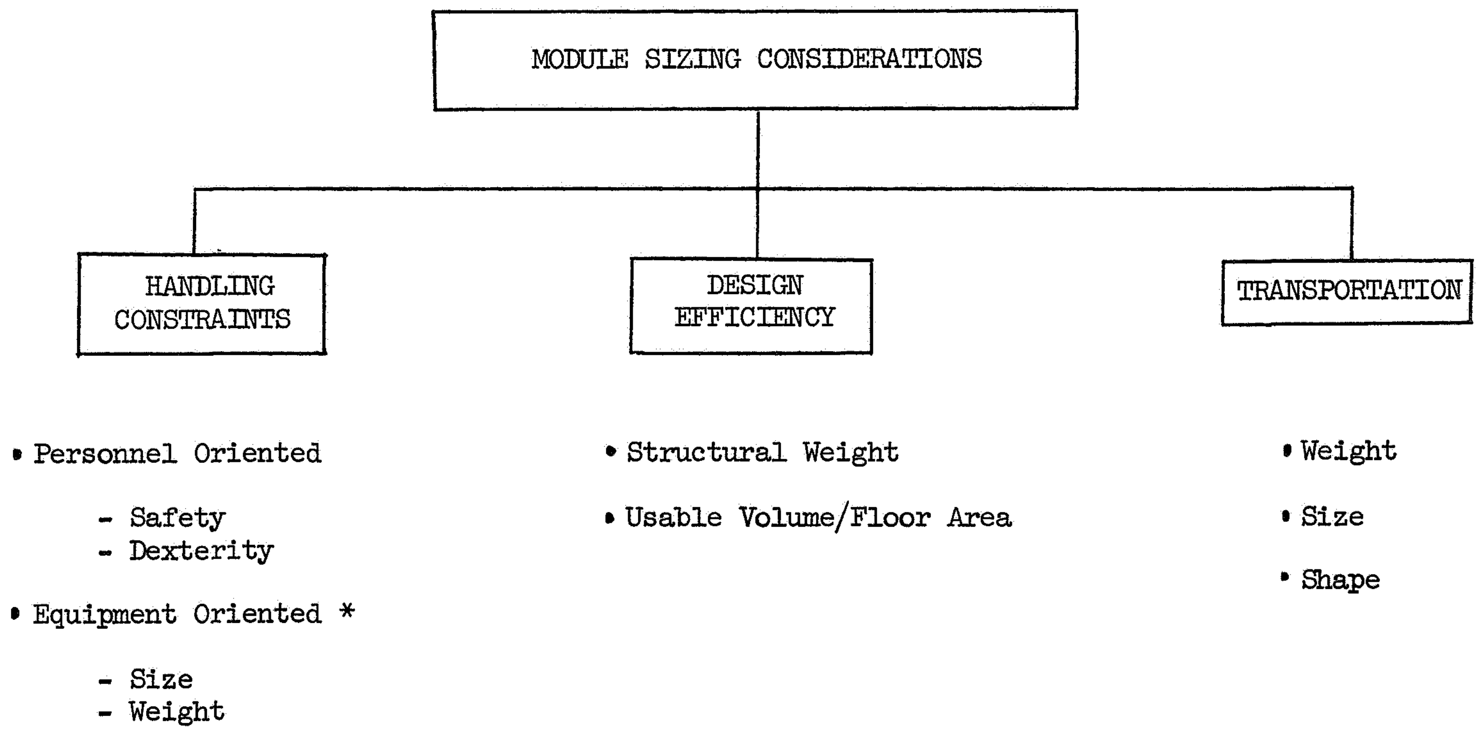
Handling Constraints

Handling constraints are imposed by both the involved personnel and the supporting equipment. Personnel constraints are the more qualitative in nature, being imposed by safety objectives and the crewman's limitations in performing EVA work. Safety considerations suggest minimizing crew direct participation particularly where large masses are involved. Also, the difficulties in performing detailed work in a spacesuit also minimizes his participation. Tasks such as construction of some form of "A" frame hoist, davit, gin pole, jib crane, etc., may be possible; however, the time required, marginal performance of a space-suited crewman, and the potential risks tend to rule them out where other options can be found. The basic approach adopted was, therefore, to eliminate manned operations where possible and to minimize the task complexity where he must participated.

Equipment oriented constraints arise from the need to augment crew capability with mechanical aids. An analysis (see Part 3, Section 2.0, Volume III of this report) of the aids suggested by a prior study (Reference 1) revealed that a simple hoist used as an attachment to a manned vehicle would provide the most flexible handling device and reduce manual operations to a simple attach and disconect operation, easily accomplished by the EVA crewman. Further, other construction oriented tasks such as observatory assembly can also be accomplished by the same equipment.

The analysis of the hoist operations on the lunar surface established the weight handling capabilities of a prime mover/hoist combination as a function of outrigger position and length. These data are based on the assumption that the mass is concentrated at the hoist lifting point and are computed on the basis of an estimated prime mover weight of about 6000 pounds.

When the assumed hoist capabilities are considered in concert with the estimated module diameter/weight relationships, some handling boundary conditions can be determined. The larger diameters tend to force the suspension point further from the vehicle, increasing the moment arm and reducing the hoist safe weight limit. If the further requirement to rotate the module through an arc of at least 90 degrees is considered, the module will be limited to a range between 10 to 18 feet diameter by 30 to 18 feet length respectively depending on the module density. These limits may be improved somewhat by



*See Volume III, Part 3, Section 2.0

Figure 2.2-1. Module Sizing Considerations counterbalancing the prime mover with a trailer; however, the system is thus more sensitive to vehicle orietnation and connection methodology. The more dense cargo modules when fully loaded would be limited to diameters between 8 to 16 feet.

Design Efficiency

The module should be designed to make maximum use of the structural weight to contain usable volume (or floor area). Figure 2.2-2 indicates the structural weight per cubic foot of a cylinder as a function of diameter for floor loadings of 20 and 40 psf. These data indicate that above approximately 16-foot diameters, the weight of the cylinder increases exponentially.

A lower limit on the module diameter is set by the dimensions of a crewman (approximately 6 feet). However, in general, the larger the dimensions, the more efficiently the volume and floor space can be functionally divided.

Transportation Constraints

The transportation system can constrain module weight, size, and shape. Since the transportation systems are indefinite at this time, two factors were considered. First, the guidelines in the contract indicated that any single module should be limited to 35,000 pounds.

Since module weight is related to diameter and length, the data can be related to potential crew and cargo modules. The mass characteristics of many crew modules were evaluated and found to have a range of densities from about 3.0 to 5.0 pounds per cubic foot. (Space station modules tended to be on the high end of the spectrum because of the meteoroid protection requirements in free space whereas a buried lunar shelter module would be on the lower boundary because of the lightweight structure possible.) A plot of projected module mass as a function of cylinder diameter-to-length ratios from 1:1 to 1:3 indicates that the diameter is constrained by the 35,000-pound maximum unit weight to 25 to 14 feet, the length varying inversely from 25 to 42 feet. (See Section 2, Part 2) Since most delivery concepts involve use of a matched pair of modules (see below), these boundaries are further reduced to 23 and 13-foot diameters with lengths varying inversely from 23 feet to 39 feet.

Secondly, the projected space vehicle environment for the 1980's was considered for potential guidelines. As indicated in Figure 2.2-3, three vehicles form the most probable logistic system.

1. The Earth Orbit Shuttle (EOS) has a cargo bay presently limited to 15 feet in diameter and 60 feet long and maximum payload weights between 25 and 44K pounds.

2. The Reusable Nuclear Shuttle (RNS) imposes only a weight constraint which is much greater than the projected module weights.

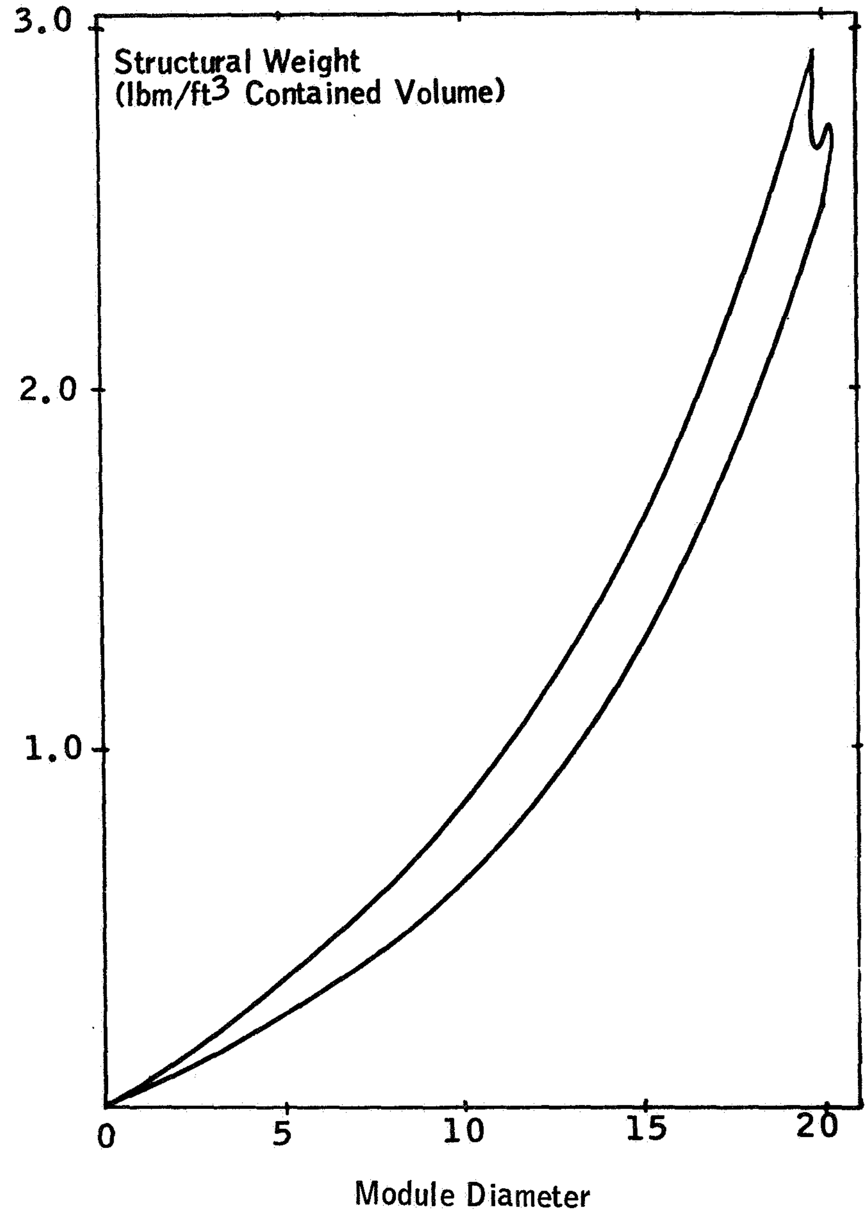


Figure 2.2-2. Weight Efficiency

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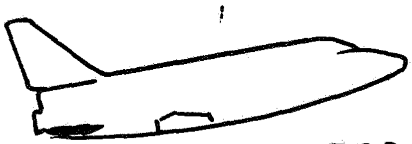
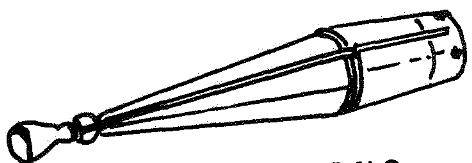
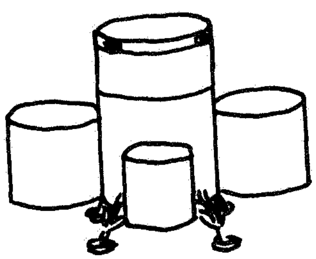
VEHICLE	SIZE (FT)	WEIGHT (KLB)	SHAPE
 EOS	15 DIA 60 LONG	• @ 31.6° x 258 NM 38 K	CYLINDER
 RNS	FLEXIBLE ≲ 33 DIA	• MANNED > 130 K • UNMANNED > 150 K	UNRESTRICTED
SPACE TUG 	11 TO 20 DIA MIN. LENGTH FOR LOW C.G.	• MANNED > 44 • UNMANNED > 66	MATCHED WT. PAIR

Figure 2.2-3. Potential Delivery Vehicle Constraints

3. The Reusable Space Tug imposes dimensional constraints although the landed weight capability is well above the 35,000-pound constraint. However, as indicated, the strap-on concept geometry would constrain the module diameter to a range between 11 and 20 feet. This is based on delivering a matched pair each trip. Delivery on top of the vehicle would make handling on the lunar surface more difficult and tends to raise the landing c.g. As indicated by Figure 2.2-4, every 5-foot increase in c.g. height reduces the potential payload by over 1200 pounds.

A summary of module diameter selection criteria is presented in Table 2.2-1. While none of these criteria are absolutely constraining, they indicate a bracketing of module diameter constraints to the range 13 to 16 feet. Since the EOS is being designed with a 15-foot diameter clearance in the cargo bay which is within the bracketed range, 15 feet was selected for the baseline shelter module.

Once the diameter is selected, the length of the module is dependent on its weight as an upper boundary, the functional requirements, and buildup plan. These are considered in the subsequent section.

2.3 MODULE OPTIONS AND TRADES

Starting with the 15-foot diameter module and approaching the 12-man base in logical increments, there are four possible combinations for the crew (see Figure 2.3-1) and the other functions can be handled with the same module concept or as indicated.

The approach selected was to first identify the crew module approach and then fit the other functions into that concept to arrive at a single standardized module.

The Three-Man Module Concept

This concept (Drawing 2284-2) is based on a 15-foot by 15-foot baseline module with a little over 2500 ft^3 of contained volume, 1500 ft^3 of which may be considered free volume. This is adequate for three men but not optimum; use of two as a pair would be more desirable but would weigh more than the 15 x 30 module and provide less volume.

Standardization on a single module size would eliminate this size from consideration if the prime mover were garaged for maintenance in a rigid module. The prime mover requires a module over 20 feet in length for garaging.

These modules would weigh about 6.5K-pounds mass and would be relatively easy to handle. An optional base complex was designed using this module size, with the cylinder horizontal to provide the largest available floor area.

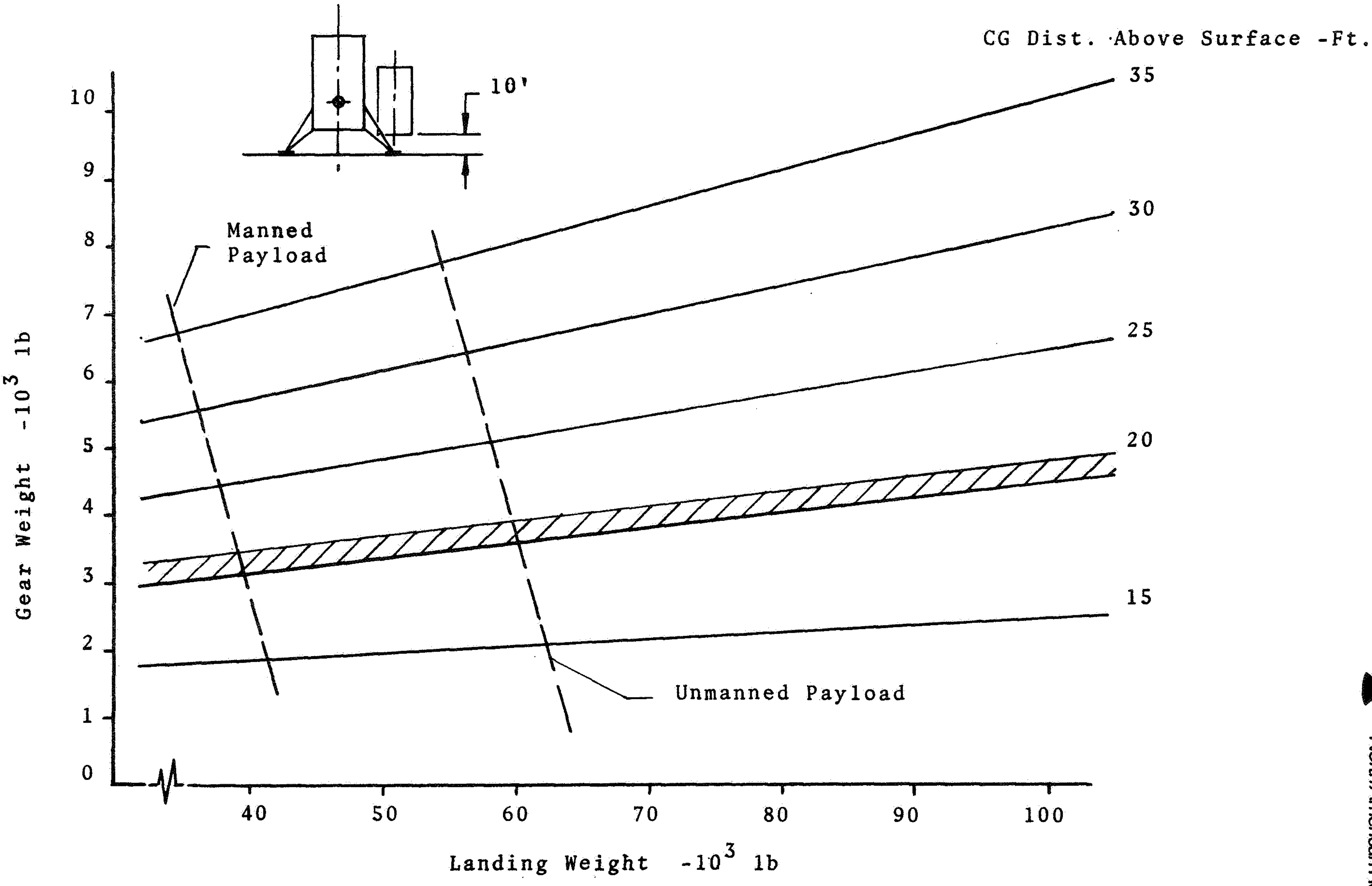


Figure 2.2-4. Cargo Difference on Tug CG and Weight

Table 2.2-1. Summary of Module Selection Constraints

CONSIDERATION	WEIGHT CONSTRAINT (Klb)	DIAMETER CONSTRAINT (ft)	LENGTH (ft)	CONSTRAINING FACTORS
Personnel	Minimize	Minimize	Minimize	Safety and dexterity
Module Density				
. Crew Modules	35	13-23	39-23	Statement of work
. Cargo Modules	35	9-17	27-17	Statement of work
Cargo Handling	4-10	10-18	30-18	Hoist arm/prime mover weight
Structural Eff.	35	<16	None	Large floor and dome spans
Potential Vehicles				
. EOS	25-44	≤15	60	Cargo bay/payload
. RNS	130-147	33	None	Payload provisions
. Tug	20-30*	11-20	Minimize	Payload and strap-on space

*Each of a matched pair.

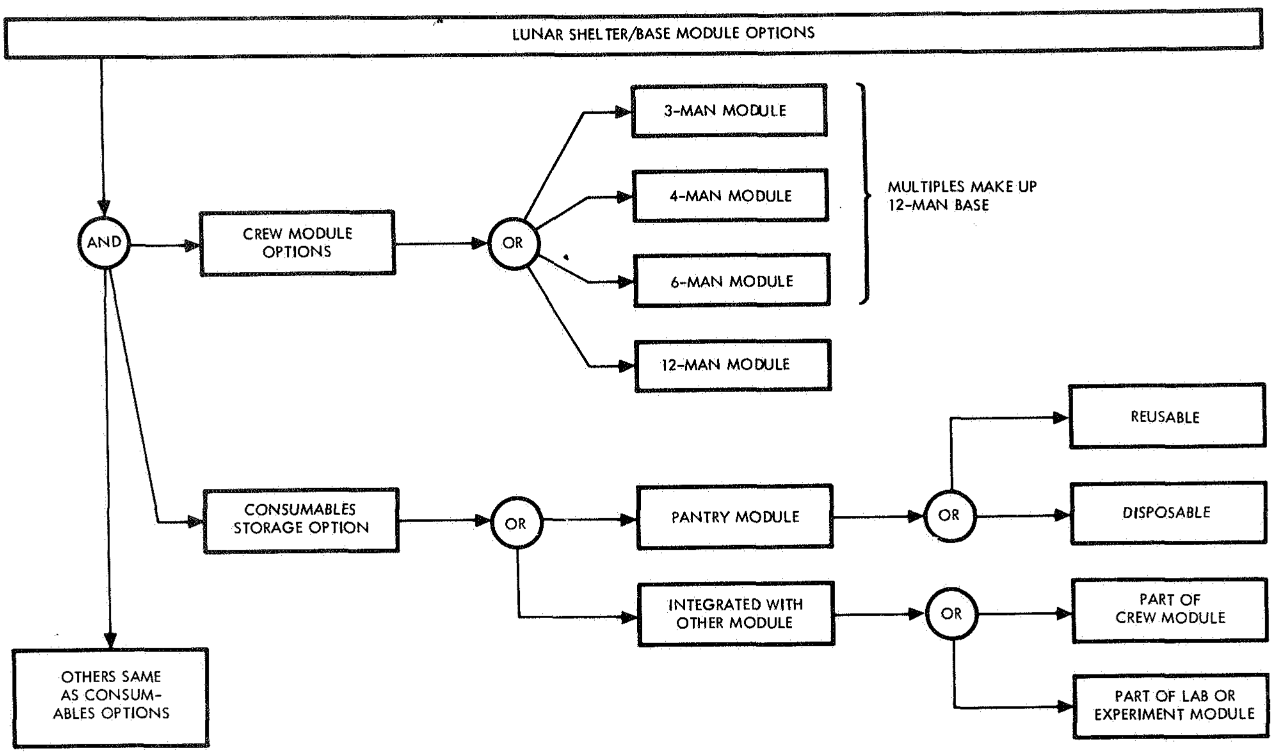


Figure 2.3-1. Shelter/Base Module Options

The Four-Man Module Concept

Drawing 2284-1 illustrates a 15 x 30-foot cylinder with two floor configurations. Also shown is a vertical orientation; however, this arrangement provides less floor area and would present greatly increased difficulties in an attempt to bury them or even sandbag them.

This configuration provides about 5650 ft^3 of contained volume, over 3000 of which is free of encumberances. They are expected to weigh less than 9.5K pounds dry and can, therefore, be handled by the lunar hoist.

These modules are large enough to contain the prime mover and any trailers and, therefore, may be used as a garage module or drive-in warehouse as well.

The baseline base configuration has been evolved around these modules since they provide adequate facilities and room for expansion as required within a manageable size.

The Six-Man and Twelve-Man Module Concepts

Drawing 2284-6 presents a representative six-man module, approximately 15 feet in diameter and 60 feet long. The contained volume is in excess of 10,000 ft^3, about 6000 of which is free volume.

Both the six-man and the twelve-man modules were eliminated fairly early in the study because of their projected weights. The six-man modules would have to be moved after arrival at the moon in order to assemble them into an integrated twelve-man base. This was considered to require an excessive investment in specialized equipment and EVA operations for base buildup. The twelve-man module concept would exceed the 35,000 pounds guideline limit on landed weight and would present additional environmental protection and operational complications since it would be impractical to remove it from the landing vehicle.

2.4 BASELINE MODULE DESIGN

The basic module shape and size has been defined in the previous sections. Specific details on bulkhead design, wall structure, module cross section and the docking/handling mechanism to define the recommended baseline modules are described in this section.

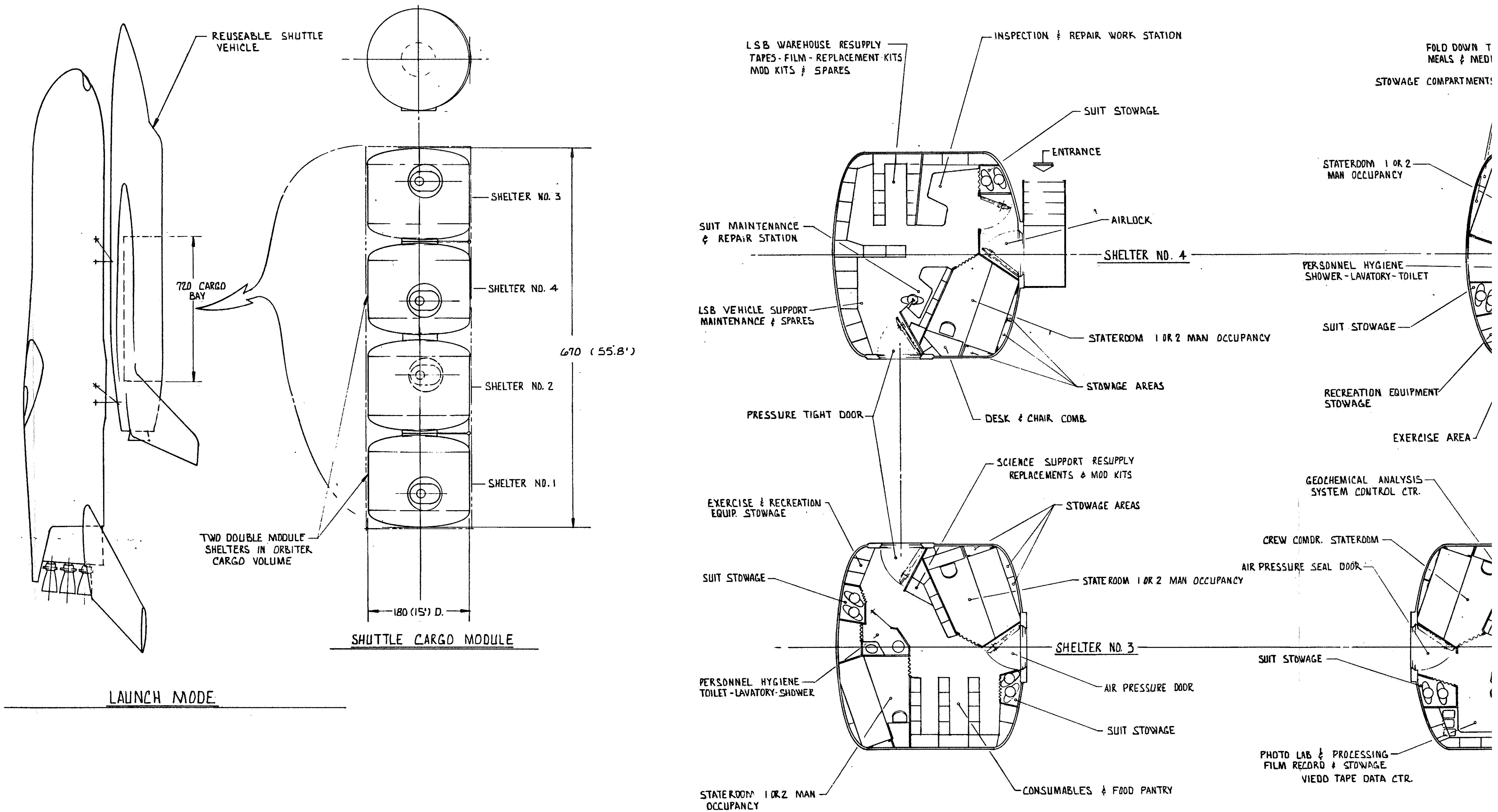
Bulkheads

The bulkhead options considered are illustrated by Figure 2.4-1. Table 2.4-1 presents the resulting trade data when only internal pressure forms the design critieria. On this basis, the hemispherical bulkhead is the lightest with the ellipsoidal heads second. However, when the docking/ space handling loads are considered, the options are reduced to those illustrated by Figure 2.4-2. These data indicate that the modified ellipsoidal head will satisfy both load requirements and is the lightest option. This is, therefore, the recommended bulkhead configuration.

Outer Walls

The outer wall construction options considered are illustrated by Figure 2.4-3, which also presents the associated weight data. An analysis of these options, the associated weight data, and other more qualitative data, results in the conclusion that the fiberglass and structural foam option is optimum in the following respects:

1. Weighs only 0.62 pound per square foot
2. Outer fiberglass and foam reduces the in-transit thermal problems
3. Potentially flammable materials are exterior
4. Smooth internal walls permit better space utilization, enhance cleanliness control, and permit a fireproof coating
5. Simple construction and, therefore, low cost



REUSEABLE SHUTTLE VEHICLE
720 CARGO BAY
TWO DOUBLE MODULE SHELTERS IN ORBITER CARGO VOLUME
SHELTER NO. 3
SHELTER NO. 4
SHELTER NO. 2
SHELTER NO. 1
670 (55.8')
180 (15') D.
SHUTTLE CARGO MODULE
LAUNCH MODE
LSB WAREHOUSE RESUPPLY TAPES - FILM - REPLACEMENT KITS MOD KITS & SPARES
INSPECTION & REPAIR WORK STATION
SUIT STOWAGE
ENTRANCE
AIRLOCK
SUIT MAINTENANCE & REPAIR STATION
SHELTER NO. 4
LSB VEHICLE SUPPORT MAINTENANCE & SPARES
STATEROOM 1 OR 2 MAN OCCUPANCY
STOWAGE AREAS
PRESSURE TIGHT DOOR
DESK & CHAIR COMB.
SCIENCE SUPPORT RESUPPLY REPLACEMENTS & MOD KITS
EXERCISE & RECREATION EQUIP. STOWAGE
STOWAGE AREAS
SUIT STOWAGE
STATEROOM 1 OR 2 MAN OCCUPANCY
SHELTER NO. 3
PERSONNEL HYGIENE TOILET - LAVATORY - SHOWER
AIR PRESSURE DOOR
SUIT STOWAGE
STATEROOM 1 OR 2 MAN OCCUPANCY
CONSUMABLES & FOOD PANTRY
FOLD DOWN T
MEALS & MEDI
STOWAGE COMPARTMENTS
STATEROOM 1 OR 2 MAN OCCUPANCY
PERSONNEL HYGIENE SHOWER - LAVATORY - TOILET
SUIT STOWAGE
RECREATION EQUIPMENT STOWAGE
EXERCISE AREA
GEOCHEMICAL ANALYSIS SYSTEM CONTROL CTR.
CREW COMDR. STATEROOM
AIR PRESSURE SEAL DOOR
SUIT STOWAGE
PHOTO LAB & PROCESSING FILM RECORD & STOWAGE VIEDO TAPE DATA CTR.

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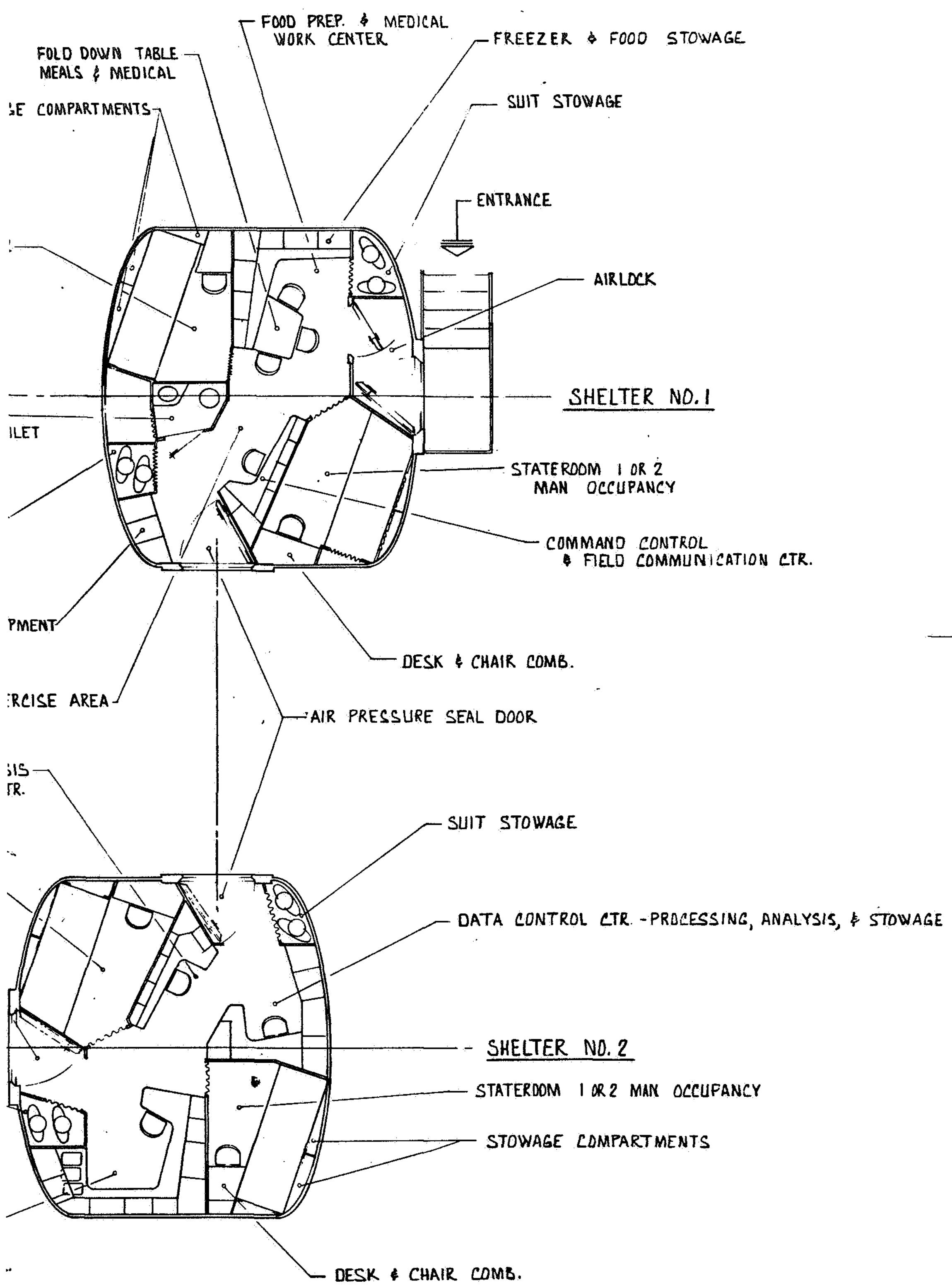

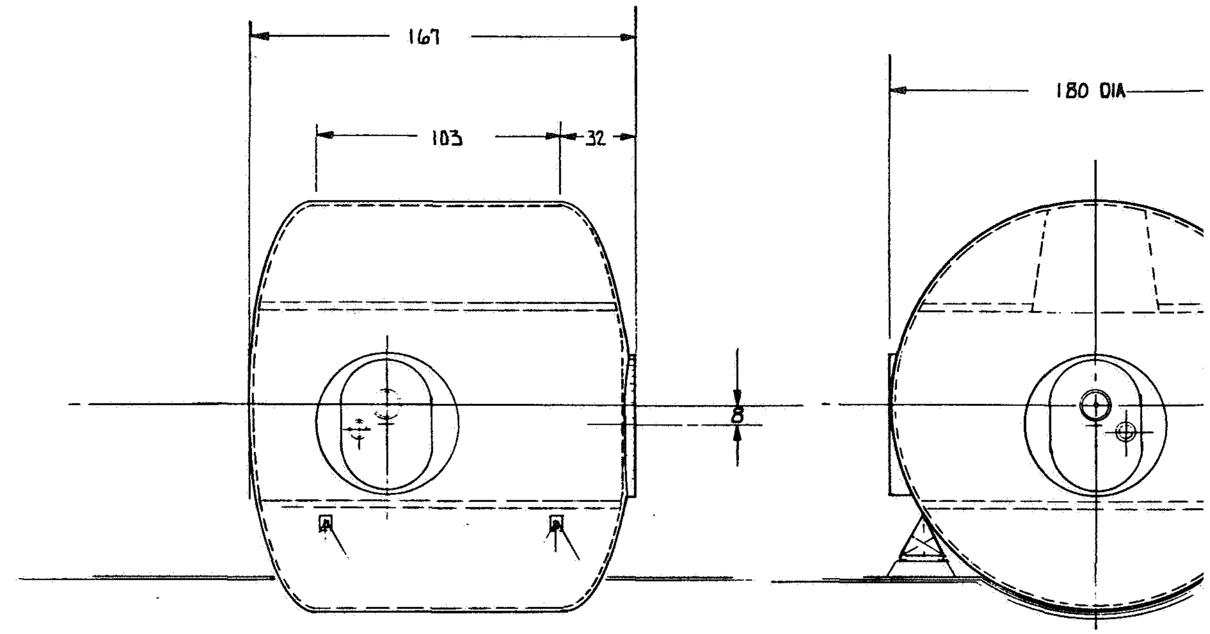

LSB MODULE - BASIC CONFIG.

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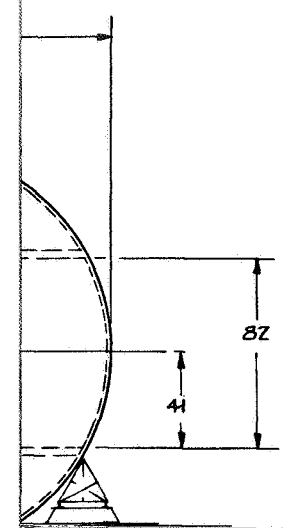

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SD 71-477

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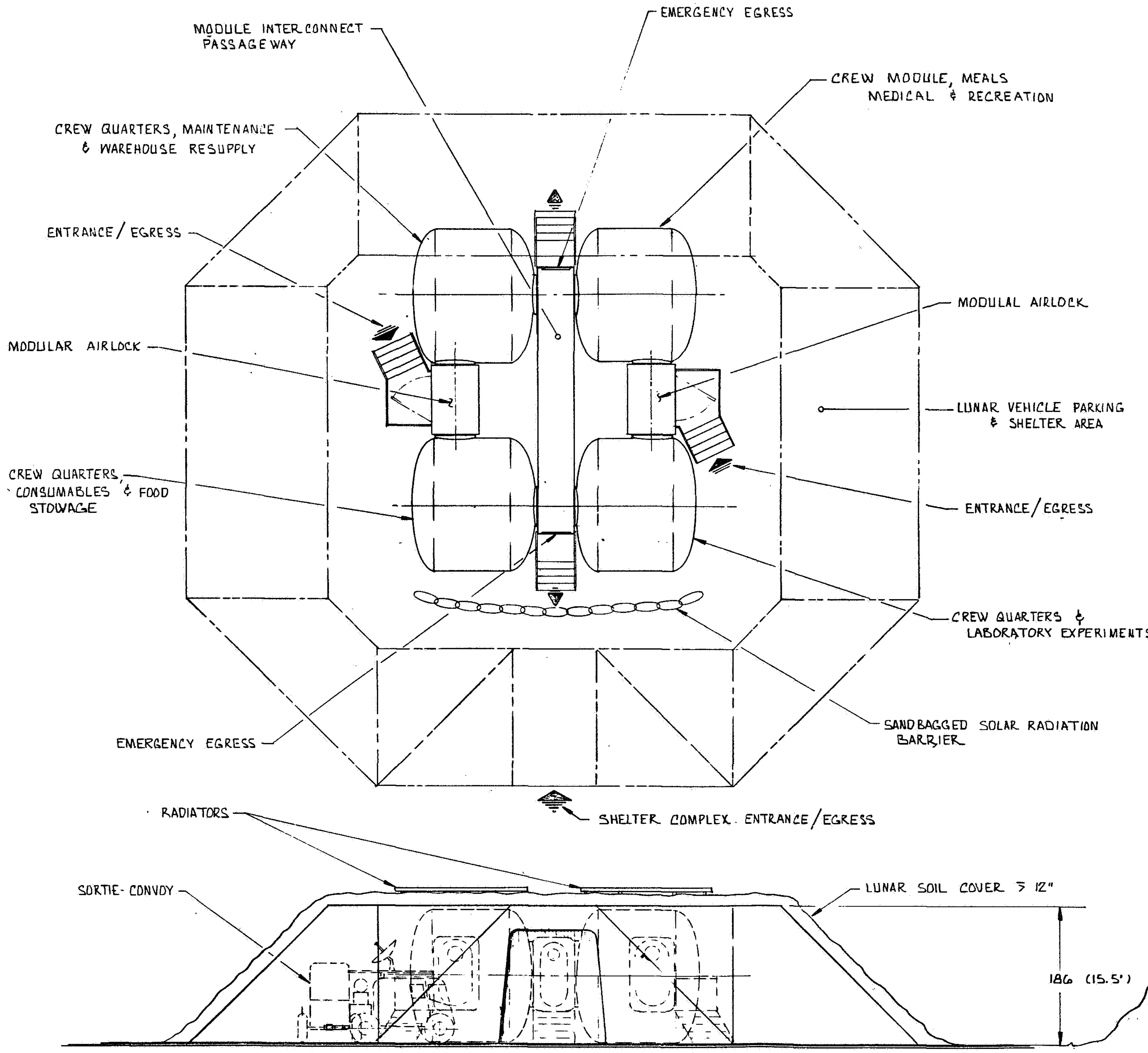
15 DIA MODULE & COMPLEX LAYOUT-LUNAR BASE SHELTER			2284-2 SHT 1 OF 2

FOLD-OUT # 3



LUNAR BASE COMPLEX - 12 MAN

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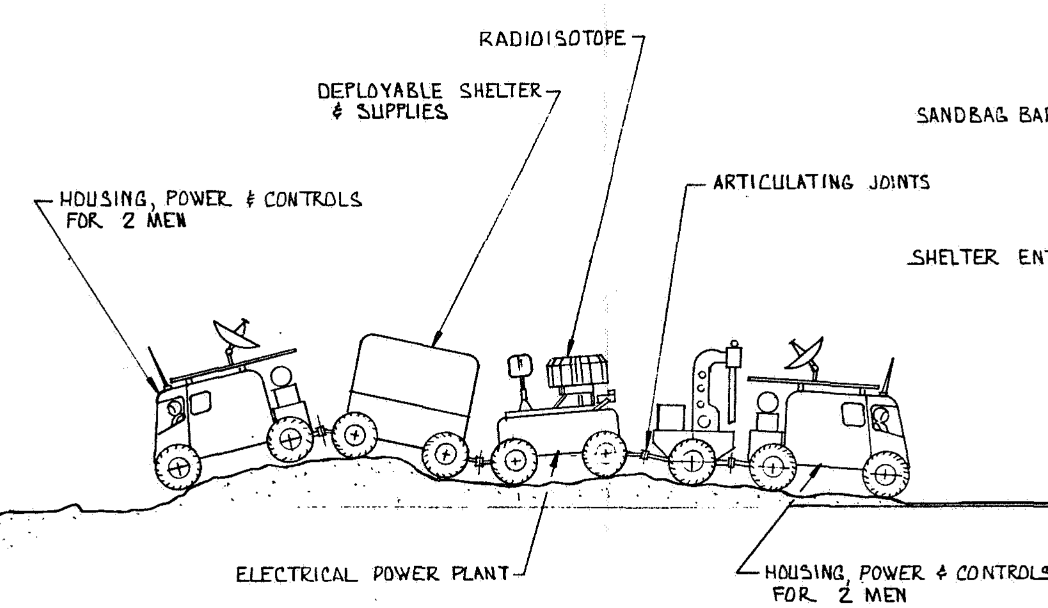
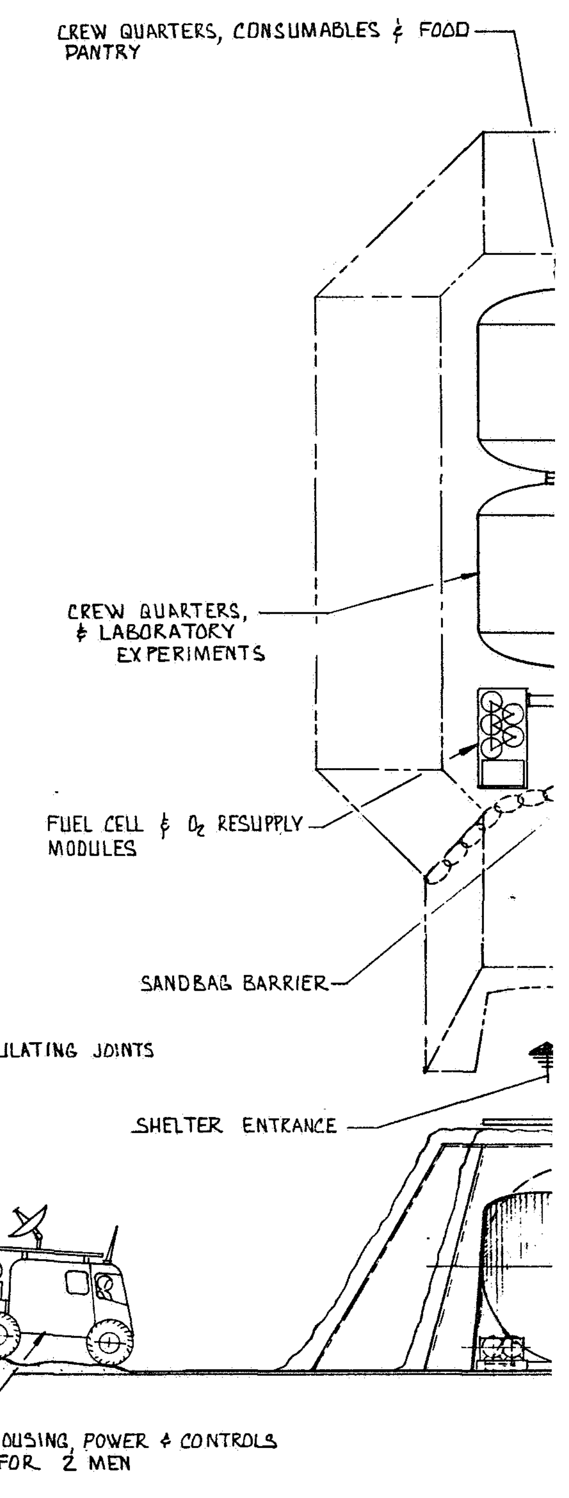


SORTIE CONVOY CONCEPT



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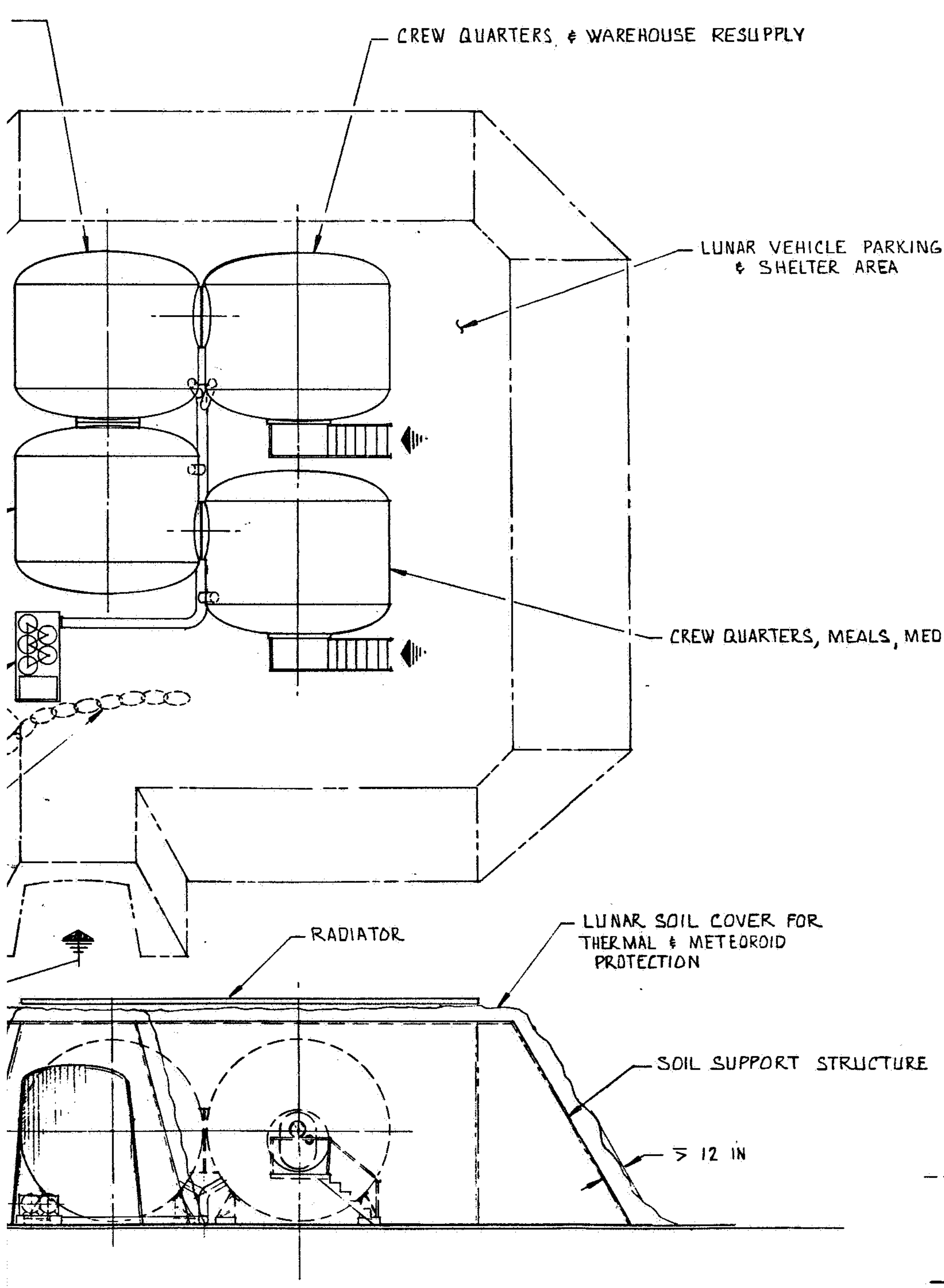
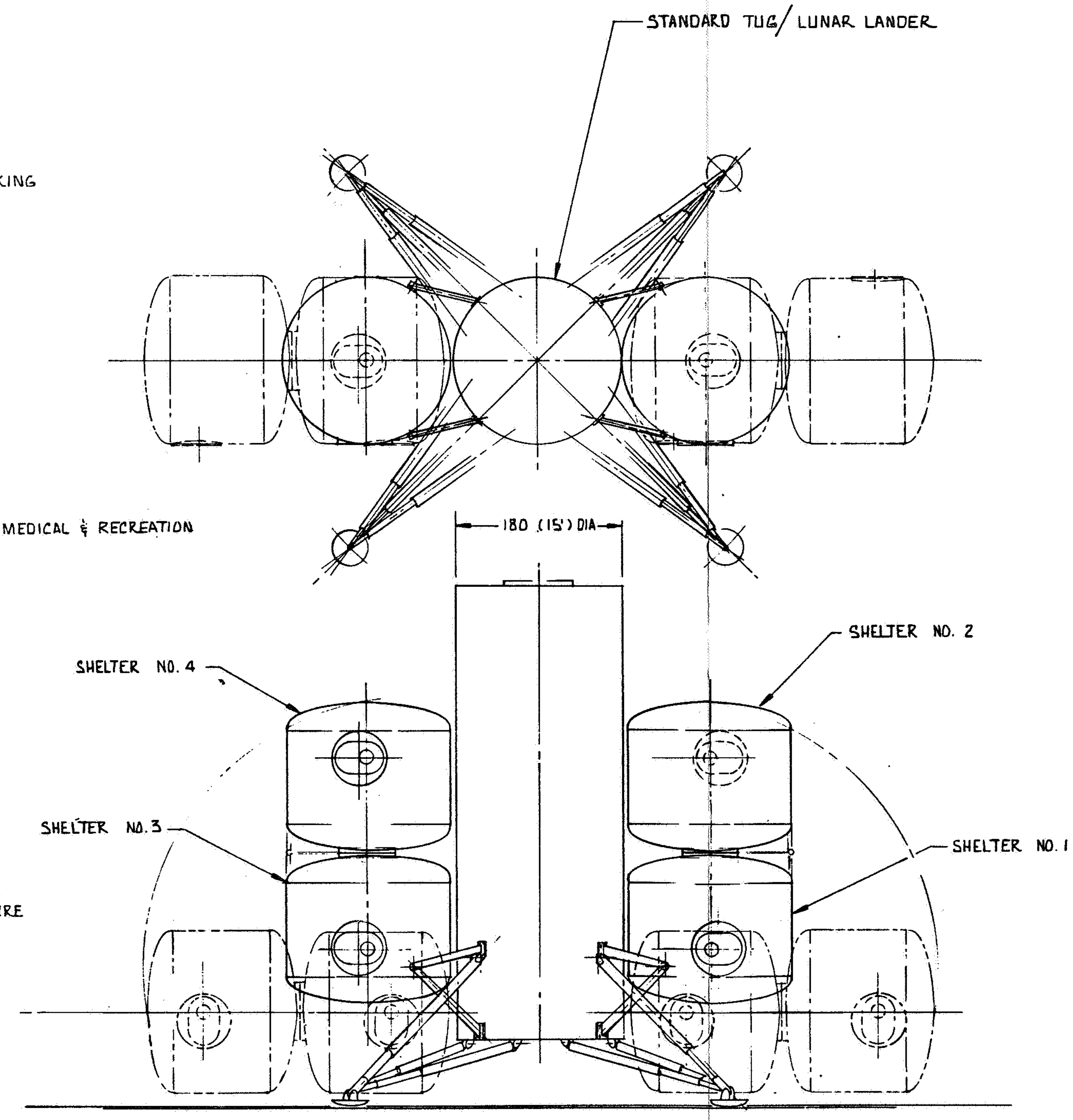


LUNAR BASE CONCEPT (12 MAN)



LUNAR SURFACE DELIVERY

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SD 71-477

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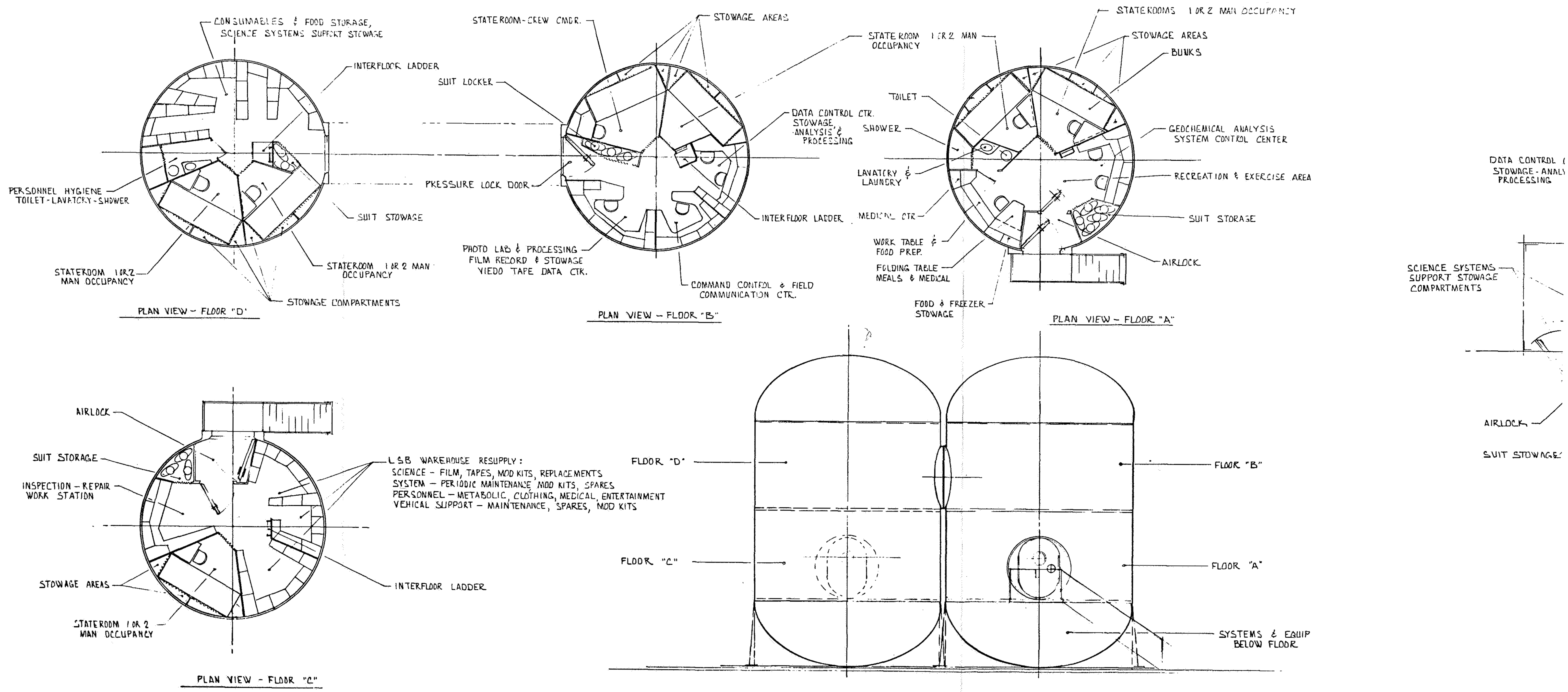
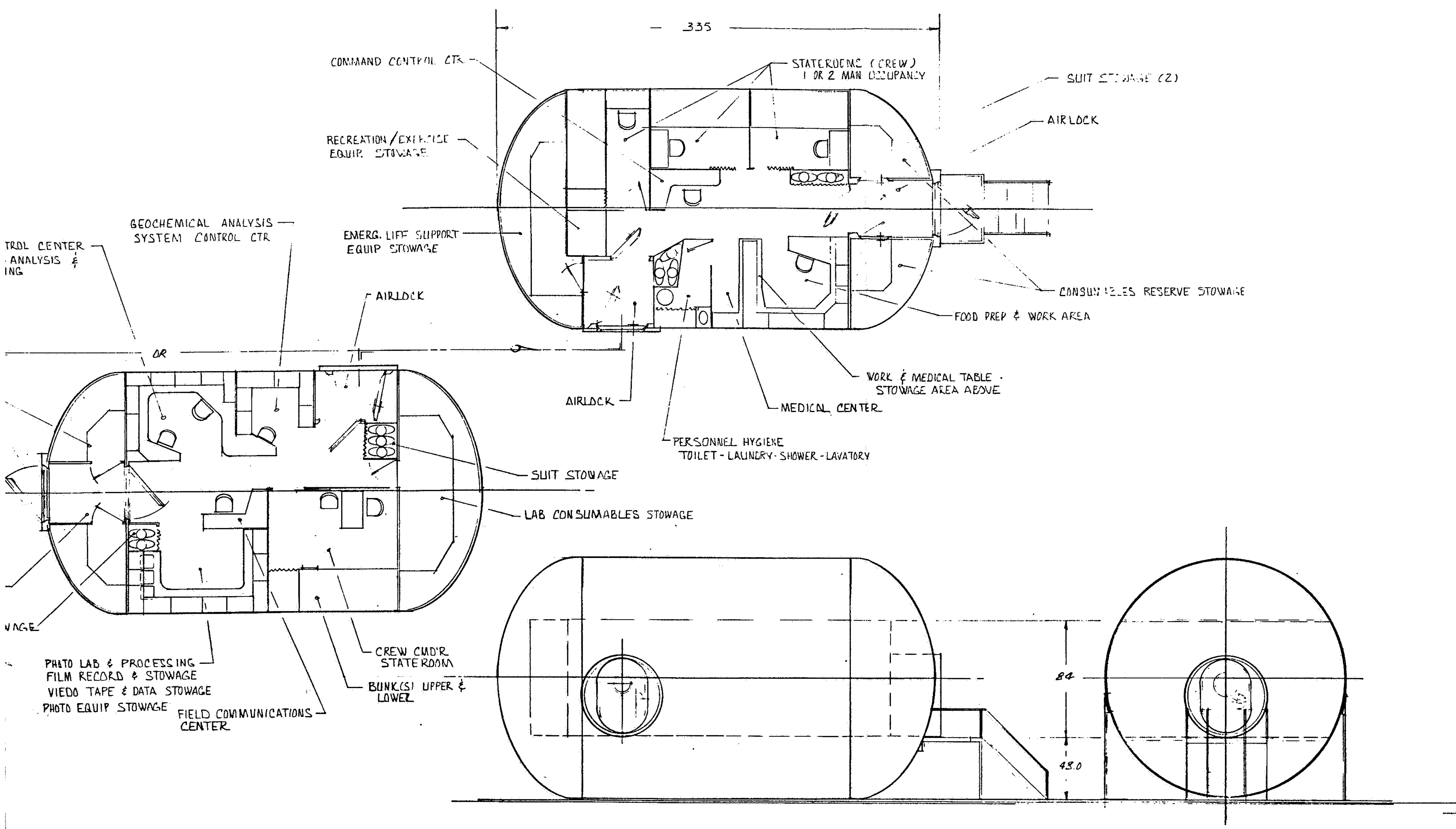
15 DIA MODULE & COMPLEX LAYOUT-LUNAR BASE SHELTER			2284-2 SHT 2 OF 2

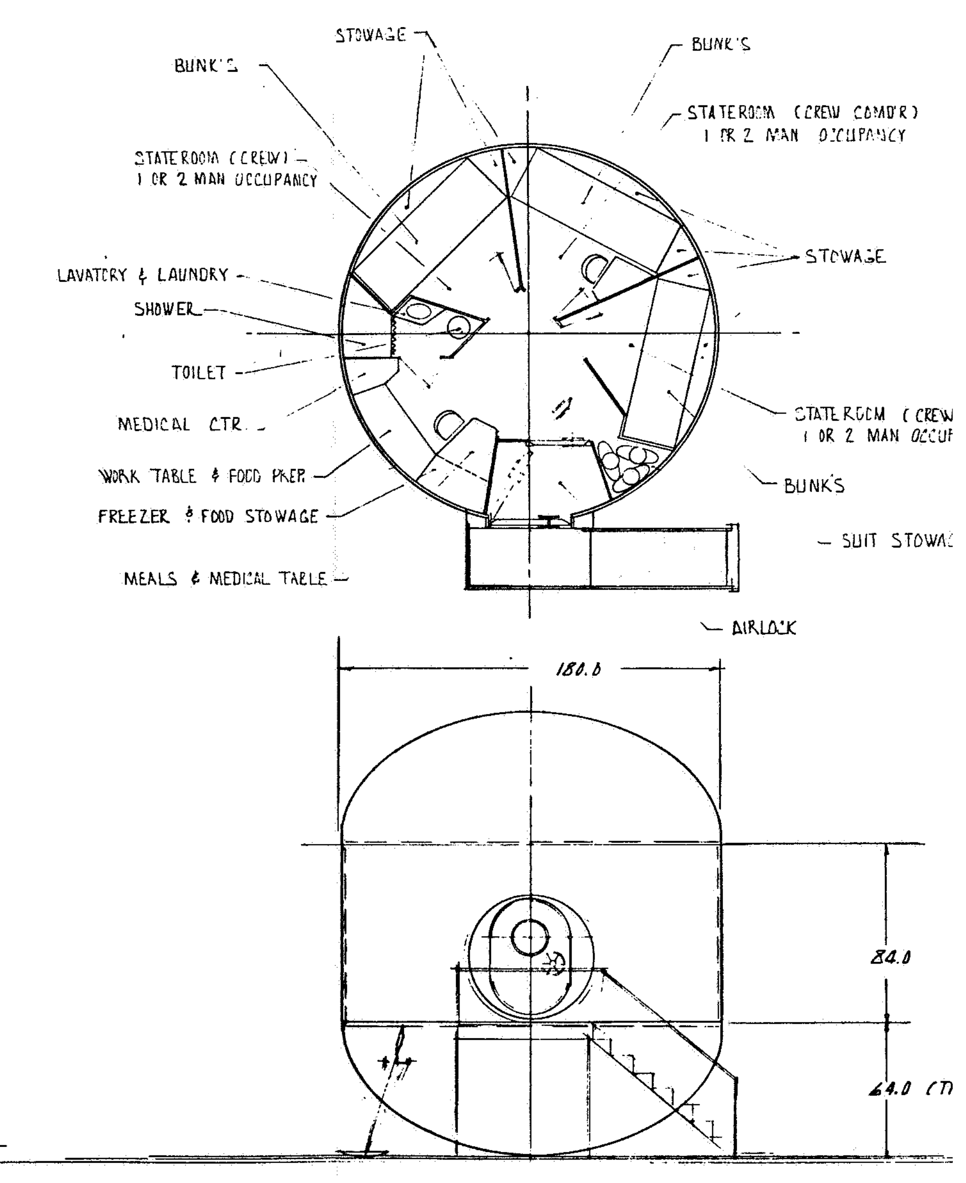


6-12 MAN COMPLEX

FOLDOUT #1



4-8 MAN MODULE COMPLEX



3-6 MAN MODULE

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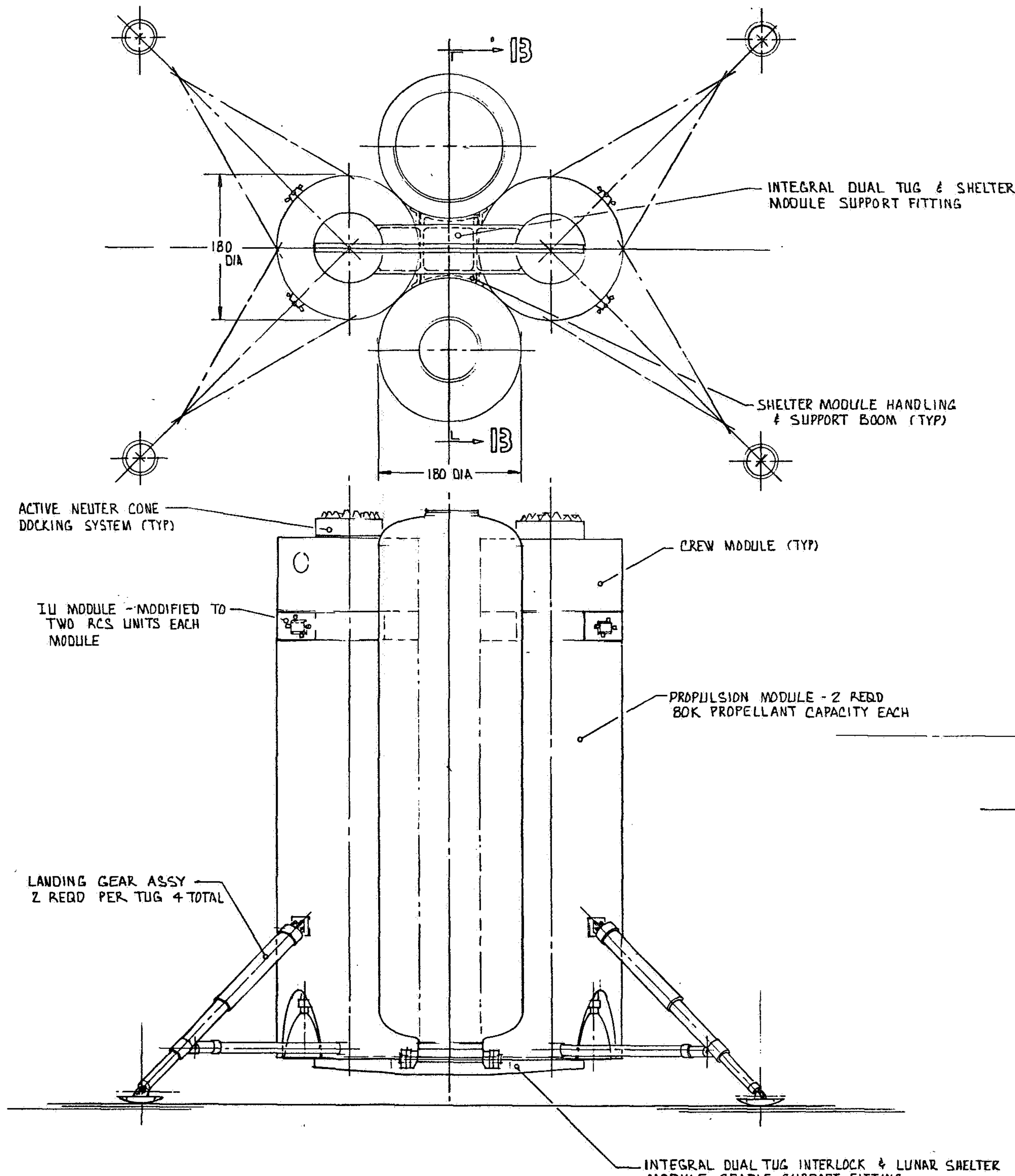
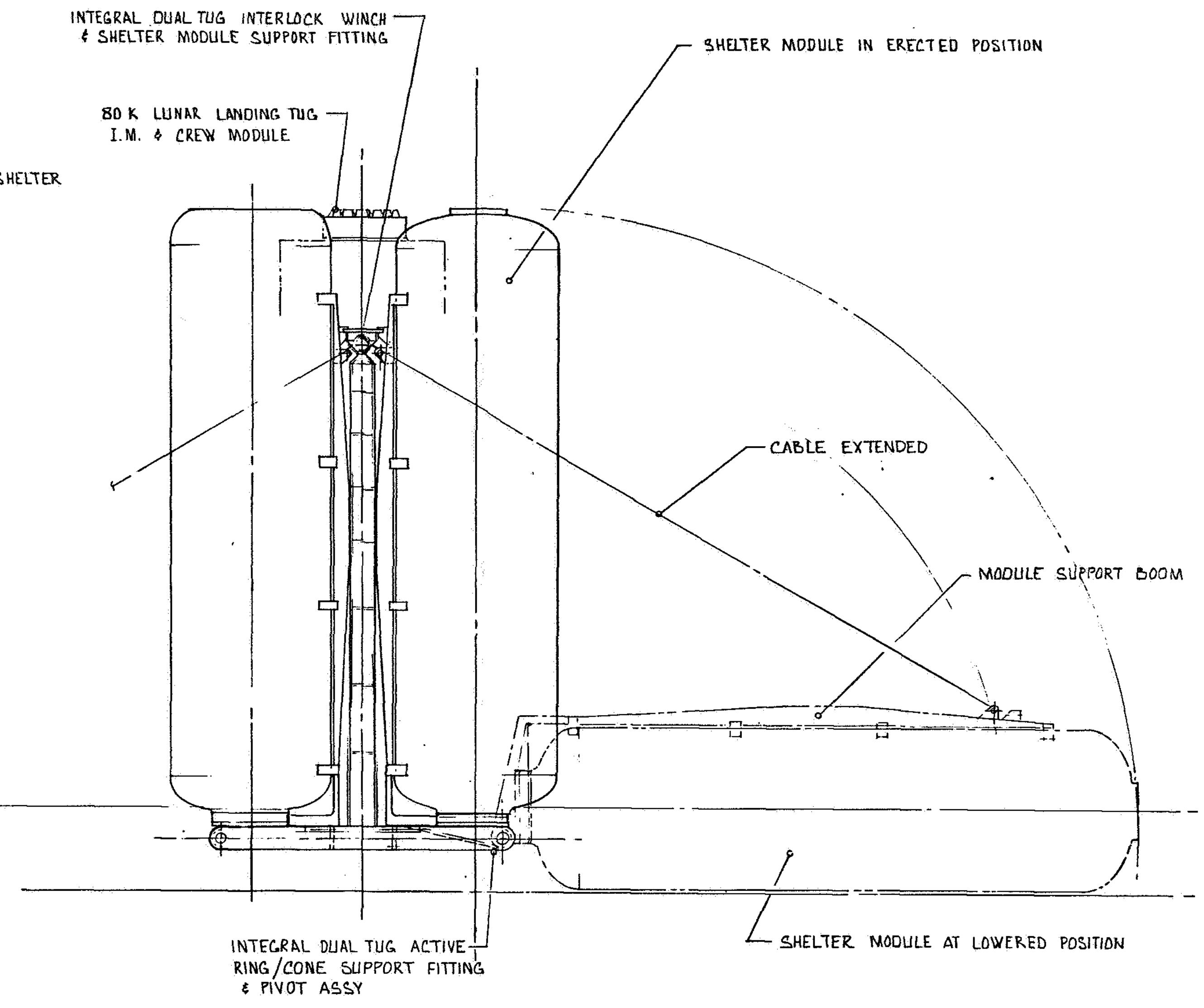
CONCEPT LAYOUT-LUNAR BASE SHELTER, CONFIGURATION STUDY		2284-1



LUNAR SURFACE DELIVERY - 1 CREW MODULE & 1 LAB MODULE
VIA DUAL MANNED RECOVERABLE TUGS



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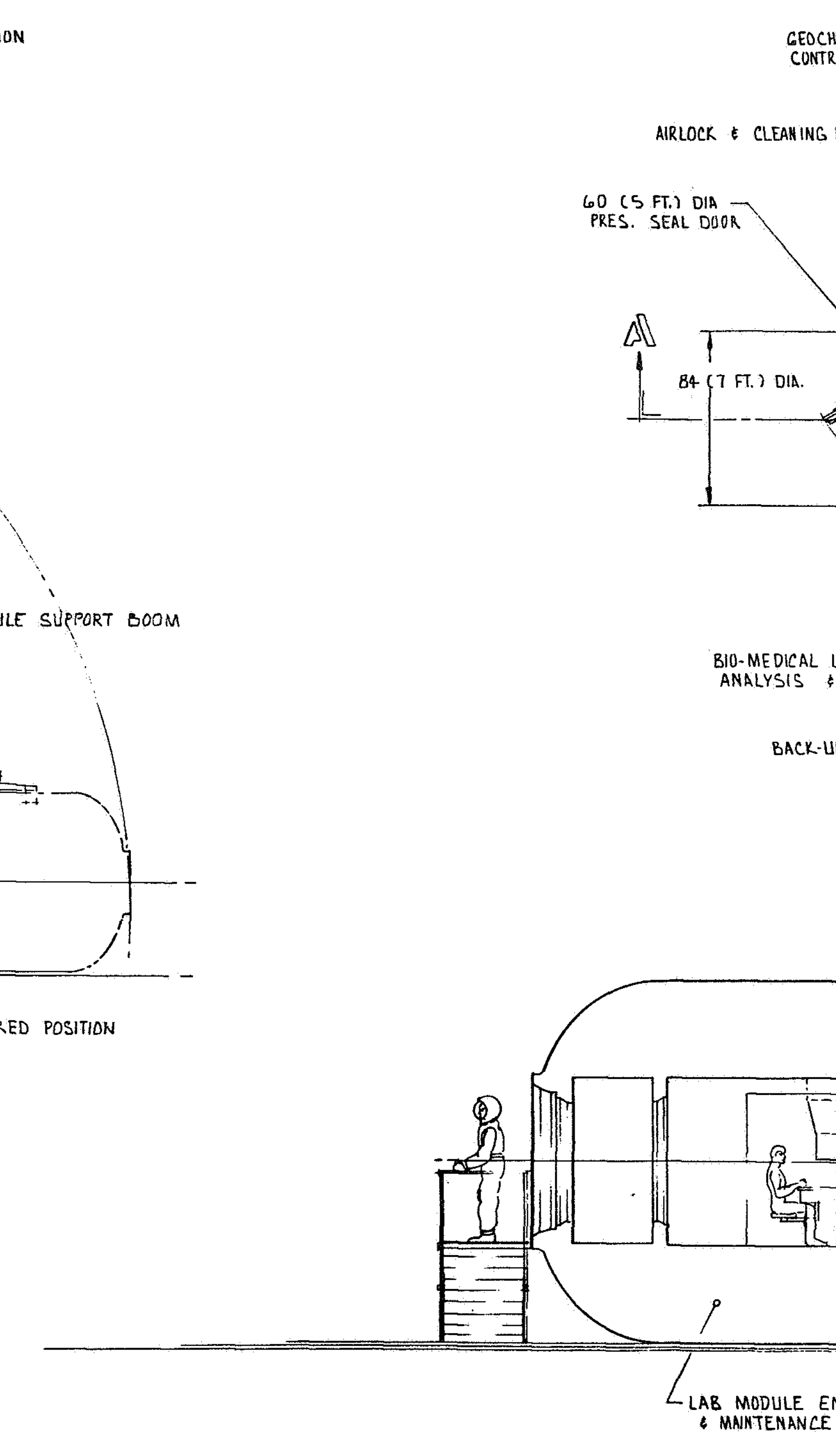

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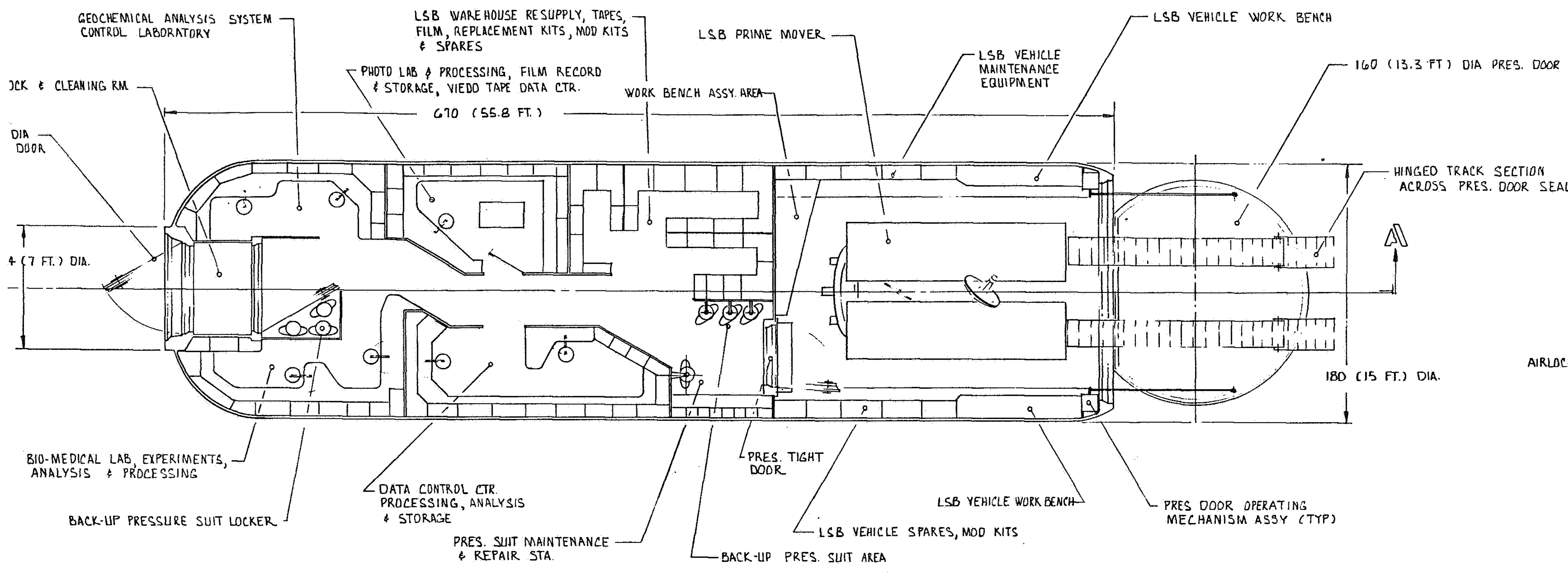
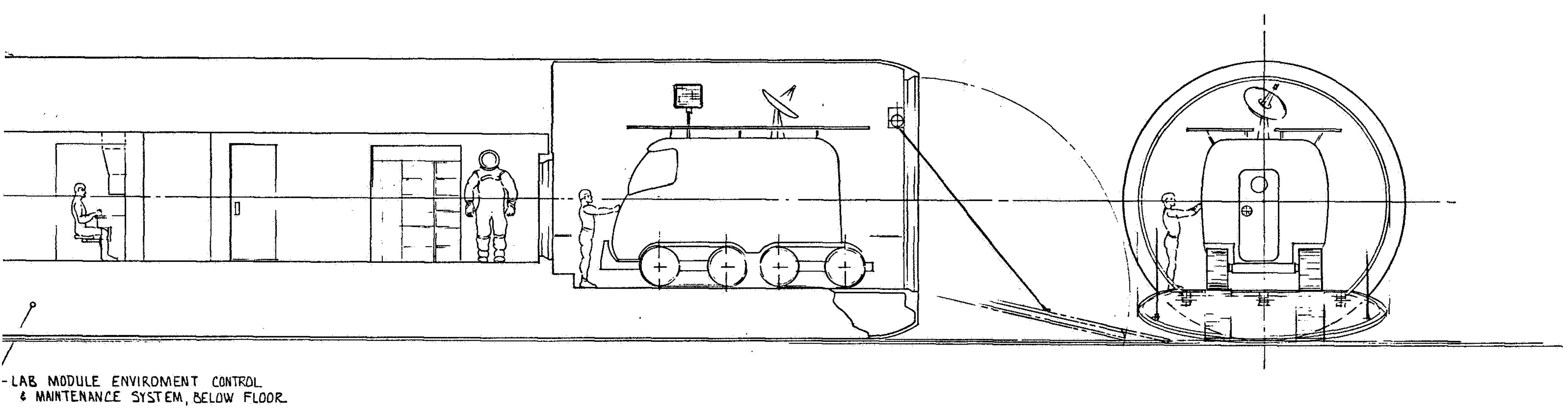
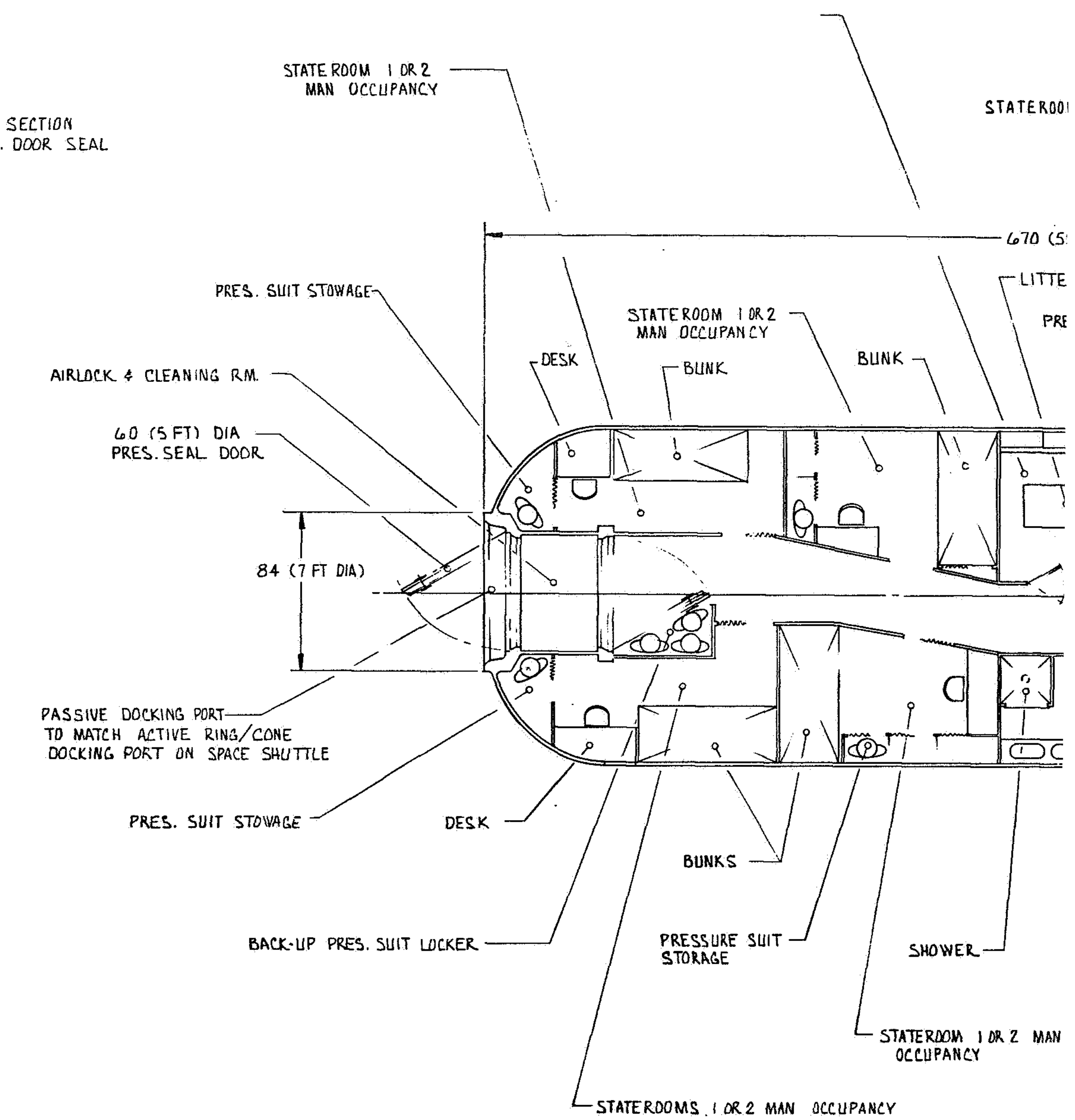


LABORATORY & LSB GARAGE MODULE

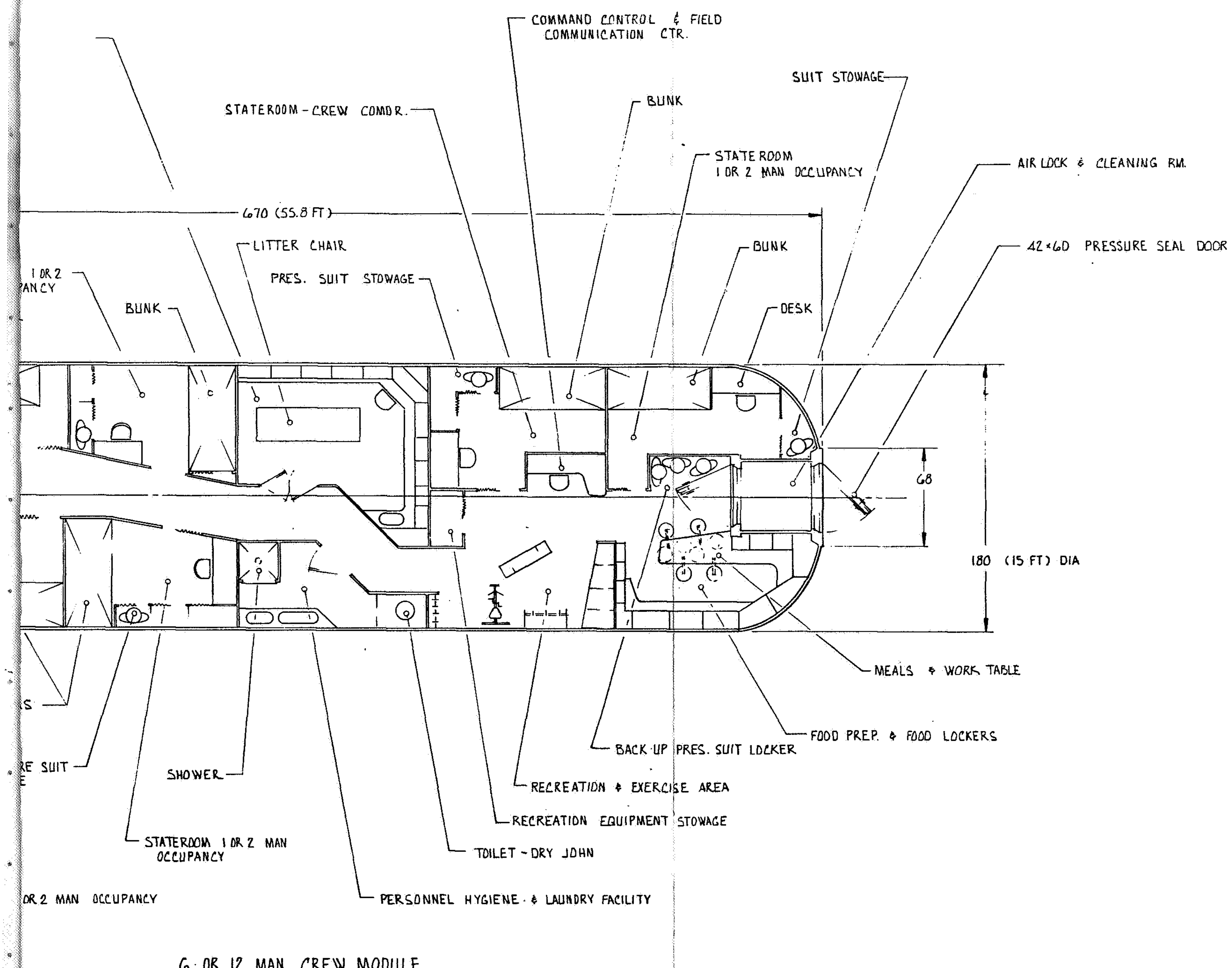


SECTION A-A



6 OR 12 MAN

Fold-out #2



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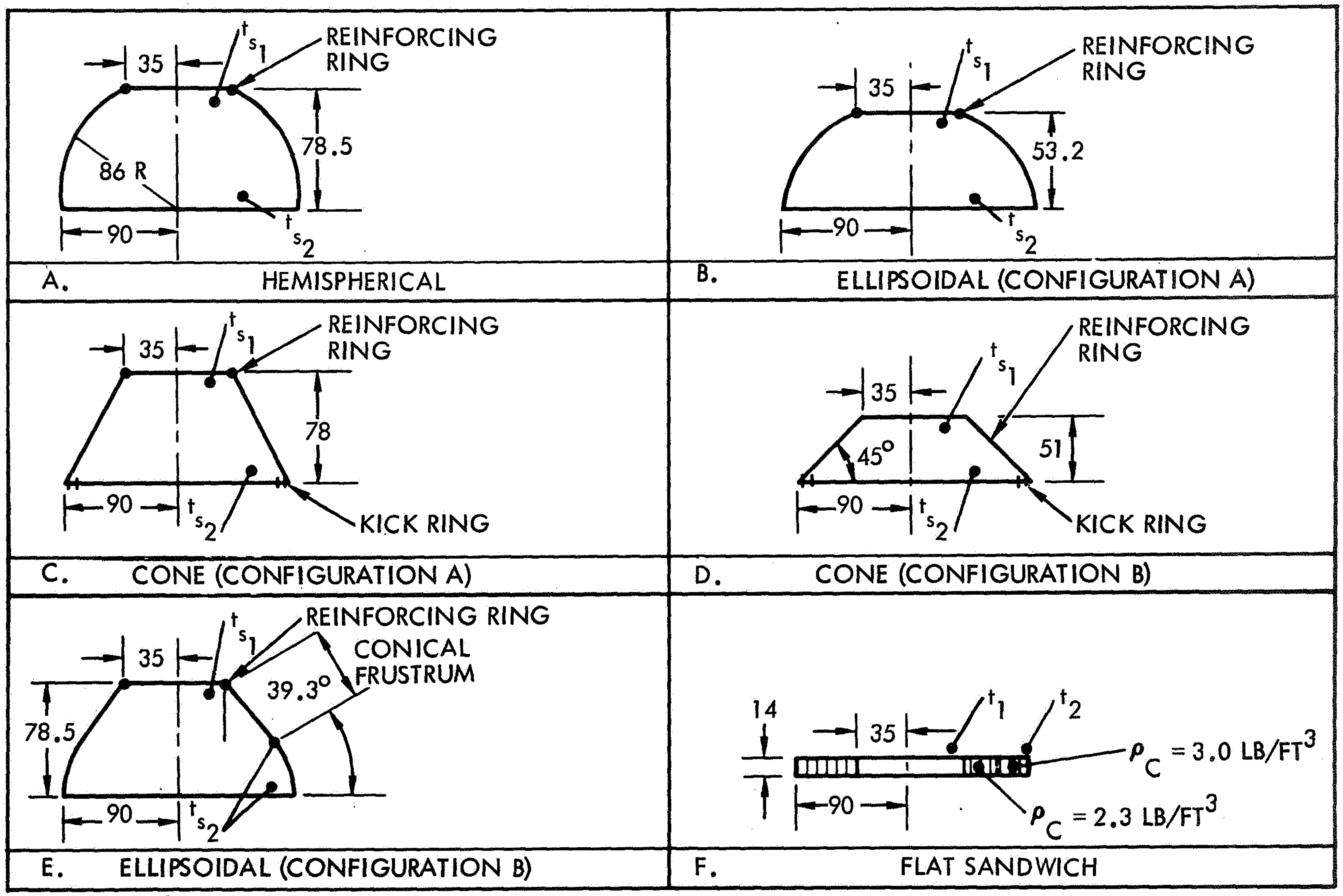
6-MAN CREW & LABORATORY SHELTER MODULE - CONFIG. STUDY		2284-6



1. BULKHEADS ASSEMBLED FROM EIGHT GORE SEGMENTS
2. WELD LAND THICKNESS = 0.10 INCH EXCEPT FOR FLAT SANDWICH

Figure 2.4-1. Module Bulkhead Options

Table 2.4-1. Structural Trades, Bulkhead Options

Note: Pressure loading only.
All skin material is 2219-T87 Al. alloy.

Configuration	t_{s_1} (in.)	t_{s_2} (in.)	Skin Weight (lb.)	Reinf. Ring Weight (lb.)	Kick Ring Weight (lb.)	Struct. Weight (lb.)
A. HEMISPHERICAL						
. Const. Skin	0.025	0.025	153	24	0	177
B. ELLIPSOIDAL (A)						
. Const. Skin	0.035	0.035	170	41	0	211
. Tapered Skin	0.035	0.025	141	44	0	183
C. CONICAL (A)						
. Const. Skin	0.050	0.050	229	6	78	313
. Tapered Skin	0.025	0.050	189	6	78	273
D. CONICAL (B)						
. Const. Skin						
. Tapered Skin	0.025	0.059	168	10	119	297
E. ELLIPSOIDAL (B)						
. Const. Skin	0.045	0.045	222	7	0	229
. Tapered Skin	0.025	0.045	200	9	0	209
F. FLAT SANDWICH						
. Const. Skin	-	-	-	-	-	-
. Tapered Skin	0.132	0.056	1,078	-	-	1,078

*To be subtracted off, if existing frames or floors meet kick load requirement.

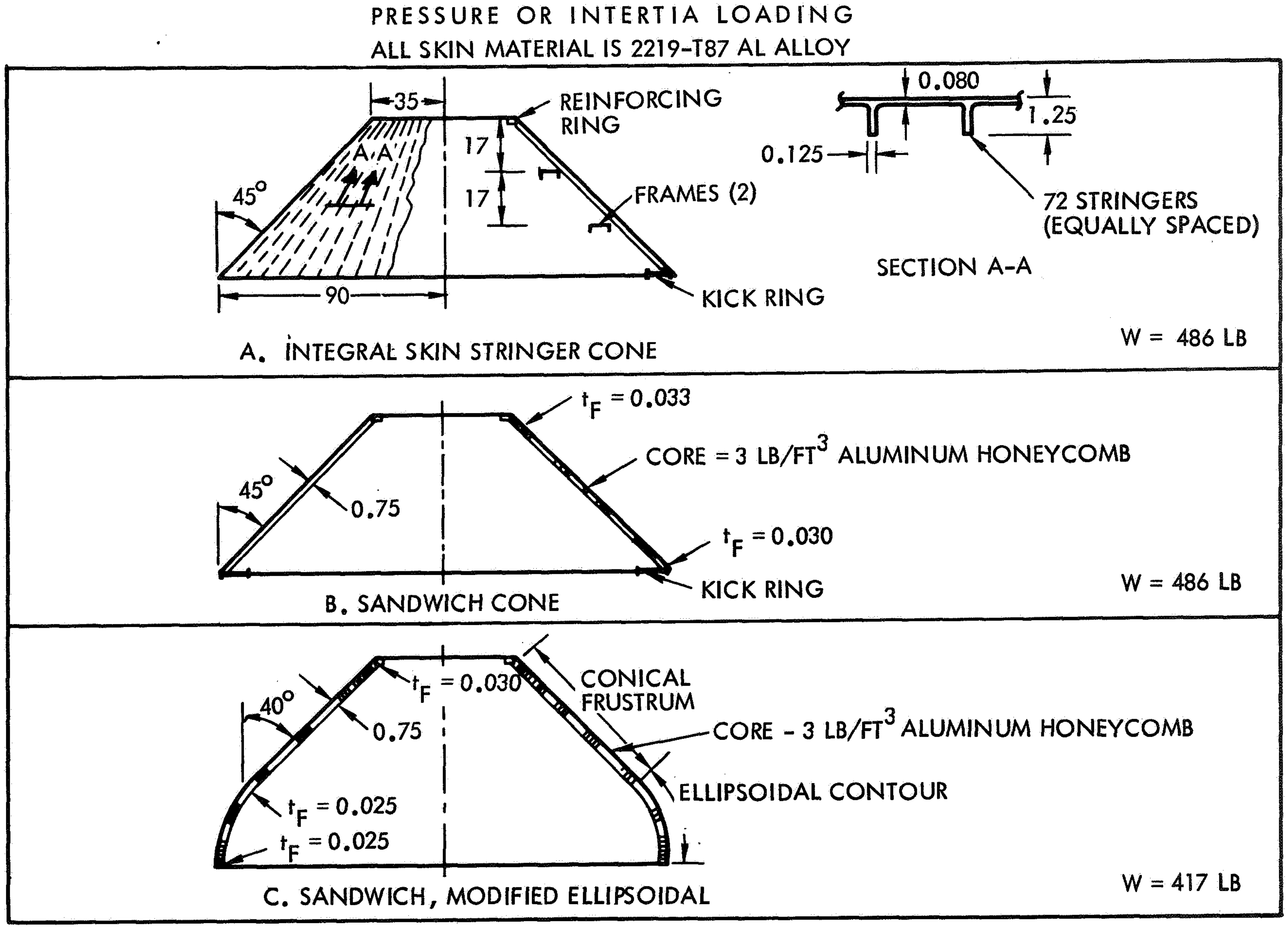
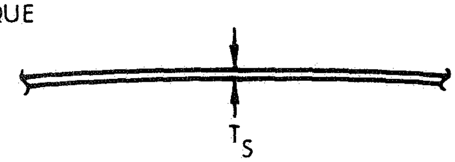


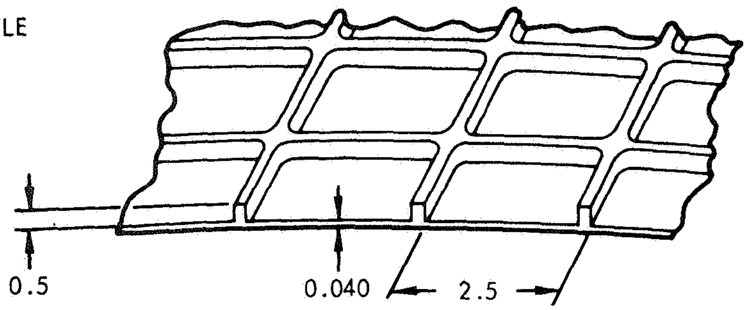
Figure 2.4-2. Structural Characteristics, Module Bulkheads Under Docking and Handling Loads

	Weight (LB/FT²)
SHEET MONOCOQUE	1.3
WAFFLE	0.63
HONEYCOMB SANDWICH	1.25
SKIN STRINGER - NO RINGS	1.05
SKIN STRINGER/RING	0.75
FIBERGLASS & STRUCTURAL FOAM	0.62

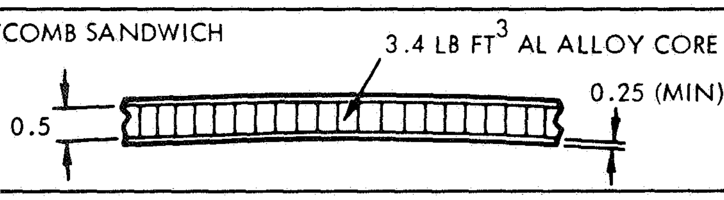
SHEET MONOCOQUE



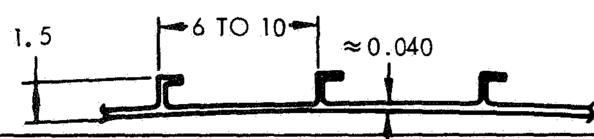
WAFFLE



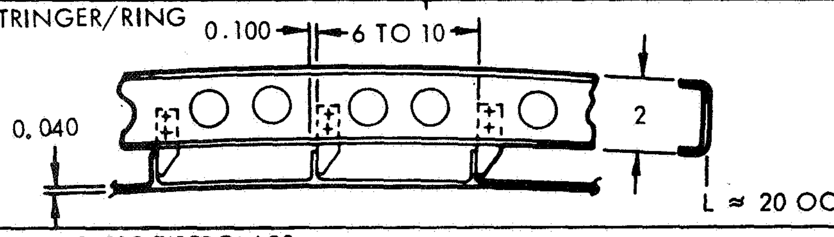
HONEYCOMB SANDWICH



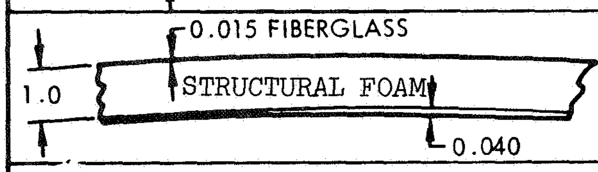
SKIN STRINGER - NO RINGS



SKIN STRINGER/RING



FIBERGLASS & STRUCTURAL FOAM



ALL SKIN MATERIAL IS 2219-T87 AL ALLOY

ALL W'S ALLOW FOR LANDS, JOINTS, ETC

Figure 2.4-3. Geometry and Weight Summary, Outer Wall Options

The recommended wall concept is, therefore, the structural foam with a fiberglass outercoating and an inner pressure wall of .040 2219-T87 aluminum alloy.

Module Cross Section

The three basic module cross section options considered are illustrated by Figure 2.4-4 along with a generalized floor plan for the two levels of options B and C. The following selection criteria are qualitative for the most part.

Option A provides a large clear floor area; all equipment is installed under or over the room area. Standard ceiling heights are feasible with relatively uncluttered rooms, creating the impression of a large free volume. However, an aisle or passage through the module must be taken out of this floor area.

Option B and Option C are similar, both have walkways on the lower deck with the equipment bays; the difference is in the aisle height and room configuration. Either option permits larger individual rooms than Option A; however, they introduce some operational problems and design complexity.

Option A was selected for the baseline since it provided the required room, more rapid through-passage is possible, and it led to a lower packing density, which helped to remain below the desired module weight boundary. (The Modular Space Station is an example of Option B.)

Module Coupling

Coupling connectors are required to permit transfer of the modules from one vehicle to another during transit operations and to provide the interface between modules after delivery to the base location. In transit, only a solid mechanical coupling is required. For the base buildup, the coupling must be made air tight. Modules which are to be pressurized need both capabilities, others do not.

Two basic options were considered, the Modular Space Station (MSS) docking system and one designed specifically for the LSB. The MSS concept was optimized for free space operations, provided an automatic pressure seal, and weighed over 870 pounds per module.

In contrast, a conceptual design of a neuter docking/handling ring was prepared for the baseline LSB modules which permitted two modes of operations involving a pressurized and unpressurized joint and two levels of assembly of a pressurizable joint or one for handling only, as required by the specific mission element.

The concept is defined by Figures 2.4-5 through 2.4-8 in a series of operational steps. Figure 2.4-8 presents a section of the joint in the pressurized mode. This concept is estimated to weight only 390 pounds per module, has more flexibility and provides a coupling that can be remotely controlled from either side of the joint. As a part of the base, it can be

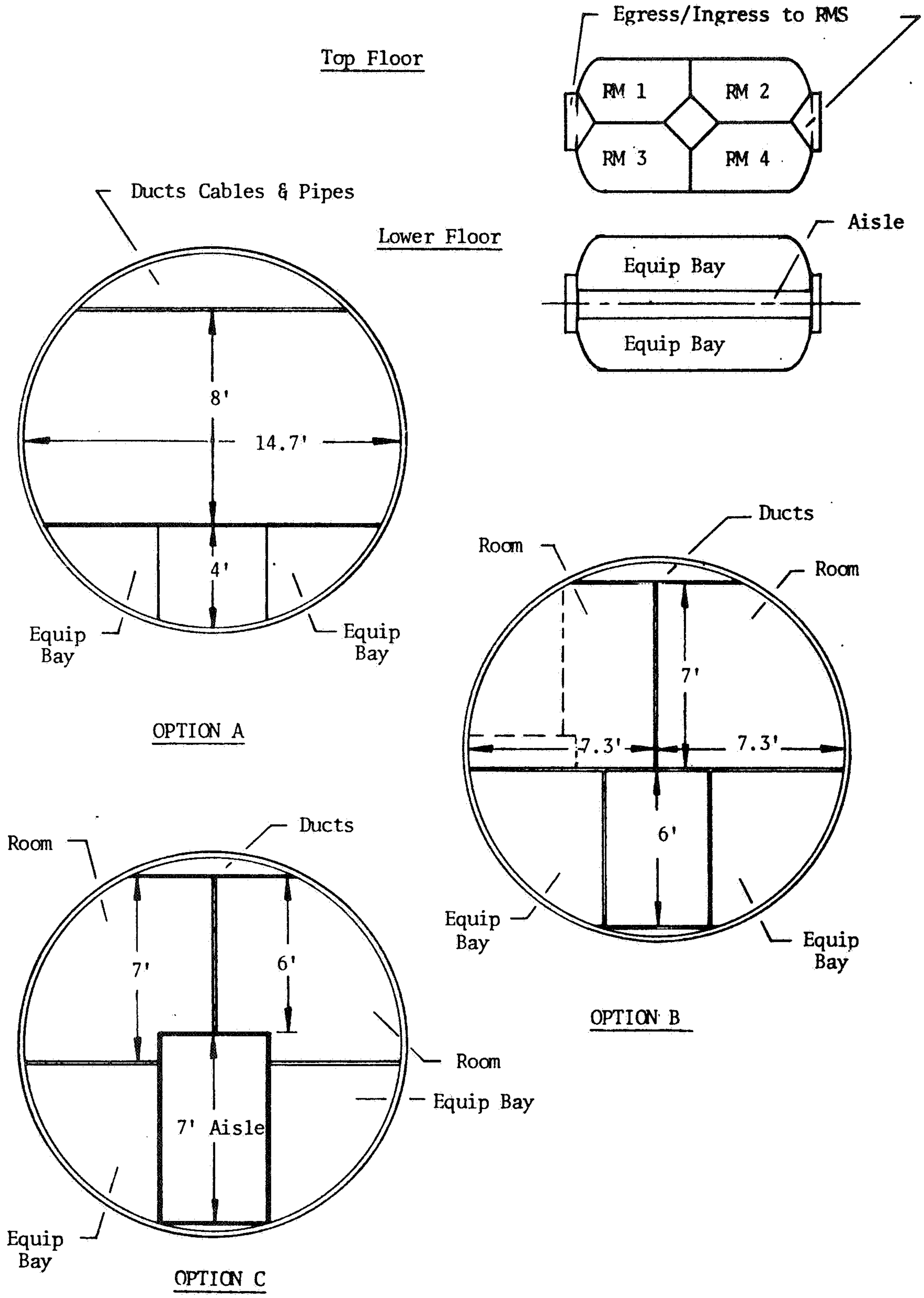


Figure 2.4-4. Module Cross-Section Options, LSB Baseline Modules

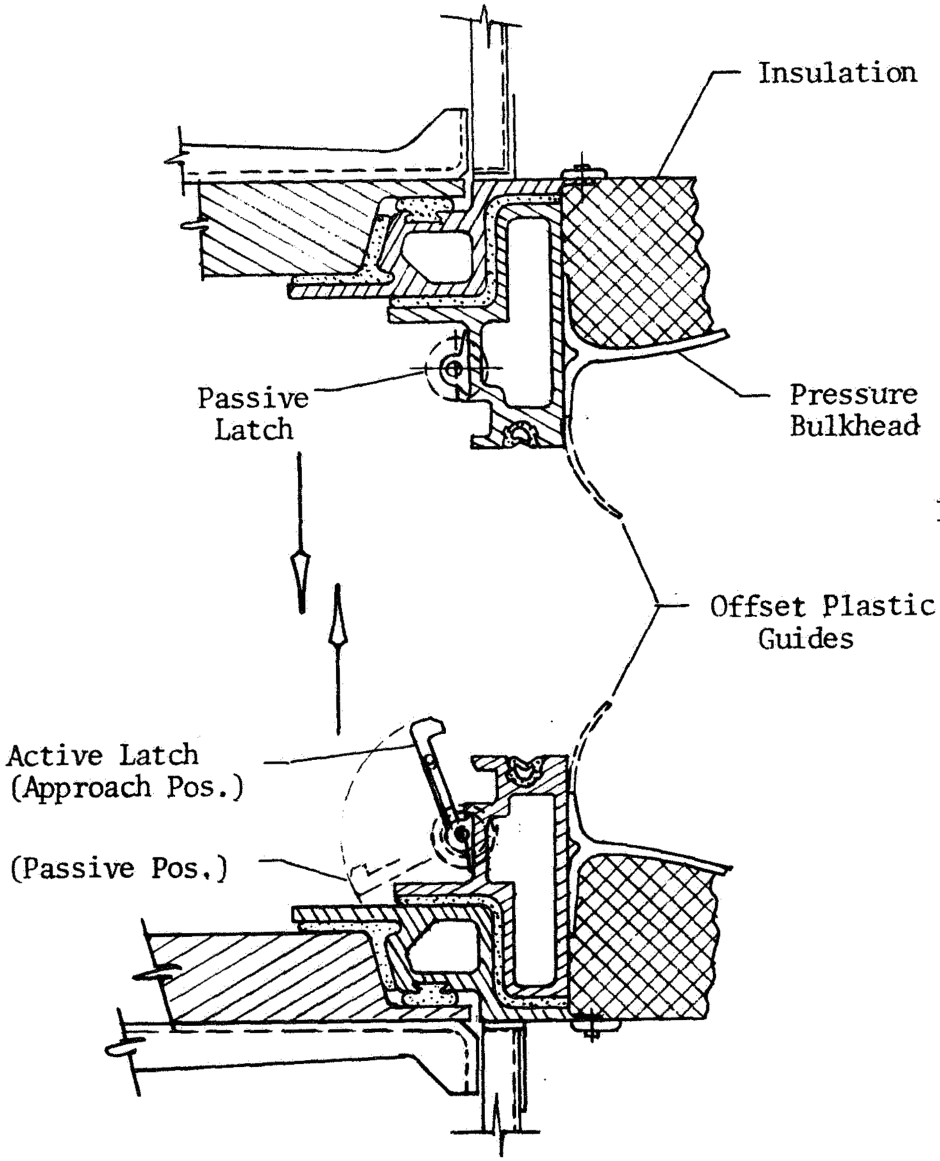


Figure 2.4-5. Personnel Hatch and Module Connector (Step 1)

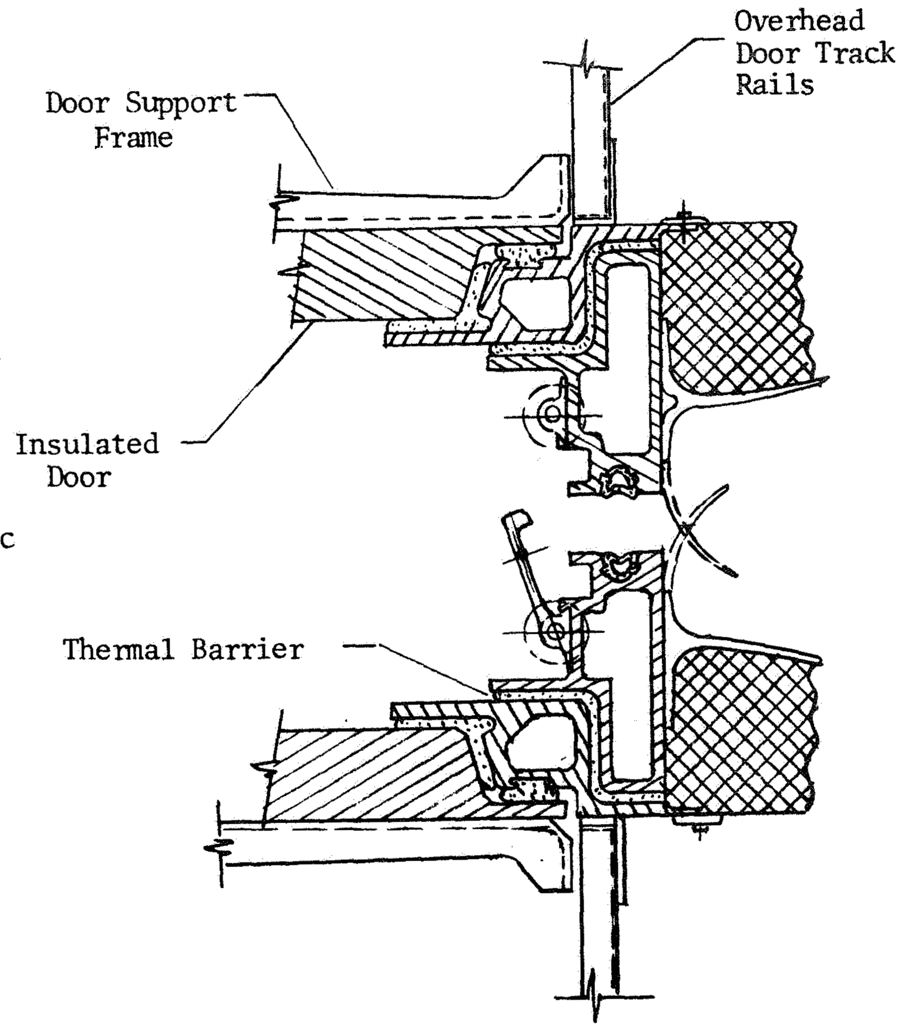


Figure 2.4-6. Personnel Hatch and Module Connector (Step 2)

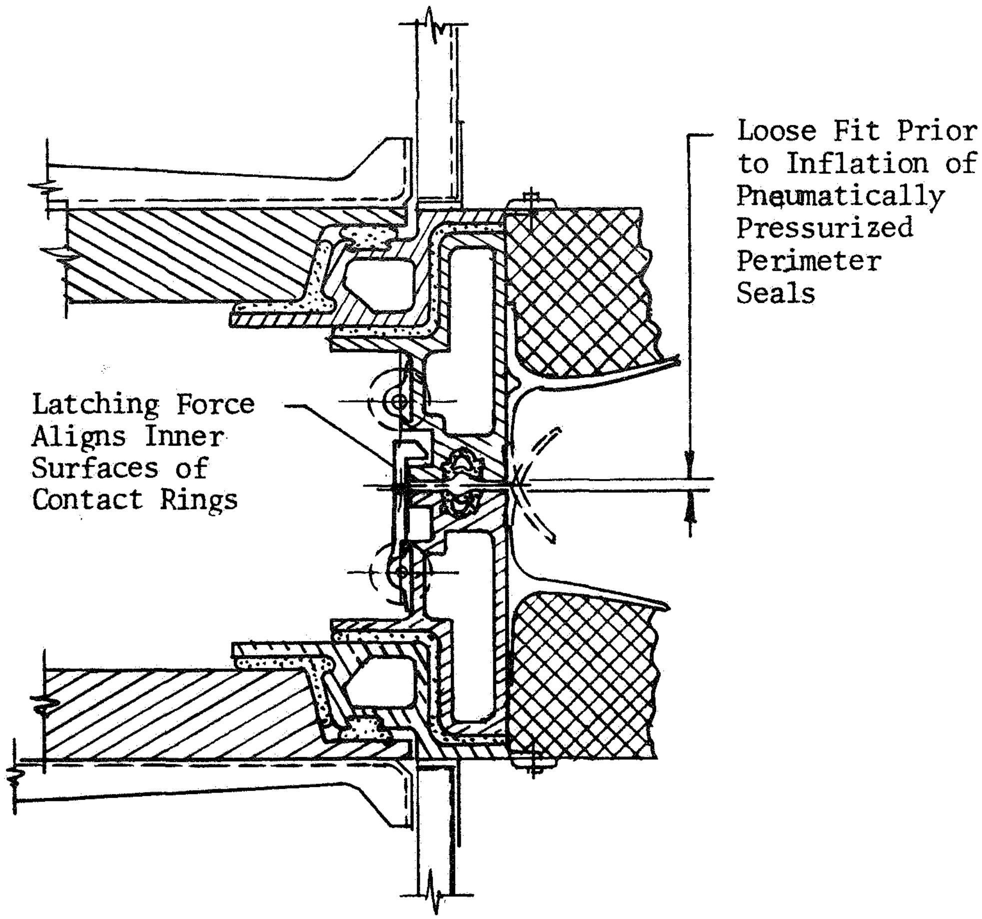


Figure 2.4-7. Personnel Hatch and Module Connector (Step 3)

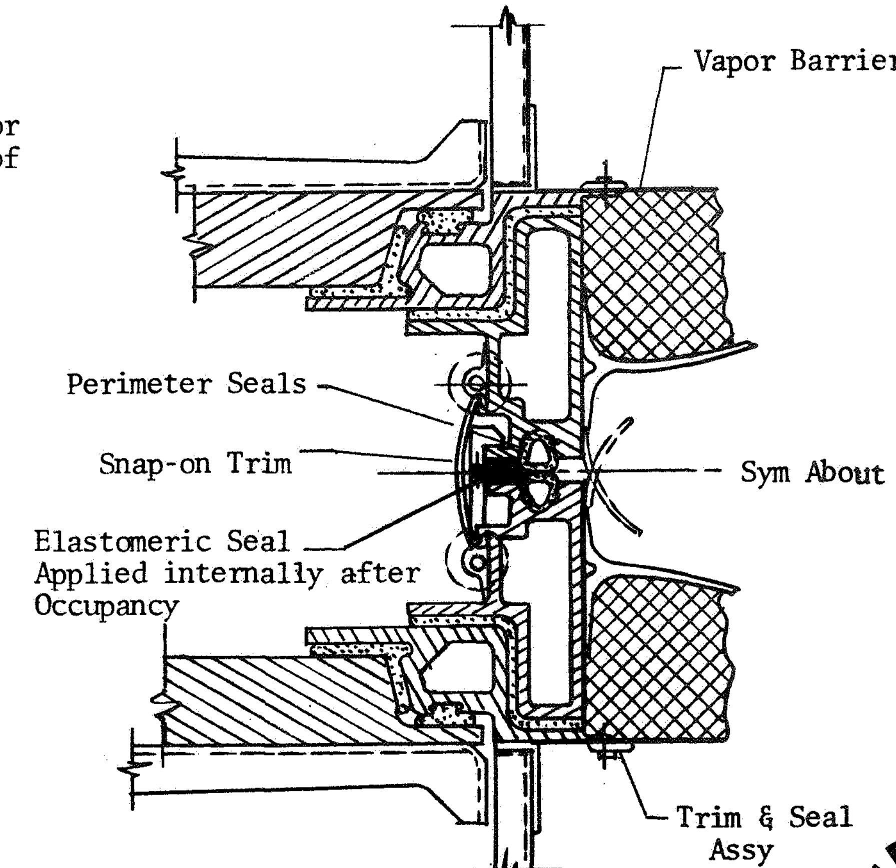


Figure 2.4-8. Personnel Hatch and Module Connector (Step 4)

permanently sealed minimizing the atmospheric loss. The same joint can also be used on the prime mover to permit the docking and shirstleeve transfer.

Recommended Baseline Shelter Module

A typical recommended baseline configuration for a shelter modules is illustrated by Figure 2.4-9. The module is 15 feet in diameter and 30 feet from port to port, so that two can be launched in one EOS cargo bay. It features semi-ellipsoidal bulkheads at each end and the walls are constructed of .040 2219-T87 aluminum alloy covered with structural foam with a fiberglass outer skin on the outside and painted with a fire retardant paint on the inside. It is of tri-level construction where the center level is for living and working with 8-foot ceilings, the lower level is for the major portion of the equipment, and the upper level is for wire, ducts, and pipes between rooms and modules. All versions of the module required for the LSB are estimated to weigh less than 10 thousand pounds dry each, will provide over 3000 cubic feet of free volume on the middle level, and can be delivered in multiples to the lunar surface using the projected vehicle environment or any other option with equivalent payload capability. The use of 10,000-pound increments will permit flexibility in matching the performance capabilities of the selected delivery vehicles.

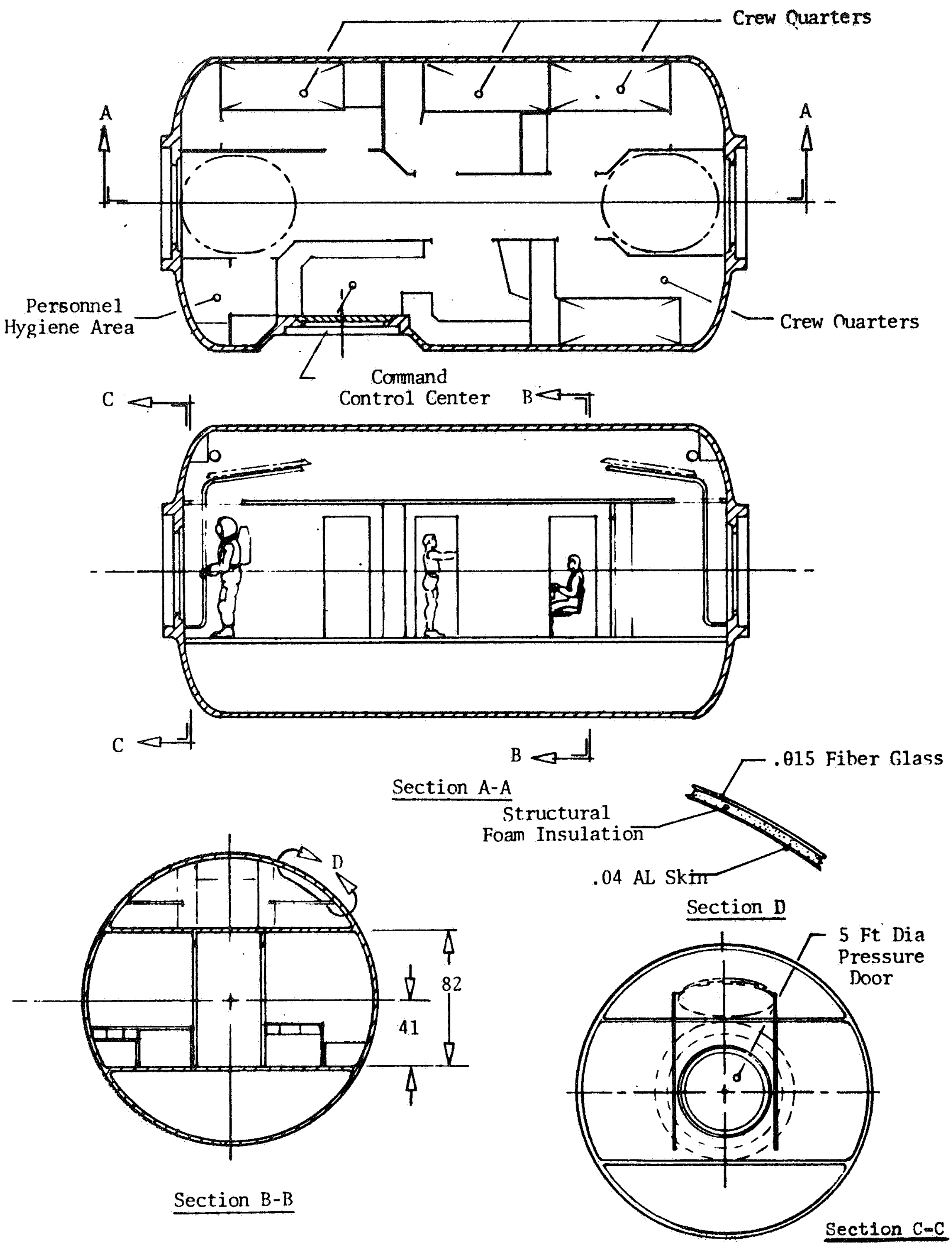


Figure 2.4-9. Typical Baseline Shelter Module

3.0 MASS BALANCE AND CONSUMABLES CONSERVATION

Since the LSB is expected to involve both fixed and mobile shelters and much of the crew time will be spent outside the LSB shelter itself, the mass conservation concept must minimize the total LSB resupply requirement. To achieve this, the concept must integrate all of the activity locations into the overall concept.

The individual elements include:

1. LSB main shelter
2. Fixed outposts (deep drill and observatories)
3. Mobile shelter
4. Prime mover
5. EVA crewman

The mass balance, therefore, includes consideration of each of these elements and their interface with the LSB. The overall concept was first developed on the basis of an integrated system approach. Subsequently, various potential interface points were evaluated to facilitate selection of the optimum concept for the individual elements based on the impact on the element and the consumables requirement.

3.1 OVERALL MASS BALANCE CONCEPT

The involved atmospheric and crew services functional requirements can be satisfied through various system concepts involving open or closed loop metabolic oxygen cycles. The major system differences are found in the carbon dioxide, oxygen, and hydrogen management functions and their interfaces. The closed loop systems recover and and reconstitute carbon dioxide and water while the open loop concepts dump either or both.

Figure 3.1-1 illustrates the total systems and consumables weights for a system sized for 12 men and program durations up to 2.5 years. These data indicate that after approximately three months, the closed loop concepts become weight optimum. However, one factor which is not readily apparent from the figure is the influence of operations away from the main shelter.

Exploration sorties can take a four-man crew away from the base as much as 90 days. If there is more than one sortie at a time, the situation is compounded; waste products such as carbon dioxide at 12.8 pounds per day and contaminated water at about 38 pounds per day are produced and must be stored, dumped, or reprocessed. Since the extended sorties make up a significant portion of the LSB mission, a closed loop/open loop selection made

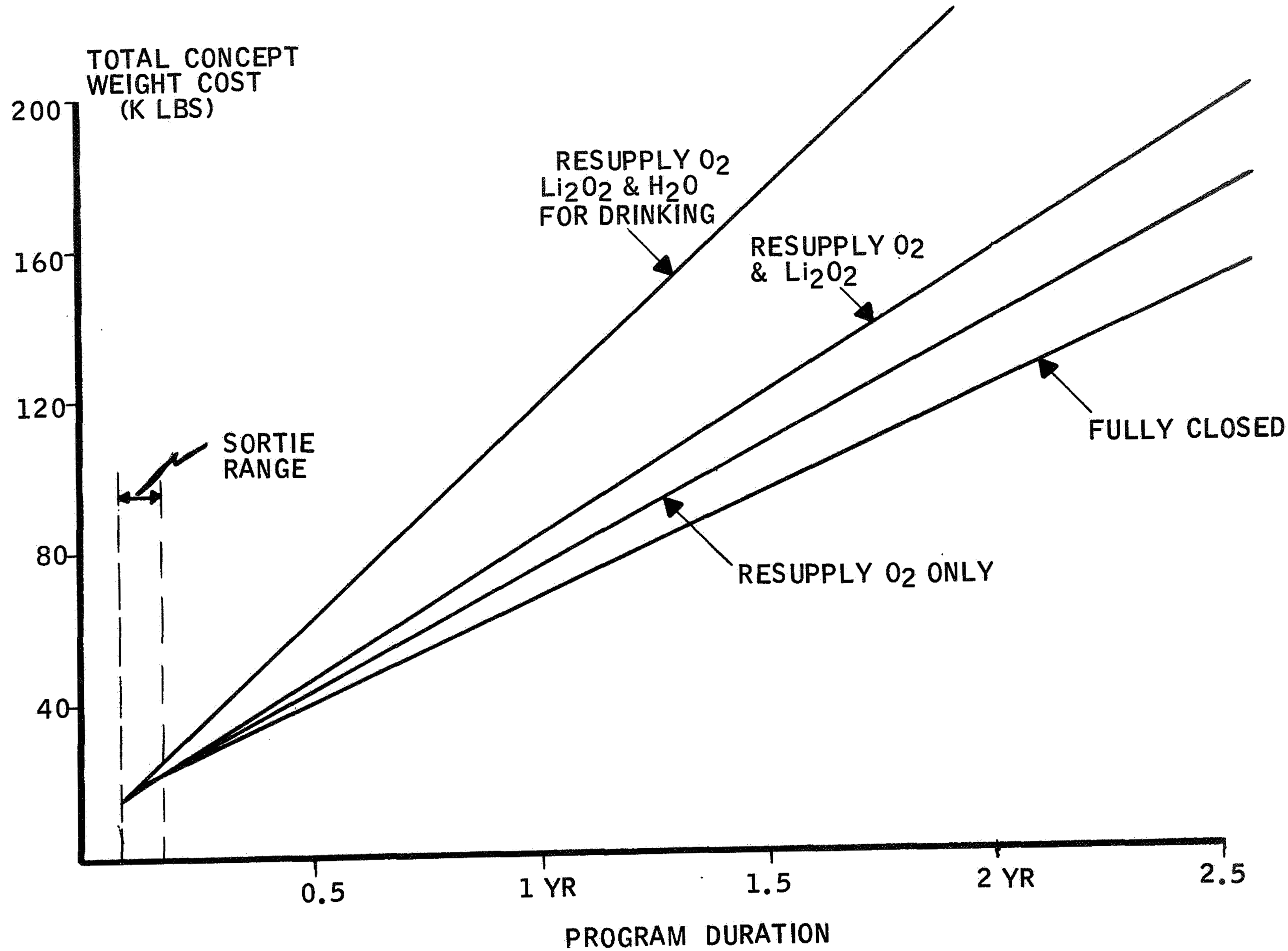


Figure 3.1-1. ECLSS Concept Trade Data (12 Men - Isotope EPS)

for the base alone may not be a weight effective decision. The decision logic must consider the LSB and sortie systems in concert. Some of the potential integrated options are illustrated by Figure 3.1-2. Basically, the carbon dioxide and water management functions are involved and interrelated. The potential options suggested are eventually closed loop; however, for the sorties there remains the possibility of a semi-closed system wherein the loop is interrupted at some point by storing the intermediate byproducts completing the processing after return to the LSB. Figure 3.1-3 presents the trade data for these options as they apply to the four-man extended sortie. These data indicate a significant weight penalty (2200 pounds) is imposed on the mobility system to provide the power plant delta weight (Isotope Brayton system assumed) for water electrolysis in a closed loop concept. To this must be added the increase weight of the trailer to carry it (550 pounds). The open loop concepts seem weight effective for the sortie duration; however, this neglects consideration of the total mission trades in that the sortie consumables must be resupplied on a continuing long term basis. The resultant concept must, therefore, be closed for the overall LSB. This can best be illustrated by Figure 3.1-4 where the total consumables cycle is illustrated with the systems interfaces.

The functions associated with atmospheric maintenance loops are grouped on the left and those associated with the water on the right. (Specific system trades are presented in subsequent sections.) For both the shelter and mobility systems, the majority of the water is confined to the "clean water loop" where a simple reverse osmosis system will recover the majority of the waste water and provide adequate cleanliness for all housekeeping functions. A smaller amount of water and the residue from the relatively inefficient reverse osmosis process is circulated through the vapor compression system to complete the water recovery and to provide potable water for drinking and food reconstitution.

It is recommended that oxygen be recovered only at the LSB through electrolysis of water. Carbon dioxide is removed from the atmosphere and reduced to water. Leakage and processing losses are made up from the excess water arriving in the form of wet food or resupplied as water depending on the food concept selected.

3.2 MOBILE SYSTEMS AND OUTPOSTS

The mass balance concept as applied to outposts and mobile units is similar to that of the LSB except that the water electrolysis unit is eliminated, thereby reducing the power costs substantially. Hydrogen and oxygen are provided to these modules from the base shelter system and water is returned in the form of waste water for reprocessing. The weight comparisons relative to electrolysis on sorties are presented in Table 3.2-1. These data are based on the 90-day, 4-man design reference sortie and are therefore, considered conservative relative to the average sortie of about 45 days. For these missions, the departure (and return) weight would be 800 pounds lower for the semi-closed concept (without electrolysis).

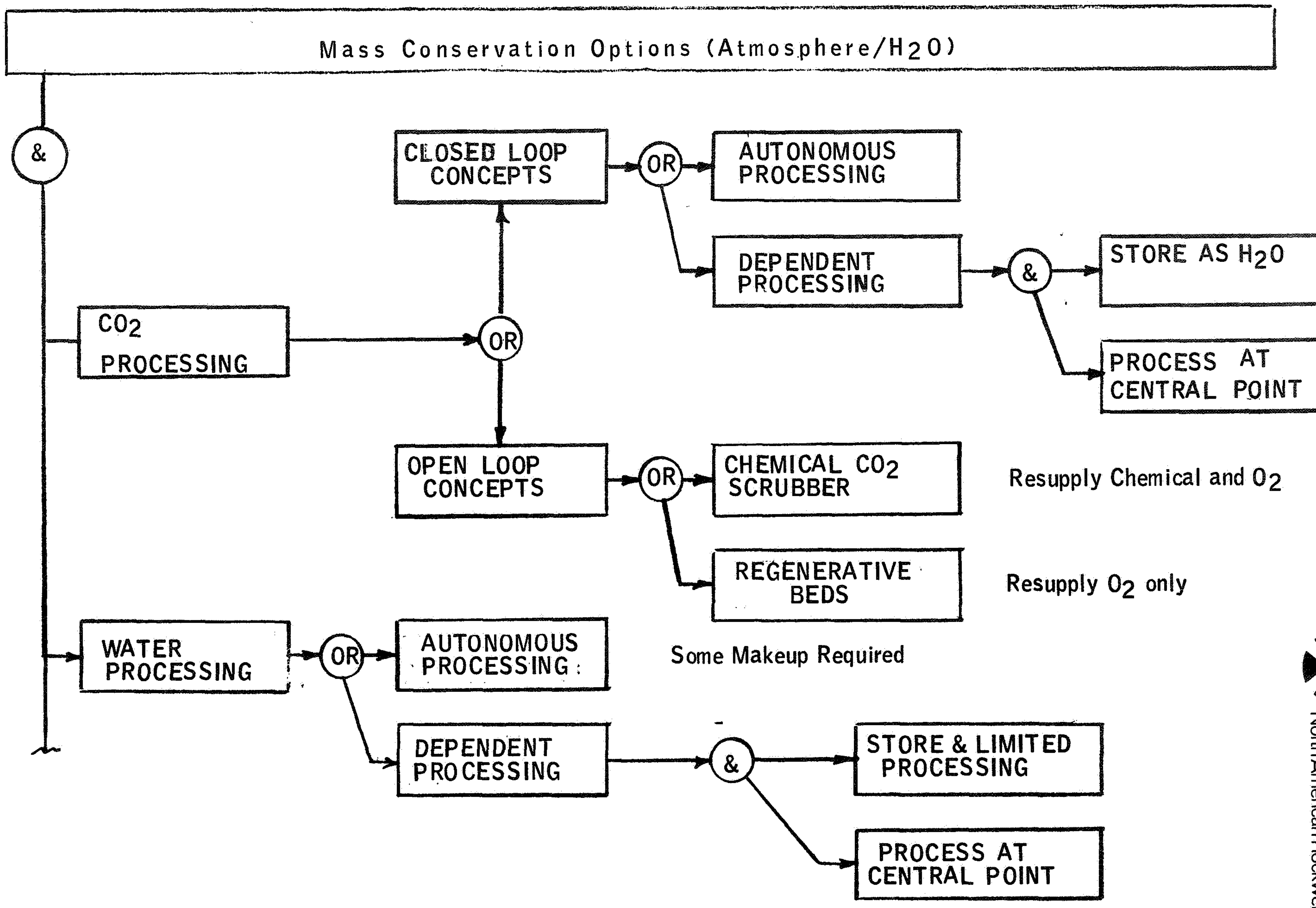


Figure 3.1-2. Mass Conservation Options (Atmosphere/H_2O)

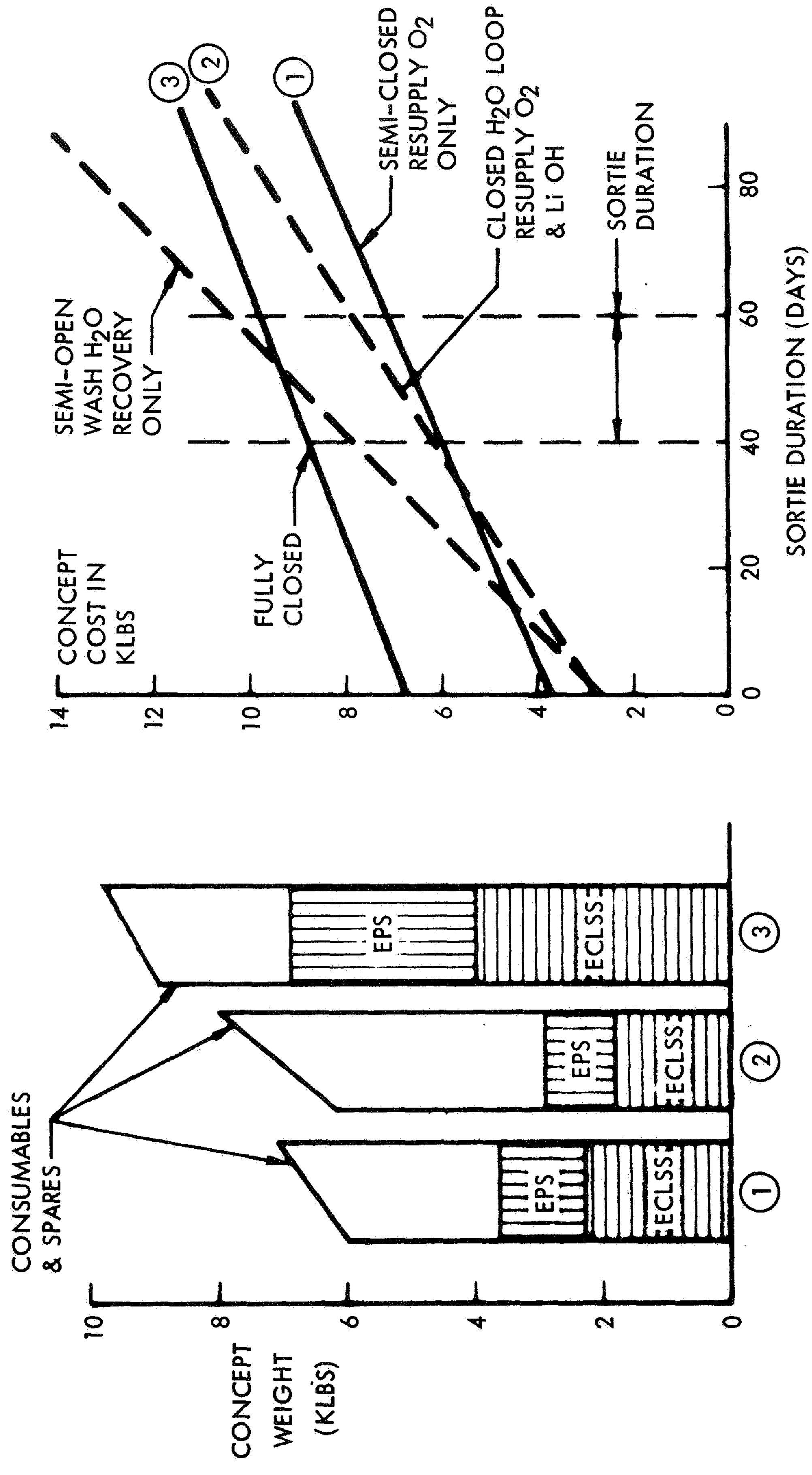


Figure 3.1-3. ECLSS Concept Trade Data - 4-Man Sortie

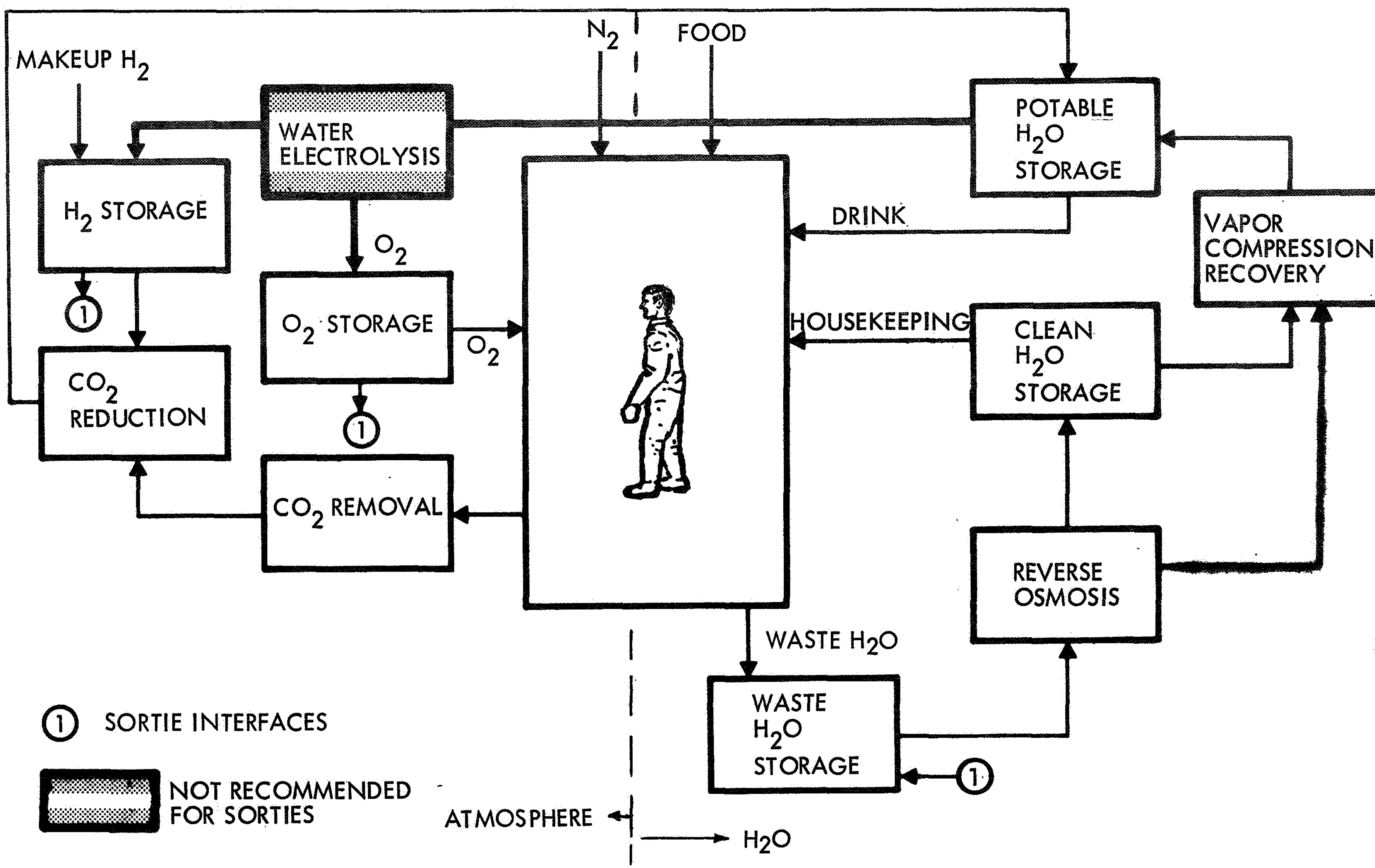


Figure 3.1-4. LSB Mass Conservation Concept

Table 3.2-1. Mass Balance Trades - Sortie
(Design Reference Sortie Case)

Function	H_2O Electrolysis (lb)	Without Electrolysis (lb)
H_2O Electrolysis Unit	190	-
H_2O Reclamation	477	477
Delta O_2 Tank	-	90
Delta O_2	-	898
Delta H_2 Tank	30.2	187
Delta H_2 Gas	21.6	133
H_2O Storage Tank	-	85
Electrical Power Penalty	2200	-
Total Weight	2918	1870

The water is recovered over the 90-day sortie from CO_2 reduction and water in food.

Ninety-pound penalty at base, and 200 watts average power

Since the sortie mission system is composed of prime movers and a mobile shelter, further consideration must be given the distribution of functions within the vehicle train. Since the prime movers are to operate autonomously for no more than 48 hours, they need not carry any of the water cycle system other than potable and waste storage tanks. The maximum water load is not expected to exceed 60 pounds if recovery is deferred until return to base or the mobile shelter.

3.3 EVA SYSTEMS

A large portion of crew time is expected to be spent external to the LSB or any shelter. Under these conditions they will be dependent on some form of Advanced Personal Life Support System (APLSS). The activity profiles of Volume II show that up to 50 percent of a crewman's metabolic budget can be expended outside the influence of a shelter system. Depending on the APLSS concept, this can involve a significant portion of the consumables budget.

The existing PLSS concept is a fully open loop design. Oxygen is transformed into carbon dioxide by a crewman during EVA at the rate of about 1.1 pound/man-day; it is in turn captured in LiOH in an irreversible process. Water is used to provide cooling through use of a sublimater at the rate of about 1.4 pounds per hour. If these concepts were used, the consumables for an LSB would increase by up to 50,000 pounds per year compared to a closed loop system.

Advanced PLSS concepts are under study by LTV and Hamilton-Standard Division of UAC, under the direction of NASA/OART. The concept that holds the greatest potential for LSB applications involves a base dependent regenerable concept. It will probably use ZnO for carbon dioxide absorption and LiBr for water absorption as it exits the APLSS evaporator-cooler. Both would be packaged in cartridge form and could be desorbed by a simple LSB desorption oven. Both items require heat and a partial vacuum to accomplish the desorption process.

This concept formed the basis of the LSB mass conservation concept and defined the supporting systems requirements.

The subsequent section presents the trade data and selected subsystem concepts which provide the capabilities to satisfy the mass balance concept herein identified.

4.0 ATMOSPHERIC AND CREW SERVICES MANAGEMENT (A&CS)

The A&CS functions provide the services necessary to sustain life in a non-terrestrial environment and enable the mission systems to perform their functions under controlled and favorable conditions. The specific requirements and objectives have been derived and defined in Volume II of this report. The summary crew support requirements are listed in Table 4.0-1, and the resulting A&CS design requirements in Table 4.0-2. The resulting impact on the LSB components are summarized in Table 4.0-3.

The functional areas included within the A&CS systems are illustrated by classification in Figure 4.0-1. These form the basis for the subsequent trade studies and subsystems definition.

Although the base is projected to achieve a 12-man total level, the buildup phase and the operational phase indicate that a modularity concept best fitted these operations. Increments of four men were best suited for the proposed operational concept and, as a previous section indicated, four-man modules were identified as the optimum physical size for the LSB. The subsequent A&CS trade studies were conducted using a four-man module-system as the baseline except where noted otherwise.

The base atmosphere must be revitalized continuously while the LSB is in use. The required functional relationships are illustrated by Figure 4.0-2. There are a multiplicity of interfaces involved in the concept selection criteria. Trade data were therefore developed for each functional element which reflected the influence of the selection on each interface. Since all interfaces cannot be evaluated on a quantitative basis at this time, the qualitative factors are treated on a comparative basis to permit identification of the optimum. These include reliability, operability, maintainability, development status and comparison program plans.

4.1 CARBON DIOXIDE MANAGEMENT

Carbon dioxide (CO_2) gas is expected to be produced by the crew at between 2.57 and 3.71 pounds per man-day. This will be divided between the base, other shelters, and the EVA system. The present guidelines require that the partial pressure of CO_2 be held below 5-mm Hg and implications are that this may be lowered to 3- or even 1-mm Hg. The selected concept should be able to achieve this capability. Oxygen must be recovered from the CO_2 in order to minimize the resupply requirements (see Section 3.0). The principal options considered are shown in Figure 4.1-1.

The CO_2 removal function trade data are presented in Table 4.1-1. The chemical scrubbers are presented to demonstrate the effect of closed loop systems as compared to the open loop systems such as LiOH. These data indicate that there is no significant differences between the closed loop

Table 4.0-1. Crew Requirements

ITEM	CHARACTERISTICS
METABOLIC REQUIREMENTS (ALL SHIRTSLEEVE)	
• Intake Requirements:	
• Oxygen Consumption	2.20 lbs/man-day
• Water - Food and Drink	6.63 lbs/man-day
• Food - Total Dry Weight	1.70 lbs/man-day
• Output Requirements:	
• Total Thermal Load	13,000 Btu/man-day
• Carbon Dioxide	2.57 lbs/man-day
• Water Loss (Insensible)	2.46 lbs/man-day
• Urine	3.62 lbs/man-day
• Feces (Wet)	0.21 lbs/man-day
METABOLIC REQUIREMENTS (WITH EVA)	
• Intake Requirements:	
• Oxygen Consumption	2.70 lbs/man-day
• Water - Food and Drink	8.50 lbs/man-day
• Food - Total Dry Weight	2.25 lbs/man-day
• Output Requirements:	
• Total Thermal Load	16,000 lbs/man-day
• Carbon Dioxide	3.71 lbs/man-day
• Water Loss (Insensible)	4.39 lbs/man-day
• Urine	3.19 lbs/man-day
• Feces (Wet)	0.27 lbs/man-day
WATER - HOUSEKEEPING REQUIREMENTS	
• Crew Washwater & Hygiene	4.0 lbs/man-day
• Crew Shower	16.6 lbs/man-day
• Dishwashing & Housekeeping	3.0 lbs/man-day

Table 4.0-2. A&CS Subsystem Design Requirements

ITEM	CHARACTERISTICS: LBS Shelter	CHARACTERISTICS: Prime-Mover & Mobile Shelter
Total Pressure	10.0 Psia Nominal	5.0 Psia Nominal
O_2 Partial Pressure	3.5 Psia Nominal 3.7 Psia (Max.)	5.0 Psia Nominal 3.5 Psia (Min.)
Diluent	Nitrogen	-
CO_2 Partial Pressure	Nominal: 5.0 mmHg Emerg. Max: 15.0 mmHg for 2 Hrs.	Same
Cabin Trace Contaminants	Continously Monitored	Same
Atmosphere Temperature	Control Range: 65 to 75°F, ± 3°F	Same
Cabin Ventilation Rate	40 Ft/Min. Nominal; 15 Ft/Min. Minimum; 100 Ft/Min. Maximum	Same
Cabin Humidity	Absolute Humidity Range: 8 mmHg to 12 mmHg ppH_2O; Relative Humidity Range: 30 to 50% approx; Minimum Dewpoint: 57°F	Same
Water Requirements Model		
. Crew H_2O Consumption:		
a. Drinking & Food Preparation	5.59 Lb/Man-Day	Same
b. In Food Supply	1.04 Lb/Man-Day	
c. From Oxidation	0.60 Lb/Man-Day	Same
. Wash Water		
a. Partial Body Hygiene 1. Hand & Face 2. Hair Groom	4.0 Lb/Man-Day	Same
b. Shower	16.6 Lb/Man-Day	Same*
c. Dishwashing & Housekeeping	3.0 Lb/Man-Day	Same*
. Experiments	4.6 Lb/Day	Same*

*Not required in Prime Mover.

Table 4.0-3. Summary of A&CS Requirements

ITEM	BASELINE CHARACTERISTICS		
	Lunar Surface Base	Mobile Shelter	Prime-Mover
Crew	12 Men	4 Men	2 Men
Metabolic Load	156,000 Btu/Day	52,000 Btu/Day	32,000 Btu/Day
Consumable Storage	180 Days	90 Days	2 Days
• O_2	26.4 lbs/Day	8.8 lbs/Day	5.4 lbs/Day
CO_2 Concentration	5.0 mmHg Nominal 7.6 mmHg Maximum	Same	Same
Temp. Selectability	65 to 75°F, Nominal	Same	Same
Ventilation Rate	40 ft/min, Nominal	Same	Same
Potable Water Usage	79.6 lbs/Day	26.5 lbs/Day	17.0 lbs/Day
Wash Water Usage	259.5 lbs/Day	82.4 lbs/Day	8.0 lbs/Day
Atmospheric Leakage	12.24 lbs/Day	1.7 lbs/Day	0.3 lbs/Day
Free Volume	17,500 ft^3	4,500 ft^3	400 ft^3
Radiator Heat Rejection	48,000 to 55,000 Btu/Hr	15,000 to 20,000 Btu/Hr	7,000 to 10,000 Btu/Hr

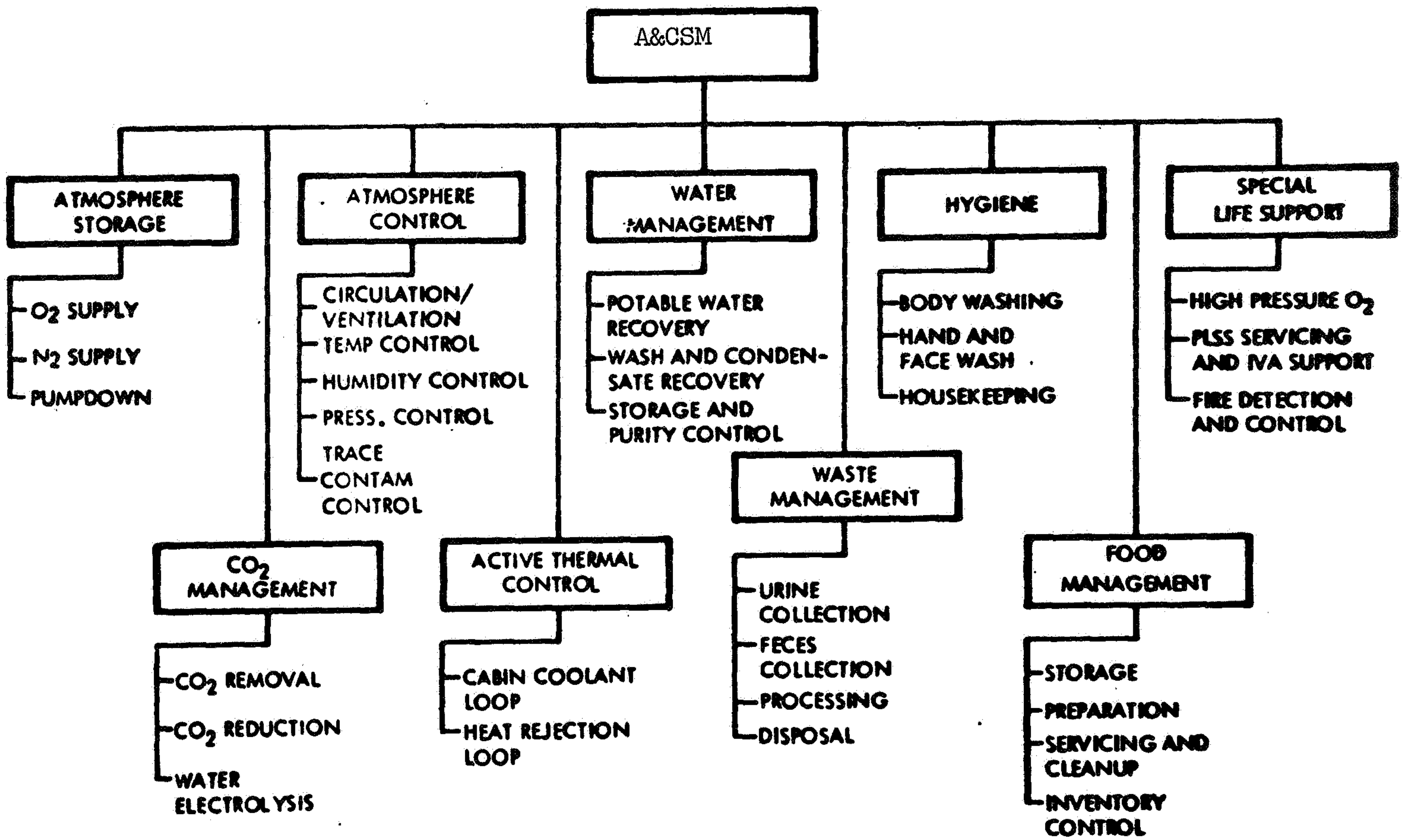


Figure 4.0-1. Assembly and Functional Breakdown, Atmosphere and Crew Services Management

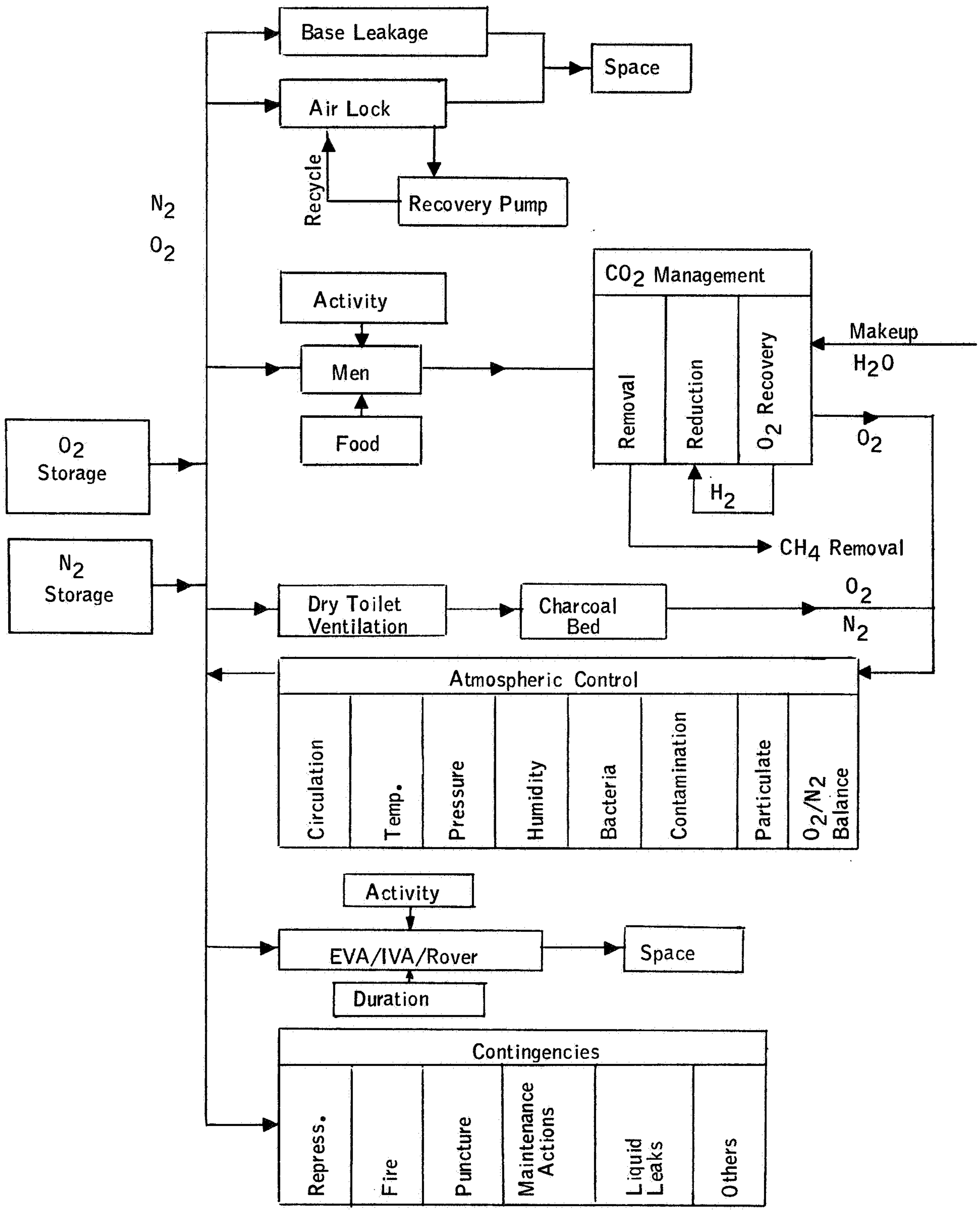


Figure 4.0-2. Atmosphere Cycle and Influence Factors

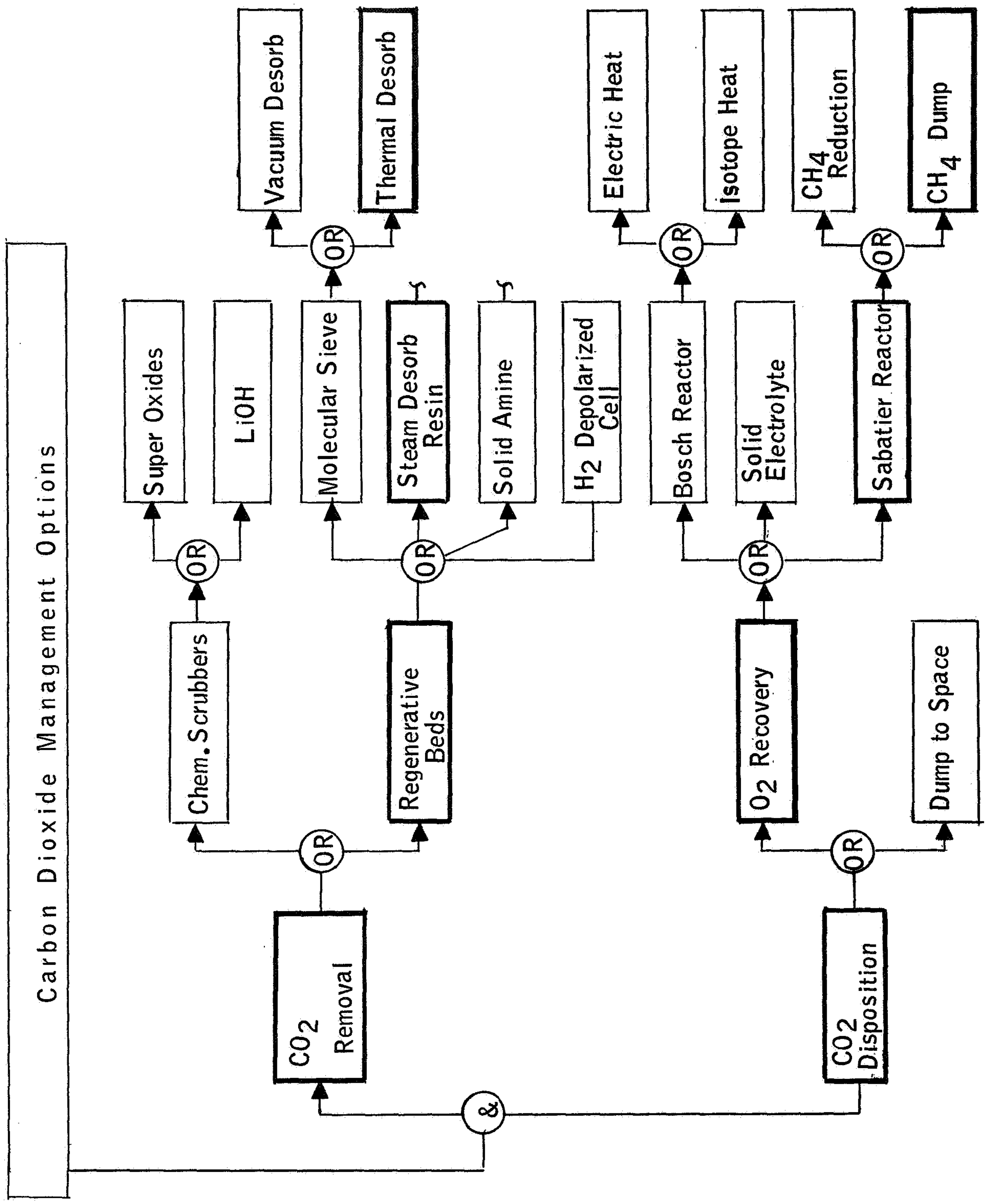

Carbon Dioxide Management Options
&
CO2 Removal
CO2 Disposition
OR
Chem. Scrubbers
Regenerative Beds
O2 Recovery
Dump to Space
Super Oxides
LiOH
Molecular Sieve
Steam Desorb Resin
Solid Amine
H2 Depolarized Cell
Bosch Reactor
Solid Electrolyte
Sabatier Reactor
Vacuum Desorb
Thermal Desorb
Electric Heat
Isotope Heat
CH4 Reduction
CH4 Dump

Figure 4.1-1

Table 4.1-1. CO_2 Removal Concept Trade Data
4-Man Module, 180-Days with 6 Months Resupply

Candidates	Related Interfaces (Quantifiable)									Other Interfaces Credits
						Power Req'd.				
	Fixed Weight (lb)	Initial Spares (lb)	180-Day Expend. (lb)	Total Installed Weight (lb)	Installed Volume (ft^3)	Motiva. Force (watts)	Heat Input (watts)	180-Day Resupply (lb)	Heat Rejection (Btu/hr)	
Mol-Sieve	280	157	-	437	15.08	150	365	10.3	1350	
Steam Desorbed Resin	200	120	-	320	11.05	150	520	7.2	2400	Waste heat usable
Solid Amine	230	198	-	428	14.75	50	1160	13.1	3200	
H_2 Depolarized Cell	170	81	-	251	6	60	-	6	2140	Reduces Sabatier Increases electrolysis
Chemical Scrubbers	18	10	3322	3348	115	150	0	3322	800	Requires many crew hours

concept options in a quantitative evaluation and selection must be made on the basis of other, more qualitative factors. A comparison of the potential reliability, maintainability and operability (based on complexity), plus the other interface factors all tend to favor the H_2 depolarized cell concept shown schematically in Figure 4.1-2. Further, this concept is somewhat lighter, uses the least amount of power and has the potential to satisfy any CO_2 partial pressure level requirement. Other studies have also identified it as the most favorable option for the time period.

The CO_2 reduction trades for the options identified by Figure 4.1-1 are presented in Table 4.1-2. Here again, the quantitative values provide less significant selection criteria than the qualitative. However, the recommended concept, the Sabatier reactor with methane dump, shows some slight margin in every respect. It has been recommended for the Earth Orbit Space Station and the Orbiting Lunar Station and is, therefore, expected to be developed by the LSB time frame. Its potential reliability and ease of maintenance add significantly to the decision criteria.

4.2 ATMOSPHERIC GAS MAKEUP, STORAGE AND PRESSURE CONTROL

Three gases are proposed for use with the recommended LSB concept:

1. Metabolic O_2 for crew support
2. N_2 for an atmospheric dilutent
3. H_2 for the Sabatier and H_2 depolarized cell concepts

The atmospheric pressure and content were set at 10 psia (3.5 psia O_2), because of the large amount of EVA and the resulting potential for bends potential. The advanced pressure suits are expected to operate at no higher than 5 psia which would result in a differential pressure of only 5 psia during the egress procedure. Since a two-gas system with N_2 is highly desirable to reduce the fire hazard, a higher overall pressure with a higher concentration of N_2 could create a personnel hazard and/or greatly extend the egress time for de-nitrogenation purposes. The 6.5 psia of N_2 provides a reasonable amount of protection against the fire hazard, the propagation rate being only 1.5 times that for a standard atmosphere.

The atmosphere systems must provide for the needs of the LSB shelters and APLSS repressurization. The losses per 4-man module were estimated to be:

1. O_2 leakage at 1.16 lb/day plus 0.24 lb/day for airlock dump = 1.4 lb/day O_2 makeup

2. N_2 leakage at 1.90 lb/day plus 0.3 lb/day airlock dump = 2.2 lb/day N_2 makeup

3. The Sabatier reactor dumps methane at the rate of 2.31 lb/day and the resulting H_2 loss is about 1.71 lb/day

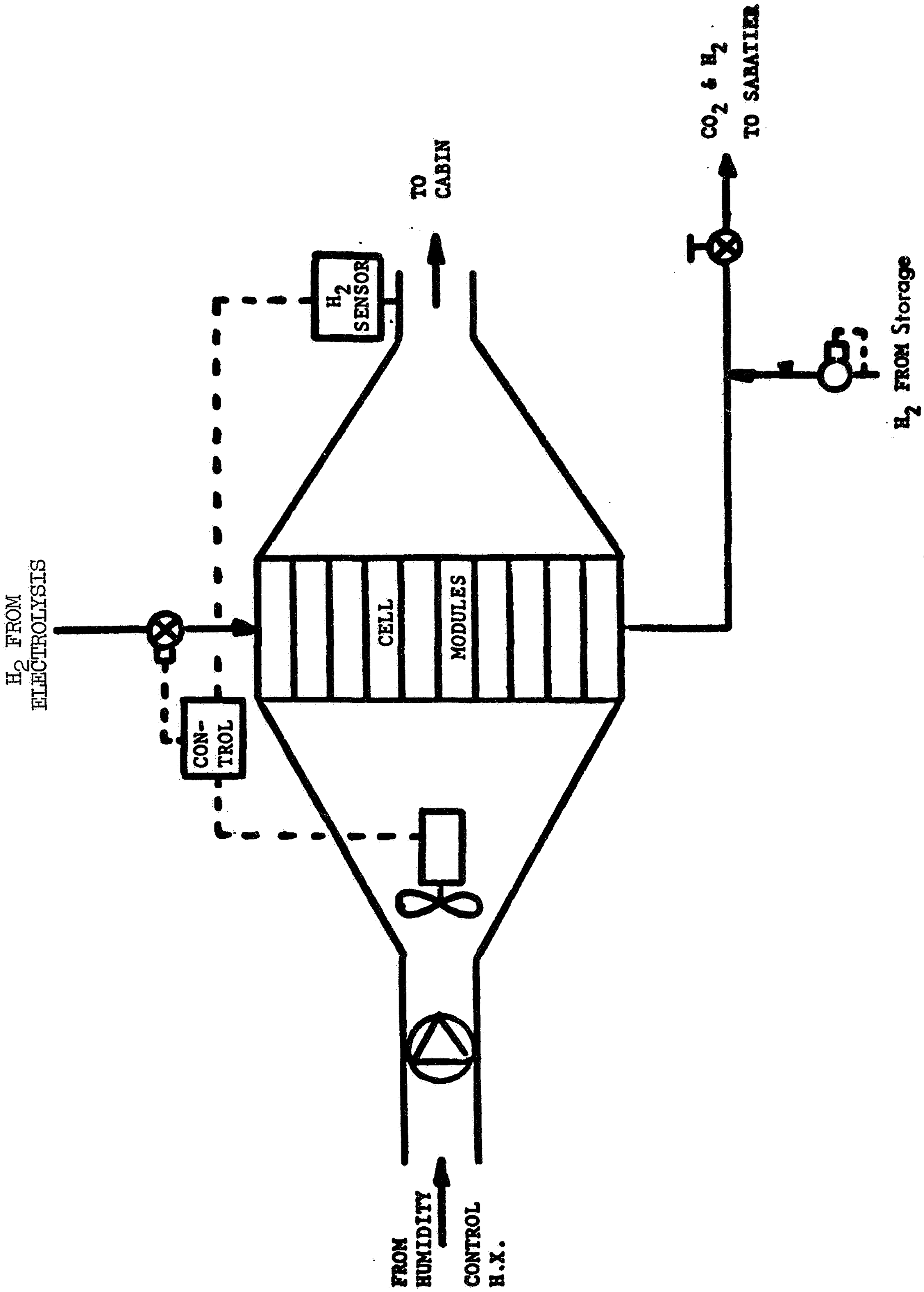


Figure 4.1-2. H_2 Depolarized Cell

Table 4.1-2. CO_2 Reduction

(4-Man Module, 180 Days with 6-Month Resupply)

CANDIDATES	RELATED INTERFACES								
	FIXED WT (LB)	INITIAL SPARES (LB)	180 DAY EXPEND. (LB)	TOTAL INSTALLED WT (LB)	INSTALLED VOLUME (FT^3)	POWER REQUIRED		180 DAY RESUPPLY SPARES (LB)	HEAT REJECTION BTU/HR
						MOTIVATING FORCE (WATTS)	HEAT INPUT (WATTS)		
SABATIER/ METHANE DUMP	38	38	13	89	5.62	100	65	1.0	1100
BOSCH REACTOR	120	70	120	310	19.05	100	250	1.8	1400
SOLID ELECTROLYTE	220	110	140	470	30.6	1280	-	2.9	2000
SABATIER/ METHANE CRACKING	185	93	120	398	25.85	600	80	2.4	2400

The makeup gas may be provided by any of the options indicated on Figure 4.2-1. Since three gases are required, the electrolysis options must consider more than one source simultaneously.

Oxygen supply for normal metabolic consumption and leakage makeup is provided directly via the electrolysis of water. Therefore, the primary oxygen source is water. Makeup water is resupplied as wet food and from water recovery from CO_2 reduction. The primary question for oxygen leakage makeup becomes one of whether to increase the capacity of the electrolysis process to produce leakage oxygen from water, or to add and resupply an oxygen storage system. When considering water electrolysis, the ECLSS water balance or water availability must be considered. Figure 4.2-2, the mass balance, indicates that with a normal food diet, which contains a high percentage of water, approximately 11 pounds/day of water are available for electrolysis. The electrolysis provides 9.96 pounds/day of oxygen for metabolic consumption and leakage, which satisfies the crew requirements.

For the mobile shelter, the electrolysis unit was eliminated and storage tanks have been included for holding the water recovered from the CO_2 reduction unit and the oxygen required (see Section 3.0).

The water electrolysis options for O_2 generation were identified by Figure 4.2-1. The resulting trade data are presented in Table 4.2-1. Of the five concepts evaluated, the quantitative data do not identify a clear optimum. However, the qualitative factors such as reliability, maintenance requirements, and susceptibility to contamination result in selection of the solid polymer concept. Indications are that the concept will work directly from waste water, thereby reducing the complexity of water management function as well.

The need for N_2 and H_2 may be considered together since the available options are closely associated. The problems associated with the delivery, handling, storage and use of cryogenic gases, particularly to the lunar surface, make it desirable to explore other options. Both N_2 and H_2 are available from the decomposition of hydrazine (N_2H_4) or ammonia (NH_3) as well as from a cryogenic storage system. Figure 4.2-3 presents the weight trade data associated with each option with the power and heat penalties included.

Ammonia dissociation produces 0.214 pound of H_2 per pound of N_2, while hydrazine produces 0.145 pound of H_2 per pound of N_2. Storage of hydrogen cryogenically (subcritical) requires 1.43 pounds tank per pound of hydrogen. As shown in Figure 4.2-3, the least weight system, based on the N_2 requirement is hydrazine (N_2H_4). It also requires the lowest resupply weight and volume. Since the hydrazine can be stored at relatively low pressure, the container shape can make maximum use of the available volume. The ammonia (NH_3) system is slightly heavier and requires larger resupply volume. The addition of a regenerative heat exchanger to the NH_3 system with electrical heaters and associated controls, and the need for a slightly larger hydrogen separator, add extra system weight relative to the hydrazine system. The cryogenic storage is heavier than the NH_3 system and the storage

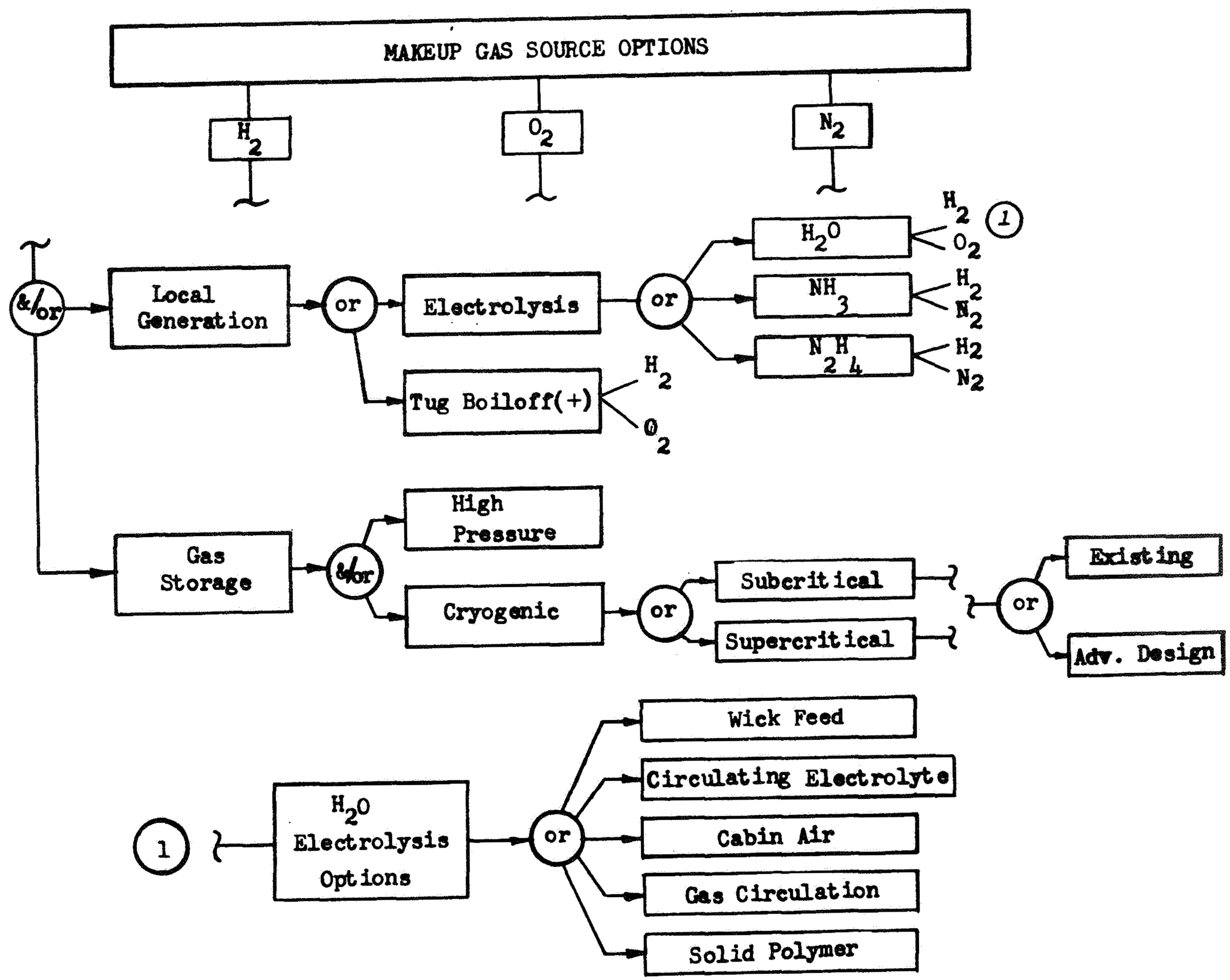


Figure 4.2-1. Makeup Gas Source Options

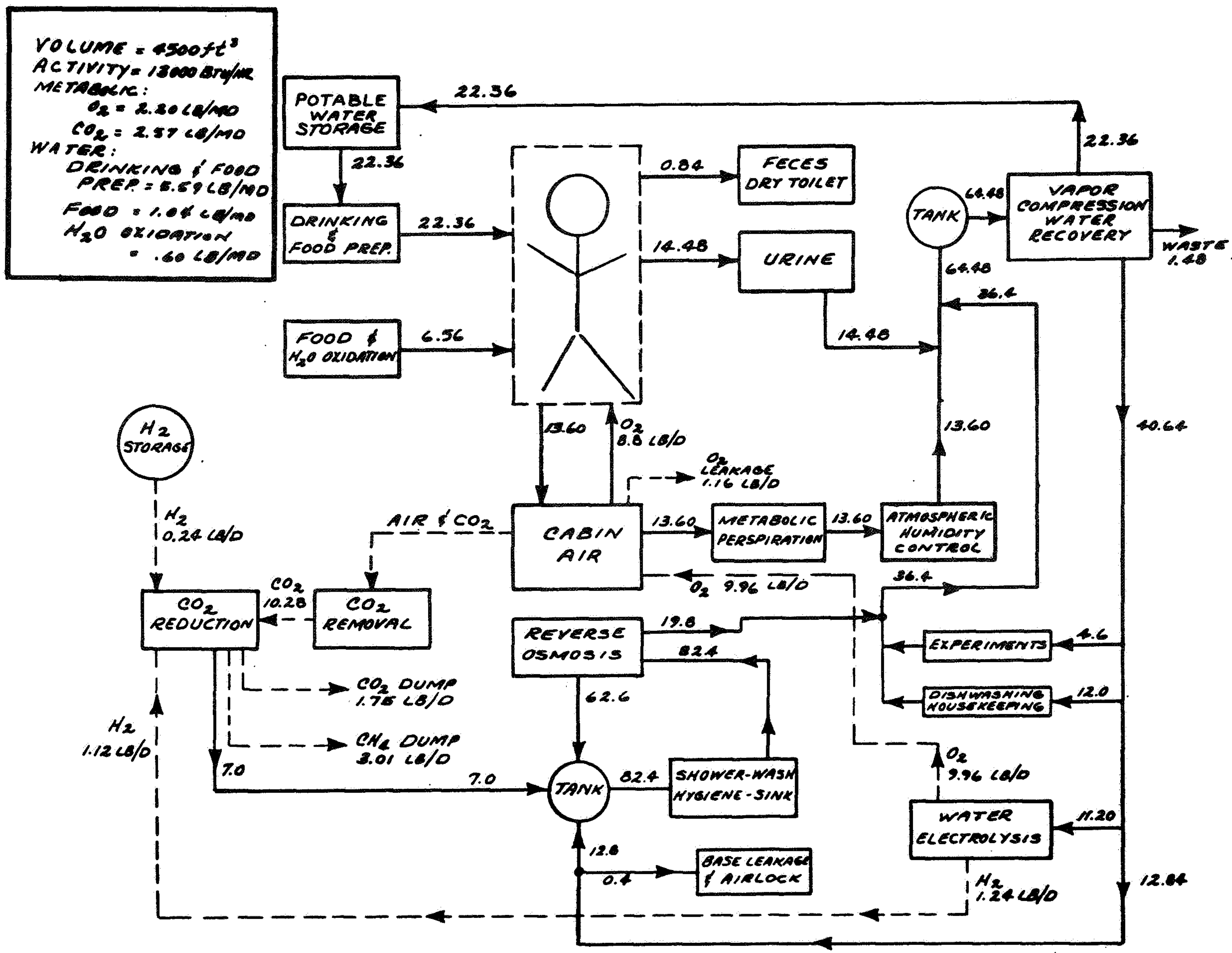


Figure 4.2-2. Four-Man Module Configuration Mass Balance

Table 4.2-1. H_2O Electrolysis System Candidate Trade Summary - Lunar Surface Base
(4 Men - 180 Days)

CANDIDATES	WEIGHT PENALTY ∿ LBS.				ELEC. POWER		VOLUME ∿ FT^3			Q BTU/HR
	Fixed	Spares	Expend.	TOTAL	Watts	Cycle	Fixed	Spares	TOTAL	
Wick Feed	140	75	-	215	2,200	Cont.	5.28	2.75	8.03	2,400
Circulating Electrolyte	200	220	-	420	2,200	Cont.	7.56	8.69	16.25	2,900
Cabin Air	240	72	-	312	3,200	Cont.	9.08	3.02	12.10	5,600
Gas Circulation	120	110	-	230	1,600	Cont.	4.53	4.02	8.55	2,400
Solid Polymer*	120	84	-	204	2,200	Cont.	4.53	3.37	7.90	2,600

*Selected system candidate based on minimum weight, power and volume.

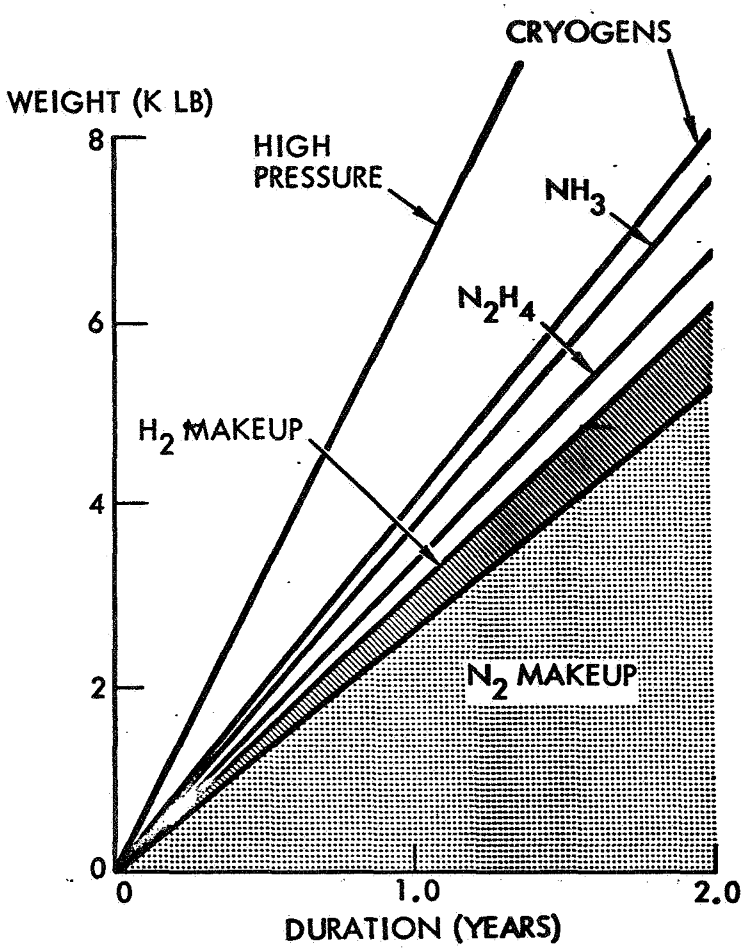


Figure 4.2-3. Weight Trade Data, Gas Storage Concepts (H_2 and N_2)

and handling considerations make this the least desirable option. Figure 4.2-4 is a schematic of the N_2H_4 recommended dissociation concept. The NH_3 process is endothermic and operates at approximately 1200 F with high power. For both concepts, N_2H_4 and a small amount of NH_3 are products from the reactor. The NH_3 impurity creates a problem in that it must be controlled to less than 50 ppm because of the toxic nature of NH_3. The solution is to add air to the reactor product stream and pass it through the catalytic oxidizer used for the trace contaminant control function. The NH_3 will be converted to N_2 and H_2, and the H_2 will combine with O_2 from the air to produce water in the catalytic burner.

The NH_3 concept offers some advantage if shelter nitrogen requirements are lower than the 20-pound/day design point. The N_2H_4 concept requires less resupply and power but more toxicity is evident than with the NH_3. Isolation of the dissociator and supply from the cabin should eliminate any risk of atmospheric contamination.

Repressurization of the LSB and outposts can be accomplished through any of the source options previously identified; however, the selection criteria are somewhat different. It must be capable of repressurizing any module within a 24-hour cycle. This involves about 3400 cubic feet of free volume for each 4-man system. The resulting requirement for repressurizing any 4-man module group is 134 pounds of O_2 and 171 pounds of N_2. The potential concepts are compared on Table 4.2-2.

The N_2 portion of repressurization can be accomplished by high pressure gaseous storage, cryogenic N_2, or N_2H_4 dissociation. Ammonia dissociation is indicated on Table 4.2-2 as an option, but has the significant penalty of requiring excessive power to repressurize within 24 hours. Nitrogen repressurization from NH_3 requires 1100 watts for five days. A comparison of the N_2 concepts indicates that cryogenic N_2 has the lowest weight and power; however, long-term storage with this concept is not feasible due to boiloff. Consequently, high pressure N_2 is preferred on the basis of weight and time. However, the N_2H_4 concept is satisfactory as well.

The oxygen portion of repressurization can be accomplished by high pressure storage, cryogenic storage, or water electrolysis. Water electrolysis requires five days and 6.7 kilowatts average power to supply sufficient oxygen. An option does exist for water electrolysis at high pressure, which would eliminate the five-day time problem; however, high pressure storage tanks would be required and, consequently, this option offers no weight advantage. Cryogenic storage for the repressurization function only indicates a weight advantage, but long-term storage cannot be satisfied due to boiloff. High pressure oxygen storage is the recommended concept since it also can be used for APLSS recharge.

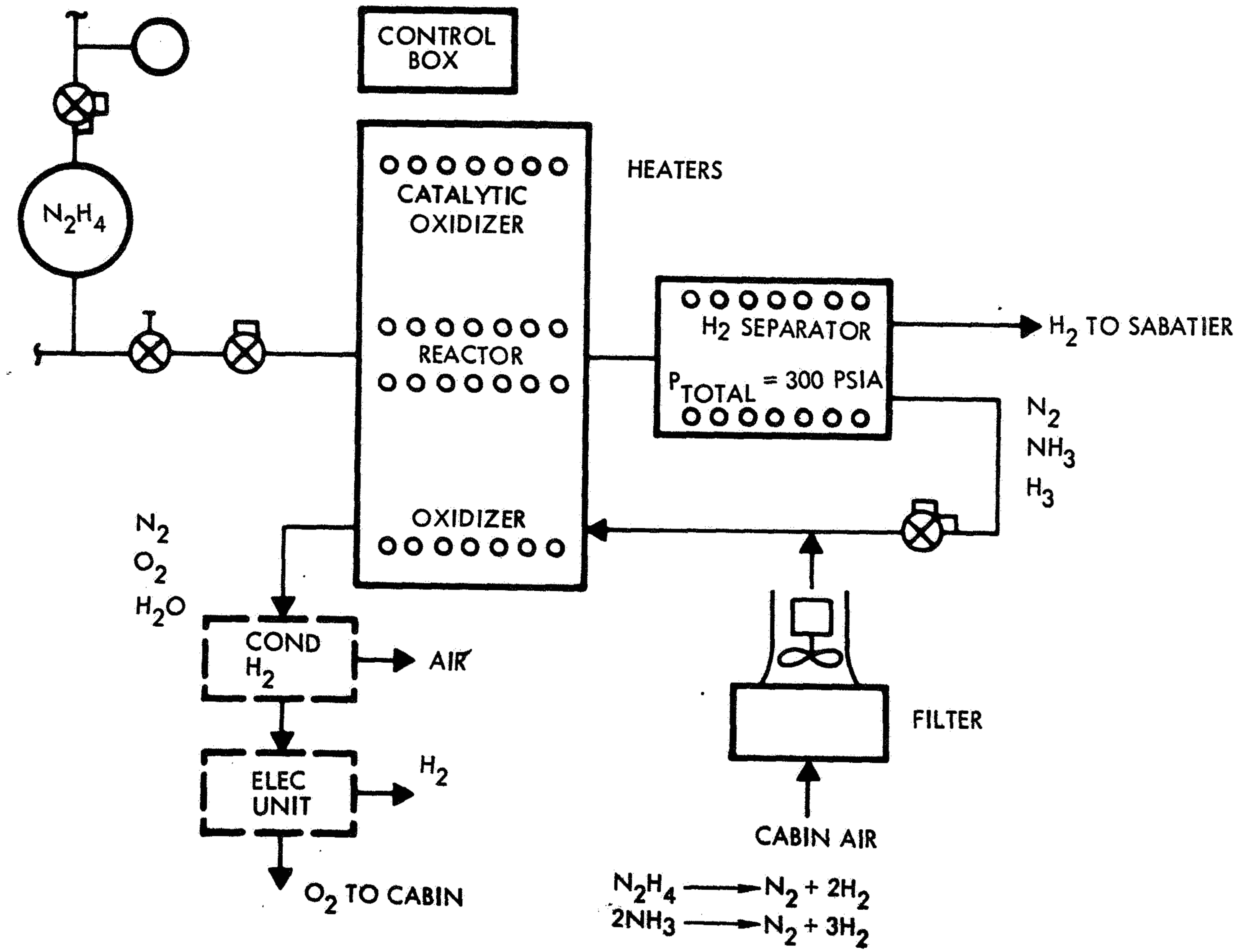


Figure 4.2-4. Hydrazine Dissociator

Table 4.2-2. Repressurization Concept Options

CONCEPT	FLUID	SYSTEM	POWER	REPRESSURIZATION TIME (DAYS)
N_2 SOURCE				
. High Pressure N_2	171 lbm	171 lbm	0	< 1
. Cryogenic N_2*	171 lbm	83 lbm	<10 watts	1
. N_2H_4 Dissociation	195 lbm	195 lbm	345 watts	1
. NH_3 Dissociation	208 lbm	189 lbm	1040 watts	5
O_2 SOURCE				
. High Pressure O_2	134 lbm	134 lbm	0	< 1
. Cryogenic O_2*	134 lbm	158 lbm	(Boil Off)	1
. H_2O Electrolysis	151 lbm	∿ 300 lbm system	6.65 kw	5
. High Pressure H_2O Electrolysis	151 lbm	∿ 800 lbm system	-	-

*Reliquefaction will be required to maintain this source.

4.3 CONTAMINANT CONTROL

The contaminant control assembly provides for the removal of particulates, bacteria detection and removal, trace gas detection and removal, and odor removal. Contaminants are those chemical compounds found in trace amounts in air or water which might be harmful to man if present in higher concentrations than in a normal atmosphere. They are likely to build up during long-term manned space missions in which the atmosphere is being regenerated. There are various sources of these contaminants; e.g., the metabolic processes of the crew that result in saliva, urine, feces, flatus, and expired air; gaseous products from food and supplies stored and used in the LSB; gaseous products resulting from the operation of the various systems within the LSB. Other sources of contaminants are the materials from which the LSB is made and any reaction products resulting from scientific investigations or material analysis.

Continuous monitoring of the atmospheric content using a gas chromatograph and mass spectrometer for trace gas detection, and an Agar tape/incubator/detector unit for bacteria detection provides the safest approach. Bacteria removal can be accomplished by filtration while trace gases can be removed by several methods.

The various contaminant management options studied for the lunar base complex are presented in Figure 4.3-1. They reduce to three basic methods: (1) nonregenerable charcoal with catalytic oxidation; (2) catalytic oxidation/sorption, and (3) regenerable charcoal with catalytic oxidation.

Table 4.3-1 presents the results of the tradeoff data of the three concepts. The data indicate that the catalytic oxidation/sorption concept is the lowest on a weight penalty basis and is comparable with the nonregenerable charcoal/catalytic oxidation concept in electrical power demand. Expendable weight is much lower for the catalytic oxidation/sorption than the other two concepts analyzed.

4.4 THERMAL AND HUMIDITY CONTROL

The thermal control function must perform the following functions:

1. Remove heat from shelter equipment and maintain their temperature between -30 and +120 F

2. Cool the potable water and the dehumidifier to 45 F

3. Maintain the shelter atmosphere at 70 $\pm$5 F

The total heat load was estimated to be about 20,000 Btu/hour per module group that would have to be rejected by any one system. About 1000 Btu/hour of this is associated with the lower temperatures in the water chiller and humidity control functions. The remainder and larger portion may be at a higher temperature. The module design and deployment concept has been planned so as to minimize heat leaks in or out of the LSB modules (see Volume II, Section 4.5).

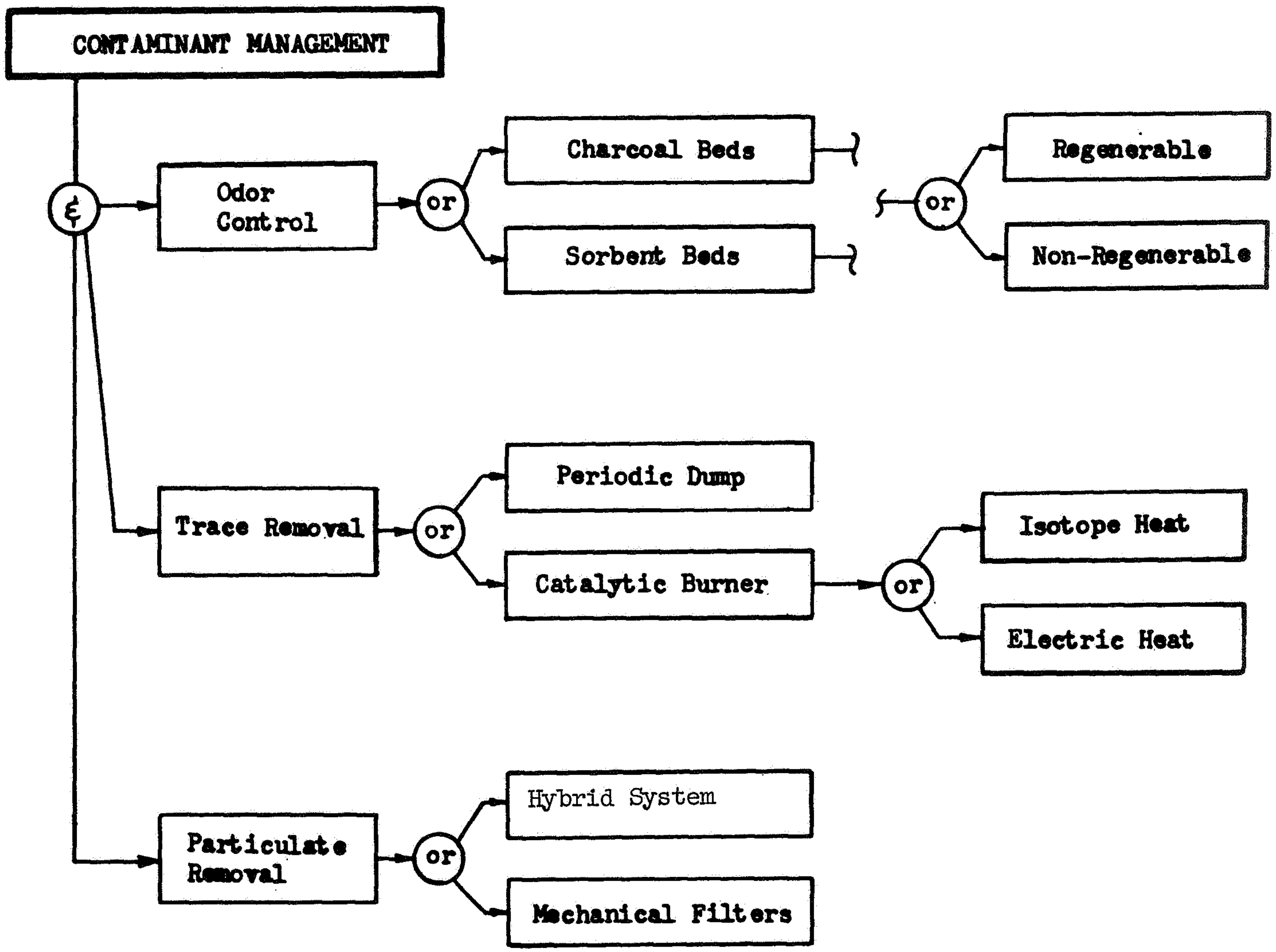


Figure 4.3-1. Contaminant Management Control Options

Table 4.3-1. Contaminant Control - System Candidate Trade Summary - Lunar Surface Base (4 Men - 180 Day Resupply)

CANDIDATES	WEIGHT PENALTY ∿ LBS.				ELEC. POWER		VOLUME ∿ FT^3			Q BTU/HR
	Fixed	Spares	Expend.	TOTAL	Watts	Cycle	Fixed	Spares	TOTAL	
Non-Regen. Char/Cat. Ox.	44	8	320	372	70	Cont.	2.47	9.89	12.36	280
Cat. Ox./Sorption	64	6	35	105	90	Cont.	3.60	1.23	4.83	340
Regen. Char/Cat. Ox.	112	11	7	130	260	Cont.	6.30	.54	6.84	800

*Selected system candidate based on minimum weight, power and volume.

NOTE: Expendables include such items as filters, catalysts or chemicals normally programmed for replacement.

Figure 4.4-1 presents the active thermal control options considered for the modules and installed equipment including the humidity control interface. The subsystems can be considered in terms of the three functions: heat removal, humidity removal, and heat rejection.

Humidity removal may be accomplished through any of the options identified on Table 4.4-1. The condensing heat exchanger has been used extensively in the past, but the requirement it imposes for a low input temperature can seriously impact the size of the space radiator. Use of the absorbtion cycle or freon cycle (vapor compression) heat pump can reduce the radiator size significantly. The absorbtion cycle system requires very little power and can be energized with waste heat. The absorbtion cycle with a condensing heat exchanger is recommended for the LSB primarily on the basis of the resulting reduction in radiator size from the higher rejection temperature. There is also a corollary reduction of electrical power and its radiator size so that the total weight saved amounts to about 300 pounds per module group compared to a condensing heat exchanger alone.

Heat removal involves both the cabin air and the equipment. A detailed analysis may be found in Appendix B to this volume. The dehumidifier concept can handle the cabin air, but the equipment cooling must be handled independently either by coldplates or ducted air. Each system has certain advantages. The coldplate has lower cooling power requirements, less weight and volume, and allows for greater heat rate and density. In addition, it is somewhat less complex than forced gas and provides a more compact installation. The ducted air system, on the other hand, has the advantage of ease in changing and replacing cooling units, less danger of electronic component failure, relative insensitivity to manufacturing assembly skill, and less critical manufacturing tolerances. Table 4.4-2 presents the penalties in weight, volume, power, and heat density that would be imposed by each of two methods.

Table 4.4-2. Cooling System Requirements (Penalties based on 14.7 psia)

Characteristic	Coldplate	Duct
Weight (lb/watt)	3.5×10^{-3}	4.8×10^{-2}
Volume (in.^{3}/watt)	0.38	3.8
Power (watt/watt)	6.3×10^{-4}	0.16
Electronic load (watts/ft^2	288	240

The ducted air system has a long record of use and proven reliability. In a properly designed system, faulty electronic components can be removed and replaced without affecting or degrading the cooling system. Conversely, for the coldplate system, any repair, replacement, or maintenance requires component removal from the coldplate heat transfer surface, with the inherent danger of downgrading the system cooling because of surface damager or improper installation on the heat transfer surface. If this should happen, the electronics could have a shorter time to failure due to overheating, thus reducing reliability.

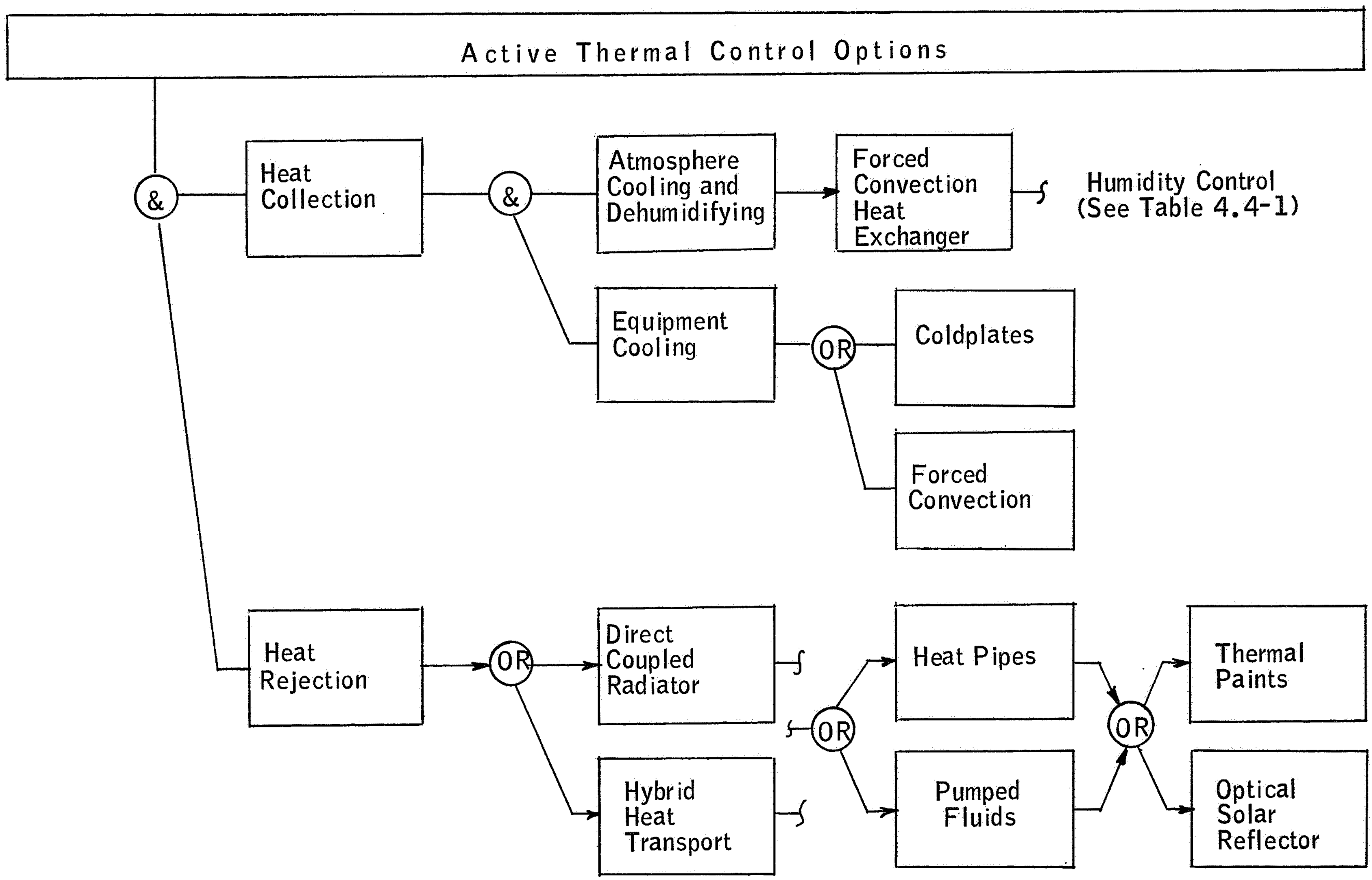


Figure 4.4-1. Module and Equipment Thermal Control and Dehumidifier Options

Table 4.4-1. Humidity Control Concept Characteristics

Characteristics / Option	Two-Bed Desiccant and Compressor	Two-Bed Desiccant and No Compressor	Thermoelectric	Freon Cycle	Condensing Heat Exchanger	Absorbtion Cycle
Required Coolant Temp. (°F)	70	50	50	100	35	100
Weight (lb)*	45	100	25	50	25	30
Volume (ft^3)	3	6	1	2	1	2
Power (watts)	300	75	1,000	1,000	50	35
Air Flow (lb/hr)	100	150	500	500	500	500
Heating Required (Btu/hr)	900	7,000	-	-	-	1,000

*Does not include power penalty or radiation penalty.

NOTE: Crew latent load only so air flows are not total latent air flows.

A further consideration is quality control during manufacture. The coldplate system requires much closer tolerances, and thus close control during manufacturing and assembly. With the ducted air system, this is not as great a problem. A hybrid system may, therefore, be the best alternative.

Heat rejection must be accomplished through some form of space radiator. The radiator must be oriented parallel to the lunar surface and deployed in such a manner as to minimize the view factor associated with the lunar surface. Horizon angles of greater than 10 degrees above the plane of the radiator will seriously degrade the performance regardless of thermal coatings.

Several coolant combinations were considered (see Figure E-3 of Appendix E). Pumping power, viscosity and operating temperatures formed the decision parameters. A dual loop concept using pure water inside and freon outside was selected. The freon will not freeze during the lunar night, permitting selective stagnation. The water inside will eliminate any hazard potential from escaping vapors.

The heat rejection capability of a radiator is also dependent upon the radiator temperature and the optical properties of the radiator surface for a given environmental condition. This is illustrated in Figure 4.4-2 for the case of a horizontal radiator at the subsolar condition. As shown, low values for the α_s/ϵ ratios and high temperatures are necessary to achieve high heat rejection capability. However, practical considerations and limitations of available materials such as surface coatings and coolants limit the specific heat rejection rate that can be achieved. The radiator operating temperature is limited by the temperature limits of the available coolants or working fluid and the radiator inlet and outlet temperatures as specified by the equipment and processes that require cooling. The values for the α_s/ϵ ratios, particularly in the lower range, depend upon the coatings or finishes that are currently available or will be available and are suitable for the lunar surface base application.

Zinc oxide (Z-93), a radiator coating developed for the Apollo program, would result in a heat rejection rate of about 20 Btu/hour/square foot for a 60 F radiator. This heat rejection rate could be significantly improved by utilizing a relatively recent development which is identified as the optical solar reflector. For this particular surface finish, the heat rejection rate would be about 80 Btu/hour/square foot for a 60 F radiator. Thus, the radiator area would be about one-fourth the size as compared to one that utilizes Z-93. This is particularly significant for the sortie convoy since a minimum area is desirable. The optical solar reflector has demonstrated under simulated and actual space conditions complete stability under ultraviolet and particulate irradiation, and is recommended for LSB applications.

Figure 4.4-2 also indicates the dependency of the radiator size on the average temperature. If the low temperature requirements (water chiller and humidity control) are satisfied with a heat pump device, as discussed earlier, the radiator outlet need not be lower than 70 F and the inlet can be as high as 120 F, providing an average radiator temperature of 95 F. The required

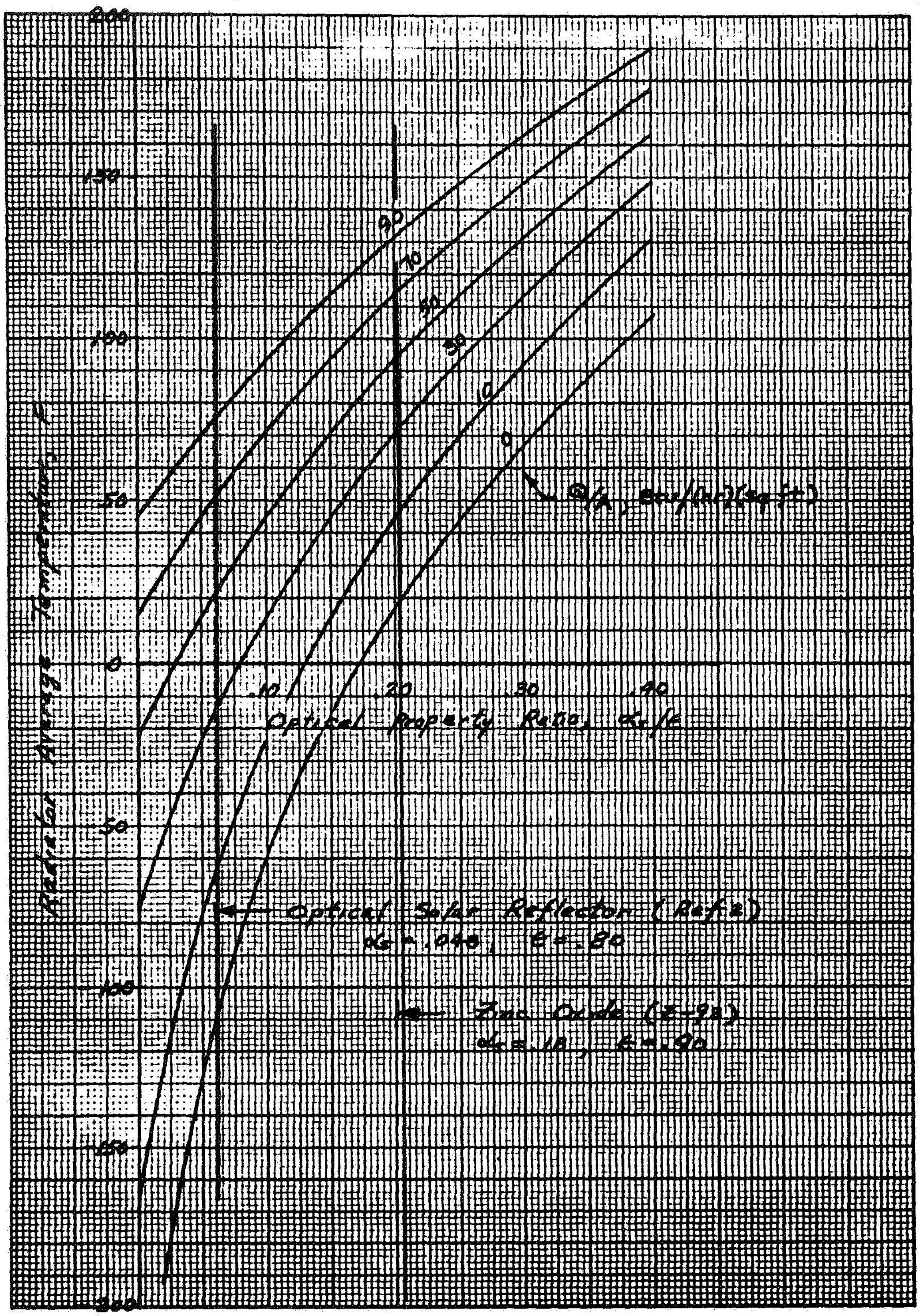


Figure 4.4-2. **Radiator Heat Rejection Rate per Unit Area at Subsolar Point**

radiator size as a function of the total heat load may be identified from Figure 4.4-3, which is based on the use of an OSR-coated radiator and conditions at the lunar subsolar point. An assumed radiator effectiveness of 90 percent was utilized.

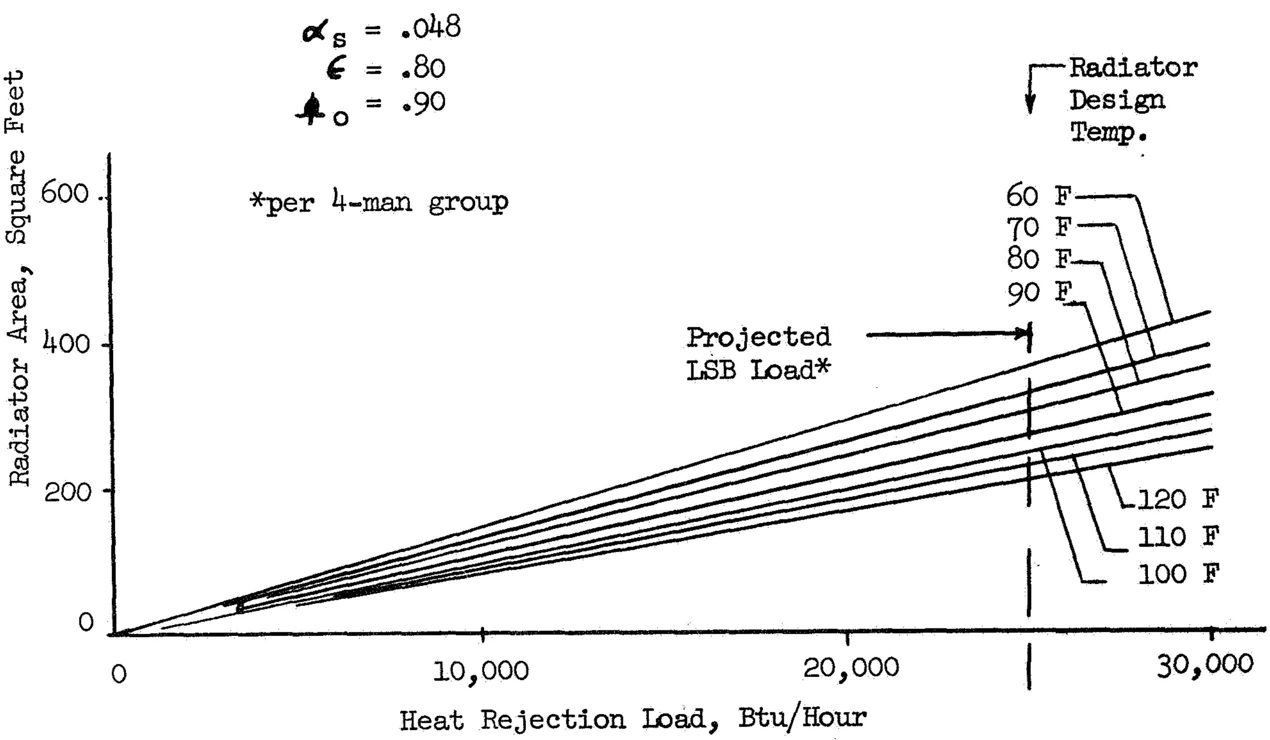


Figure 4.4-3. Area Requirement for Radiator with Optical Solar Reflector

Figure 4.4-4 presents the resulting recommended active thermal and humidity control concept. Low power pumps are used to assure proper circulation of the fluids within the respective loops

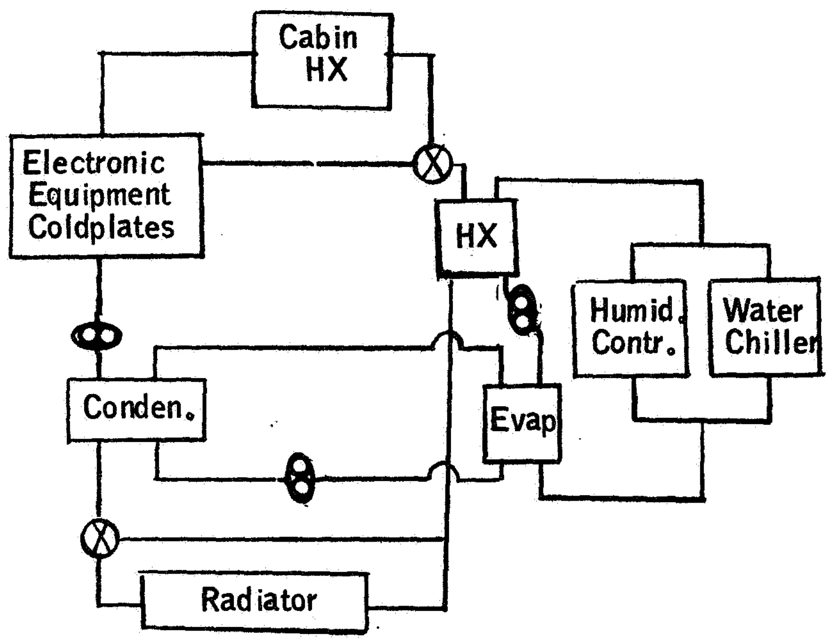


Figure 4.4-4. Recommended Active Thermal Control Concepts for LSB Modules

4.5 WATER MANAGEMENT

Over 30 pounds of water per man are utilized each day by the LSB. In order to minimize the impact on the logistics system, recovery and reclamation of all or as much as feasible is highly desirable. The waste water has several levels and types of contamination to be removed and the reclamation concepts vary considerably in their purification capabilities. Figure 4.5-1 presents the water management options for a unified system producing potable water. However, since the wash water is not directly consumed by the crew and can therefore be of lesser quality, tradeoffs between the two basic concepts are indicated before selecting a water management approach. The first is that of a unified concept where the output quality would be the same for all recovered water. The second is a dual recovery concept where wash water is recovered with a quality consistent for washing, but not for crew consumption, and the remaining waters are processed to potable standards. It should be noted that consideration of both multifiltration and reverse osmosis is limited to condensate and wash waters. Testing on other programs has shown that with these two concepts, urine is not recoverable to the required potability standards and a dissociation concept is required.

The vapor compression cycle was identified as optimum for the unified concept from the data shown in Table 4.5-1. Water reclamation for the LSB, utilizing just the vapor compression cycle in a unified concept, was compared with a dual system concept using a reverse osmosis concept for housekeeping water and a vapor compression cycle for potable water. The results are presented in Table 4.5-2.

These data indicate that although the initial system weight is slightly higher for the dual mode concept, the difference in the total delivered weight favors the dual mode, amounting to over 4000 pounds in the first year. The resulting recommended water management concept is presented in Figure 4.5-2. Dishwashing water and urine are processed directly through the vapor compressions cycle to provide the required purity level.

The water management system for the prime mover will be somewhat simpler than those used in the LSB and the mobile shelter because of the reduced processing provisions which are required, and the fewer functions in the mobile vehicle involving use of water. The personal hygiene provisions in the prime mover will be similar to those used in the Apollo command module and will involve limited use of water. The urinal design will also be similar to that used on Apollo which requires no water for flushing. Water storage tanks will be sized to hold the processed water from the CO_2 reduction unit.

The water storage and purity control system is an area where multiple solutions are not available, but its selection rests heavily with subsystem integration requirements and design.

The recommended water and storage system consists of heated water storage tanks, redundant recirculating water pumps, a water quality monitoring system and auxiliary equipment, valves and controls and distribution plumbing. Water quality and redundancy requirements of each loop dictate

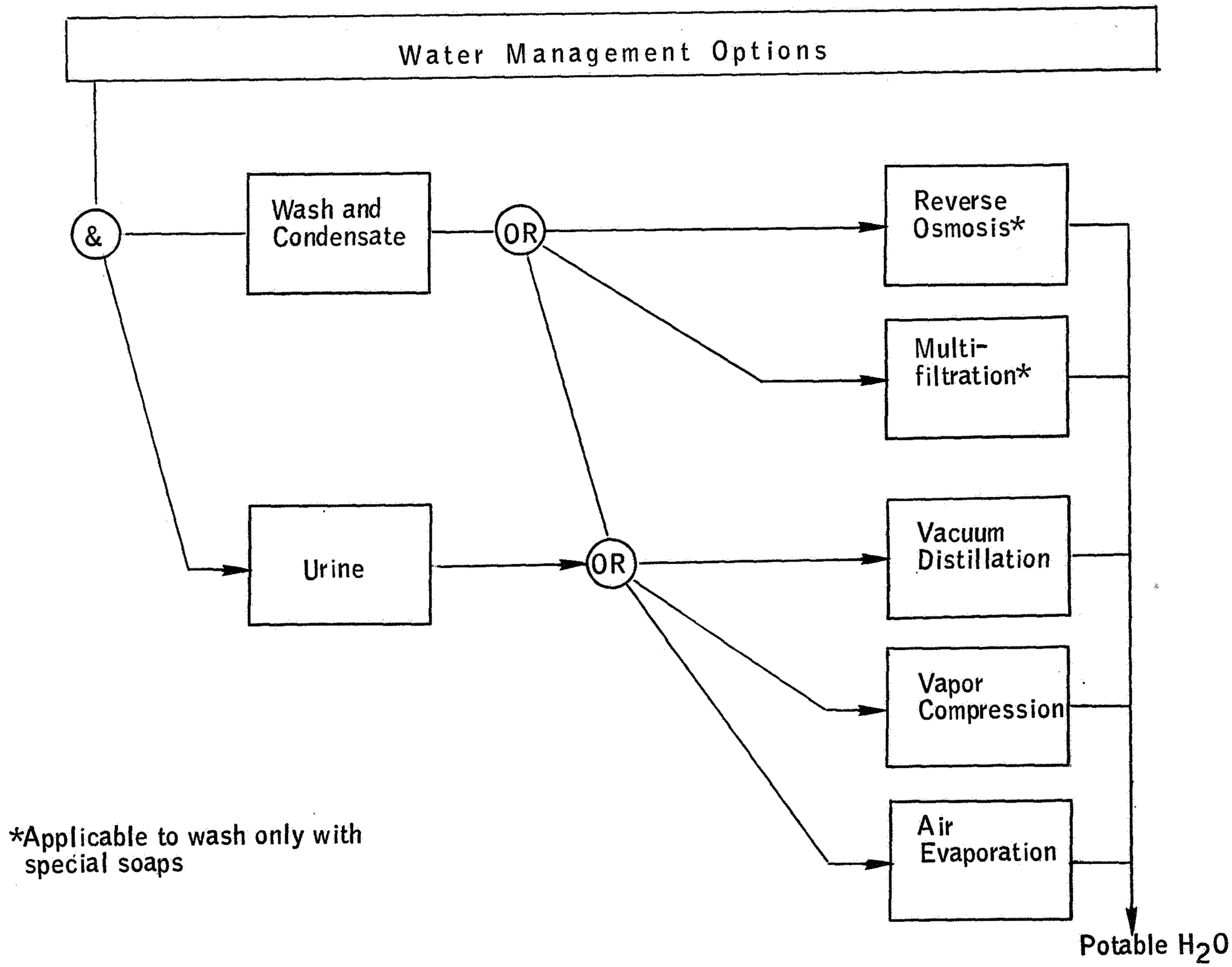


Figure 4.5-1. Water Management Concepts, Unified System

Table 4.5-1. Water Reclamation - System Candidate Trade Summary, Unified

CANDIDATES	WEIGHT PENALTY ∿ LBS.				ELEC. POWER		VOLUME ∿ FT^3			Q
	Fixed	Spares	Expend.	TOTAL	Watts	Cycle	Fixed	Spares	TOTAL	BTU/HR
Air Evaporation	110	133	56	299	620	Cont.	11.0	21.8	32.8	2,300
Vapor Compression*	265	260	21	546	220	Cont.	26.5	32.3	58.8	650
Vacuum Distillation Pyrolysis	265	296	9	569	1,080	Cont.	26.5	35.0	61.5	3,350
Vapor Diffusion	340	68	16	424	800	Cont.	34.0	9.7	43.7	3,000

*Selected system candidate based on minimum weight, power and volume for the 4-man module group.

NOTE: Expendables include such items as filters, catalysts or chemicals normally programmed for replacement.

the number of storage tanks required. Water stored in tanks must be maintained at a pasteurization temperature of 160 F and be constantly recirculated through all distribution loops and storage tanks to provide positive bacteria control. The water quality monitoring system provides continuous monitoring of the water that is in use to ensure that only safe water is circulated. After a tank is filled, a check will be made of its potability. If it is acceptable, the tank is put on-line and continuous monitoring is effected.

Table 4.5-2. Water Reclamation Concept Trades (12-Man System)

Factors	Unified Concept	Dual Concept
Systems weight (lb)	390	500
Spares (lb)	520	375
Power (kw)	1.5	0.8
180-Day expendables (lb)	1800	145
Volume (ft^3)	55	30

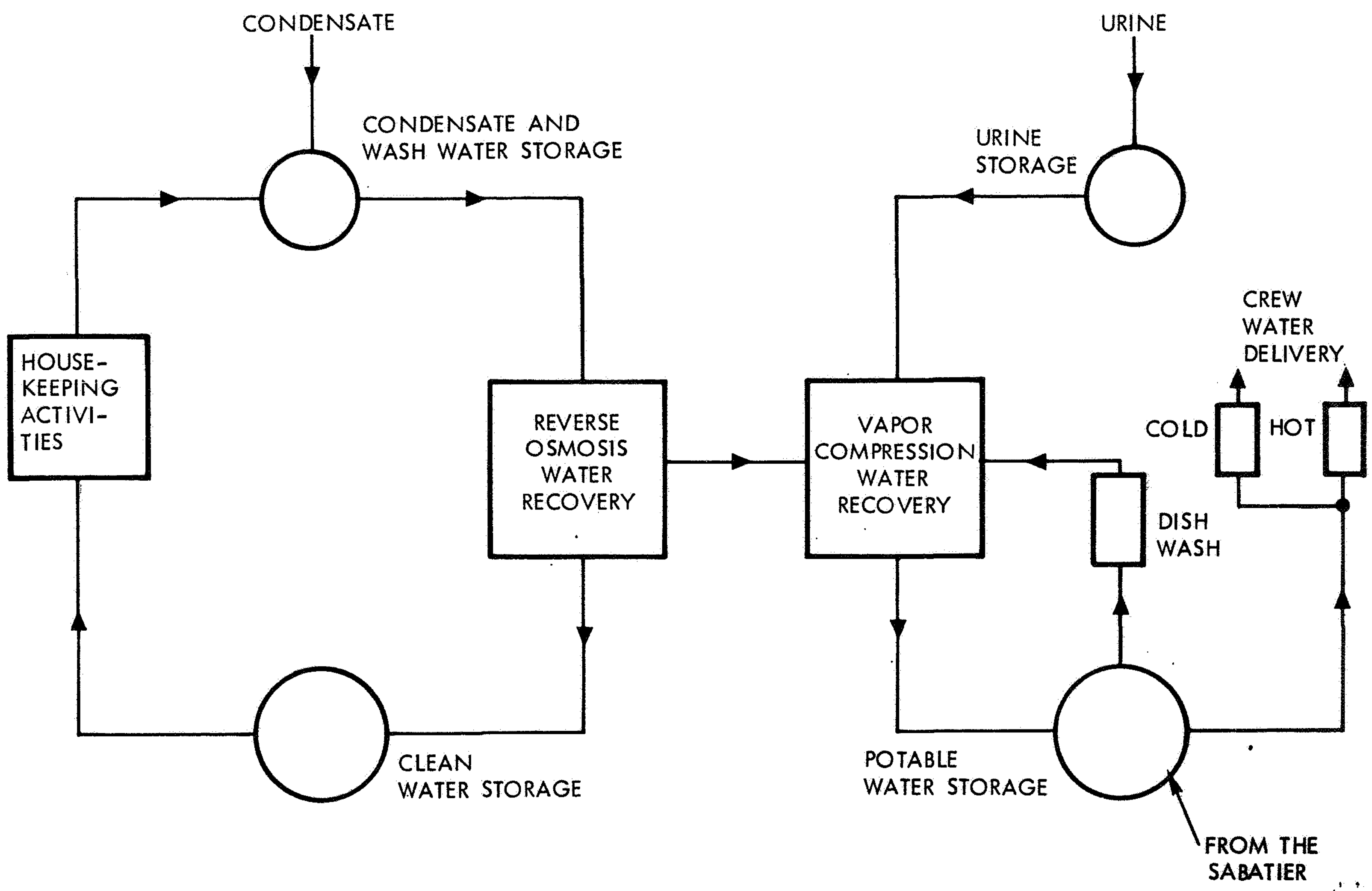


Figure 4.5-2. Water Management Schematic

4.6 WASTE MANAGEMENT

The waste management function can be separated into two subfunctions as indicated by Figure 4.6-1, which also presents the potential options for the required functions. The selection of a system concept may be dependent on ecological motivations, as well as the usual weight and cost considerations. The recommended solutions are therefore sensitive to these considerations and the more psychologically oriented factors.

Biological waste, such as feces, may be collected by any of the six basic concepts identified on Table 4.6-1. Although concepts 1 and 2 are lighter, acceptance of their functional capabilities does not approach that of the remaining systems. The Dry John (dry tank system) most nearly approximates the earthbound concepts in use. The other concepts require water and present complications in the recovery and purification process. The Dry John is recommended for all LSB applications, including the mobile systems.

Table 4.6-1. Toilet System Summary Trade Data, 12-Man LSB

System Options	System Weight (lb)	180-Day Resupply Weight (lb)	Peak Power (watts)
1. Bag system with manual transfer	47	255	67
2. Bag system with mechanical transfer	61	255	67
3. Dry tank system	109	577*	215
4. Dry tank system with anal spray	415	647*	635
5. Wet system with waste H_2O slurry	393	153	820
6. Wet system with reclaimed H_2O slurry	815	697	950

*Includes 422-pound air dump to vacuum (pumpdown system could reduce to 100 pounds)

Trash includes any unwanted material from food wrappers to used clothing. The list is extensive and the resulting quantity can easily reach a mass of over 30 pounds per day for a 12-man base and a volume of over 1.5 cubic feet per day. This amounts to over 11,000 pounds for one year, much

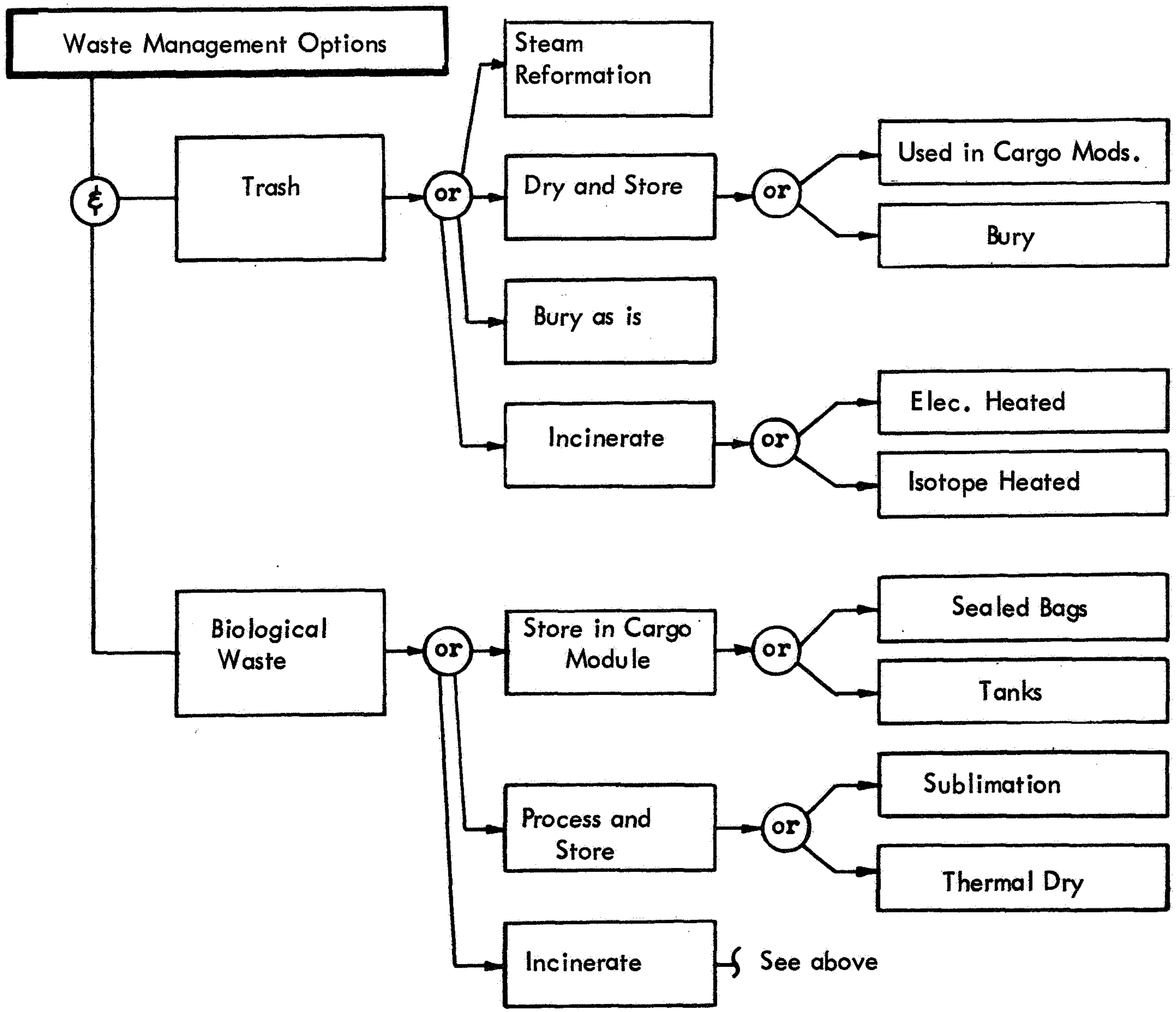


Figure 4.6-1. **Waste Management Options**

of which can present a contamination threat to the LSB if retained in its initial form. The material must therefore be disposed of external to the LSB.

Processing can vary from isolated storage in a container or unpressurized cargo module, to advanced systems such as wet oxidation or steam reformation. Drying of wet waste materials in a vacuum to a water content of less than 10 percent produces a biostatic state rather than sterilization. Incineration is an efficient mass and volume reduction technique in that only one to two percent of the original waste remains as ash, but the process requires one to two pounds of oxygen per pound of waste which is considered excessive. Thermal decomposition requires large amounts of energy (1300 watt-hours per pound of waste), but incurs no oxygen weight penalty. A residue of approximately 12 percent remains. The application of a quantity of oxygen at the end of the thermal decomposition cycle improves efficiency and reduces processing time.

Steam reformation is a process used to produce hydrogen commercially and shows potential as an LSB waste-processing technique, particularly for waste reuse. Trash is reduced to almost pure H_2, CO_2, N_2 and inorganic ash by exposing it to supercritical steam at approximately 1000 F. Water weight and energy penalties are associated with steam reformation.

It is felt that the most reasonable condepts are (1) vacuum drying, (2) germicide or chemical additive, (3) incineration, and (4) steam reformation. The weight, power, and volume for each of these concepts are indicated in Table 4.6-2.

Vacuum drying plus surface burial is recommended because of simplicity, a low residue to be disposed of overboard, and low average power. The chemical concept was rejected primarily because of the uncertainty of contamination control under a range of conditions and the large weight and volume of stored waste. The incineration concept was rejected because of the large resupply weight of oxygen, and the steam reformation concept was rejected primarily because of poor development status.

Conceptually, the system is envisioned to consist of a drying chamber that would receive wet wastes that are susceptible to bacteria growth. The waste would be dried and sterilized at 250 F. The chamber would be operated once each night for six to eight hours. The waste would be taken outside the LSB for burial.

Table 4.6-2. Trash Disposition Trade Data

Criteria	Integrated Vacuum Drying	Germicidal Additive	Incineration	Steam Reforming
Total Weight (lb)	606	2,362	5,870	1,275
Fixed Spares	676	1,869	1,550	1,275
Resupply	676	493	4,320(Oxygen)	0(Water)(4,320)*
Off Loading (lb)	4,320	8,640	440(Ash)	440(Ash)
Power Peak (watts)	1,315	300	1,000	700
Volume (cu ft)	270	413**	126	125

*Nominal resupply is zero provided that the water required is recovered.

**Requires a 320 cu. ft. collection chamber to store waste for 180 days.

4.7 CLOTHING AND LINENS MANAGEMENT

Volume II, Section 4.7, defined the clothing requirements for a typical LSB crewman. How these requirements are satisfied has been the subject of the clothing management trade studies which also included other laundry items such as facecloths and towels.

The two basic options are whether to provide a laundry or no laundry. There are many suboptions as illustrated by Figure 4.7-1. These options were evaluated for their impact on the base, personnel and logistics, and the results are summarized in Table 4.7-1. The "universal" concepts imply interchangeability of clothing between crews and crew members (to some degree) while the "personal" concepts imply individualized clothing.

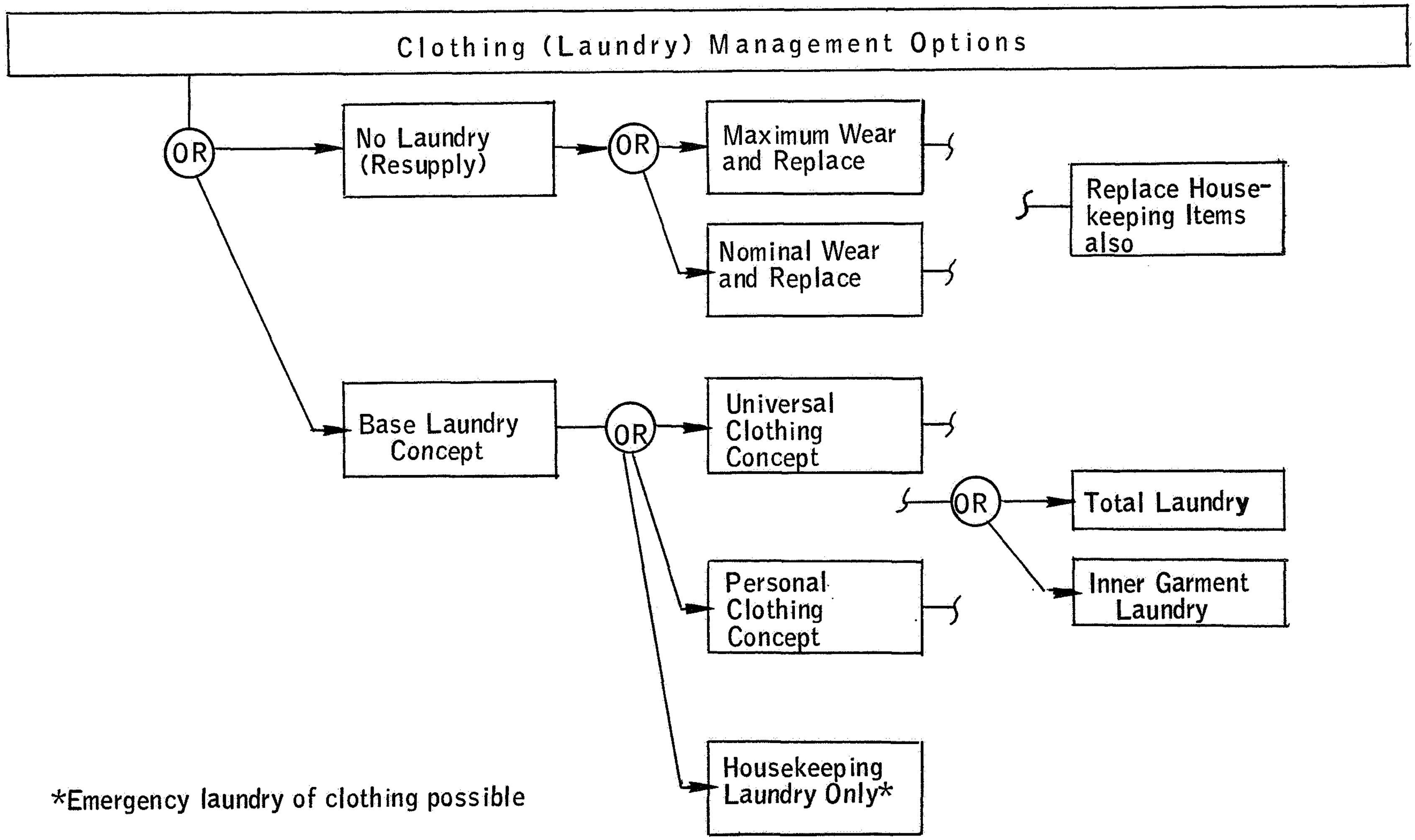
The weekly laundry load for the nominal wear frequency is 73 pounds per week. Assuming a washing machine capacity of 6 to 12 pounds as a practical range (home laundry ~ 8 pounds), it appears that a convenient size would be either 6 pounds or 12 pounds. If each man washes his own clothes, the best size would be 6 pounds, resulting in two loads each day, 6 days out of 7. The crew time indicated is based on a 6-pound washing machine capacity. Cycle time is estimated to be at least one-half hour. Crew time is required to collect soiled clothing, deliver it to the laundry area, activate the laundry equipment, return when the cycle completes to unload and possibly fold clean clothing and return the clothing to the storage area. Crew time may also be required to manually clean special bedding or outer garments because of the use of special materials.

Prior estimates for clothing densities have ranged from 18 to 50 pounds per cubic foot. A clothing storage density of 20 pounds per cubic foot was used for preliminary design. The hardware weight for the no-laundry cases is basically shelf penalty. The hardware weight for the laundry cases includes the washer/dryer assembly and reverse osmosis water recovery unit weight with spares.

The trade data indicate that the concepts are not widely separated for the two-year program and as a result, the decision process may center around the cost factors rather than weight alone. The NR space station study indicated that the development cost for the washer/dryer/sterilizer assembly would far exceed the cost of replacing the clothing and linens. It is therefore recommended that no laundry facility be considered for LSB applications unless it is developed for some other program.

4.8 FOOD MANAGEMENT

The food management function provides for serving, cleanup, inventory control, preparation and storage subfunctions. In the latter, two of these are pacing factors. Food is required at the rate of about 1.7 pounds per man-day (dry). It may be wet or dry form but, if dry, the equivalent water must be resupplied with the food and the resulting delivered weight is



*Emergency laundry of clothing possible

Figure 4.7-1. Clothing and Laundry Management Options for LSB

Table 4.7-1. Clothing/Laundry Management Trade Data

Option	System Weight (lbs)	Consumables (2-Year Program) (lbs)	Power (Watts)	Crew Time Hrs/Wk	Crew Time Consumables (lbs)	Two-Year Program Weight (lbs)
NO LAUNDRY						
. Max. Wear	250	3,200	0	1.5	300	3,750
. Nom. Wear	350	5,100	0	1.5	300	3,750
BASE LAUNDRY						
. Universal Total	600	1,000	350	6.0	1,150	3,450
. Universal Inner	580	2,200	320	4.0	770	3,870
. Personal Total	450	1,200	350	6.0	1,150	3,150
. Personal Inner	550	2,600	320	3.5	670	4,140
. Housekeeping	700	4,000	200	2	390	5,290

equivalent. Therefore, food weight is not a relevant issue. The issues really center around the preservation form (state), crew preferences, and the required support facilities. The options are illustrated by Figure 4.8-1.

Based on current experience, the crew would prefer fresh or frozen food and since a continuing supply of fresh food is impractical at lunar distances, frozen is the selected alternative. Even if frozen food is primary, a freeze dry reserve is required for the extended sorties and in case of an emergency power loss. Selection of frozen food as one-third to one-half the menu will necessitate a 100-cubic-foot freezer at the base and the equivalent capability in each logistics resupply mission.

The impact on the logistic concept is perhaps more severe than on the base complex. Since the transit time will exceed three days, some form of active refrigeration will probably be required.

The 100-cubic-foot total capacity could be achieved in several ways. Frozen food could be stored at one large location (e.g., in the cargo module) with a smaller freezer in the galley, one large freezer in the galley, one half-size freezer in each pressure volume, or only in the cargo module. The first option is recommended assuming the cargo module contains an active freezer and is close to the galley since the food transfer operations would be minimized. There is no requirement for frozen food in emergency situations. The frozen food stores could be lost and the crew could stil utilize the emergency stores of freeze-dry packed food.

Whirlpool Corporation performed a freezer concept trade study for space stations in which the following concepts were considered: (1) cryogenic expansion, (2) thermoelectric, (3) water sublimation, (4) gas cycle freezer (piston compressor), (5) turbocompressor freezer, (6) absorption refrigeration, and (7) space radiator integration. A turbocompressor-type cycle (Concept 5) was recommended.

An oven is required which is capable of either warming foods or for actual cooking and baking. To a large extent, the oven must fulfill cooking needs similar to those encountered in earth situations. For the preliminary sizing, it has been assumed that the oven should be capable of accommodating a minimum of six TV-type frozen dinners at one time.

Nine oven concepts evaluated for the EOSS were examined and the resulting recommendation for the LSB includes a microwave oven and a resistance oven with estimated weight and power characteristics as listed below

	Weight (lb)	Quantity	Peak Power (watts)	Operation (hr/day)	Power (watts) (24-hr avg)
Microwave	75	1	1500	1.3	108
Resistance	110	1	2000	1.6	133

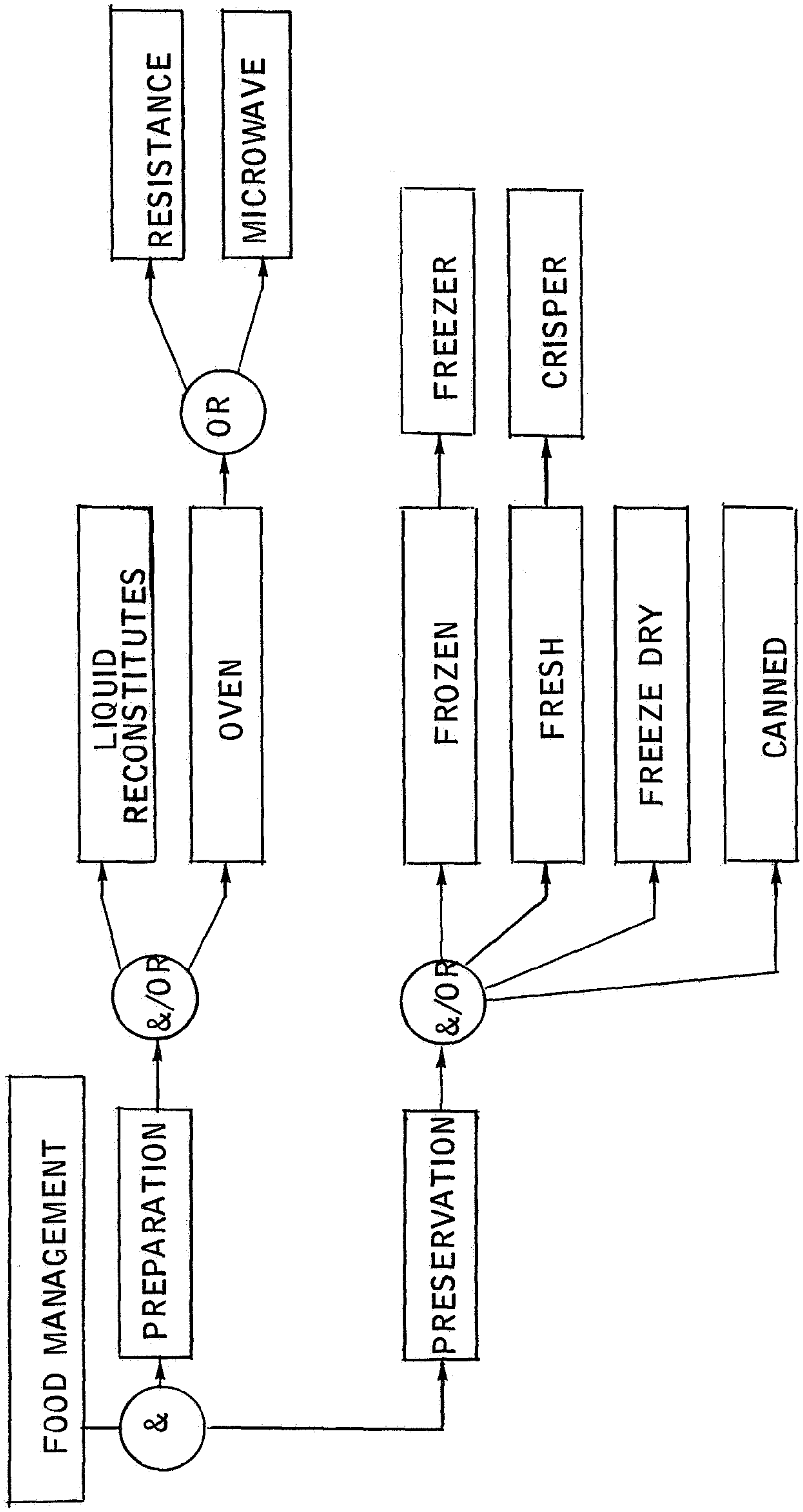


Figure 4.8-1. Food Management Options

The primary selection rationale for the microwave oven is fast cooking time. The microwave oven will enhance galley flexibility and operations by (1) providing capability to thaw frozen food, (2) heat snack items quickly, and (3) operate well in low gravity. It is also significant that a microwave oven does not require great power. Two ovens were selected, primarily because of advantages in cooking operations. The resistance oven is selected as the baseline cooking unit. It is capable of cooking some food that a microwave oven cannot handle well. It can also brown foods and is more familiar to the crew.

The evaluation of utensil use and a dishwasher is related to packaging and serving. Use of individual packaged food would preclude need for reusable utensils and, therefore, a dishwasher. The selection of some bulk packaging and preparation requires eating utensils and serving trays. It is anticipated that a dishwasher would save weight and minimize weight.

Recording is required for food stores inventory and crew intake/medical measuring. Provision should be made for food recording in the galley design. The primary options for a recording system are (1) manual recording, (2) a small bookkeeping machine, and (3) console link to the Data Management System (DMS) utilizing software. It is tentatively assumed that DMS integration is the preferred concept.

4.9 EGRESS/INGRESS PROVISIONS

Egress/ingress requirements were summarized in Section 1.0 of this volume and can be functionally separated as shown by Figure 4.9-1. These requirements suggest a diversity of requirements such that one concept may not satisfy all requirements in an optimum manner. The airlock volumes required vary from the two-man airlock to a garage-size volume. The resulting design and operational concept options are identified in logic form by Figure 4.9-2. The factors which influence concept selection are:

1. Influence on workday
2. Power required to pump gas volume
3. Volume of receiver
4. Mass loss/operational costs
5. Time and pump ratio
6. Number of cycles
7. Volume required

The influence of each of these factors is analyzed individually in the subsequent paragraphs.

The time required for the egress/ingress cycle impacts the EVA workday to such a degree to make it the primary driver in concept selection. Over one man-day (12 man-hours) is lost every time a six-man crew passes through the egress/ingress cycle. This factor is illustrated by the data of Figure 4.9-3, where the timelines present minimum time required to accomplish a cycle and the resulting impact on the daily work budget. Four cycle will take up more than half the workday. The conclusion drawn from these data is

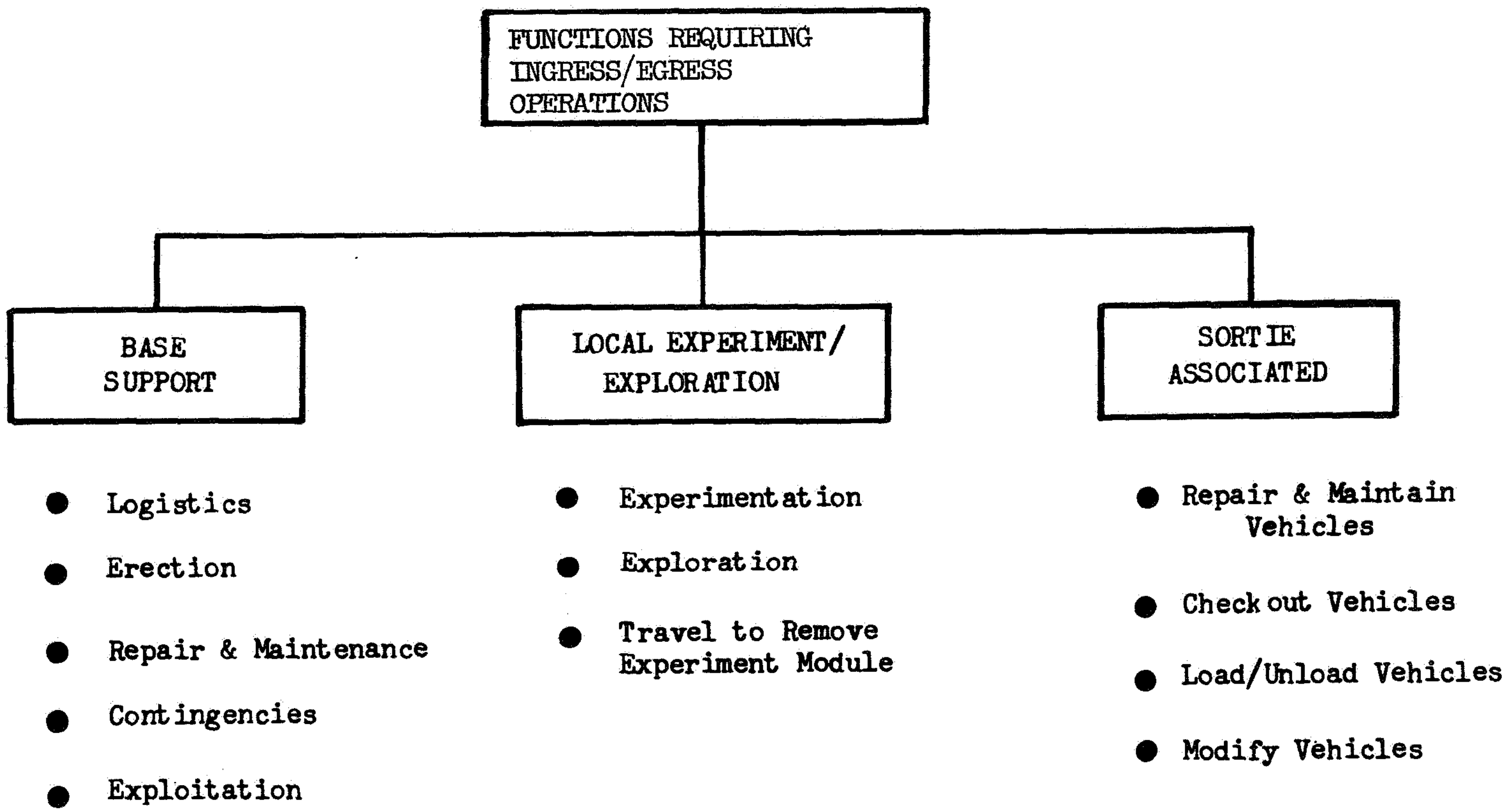
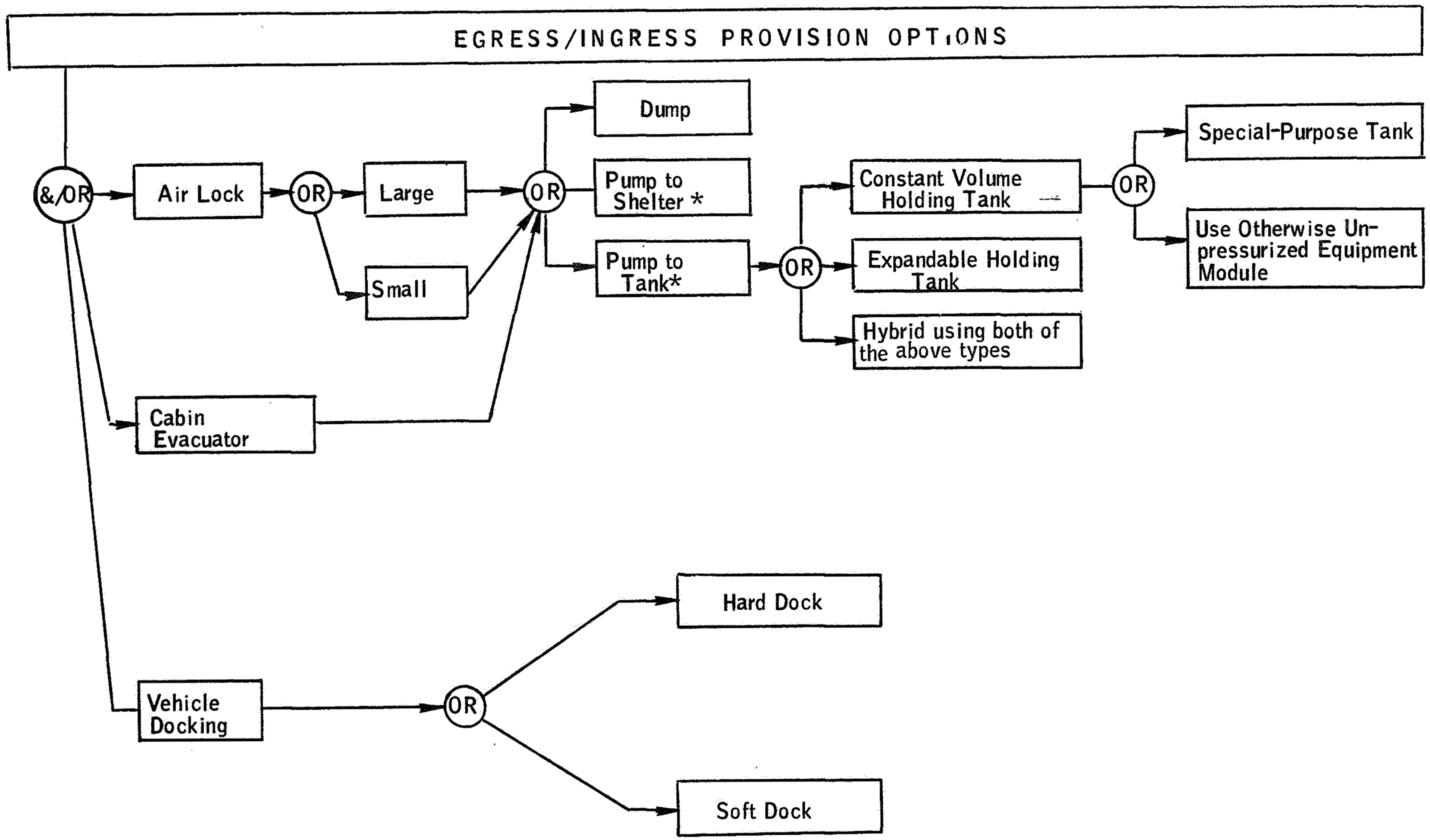


Figure 4.9-1. Possible LSB Mission Ingress/Egress Interfaces



*Variable pump-down rates

Figure 4.9-2. Egress/Ingress Provision Options

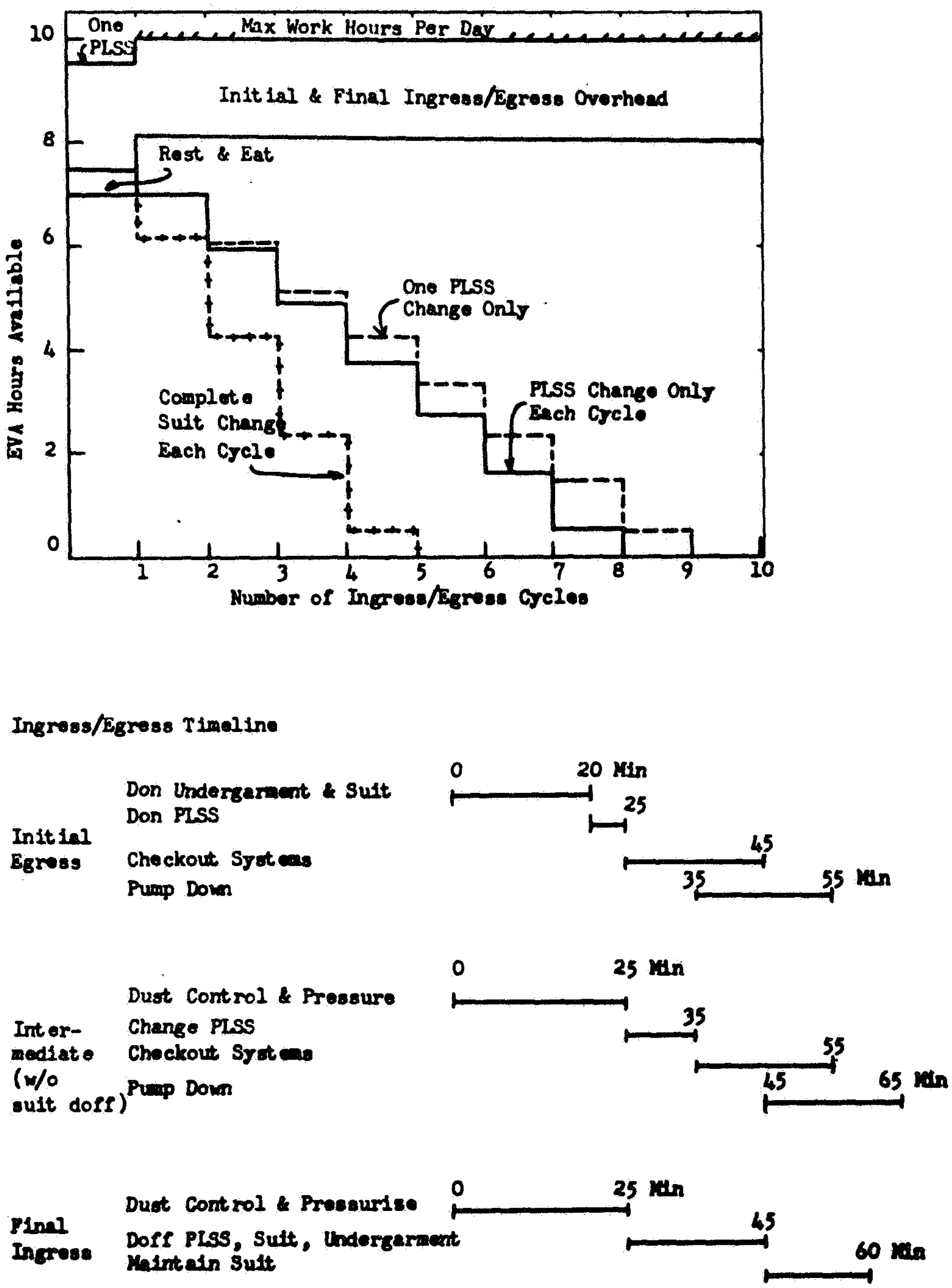


Figure 4.9-3. Ingress/Egress Work Time Influence

that the number of in-out cycles should be limited to one per day and eliminated where possible. In addition, special efforts should be taken to reduce the time factors.

The power required is directly related to the pumpdown time, lock size and air dumped as indicated by Figure 4.9-4. These data have been calculated for a 100-cubic-foot airlock and if it were increased to accommodate a 4- to 6-man work party, the time would increase proportionately up to as much as one hour if the same pressure level is achieved prior to egress. Higher pumpdown rates require more power, but the weight trades favor the fast pumpdown, high power drain concepts in order to save crew work time.

The receiver volume influences the pumpdown time and power costs. Selection of a receiver should therefore be based on minimizing time, power and base weight. Use of the total base contained volume (~ 36,000 cubic feet) for temporary storage of the airlock gas will provide a satisfactory receiver with no new components required. The low back pressure minimizes pump power and the work required, and the time is also thereby minimized. The cabin pressure rises only from 10 psia to 11.3 psia, which is well below any danger level.

The final residual mass loss at egress influences the time factor and the resupply requirement as shown by the data from Figure 4.9-4. The mass loss at pressures below about 0.1 psia are insignificant when compared to the effects of the increased time in egress. Saving half of the mass remaining at 0.1 psia would take over twice the time it took to reach that level. The weight saved amounts to less than 0.2 pound for a two-man airlock, compared to the cost of supporting the crewman for the added time which is about 1.2 pounds.

The recommended airlock concepts can best be identified from Figure 4.9-5. At least two concepts are required, one for personnel egress/ingress and one for vehicles. A large airlock ($\lesssim$900 cubic feet) is indicated in order to minimize the number of cycles (and permit dust control). To hold the pumpdown time for this airlock to 20 minutes, a 100 cubic feet per minute pump is required.

A further recommendation involves provisions for hard or soft vehicle docking to permit shirtsleeve transfer and eliminate the ingress/egress delays associated with airlock operations when surface vehicles are to be employed for transfer to a working site or for enclosed experimentation. In addition, pressurized connections to the working sites should be provided where the physical situation permits for the same reason.

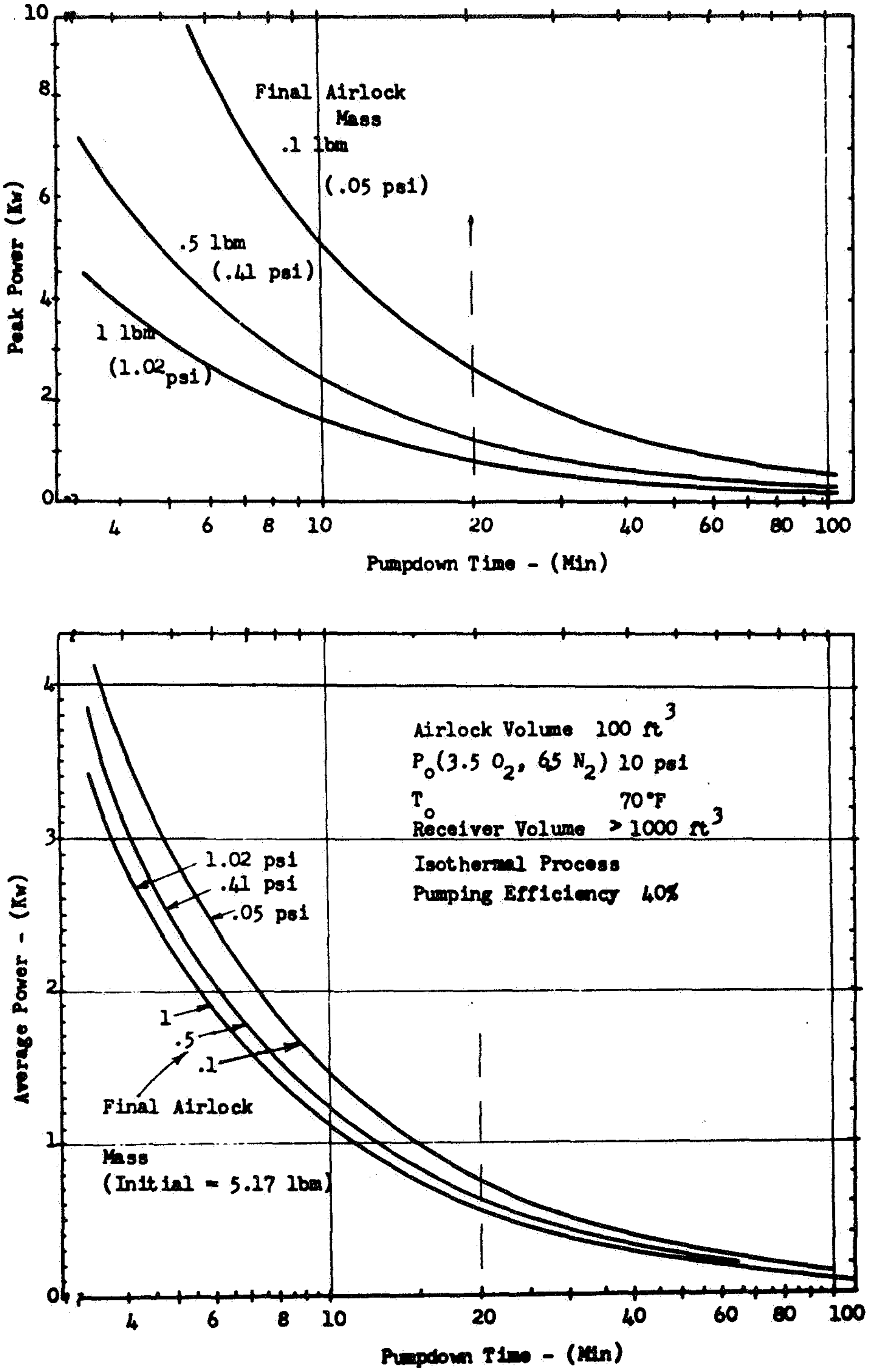


Figure 4.9-4. Average Pump Power & Peak Power vs Pumpdown Time

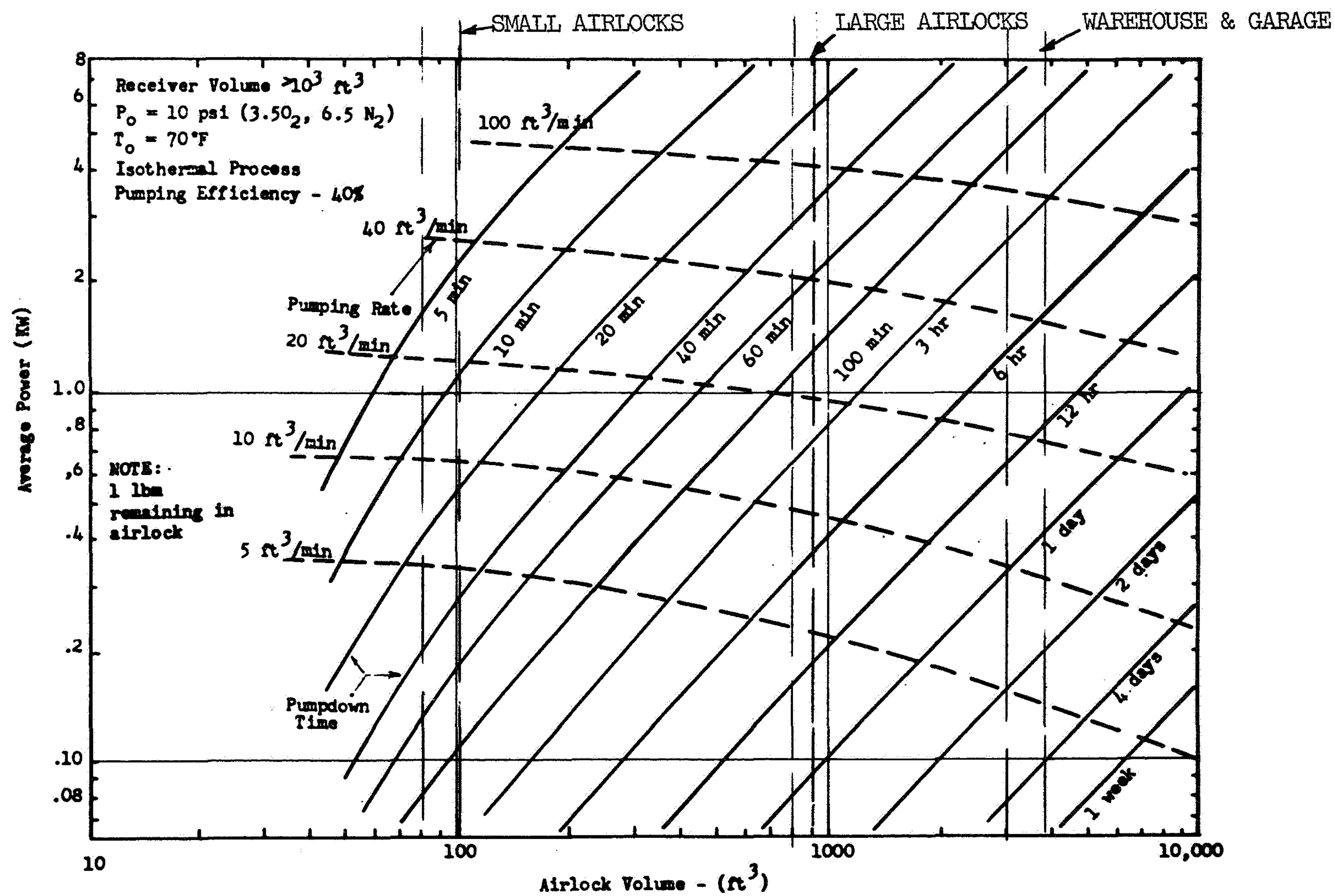


Figure 4.9-5. Airlock Operational Characteristics and Design Data

4.10 DUST CONTROL

Data from Apollo Missions 11, 12 and 14 have indicated that the lunar dust presents a health and systems hazard. The extended operations in the LSB will require particular attention to this problem. Holmes and Narver Incorporated provided the following supporting study as subcontractors.

4.10.1 Particle Size and Properties

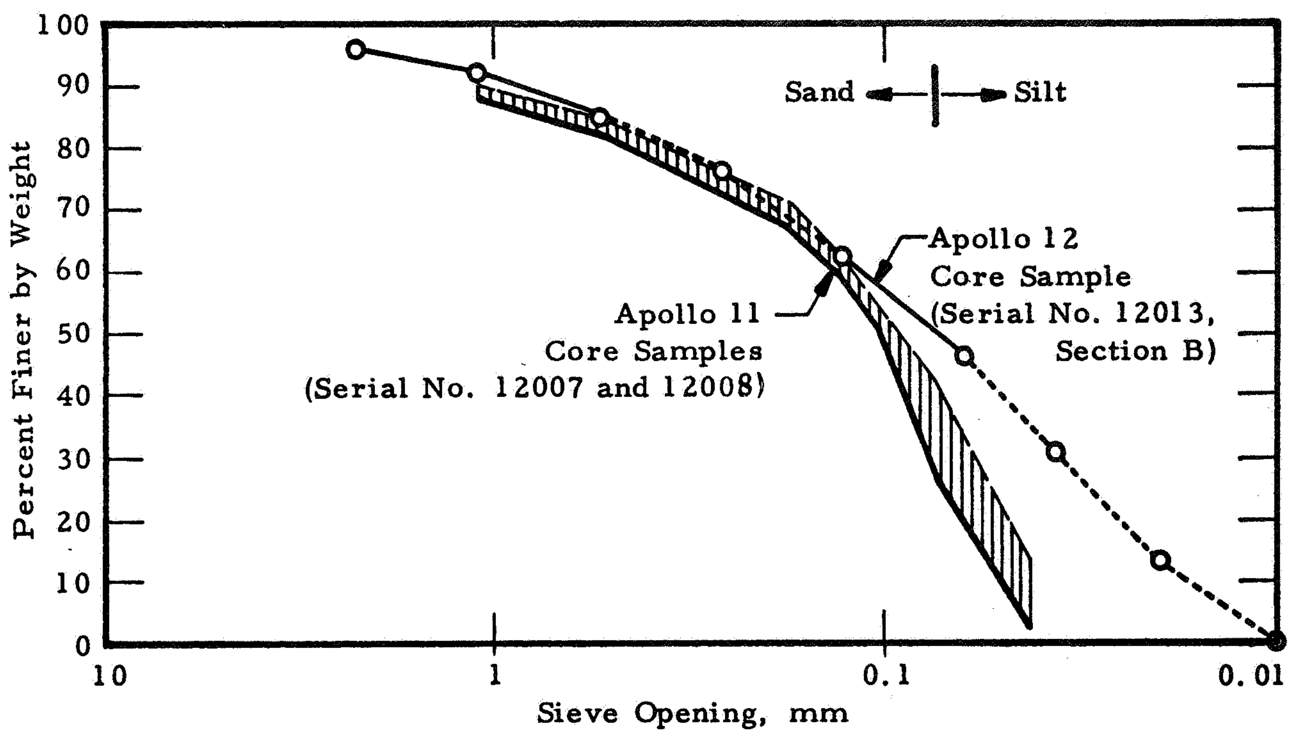
In Figure 4.10-1, a comparison of results of sieve analyses from Apollo 11 core-tube samples and Apollo 12 samples is presented. It is shown that the average particle size is approximately 75 microns and that the percentage by weight of particles below 10 microns is 2 percent or less. The largest particle may be taken to be of the order of 2000 microns.

Further information on the fine particles was obtained by examination of Surveyor 3 by the Apollo 12 team. Some fine debris found clinging in the recessed area under the support collar was analyzed by emission spectroscopy. The remaining debris found in the recess under the collar has received only low-power microscopic examination. This remaining debris appears to be lunar fines and contains various minerals with a wide range of particle sizes up to approximately 150 microns. An examination of one of the screws and its matching washer showed a substantial number of spheres and angular particles that range from a fraction of a micron to approximately 4 microns. The absence of particles larger than 4 microns in this instance may be due to their absence in the original source of dust, but it is more likely that the mass-to-adhesion characteristics are such that the larger particles fell off during or after the return to earth. This explanation is substantiated by the observed loss in adhesive qualities when exposed to the Lunar Module (LM) shirtsleeve environment.

The mean constituents of lunar soil are fine-grained to glassy rocks of basaltic affinity and coherent breccia of undetermined origin. Based on Apollo 11 data, the mineral content of the lunar soil is primarily ilmenite, pyroxine, and plagioclase and either albite or anorthite. All are insoluble in water, alcohol, or acids.

Transparent glass of a variety of colors, including amber, deep red, brown, pale green, yellow, and colorless makes up a conspicuous but relatively small proportion of the soil. They consist primarily of SiO_2, Al_2O_3, FeO, and CaO. Their proportion increases with decreasing grain size, reaching approximately 4 percent in the fraction finer than 10 microns. Apollo 12 data show a higher percentage of the glasses (20 percent) and no significant amount of ilmenite.

Magnetic properties of moon samples have been the subject of many experiments. The general consensus is that a fairly stable remnant magnetization exists.



NOTE: The dashed part of the Apollo 12 curve is for material finer than 0.063 mm (No. 230 sieve).

Figure 4.10-1. Comparison of Results of Sieve Analyses from Apollo 11 Core-Tube Samples and Apollo 12 Core-Tube Sample

Based on examination of both rock and fines, it is concluded that native iron, or possibly nickel-iron, of submicroscopic particle size is the most important magnetic constituent with minor contributions from ilmenite, paramagnetic iron minerals, and other iron-titanium oxides. Remnant magnetization induced on earth acquires a viscous magnetization and does not appear to have a significant stable remnance. The moon samples exhibit a natural remnance showing some stability.

It is clear from the above that any magnetic removal or control process will have to be based on the paramagnetic properties of iron minerals. The antiferromagnetic behavior if ilmenite does not preclude sufficient values of the magnetic susceptibility to base a removal process on an induced magnetic field. However, a passive process dependent on the ferromagnetic properties of native iron and glass fractions is not sufficient.

The mass-to-charge ratio was generally less than $m/e = 120$, and the largest part had $m/e < 55$. The dielectric constant is approximately 2.0 to 3.0.

4.10.2 Dust Removal Problem

The LSB airlock chamber will be the area used for final dust removal before the occupants enter into the habitable areas. The amount of dust and lunar soil particles that would be carried into the airlock would consist of those particles that were not removed by brushing prior to entering. The particles will probably thoroughly coat the personnel and equipment entering the airlock with a thin layer of fine dust. Larger concentrations of dust and soil will probably fill many crevices in the astronaut's boots or other equipment with caked particles. Particle concentration for the proposed dust collection system will vary from an occasional extremely heavy loading from trying to clear crevices to a very light loading after the crevices are cleared and the surface dust is collected. Particle concentrations for three different conditions are established.

1. Removing soil and dust from crevices:

   Assumptions

Soil density	1.5 gm/cc
Dust and soil in crevice	15 cc
Flow rate of collection system	0.1 m^3/sec
Time required to clear crevice	1 sec

   $$\text{Concentration} = \frac{15\text{cc} \times 1.5\ \text{gm/cc}}{0.1\ \text{m}^3/\text{sec}\ \text{x/sec}} = 225\ \text{gm/m}^3$$

2. Removing fine layer of dust from surfaces of personnel and equipment:

   Assumptions

Time required to clear 1000 sq cm	1 sec
Amount of dust covering 1000 sq cm	1 gm

   $$\text{Concentration} = \frac{1\ \text{gm}}{0.1\ \text{m}^3/\text{sec}\ \text{x/sec}} = 100\ \text{mg/m}^3$$

3. Removing dust suspended in the airlock atmosphere:

<u>Assumptions</u>

Volume of airlock (use 140 cu ft)	4 m^3
Volume of dust suspended	0.5 cc

$$\text{Concentration} = \frac{0.5 \text{ cc} \times 1.5 \text{ gm/cc}}{4 \text{ m}^3} = 188 \text{ mg/m}^3$$

The cleaning requirement determines the system design parameters. In the earth's atmosphere, particles smaller than 0.5 micron are normally exhaled while those larger than 10 microns are separated and retained by the upper respiratory tract. Particles between 0.5 and 10 microns are most likely to settle in the lungs and are of concern to industrial hygienists. Another cleanliness level often used is the Threshold Limit Value (TLV) established by the American Conference of Governmental Industrial Hygienists. However, TLV is used to establish safe levels of continuous long exposure while working in a dust laden atmosphere and is not applicable to the higher level of cleanliness required in the LSB.

The dust control system will provide a minimum cleanliness to the LSB atmosphere that equals or betters the air cleanliness found in an air-conditioned building on earth. Dust content in a typically air-conditioned building seldom exceeds 2 mg/cubic meter and is usually less than 0.2 mg/cubic meter of air. Particle distribution in the LSB atmosphere is assumed to roughly correspond to that found on earth (Figure 4.10-2) corrected for 1/6 g.

4.10.3 Dust Removal Options

Various methods and types of dust collection equipment might be employed in formulating a dust control system for a lunar shelter. Parts of the system might precede entry into the airlock in order to ease the cleaning load and disposal problem on the equipment located within the shelter. Hand brushing represents the simplest concept; it may be either electrically powered or hand-driven. Brush motion might be either translational or rotary with the brushes being either tufted or channel lock. Nylon and plastic fibers should not be used outside the shelters; however, polypropylene and teflon may be used. Other candidate fiber materials are beryllium copper, stainless steel, or tungsten. The best fiber material would appear to be fiberglass covered with teflon which is the same material as the outer layer of the astronaut suit.

Various types of shower systems might be considered. The fluid might be water, solvent, or air. Solvents would have lower surface tension and would be more effective than water alone. However, the shower compartment would have to be airtight and the internal pressure increased sufficiently to ensur nonevaporation of the water or solvent. The particles in the 30- to 50-micron range form a mud or rouge when mixed with water. It is feared that over a period of several days, the roughe could penetrate the suit fabric, seals and joints, possibly causing seizing of joints and excessive seal wear. A water or solvent shower system rapidly becomes impractical as means for pumping, storing, spraying, filtering and replenishment of the fluid are reviewed.

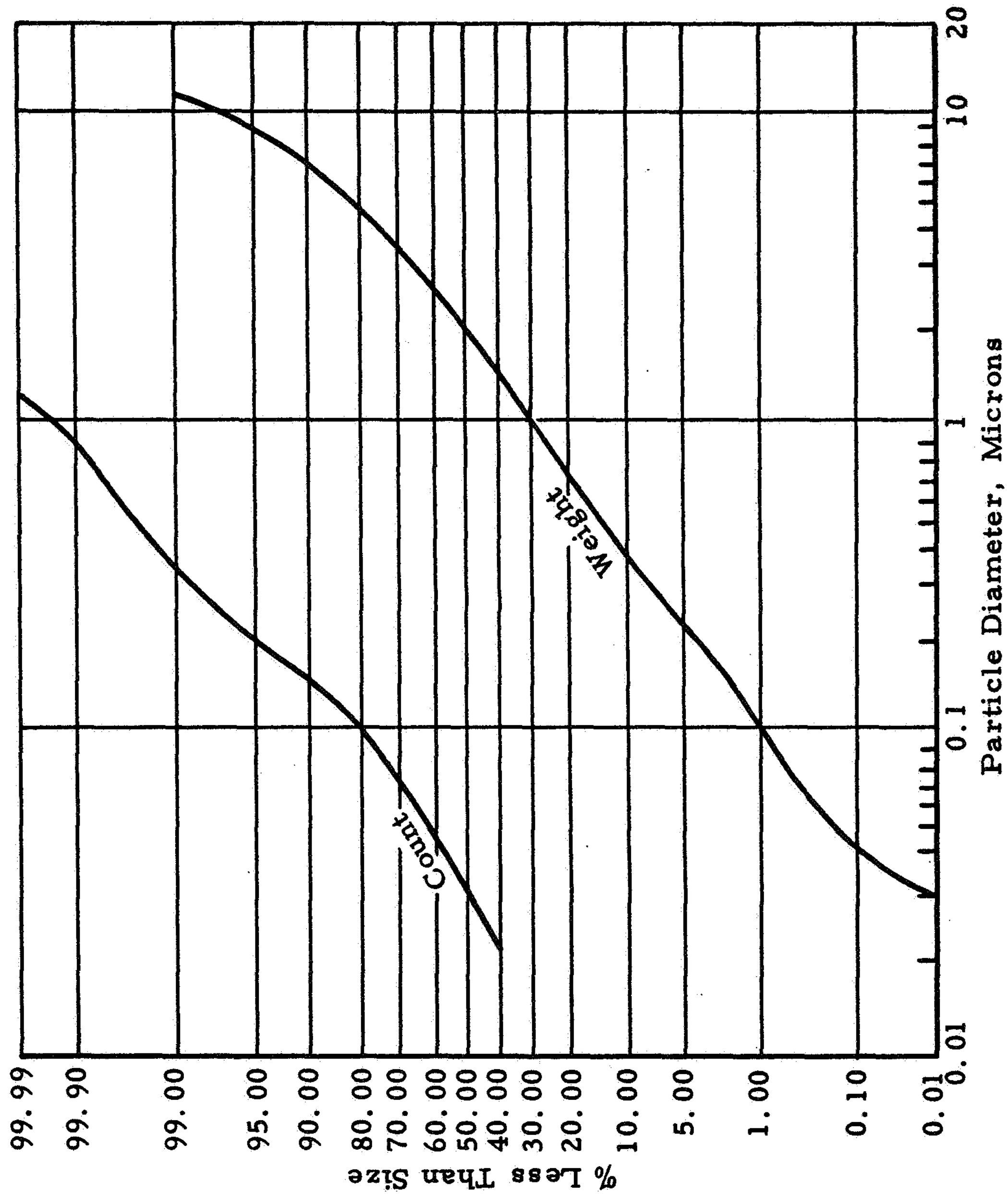


Figure 4.10-2. Particle Size Distribution of Earth Atmospheric Dust

The air shower deserves consideration. Air jets could be directed to dislodge dust off the astronaut and his equipment as purge air transports the dust from the compartment into a suitable dust collector. Although effective, this system could fill the airlock with large clouds of dust thus reducing astronaut visibility and causing contamination of the atmosphere used for breathing if his helmet is removed. However, if the air jets were operated during the initial repressurization cycle, his helmet would still be on and a recirculation system could rapidly remove the dust from the air.

Dust control by segregation methods pivot about attempts to preclude entry of soil and dust into the shelter interior by procedures for keeping contaminated parts out. Possible variations include:

1. Remove and Hold. Selected contaminated parts of the space suit (boots and gloves) would be removed in an airlock or entrance room and stored there until reused. The suit could also be removed and stored.

2. Remove and Exchange. The contaminated suit is removed and exchanged for a clean suit. A discardable undergarment could function as a secondary measure to prevent dust from being carried into the working chambers.

3. Remove and Clean. The contaminated suit could be removed and placed in a chamber which acts as the cleaning (or scrubbing) chamber for the suit, while the man proceeds to the internal chambers.

Experience obtained in the Apollo command module indicates that lunar dust loses its adhesive characteristics when exposed to shirtsleeve conditions. It is highly probable that dust particles will become airborne on the air currents created during pressurization of the airlock. It is at this time that the highest concentration of particles most harmful (0.5 to 10 microns) to man occurs. The suspended dust particles should be quickly removed prior to the removal of a helmet for hygienic reasons and to preclude redeposit of particles on the astronaut with subsequent introduction into the shelter interior.

A high-capacity vacuum system might be used initially to purge the airlock and entrain dust kicked up during the process of cleaning boots, suits, and equipment. The high-capacity system should be operated continuously while cleaning is in progress, thereby permitting cleaning equipment without inhaling dust or carrying particles into the shelter.

4.10.4 Concept Synthesis and Evaluation

Four system concepts were synthesized from the foregoing; they are summarized by Figure 4.10-3 along with the trade data.

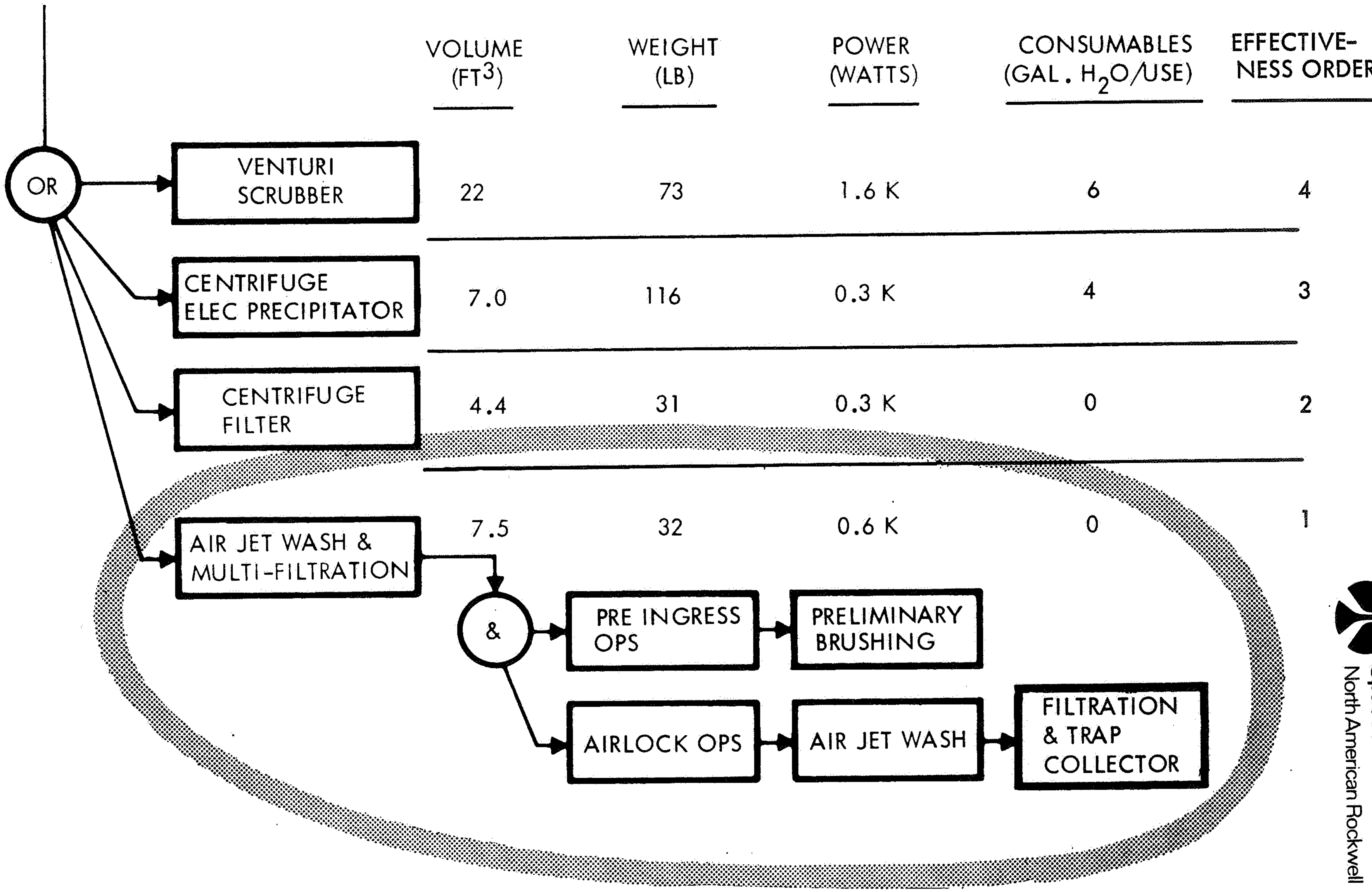


Figure 4.10-3. Dust Management Options and Trades

Venturi Scrubber System

The dust collection cycle of this concept begins as dust laden air is drawn into the system by a blower which provides the motive force for pushing the air through the venturi and into a cyclone separator. The blower can be either axial or centrifugal. Water sprayed into the venturi throat is atomized and entrains dust particles by impingement. Collection is enhanced as any remaining dry particles become nuclei for condensation in the pressure-regain section of the venturi. As the air/water/dust mixture swirls through the cyclone separator, water and entrained dust particles migrate to the cyclone wall. The slurry formed on the wall drains into a receptacle before passing on to a water/dust separation device for further processing.

Water from the separation device would be piped to a storage tank for subsequent injection into the venturi. The water rate would be approximately 20 gpm at 15 psi with sufficient capacity to operate 3 minutes until the separation device can supply water for reuse.

Although the venturi scrubber dust collection system will provide satisfactory performance, the weight required for the large cyclone collector and the complexity of the system are decided disadvantages. The amount of water plus its requirement for associated equipment, i.e., pump, storage tank, water/dust separation device (requiring development) makes this system highly unfeasible.

Dynamic Centrifugal Separator and Electronic Precipitator

The dust collection system will consist of a dynamic centrifugal type collector which employs centrifugal force to collect dust particles at the periphery of its casing where they are drawn off in a concentrated stream. The concentrated dust stream will be passed through an inertial separator which will consist of a louvered chamber to separate the dust from the gas by changing the direction of the secondary gas flow. The gas leaving this collector will have most of the dust particles over 10 microns removed; it will then pass through an electronic type precipitator for removal of dust particles under 2 microns.

The electronic type precipitator consists of a number of cells in one housing. The cell is a single, compact unit which contains both the ionizer section and the dust collecting plate section. All dust particles in the airstream pass first through the ionizer where current flowing from the ionizer wires to the ground electrodes produces a screen of ions. This screen gives an electrical charge to all dust particles passing through it. The gas stream then carries the charged particles into the bank of collector plates. Alternate plates are charged with a positive potential. Every other plate is grounded. As the positively charged plates repel the positively charged particles, the particles are attracted to and collected by the grounded plates. Periodically, the entire cell is washed with a built-in washing system, and the collected dust is separated from the recirculating water.

This option provides the advantage of a complete self-cleaning system. Other than this advantage, the system not only has many shortcomings in physical characteristics as compared with other option but the system would require further development to be feasible for a lunar base shelter.

Dynamic Centrifugal Separator and Disposable Impingement Filter

The collection system is identical to the prior one with the exception that the electronic precipitator is replaced with a disposable impingement filter, simplifying the method for removing and collecting dust particles under 10-micron size. It does retain the disadvantages noted for a dynamic centrifugal collector. The impingement filters would be sized to provide a minimum number of replacements.

Impingement-Type Vacuum Dust Collection System

This system consists of a separate vacuum cleaning unit for the initial cleaning and then a fast air change within the shelter airlock, providing a 30-second air change after repressurization. This option was subsequently modified during the design phast to reflect the air shower operations defined by the functional flow of Figure 4.10-3.

A preliminary brushing operation is performed prior to entry into the airlock. As repressurization is initiated, the incoming air enters the jets of the air shower, blowing the dust off the suits. The airlock air is recirculated every 30 seconds in the shower area and somewhat less often in the remaining area. The filters required are listed in Table 4.10-1.

The air jet wash and multifiltration was selected on the basis of the data presented in Figure 4.10-3 and its application to the LSB design concept.

Table 4.10-1. Filter Requirements, LSB Dust Control

Filters	Minimum Efficiency At Degree Of Filtration Noted (%)	Size	Holding Capacity (cc)	Material	Degree of Filtration (microns)
Vacuum Cleaning Unit	90	400 sq. in.	17,620	Latex - impregnated paper bag	≥ 3.0
Fine Particle Filter	90	18"x18" x12" deep	150	Fiberglass	≥ 0.5

5.0 ELECTRICAL POWER SUBSYSTEM (EPS)

The primary functions of the EPS are to generate, regulate, condition, store and distribute all electrical power required by LSB functions and activities over the entire duration of the base life, including power for remote and mobile activities. The basic partitioning is to divide the electrical power requirements into two classes: mobile and stationary; and divide the subsystem functional requirements into the source, the converscion concept, energy storage, distributing and conditioning.

5.1 REQUIREMENTS DEFINITION AND INFERENCES

The LSB power requirements stem from a diversity of systems and locations, both mobile and stationary, as illustrated by Figure 5.1-1.

5.1.1 Fixed Site Requirements

The major users of electrical power in the LSB area are the atmospheric and crew services (A&CS), experimental and scientific equipment, the observatory, and various housekeeping operations (consisting of data processing, communications, status displays, etc.). The estimated A&CS requirements are based on a 12-man, closed-loop system operating at a power level of about 1.0 kilowatt per man. Assuming a continuous 12-man loading to be the average A&CS load over a 3-year period, the energy requirement is 315.4 megawatt-hours.

The projected load profile for the operation of LSB scientific and experimental equipment over a 36-month period is shown in Figure 5.1-2. The power levels and duty cycles shown in this profile are based on a preliminary analysis of the scientific operations. Three work shifts per day are assumed. Excluded from this profile are A&CS, deep drilling, and observatory loads, which are estimated separately. The cumulative electrical energy requirements based on this profile are shown in Figure 5.1-3. It can be seen that approximately 31.4 Mw-hours of electrical energy is required for the three-year operating period.

The power requirements of the observatory were estimated from the data available from former studies and earthbound observatories. The telescopes are the major power users of all the observatory equipment. The X-ray and radio telescopes require 20 and 25 watts of power respectively, and both operate continuously for approximately 16 hours per day. The optical telescope requires 4 kilowatts, and operates on a maximum duty cycle of 24 hours per day for up to 14 days per month. It was assumed that the observatory will not be fully operational during the first year; therefore, its three-year energy requirement was estimated by commencing the duty cycle at the beginning of the second year. The total estimate for the observatory operation was 32.8 Mw-hours.

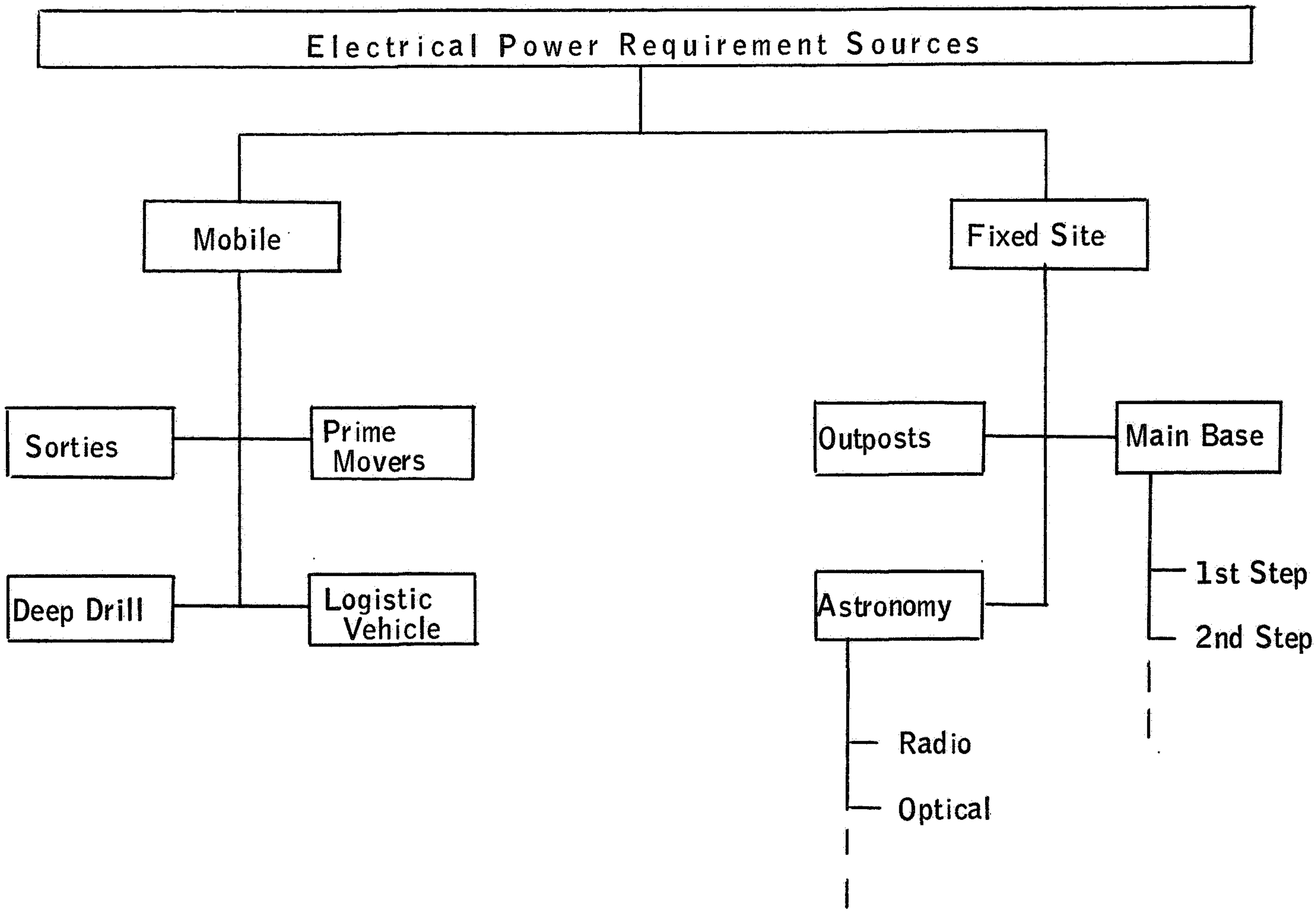


Figure 5.1-1. Electrical Power Requirement Sources

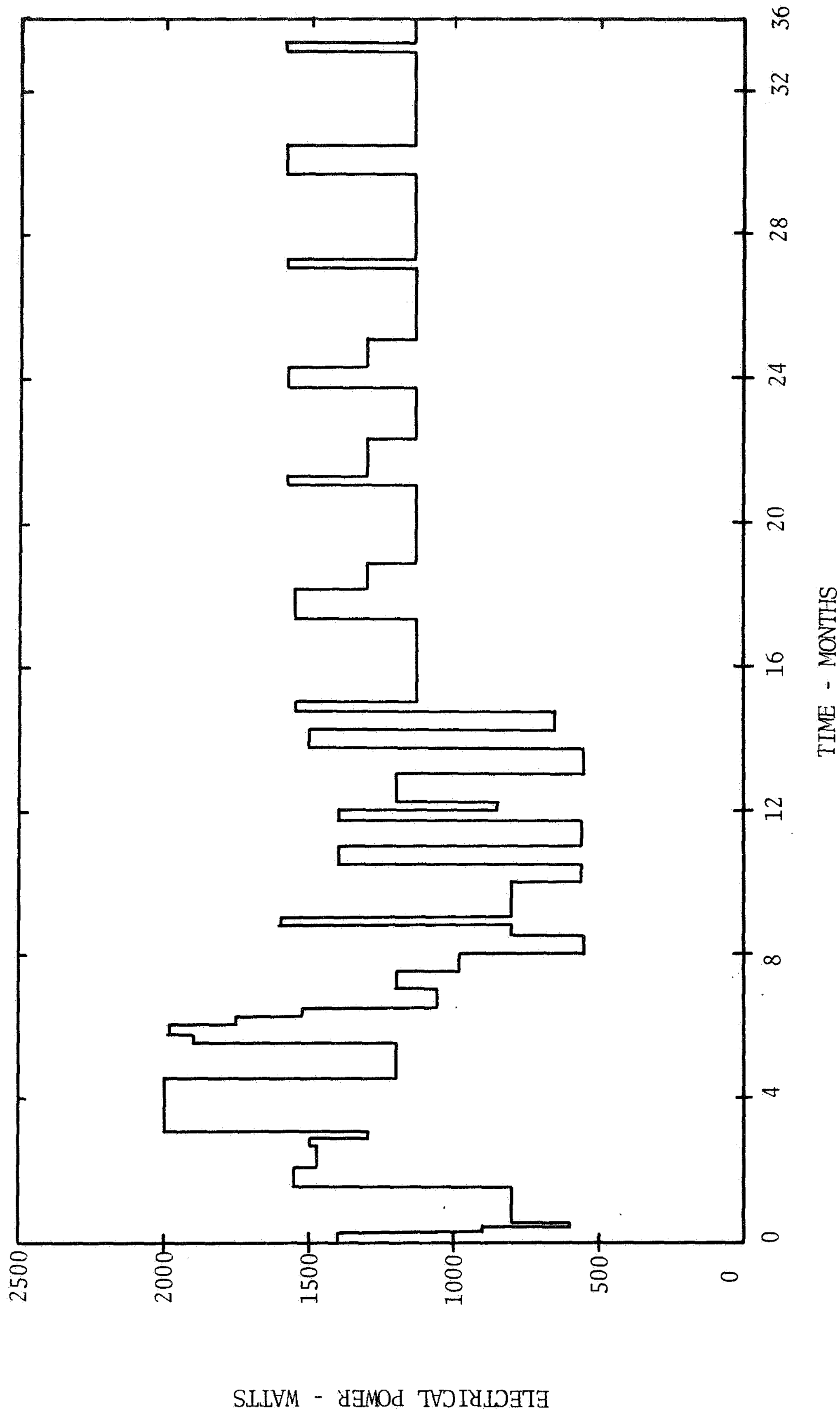


Figure 5.1-2. Preliminary Electrical Load Profile Lunar Surface Base Science Equipment

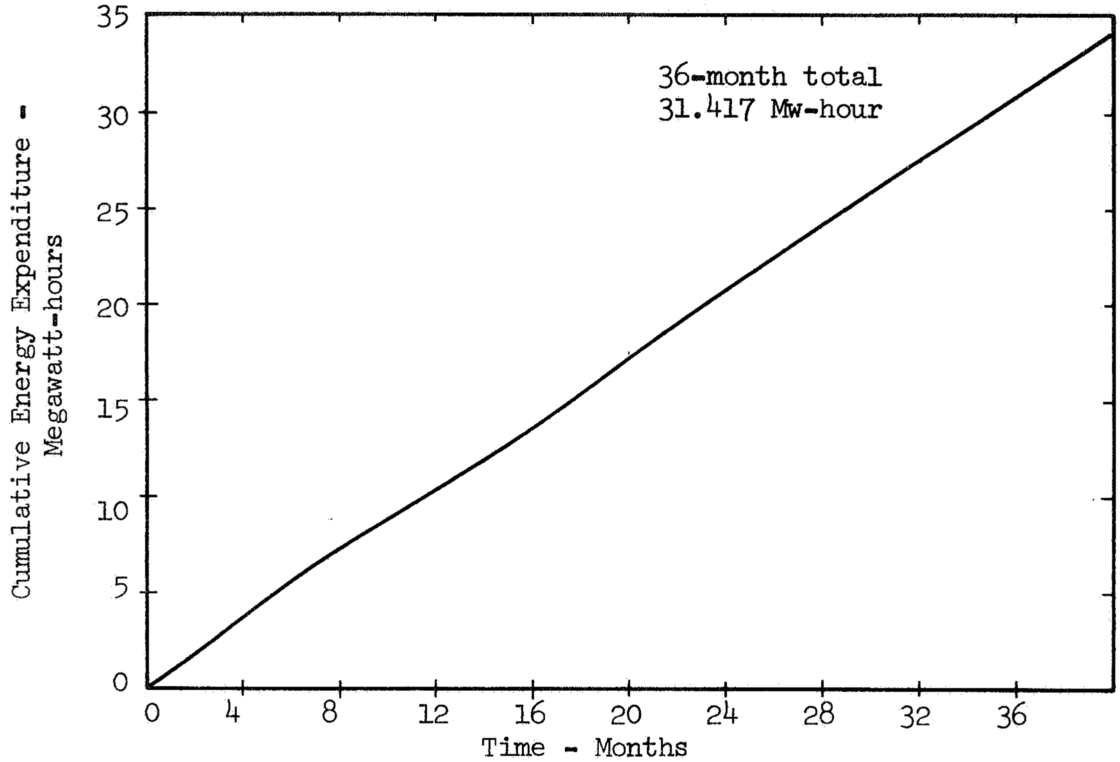


Figure 5.1-3. Preliminary Cumulative Electrical Power Requirements, Science Equipment

The remaining LSB electrical loads may be grouped under the heading of "general housekeeping" loads. Included in this category are activities such as data processing, communications, food preparation, lighting, and other miscellaneous activities of a sustaining nature which consume appreciable electrical power. Such loads constitute a continuous, average electrical load of 2 kw for a three-year period. "General housekeeping" requirements will, therefore, amount to 53.6 megawatt-hours.

5.1.2 Mobile Site Requirements

Continuous activities which are too distant (~ 2000 feet) from the LSB shelter complex to be supported by main LSB power are considered to be mobile site activities.

Deep Drilling

Operations at each drilling site were assumed to consist of a 7-hour shift per day for 50 days. Figure 5.1-4 depicts a typical shift power profile. This profile was based on a 2.5-hour period of drilling at a power level of 12 kw, interrupted by a randomly placed half hour break; and a 2.2-hour period of nondrilling operations at a power level of 2 kw. Over a span of three

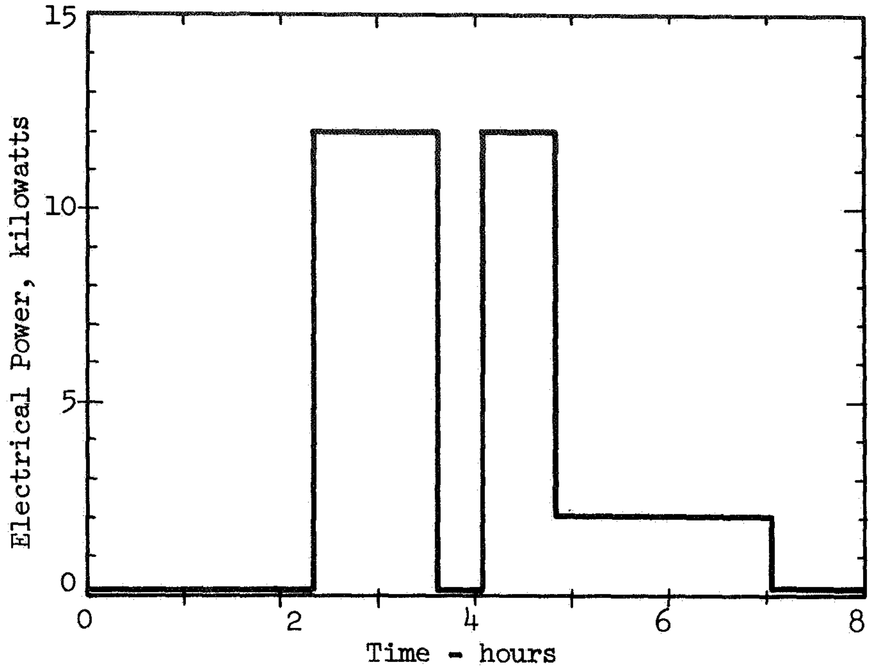


Figure 5.1-4. Power Profile for One 7-Hour Shift of Deep Drilling

years, allowing for contingencies, it was assumed that four sites will be drilled. This resulted in a requirement for approximately 5.7 Mw-hours of electrical energy and a daily average power of 3.6 kw.

Atmospheric and crew services (A&CS) requirements were based on a three-man crew at each site, operating in a semi-closed loop mode. At 550 watts per man, and assuming 200 days of manned operation at each site, the A&CS electrical energy required will be 31.7 Mw-hours. The remaining outpost functions are assumed to constitute an average continuous load of 200 watts, resulting in a requirement of 3.8 Mw-hours.

Logistics Vehicle Support

There may exist a requirement for the cryogenic reliquefaction of tug propellants to prevent excessive boiloff loss during extended stay periods on the lunar surface. The electrical power required for the reliquefaction equipment would be proportional to the lunar surface cycle temperature over a lunar day, with a time lage resulting from the effects of insulation. The estimated power profile for one tug is shown in Figure 5.1-5. The average power level is approximately 5 kw and the energy requirement for one tug is 3.36 Mw-hours per lunar day, or 21.6 Mw-hours per 180-day (resupply) period.

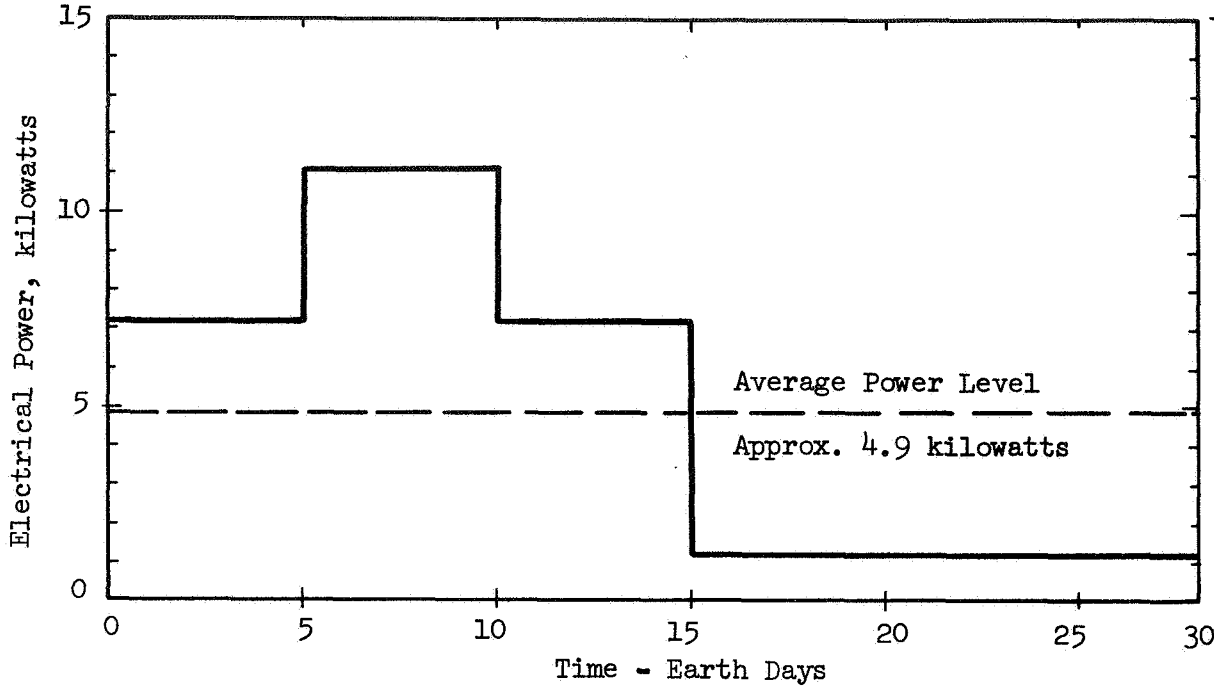


Figure 5.1-5. Power Profile for Cryogenic Reliquefaction of One Tug

Extended Sortie Requirements

The extended sortie mission is one of the major operations planned for the LSB program. The functional power requirements assumed for a typical sortie mission are summarized in Table 5.1-1.

The average sortie was assumed to involve 62 days of vehicle usage during which the sortie mobile power supply must supply all transportation and field support power. Figure 5.1-6 presents a power profile for the 62 days of vehicle usage. Superimposed on the profile at the top are reference marks to identify the various mission phases, and to show the daylight/night periods. Figure 5.1-7 shows the cumulative expenditure of electrical energy as the sortie mission proceeds. The electrical energy required for one sortie is on the order of 5.3 Mw-hours. The total three-year sortie electrical energy expenditure will be about 74 Mw-hours.

Table 5.1-1. Extended Sortie Power Requirements

MOBILITY (8 hours driving time per day)		
Motive power - 51,700-pound vehicle train		
night driving @ 1.8 mph		74.448 kw-hrs/day
day driving @ 3.5 mph		144.760 kw-hrs/day
Auxiliary driving power		
navigation	58 watts	
TV vision	46 watts	
controls	20 watts	0.993 kw-hrs/day
A&CS (4 men)		
semi-closed loop @ 0.55 kw/man		52.800 kw-hrs/day
Vehicle lights	100 watts	0.800 kw-hrs/day
FIELD SHALLOW DRILLING		
6.5 kw for 3.5 hours per each 48 hours while on location		
OTHER REMOTE SITE ACTIVITIES		
About 100 watts average continuous power during site staytime		

5.1.3 Summary of Electrical Energy Requirements

Table 5.1-2 presents in summary form a first order approximation of the electrical energy requirements which must be met for a three-year LSB program. Cryogenic reliquefaction of tug fuel has not been included as a requirement in this first approximation. Examination of this summary indicates that a total energy requirement of 549 Mw-hours, 79 percent is expended in the main LSB compound area, 7.5 percent in remote site applications, and 13.5 percent in extended sortie missions. The average power levels are approximately 18 kw for the main LSB, 3.6 kw at an outpost site, and 3.6 kw in a sortie. This suggests the possible desirability of employing EPS modules having an output capability of about 3.6 kw.

Examination of the classes of electrical loads categorized reveals that a substantial part of the total load is comprised of mobile, and widely dispersed stationary loads. This is particularly true in the formative stages of LSB development when most of the activity will be directed toward site preparation, materials transport and exploration. As the buildup proceeds, the magnitude of fixed LSB power requirements will increase. However, the mobile and remote site stationary power requirements will also increase as sortie and remote site drilling operations are commenced.

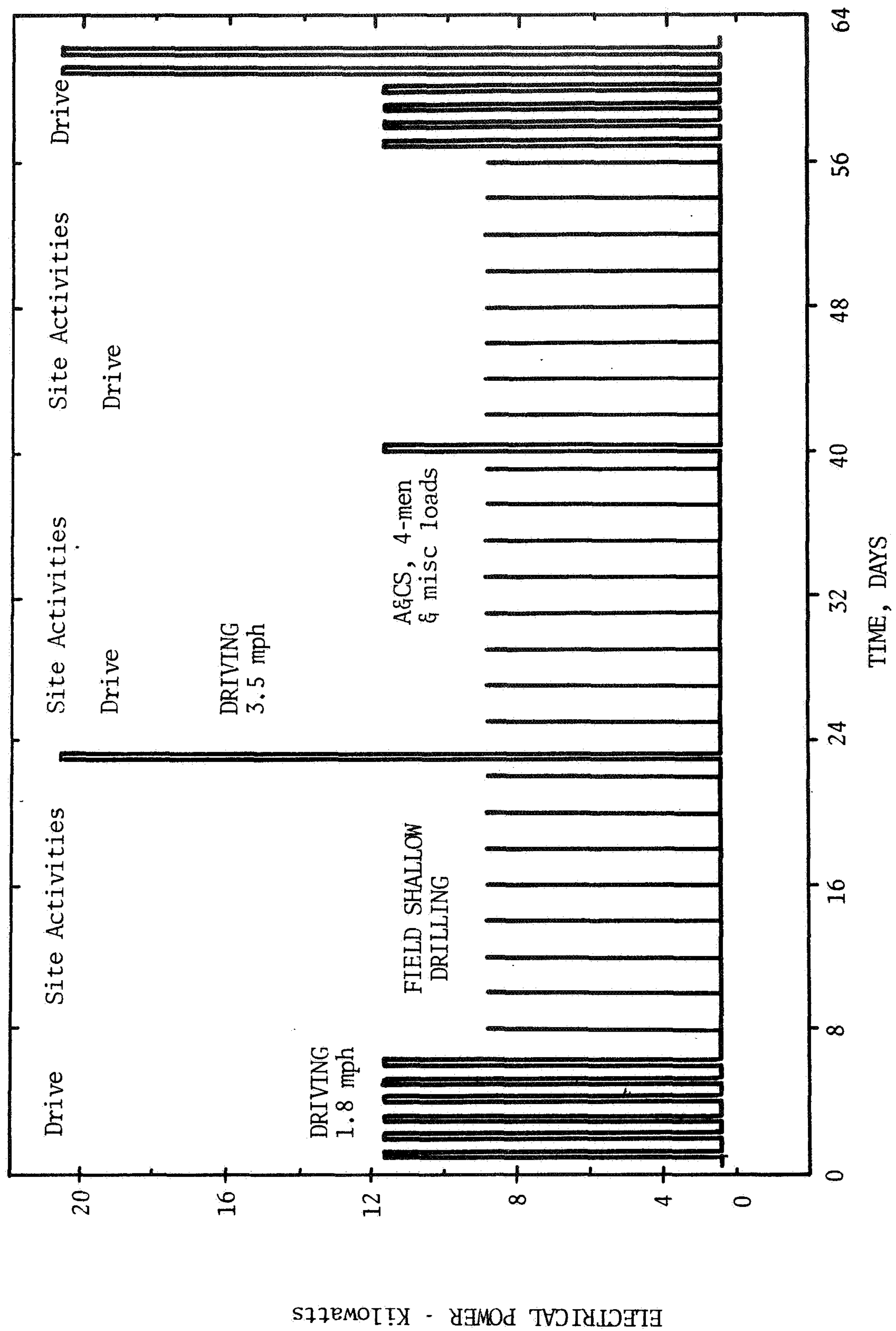


Figure 5.1-6. Electrical Load Profile 62-Day Sortie Mission

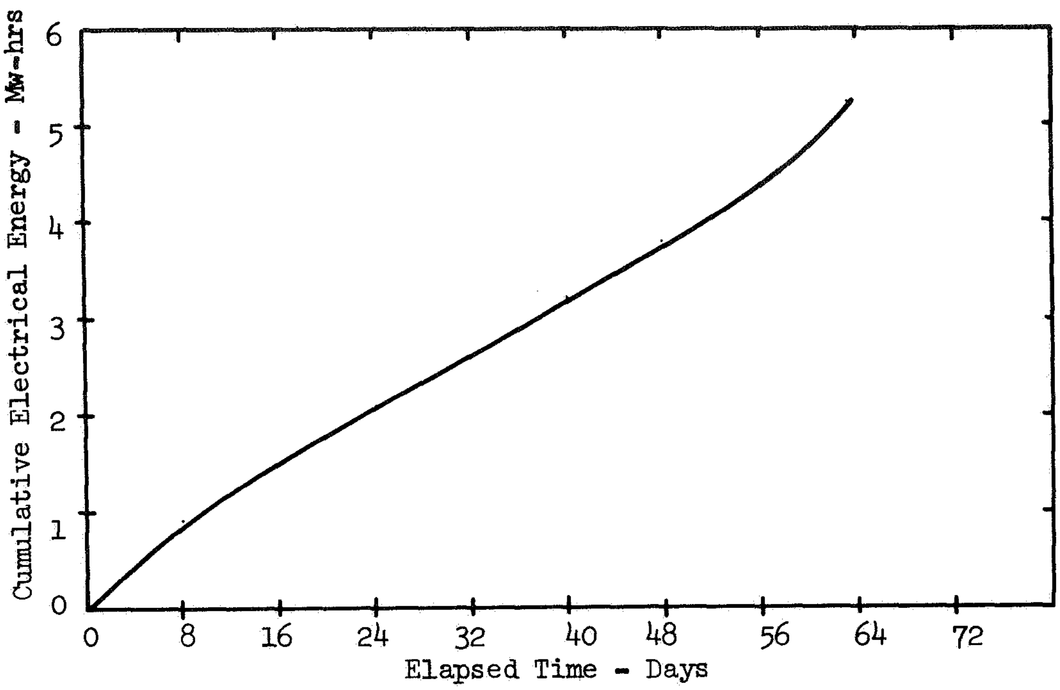


Figure 5.1-7. Cumulative Electrical Energy, 62-Day Sortie Mission

Table 5.1-2. LSB Electrical Energy Summary (3-year Program)

	Average Power (kw)	Total Energy (Mw-hr)	Considerations
Fixed Site			
A&CS	12.0	315	12 men
Science	1.2	31	Base on site
	4.0	33	Observatory
Housekeeping	2.0	54	Comm., data, maint., etc.
Mobile Sites			
Deep drill outpost	3.6	6	50 days/site, 4 sites
Outpost housekeeping	1.8	36	3 men, 200 days/site, 4 sites
Sorties	3.6	74	62 days/sortie, 14 sorties
Logistic vehicle support	(4.9)	(130)	(Reference only, not included)
Total		549	

In view of the nature of the loads, and the participation of personnel in activities associated with the loads, it is clear that the power requirements follow the man to a large extent. It would, therefore, be desirable to provide electrical power hardware which has high degrees of modularity and mobility. This type of EPS hardware also enhances the compatibility with the physical capabilities of the logistics delivery system and the delivery of EPS units in a near-operable state of readiness.

5.2 SUBSYSTEM OPTIONS AND TRADES

5.2.1 Electrical Power Source

In selecting an electrical power source, the total energy, the average power and the user locations all influence the selection process. Figure 5.2-1 identifies the subsystem options which might be considered.

Figure 5.2-2 indicates typical power source parametrics in terms of specific power as a function of time. For example, a 400-pound space nuclear reactor that consumes one pound of U-235 in one year has an enery storage of 24 Mw-hours thermal per pound of reactor. Radioisotope power also provides a basic source of thermal energy that is very compact and lightweight. Pure Pu-238 can produce 2.2 Mw-hours thermal per pound of isotope per year. At a conversion efficiency of 20 percent, approximately 420 pounds of this isotope would be capable of providing the required 550 Mw-hours of electrical energy. By way of contrast, fuel cells have an energy output of about 1.25 kw-hours per pound of reactants and would, therefore, require about 440,000 pounds of reactants for the LSB application. Moreover, fuel cells have not demonstrated lifetimes approaching three years of operation.

The only alternative to carrying a stored energy source to the lunar surface is to use the environmental energy afforded by solar radiation. From the standpoint of state-of-development and availability, solar cells would be the obvious choice for photovoltaic conversion. Several types of photovoltaic converters are under development, but only single-crystal silicon solar cells have been used in space. The performance of these cells is well understood, and they will continue to be widely used. Unfortunately, because of the long lunar night a massive solar cell/battery system would be needed to supply electrical energy of the magnitude required by the LSB. More than 5,600 square feet of solar array area and more than 300,000 pounds of secondary batteries would be necessary.

These considerations lead to the conclusion that any systems requiring consumables can be dropped because of the high cost of tranportation to the lunar surface.

A concept utilizing regenerative fuel cells combined with solar cells was examined as a potentially useful option for the LSB since it would minimize the consumables resupplied. However, the long lunar nights and mobility requirements impose penalties that make the option undesirable from both a weight and operational standpoint. To implement an autonomous 3.5 kwe mobile power module, the following elements are required:

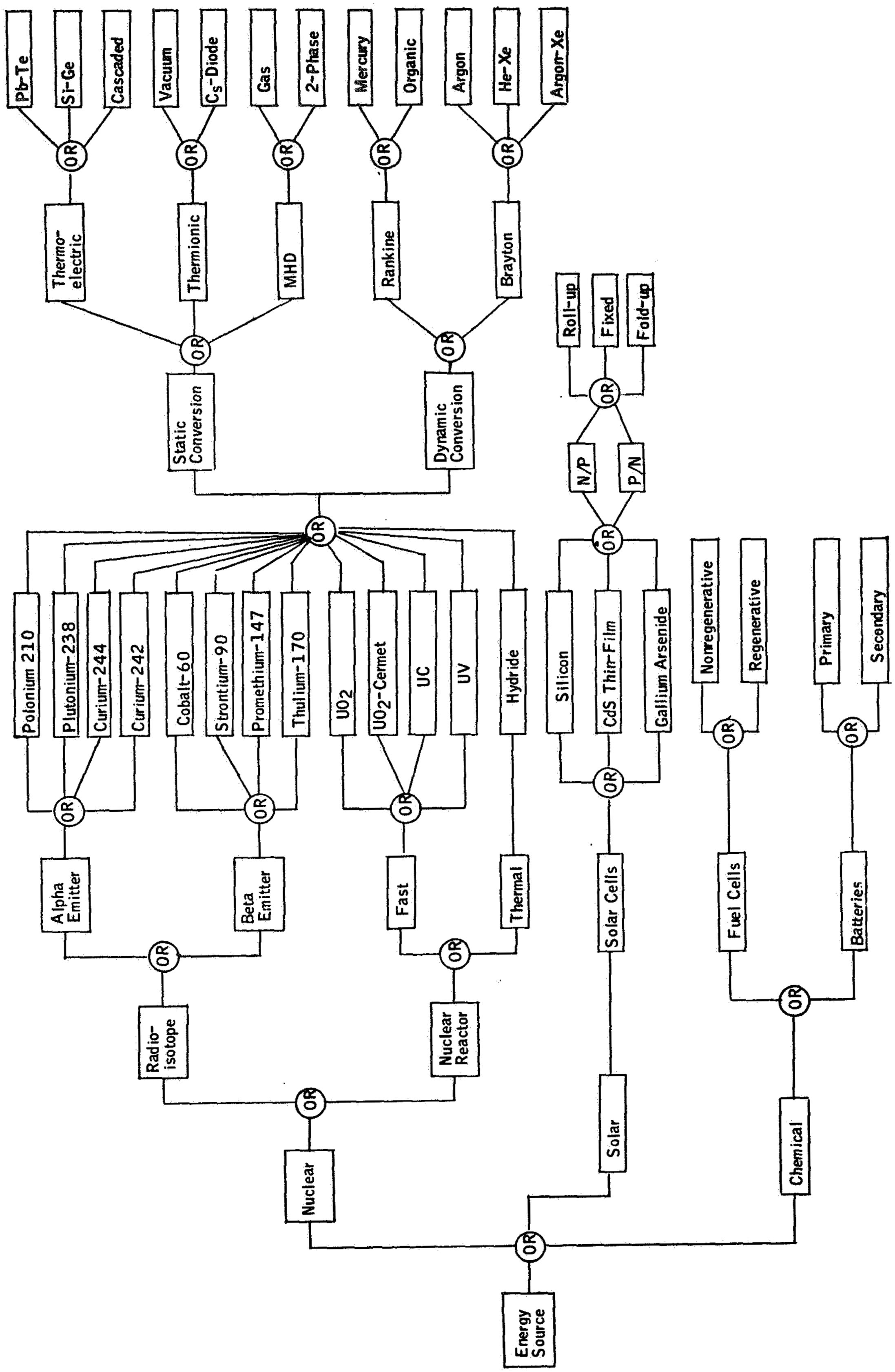


Figure 5.2-1. Electrical Power System Basic Trade Tree

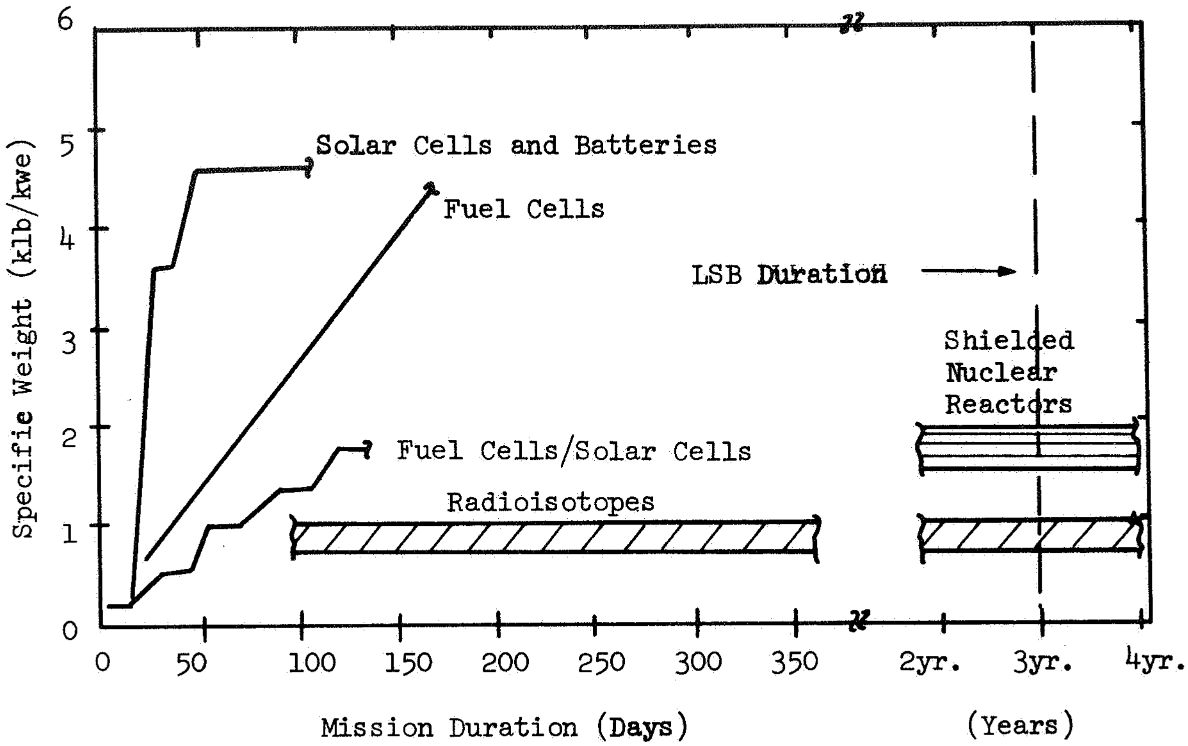


Figure 5.2-2. Typical Electrical Power System Parametric Data

1. A 3.5-kwe fuel cell system for lunar night operations with cryogenic or high-pressure gas storage facilities for 14 days duration and water tanks for the byproduct.

2. An electrolysis unit to recover the oxygen and hydrogen during the day.

3. A reliquefaction unit to return the gases to cryogens or compressors and radiators to return to a high pressure storage system.

4. A solar array system to provide power during the day to operate functions 2 and 3 in addition to providing the required 3.5 kwe during the daylight hours.

5. A trailer to carry it all.

It was found that almost 27 kwe of power was required to be provided during the day for the regeneration capability. The resultant solar array area would be over 8600 ft^2 and the module weight on a trailer would exceed 32 thousand pounds. Thus, this concept would be producing more power during the day than the total average LSB requirement in order to provide only one sixth of the night-time load. Further, the mobility of the large array is questionable.

The conclusion reached is that only a nuclear reactor or a radioisotope system is compatible with the required energy output within the practical weight and volume limits.

Approximately 1300 different radioisotopes are known to exist, and the ranges of properties exhibited by these substances vary widely. Some have half-lives of considerably less than a second, while others have half-lives measured in eons of time. Screening on the basis of the following physical property criteria reduces this population to the 17 potential fuels listed along with their pertinent properties in Table 5.2-1.

1. The half-life should be greater than 100 days and less than 100 years. The 100-day limitation eliminates the many short-lived isotopes that would present severe fuel processing and power-flattening problems. Fuels should have a half-life of at least a few months to account for encapsulation time, mission delays, and also to permit some stockpiling. Radioisotopes with half-lives over 100 years almost always have unacceptably low specific powers.

2. The specific power should be greater tha 0.1 watt/gram. This criterion is established to eliminate the many nuclei that emit a few weak particles but still have acceptable half-lives. The larger fuel capsules associated with low specific power fuels lead to higher shield weight and lower generator efficiencies.

3. Pure or nearly pure gamma emitters should be eliminated because of their shielding and ground-handling problems.

4. A fuel form should exist which is relatively noncorrosive, compatible with structural materials, stable in time, and so insoluble in water that the entry of the radioisotope into the biosphere in the case of an accident is improbable.

5. A fuel form must exist which has chemical stability and good engineering properties at high temperatures. More specifically, the upper temperatures of interest are from 500 C to 1400 C. The engineering properties of interest are the practical power density, melting point, dimensional stability, gas evolution (e.g., helium buildup in alpha emitters), thermal conductivity, and density.

These radioisotopes were further screened according to the major radiations which they emit. Gamma emitters were eliminated from consideration because of the need for excessive shield weight and impact on the mobile units. The beta emitters, with the exception of Promethium-147 and Thulium-170, also require excessive shielding. Of the alpha emitters, Polonium-210, Plutonium-238, Curium-242, and Curium-244, are the remaining and most likely candidates. Shielding and cost considerations narrow these six radioisotopes down to Polonium-210 (Po-210) with a half life of 139 days for short duration applications and Plutonium-238 (Pu-238) with a half life of 88 years for long duration

Table 5.2-1. Potential Radioisotope Fuels

Radioisotope	Half-Life (years)	Specific Power, Psp (watts/gram)	Remarks	Major Radiation
Tritium	12.26	0.36	Gaseous, OK for atomic batteries; other forms have too low Psp	β
Cobalt-60	5.26	9.00	Hard γ. Shielding problems	γ, β
Krypton-85	10.40	0.55	Highly compressed gas. Nuclear safety	γ, β
Strontium-90	28.00	0.93	Good for terrestrial purposes (SNAP 7). Heavy shielding	β, X
Ruthenium-106	1.00	31.00	Heavy shielding, unpredictable chemistry	β, γ
Cesium-137	30.00	0.27	Heavy shielding, low Psp	β, γ, X
Cerium-144	0.78	25.0	Heavy shielding, extremely toxic	β, γ, X
Promethium-147	2.50	0.37	Relatively unavailable, low Psp, very expensive	β
Thulium-170	0.35	13.00	Short half-life Moderate shielding	β, α
Polonium-210	0.38	140.00	Expensive, short half-life	α
Actinium-227	21.20	15.00	Heavy shielding, expensive	β, γ
Thorium-228	1.91	161.00	Heavy shielding, expensive	β, γ
Uranium-232	74.00	4.80	Heavy shielding	β, γ
Plutonium-238	88.00	0.55	Weak γ, long half-life, fair Psp	α
Curium-242	0.45	120.00	Short half-life Moderate shielding	α, η
Curium-244	18.00	2.8	Moderate shielding too heavy	α, η
Mixed Fission Products (MFP)			Partially processed wastes, major isotopes are Strontium-90 and Cesium-137, costly separation processes	

applications. Therefore, the AEC has concentrated on these two isotopic fuels for their heat source development effort. A detailed description of Polonium-210 and Plutonium-238 is presented in Table 5.2-2.

Table 5.2-2. Po-210 and Pu-238 Characteristics

	Po-210	Pu-238
Watts/gram, pure	141	0.56
Half-life, years	0.38	88
Isotopic purity, percent	95	80
Compound form	Metal	PuO_2
Active isotope in comp., percent	95	70
Watts/gram, compound	134	0.39
Density of compound, $\frac{gm}{cm^3}$	9.3	10
Watts/cm3, compound	1210	3.9
cm^3/kwt	0.83	257
Radiation, major	α	α
Mev α particle	5.3	5.49
Mev γ radiation	0.8	0.04 *
μ Currie/cm^3	7×10^{-11}	7×10^{-13}
$/watt (future)	20	540
MPC_{air}, $\mu C/cm^3$ **	7×10^{-12}	3×10^{-13}
MPC_{water}, $\mu C/cm^3$ **	2×10^{-7}	10^{-5}

* No Pu-238 present
** Maximum permissible concentration, micro-curies/cm^3

In the final selection process, availability of the isotope is a primary consideration. Figure 5.2-3 presents a recent projection of the availability of Plutonium-238. The LSB requires approximately 550 megawatt-hours of electrical power for three years of operation. At 20 percent conversion efficiency, 105 thermal kilowatts would be required which is well below the estimated availability in the LSB time period. However, if other potential users are considered, the availability of sufficient quantities for the LSB may be marginal.

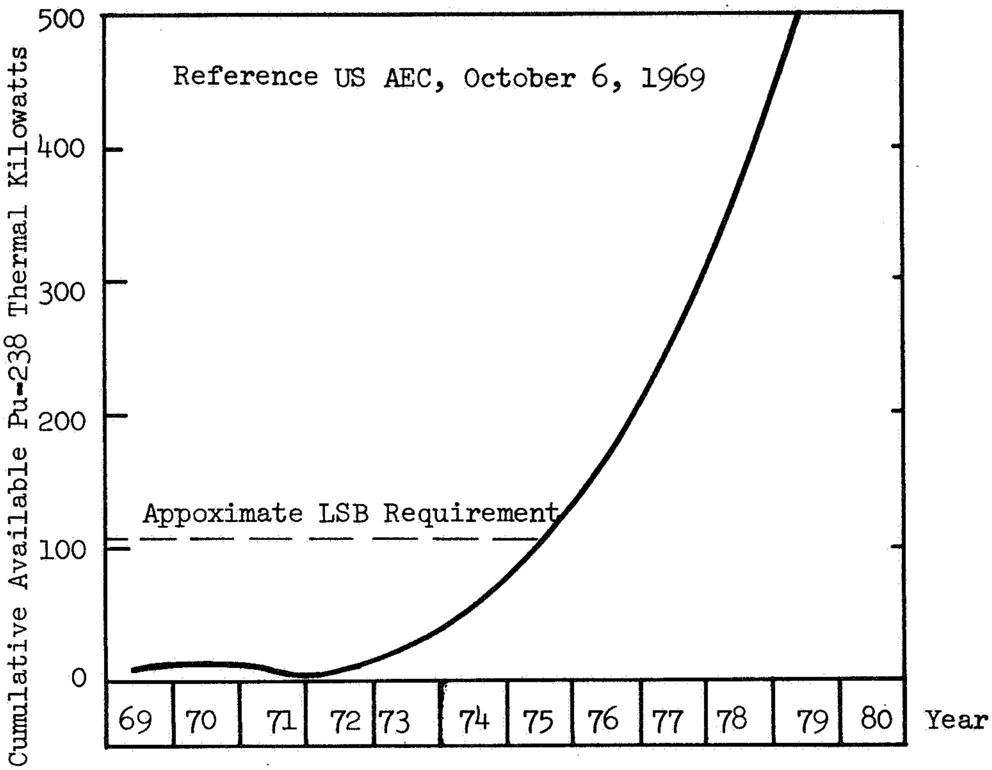


Figure 5.2-3. Potential Cumulative Availability of Pu-238

The alpha-emitting Plutonium-238 radioisotope is clearly the best choice for the LSB; however, Polonium-210, which also has minimal shielding requirements similar to those of Plutonium-238, is more readily available. The major disadvantage of Polonium-210 is its short half-life of 139 days; but this time is not incompatible with the nominal LSB resupply cycle of 180 days. Therefore, the candidate energy sources are the thermal nuclear reactor and the radioisotope Plutonium-238 with Polonium-210 considered as an alternate. The application, advantages and disadvantages of these sources are summarized in Table 5.2-3.

Table 5.2-3. Summary of Energy Source Trade Factors

ALTERNATIVE	ADVANTAGES	DISADVANTAGES
Pu-238 radioisotope	Good reliability	High isotope cost
	More mission flexibility	More limited isotope availability
	High growth potential	Probably require recovery after mission
	Low shielding required	Constant heat output, requires heat rejection provisions during transport
	Easily handled by personnel	Requires recoverable transport containers
Po-210 radioisotope	(similar to Pu-238)	(similar to Pu-238)
	Cost per thermal watt about 1/30th that of Pu-238	Short half-life (139 days) Resupply required. Program costs higher.
	May be interchanged with Pu-238 in EPS	Auxiliary heat rejection means needed during first half-life
Nuclear Reactor	Less expensive than radioisotope	Heavy shielding required
	Hardware more readily available	Once activated, cannot be readily approached for maintenance or repair
	Relatively passive during launch and transport	Shielding requirements limit use to stationary powerplant
	Can be shielded by burial in lunar soil	

Consideration of the pros and cons of nuclear reactor versus radioisotope energy sources leads to the choice of the nuclear reactor as the most cost effective solution for stationary, central-plant type of power generating system. However, weight including shielding is of paramount concern for the mobile units. Furthermore, the distribution wiring required to service numerous loads at various distances from a central LSB powerplant is appreciable. Table 5.2-4 shows the weight per conductor-mile of aluminum transmission line for the transmission of 3.3 kilowatts to a remote site with a 1 percent loss assumed. The savings shown in line weight by high voltage transmission would be offset significantly by the weight of conversion equipment at both ends of the line.

Table 5.2-4. Weight of Aluminum Transmission Line From Central Station to User

Assumptions: 1% loss/line-mile; 3.3 kilowatts transmitted

Voltage	Cross-section (in^2)	Weight lb/conductor mile
30 vdc	68.00	431,000
1000 vdc	0.07	444

A major argument in favor of modular radioisotope EPS's is that the buildup of modules can proceed in accordance with the buildup of the LSB facilities. Modules would be delivered as they are needed, and being mobile, they could be delivered to the load site. Hence the effort necessary to construct a complex central-station power distribution network would be avoided completely. Additionally, the mild radiation environment presented by the isotope systems would substantially lessen the hazards to personnel working in proximity to the loads.

5.2.2 Power Conversion

Two heat cycles, the Brayton and Rankine, and several thermoelectric conversion concepts, Silicon Germanium (SiGe) and Lead Telluride (PbTe) were considered for power conversion. In addition, several working fluids were investigated for the Brayton and Rankine conversion.

Organic Rankine turbine electric power generating systems have been successfully operated for sufficiently extended periods of time to confirm their potential for reliable, highly efficient operation. The inherent advantages of the organic system stem from its low operating temperature and its use of a noncorrosive fluid which expands into the super heat region. Net cycle efficiencies of approximately 17 to 21 percent are easily obtained while operating at turbine inlet temperatures of 700 F. However, low temperature operation results in a substantial radiator area requirement for the rejection of waste heat. Although the area requirement is considerably less than that of the Brayton cycle, the organic Rankine requires a larger radiator than higher temperature systems such as the Mercury Rankine or thermoelectric systems.

In order to improve the efficiency of the basic Rankine cycle, a regenerator can be used to recover the superheat in the vapor at the turbine exhaust by causing the turbine discharge vapor to pre-heat the liquid entering the boiler. This results in an increase in thermal efficiency of about 50 percent.

The Brayton cycle power system appears attractive over the power range from 1-2 kilowatts up to 10-20 kilowatts. Components have been built and tested in the 3-8 kwe power range. Below 1-2 kilowatts the isotope thermoelectric systems offer advantages of cost, simplicity, and state-of-the-art. At the higher power range range the Brayton cycle is limited by isotope availability and required radiator area. The Brayton cycle, with a system efficiency of over 20 percent, is able to utilize the limited isotope inventory more efficiently than any competitive system. The large raditor area required for the Brayton cycle also limits the upper power range. For Brayton systems optimized for high efficiency, the specific radiator area may range from 50 to 80 square feet per electrical kilowatt. Thus a 3.5-kilowatt system may require nearly 280 square feet of radiator area.

The two most widely accepted semiconductor materials for thermoelectric converters are Silicon Germanium and Lead Telluride. Silicon Germanium is the easier to fabricate, is more stable, and tends to degrade less than Lead Telluride. Its hot-side operating temperature is on the order of 1000 - 1500 F, which results in radiator temperatures of about 400 - 600 F. The conversion efficiency ranges from approximately three to five percent.

Lead Telluride converters yield a higher conversion efficiency, ranging from about five to seven percent. However, because this material degrades at high temperatures, its hot-side temperature is limited to 1100 F. Consequently, the radiator area requirements are roughly 40 percent greater for Lead Telluride than for Silicon Germanium systems. In addition, Lead Telluride has a very low tensile strength, and means for keeping the material in compression must be incorporated in the design of Lead Telluride converters. The main advantage of Lead Telluride over Silicon Germanium is its higher efficiency, which lead to less fuel inventory. Its main disadvantage is that it requires a larger radiator. The total systems weight is about the same for both materials.

The fact that Lead Telluride converters operate at a lower temperature range and are more efficient than Silicon Germanium converters suggest a cascade arrangement. The objective is to recover part of the energy rejected by a Silicon Germanium converter by means of a heat exchanger which couples the Silicon Germanium waste heat to the hot side of a Lead Telluride system. The heat rejected from the cascaded system is that which is rejected from the cold side of the Lead Telluride converter. Such a system is workable and can be optimized by designing the heat exchangers to have both converters operating at their optimum temperature points. Potential performance improvements over a single-type converter are impressive, as is evident from the comparison estimates of Table 5.2-5. The chief disadvantage of the cascade approach is that it requires the development and qualification of both the Silicon Germanium and the Lead Telluride converters.

Figure 5.2-5. Estimated Performance Comparison of Single and Cascaded SiGe and PbTe Converters

Fuel: Pu-238 - Output: 2.1 kwe			
Parameter	SiGe	PbTe	Cascaded
System weight (lb)	3265	2870	2200
Radiator area (ft^2)	135	200	150
System efficiency (percentage)	3-5	5-7	7-9

5.3 RECOMMENDED MODULAR MOBILE EPS CONCEPT

Because of the mobility and modularity requirements, the radioisotope systems exhibits a significant advantage over the shielded nuclear reactor system. Table 5.3-1 presents the summary data on LSB EPS candidates. These data present the important evaluation parameters as they have been compiled for a 3.5-kwe EPS module. As an illustration of the effect of the selected module size on the selection, a 17.5-kw nuclear reactor central-station generator (without any distribution system weights) would weigh only 8600 pounds, an increase of only 1600 pounds over the 3.5-kw reactor system.

The recommended system concept is the Plutonium-238 radioisotope source, if the isotope is available in sufficient quantities, with two redundant organic Rankine cycle converters. The selection of the radioisotope source over the nuclear reactor is based mainly on weight and radiation considerations for the mobile units. The selection of the organic Rankine cycle over the Brayton cylce is based on radiator area and on weight, which are prime factors in the design of a mobile EPS module, or "power cart", suitable for application to a sortie mission. Although the Brayton cycle would make better use of the isotope inventory (it is 20 percent efficient compared to 15 percent for the organic Rankine cycle), the weight and radiator area considerations were overriding factors in the choice.

Table 5.3-1. Electrical Power Source Trades (Based on 3.5 kw module)

OPTION	SYSTEM WEIGHT (KLB)	VOLUME (FT^3)	CONSUMABLES (180 DAYS) (KLB)	AVG HEAT REJECTED (KW)	SHIELD WEIGHT (LB)	OTHER CONSIDERATIONS
RADIOSOTOPE						
Pu 238 - Brayton	2.0	230	0	14	20	Isotope may not be available
Pu 238 - Rankine	1.6	200	0	20	20	
Pu 238 - TE	4.9	200	0	70	25	
Po 210 - Brayton	2.1	235	0.9	27	150	Isotope resupply required
Po 210 - Rankine	1.7	205	1.0	29	150	
Po 210 - TE	4.3	200	2.8	135	200	
REACTOR						
Rankine	6.1	400	0	20	19K	Inefficient size
Brayton	7.0	450	0	15	15K	Inefficient size

The concept is composed of two organic Rankine power converters driven by an isotope heat source as illustrated by Figure 5.3-1. The schematic indicates the converters in parallel redundancy with a cascaded thermoelectric converter as a final backup source. The thermoelectric converter is brought into operation by closing down part of the radiator and permitting the temperature to rise to the optimum level for the cascaded converter. About 1.2 kwe is produced in this mode. The system can operate on either Plutonium-238 or Polonium-210. A power-flattening auxiliary radiator is added for Polonium-210 usage during early periods in the isotope's half-life. The concept selection is, therefore, insensitive to the availability of the selected isotope. A preliminary specification for the power module is contained in Appendix C.

The characteristics are listed below for one power trailer:

System Weights		
Primary system		1605 pounds
Battery system (peak loads)		700 (10,000 ah)
Power conversion and control		300
Thermoelectric converter		150
		2755
Trailer		1020
	Total	3775
Total System Volume		200 cu. ft.
Radiator Area		175 sq. ft.
Auxiliary Radiator Area		38 sq. ft.

Six of these are required to support the total LSB activities, three of which, at any one time, will be dedicated to the LSB main shelter support. The main shelter will be powered through a J-box which permits connecting and disconnecting the power trailers as required. With this concept, the power source can follow the man and be divided at the rate of 3 to 4 men per module, depending on the mission.

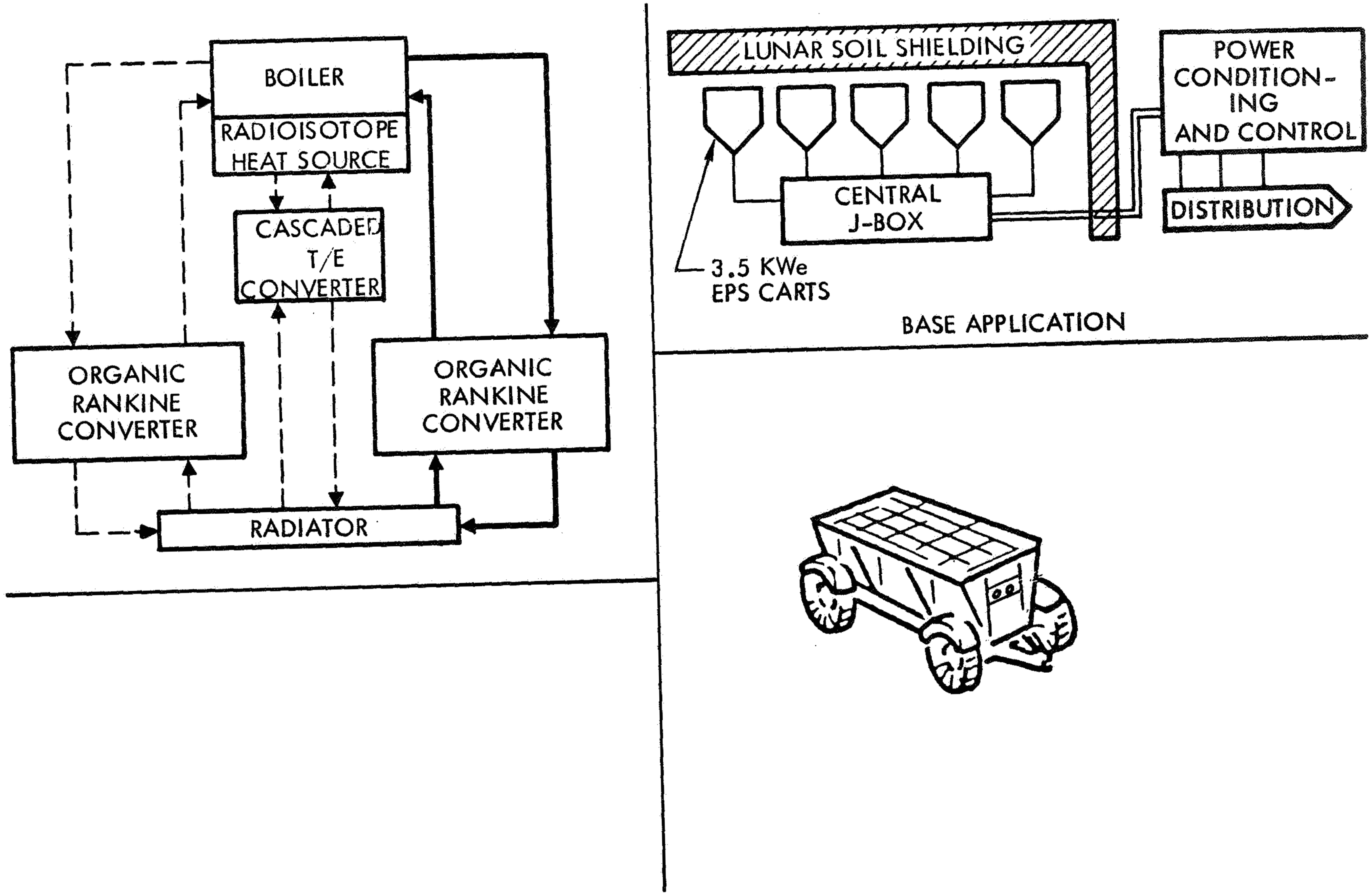


Figure 5.3-1. Modular Mobile EPS Concept, LSB Applications

6.0 COMMUNICATIONS

The communications subsystem provides a means for exchange of information among personnel and equipment at the base, on exploratory sories, at installations separate from the base, and between base elements and earth. In addition, communication is required to support the landings of vehicles performing logistics support. It interfaces extensively with the data management system as illustrated by Figure 6.0-1.

Basic subsystem functional requirements are similar in many respects to those established for the Earth Orbit Space Stations and the Orbiting Lunar Station and concepts developed in these studies are applicable to the LSB. Key subsystem problems unique to the LSB are associated with communications between elements beyond line of sight, and with the processing and transmission of the experiment data.

6.1 REQUIREMENTS DEFINITION AND INFERENCES

The requirements for communications links are somewhat indeterminant at this time. The spectrum of potential links is illustrated by Figure 6.1-1. However, all of these links may not be required. Further, the type of data to be handled and, therefore, the link quality requirements are only generally defined. Communications requirements include both internal and external exchange of information. The links and the types of information transferred are indicated in Table 6.1-1.

Internal communications include audio, video and data. The audio includes an intercom and paging capability in all areas of the base. A telephone capability is also needed; that is, a capability to select and signal specific locations in the base. The paging also could be capable of entertainment distribution and would carry audible monitor and alarm signals.

Video capability is required for commercial quality color TV camera locations in all areas and immediately external to the base. The cameras provide a capability to monitor and assess conditions in the base from the control or a work area, and to originate video for transmission to earth for scientific and operations support. Monitor capability is required in all areas to allow distribution of information from other areas or from earth. The monitors would generally be individual sized units with the exception that one should be about a 14-inch screen for group viewing.

Data distribution would provide access to the data bus in all areas of the base and immediately external to the base for access to the data subsystems. Table 6.1-2 summarizes typical requirements for the internal communications.

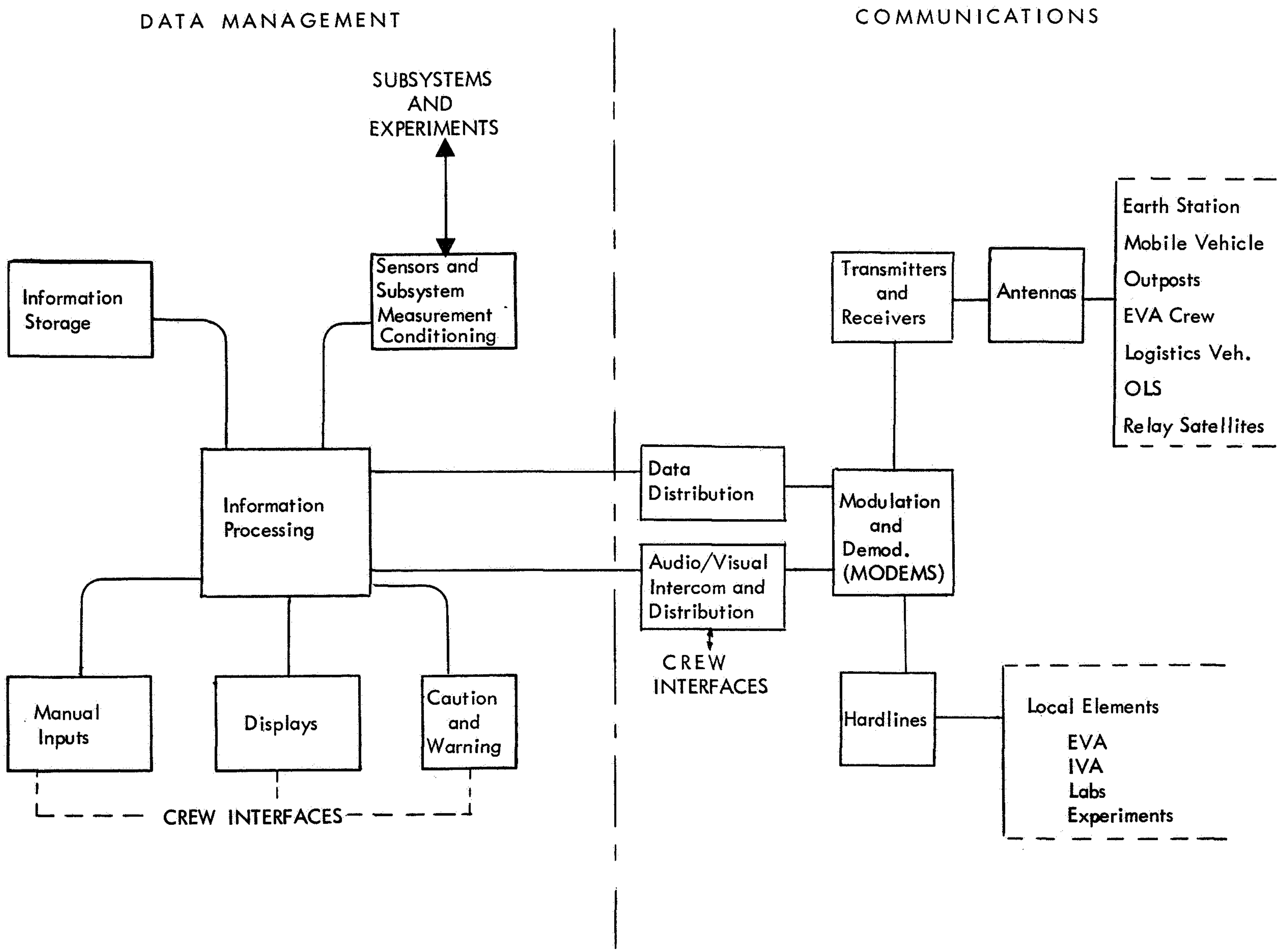


Figure 6.0-1. Communications and Data Management Functional Elements and Interfaces

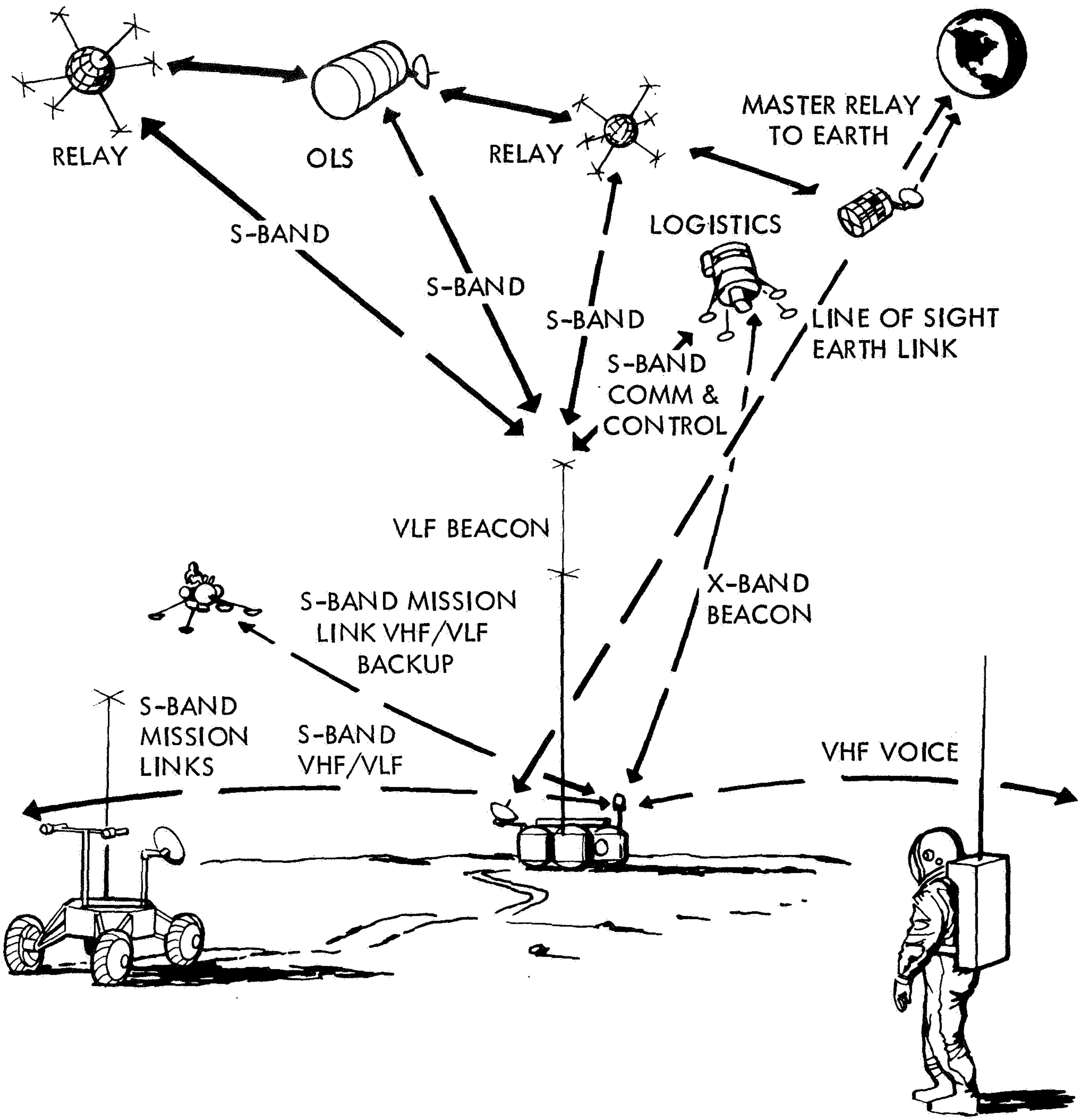


Figure 6.1-1. Potential LSB Communications Links

Table 6.1-1. Communications Links Required

Terminal / Origins	Base	Earth	Logistics Vehicle	LFU	Sorties	EVA	Fixed Sites	OLS
Base	Internal Audio Video Data	Voice Data Video	Voice Command Guidance (radar bcn)	Voice Command Guidance (radar bcn)	Voice Command Guidance (radar bcn)	Voice Guidance (LF bcn)	Voice Commands	Relay Voice Data Command Video
Earth	Voice Data		Voice Command	Voice Command	Voice Command	Voice	Voice Command	Relay Voice Data Command Video
Logistics Vehicle	Voice Data Beacon Interrog.							
LFU	"	Voice Data			Voice	Voice	Voice	Voice Data
Sorties	Voice Data Video	Voice Data Video		Voice		Voice	Voice	Voice Data
EVA	Voice Biomed Data			Voice	Voice	Voice	Voice	
Fixed Sorties	Voice Data Video	Voice Data Video		Voice	Voice	Voice		Voice Data Video
OLS	Relay	Relay	Relay	Voice Cmd.	Voice Cmd.		Relay	

Table 6.1-2. Internal Communications

Locations	
External hardware	Primary control
Recreation area	Backup control
Staterooms	Work positions
Airlocks	Garages
Capabilities	
Primary telephone	4 kHz
Backup intercom	4 kHz
Video camera	4.5 MHz
Video monitor	4.5 MHz
Digital terminal	1 Mbps
Public address and alarm	10 kHz

The external communications are summarized in Table 6.1-3 and include requirements for transmission and reception of voice, data, commands, video, and guidance in terms of a radar or radio beacon.

Table 6.1-3. External Communications

Voice	2.5 kHz	Between all manned elements
Commands	200 bps	Earth to all elements except EVA crew Base to all elements except earth, EVA crew
Video (Color)	4.5 MHz	Base to earth, earth to base, fixed sites to base and/or earth
Video (Single Frame)	2 kHz	Sorties to base or earth (time share with data)
Radar Beacon	X-Band	Transponder for flight vehicle radar - near landing sites
Homing Beacon	LF	Base broadcast for homing, voice or code broadcase, recall, alarm
Data		
Base to earth	50 Kbps 20 Mbps 1.6 Kbps	Remote sorties to base, 12 Kbps Remote fixed to base, 10 Mbps
Earth to base	50 Kbps 1.6 Kbps	
Basic data (all elements)	1.6 Kbps	

Voice is assumed to be a requirement between all manned program elements to provide a capability for verbal coordination. It was assumed that a bandwidth of 2.5 kHz would be adequate. Variations from this would be a function of specific link optimizations and would not affect the gross parameters.

Commands are assumed to be 200 bits per second. These are required to permit remote activation or deactivation of the base and associated elements. The function also allows remote control of experiments and mobile elements.

The communications maximum link quality and associated constraints are summarized by Table 6.1-4. These requirements form the basis for the options trade.

Table 6.1-4. Communications Link Quality Requirements Summary

Link	Effective Syst. Gain (dbw)	Maximum Bandwidth (MHz)	Constraint
LSB - Earth	39.5	4.5	Color TV
LSB - Orbit	-31.3	2.9	B&W TV
LSB - Surface Stations*			
Fixed local	-78.2	2.9	B&W TV
Fixed remote (via earth)	67.8	1.0 - 2.9	Facsimile
(via relay)	-39.2		
Local mobility	-78.2	0.5	Voice
Remote sorties	-76.2	1.0	Nav. & Map.
*Based on 100-ft masts at fixed stations			

Video is primarily required for the exchange of scientific and technical information between the base and earth. A secondary requirement is for entertainment and general information on a noninterference basis. This video function is assumed to a a 4.5 MHz commercial quality color link. An additional requirement for video results from the support of remote control operations. The 30 frames per second color link is considered desirable for this purpose; however, past studies have indicated that single frame pictures requiring several seconds combined with automation of remote equipment would be adequate. This class of video is therefore assumed to be included along with sortie data requirements, with the restrictions that the base display and central configurations would not preclude the use of high quality video in special cases.

The flight vehicle guidance requirement consists of a beacon transponder for each landing site associated with the LSB. The base interface would be to activate and deactivate units, perform maintenance, and to supply power to the units. Installation requirements would be dictated by the vehicle design. However, an assumption of X-band transponders located on opposite sides of a single landing site, or adjacent to each multiple landing site in a base area was assumed as a typical design requirement.

The navigation for EVA and sortie operations is an area receiving considerable attention in various studies and is discussed in some detail in Appendix D to Volume II. The requirement assumed for the base is a low frequency signal originating at the base which will allow homing to be performed by obtaining a relative bearing to the base. The signal would also serve as a voice and code broadcast of general information, alert and warning, and recall information. A nominal effective radius must approach 200 miles from the base.

6.2 COMMUNICATIONS LINK OPTIONS AND TRADES

The communications link requirements may be summarized and grouped as indicated by Figure 6.2-1, where the associated potential options are also identified. Earth links, space links, and surface links form the major classifications and the trades were performed on this basis.

6.2.1 Earth Links - Options

The S-, C-, X-, and K-bands as well as laser operation were investigated for the link frequency. S-band is attractive in that the existing MSFN facilities are designed for that band and present indications are that the network will maintain these frequencies. C-band and X-band are heavily occupied by commercial and military allocations which make the areas undesirable for wide band lunar links. K-band is attracting much attention in that wide band allocations may be made available, and high gain and narrow beamwidth are possible with small antennas at that frequency. Figure 6.2-2 shows characteristics of standard parabolic antennas. It can be seen that 15 to 17 db additional gain is realized by both the LSB and the MSFN antenna for any given diameter by going to a K-band system. However, the additional path loss offsets the gain of one antenna, with a net gain left of 15 to 17 db. This advantage is further offset by several adverse features. A 30-foot diameter S-band antenna would have a 3 db beamwidth of about 3 degrees and the half-degree moon would be entirely within the 1 db beamwidth. A 30-foot diameter K-band would have a half power beamwidth of about 0.15 degree. Figure 6.2-3 illustrates the loss in gain as a target moves off axis for a standard parabola, which approximates the performance of other high gain antennas. Without considering pointing errors, it can be seen that the antenna could not communicate with both a surface element and an orbiting spacecraft, a desirable feature for LSB systems. Further, at K-band, the earth links require a rain margin. Essentially, alternate stations must be available, or link outages must be accepted with sites subject to rainfall.

Lasers have been operated in a number of communications links. However, overall power and weight advantages do not seem to be gained for the space element unless extremely high bit rates are considered. Continuous tracking is required, and weather dependence exists. No advantage appears to exist for the LSB. It is considered unlikely that the MSFN will incorporate laser ground stations.

S-band is recommended as the earth link. The lunar orbit elements are expected to also be on S-band. A potential shift to K-band by the MSFN would be primarily to obtain additional spectrum allocations, and the problems

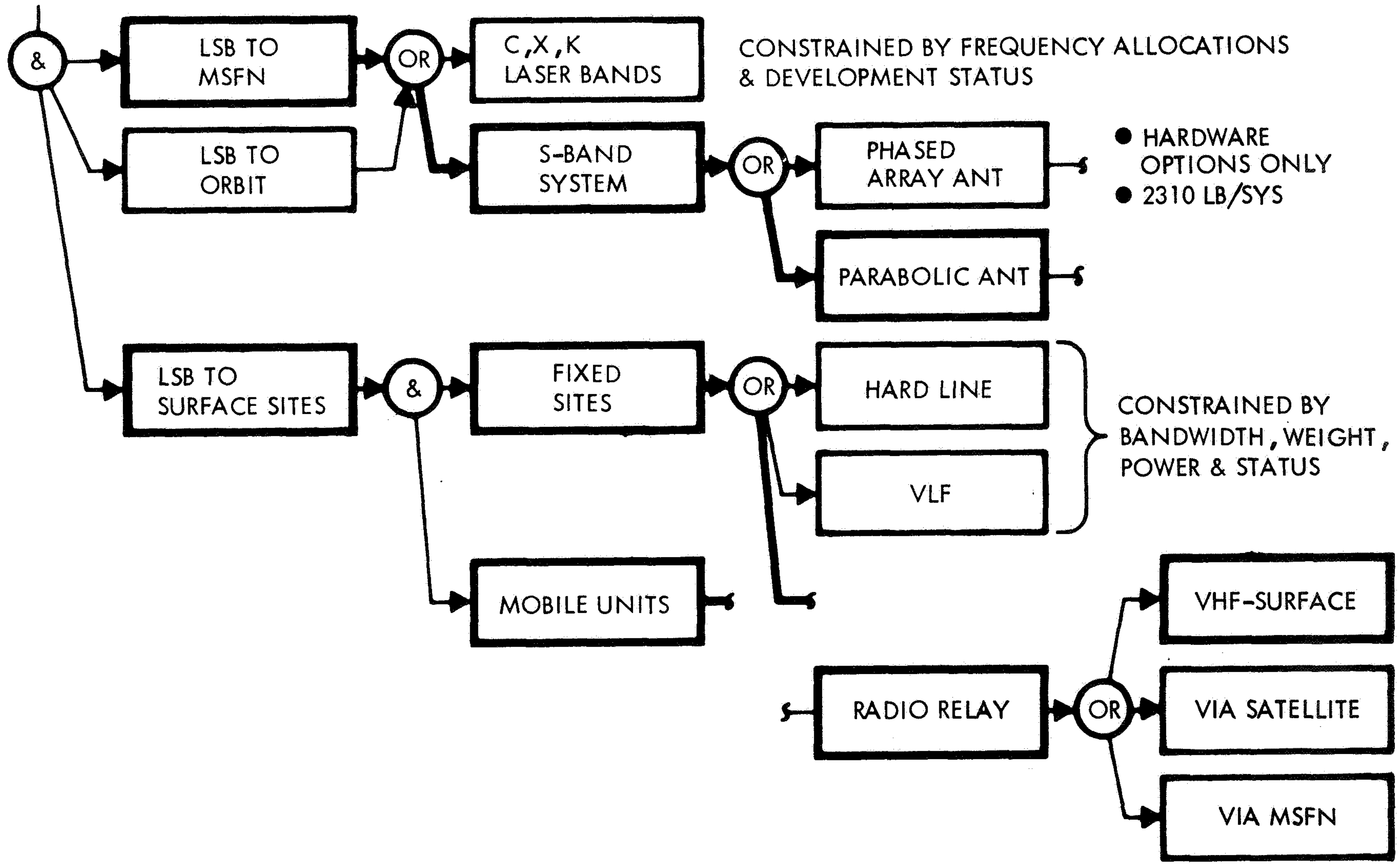


Figure 6.2-1. Communications System Options and Trades

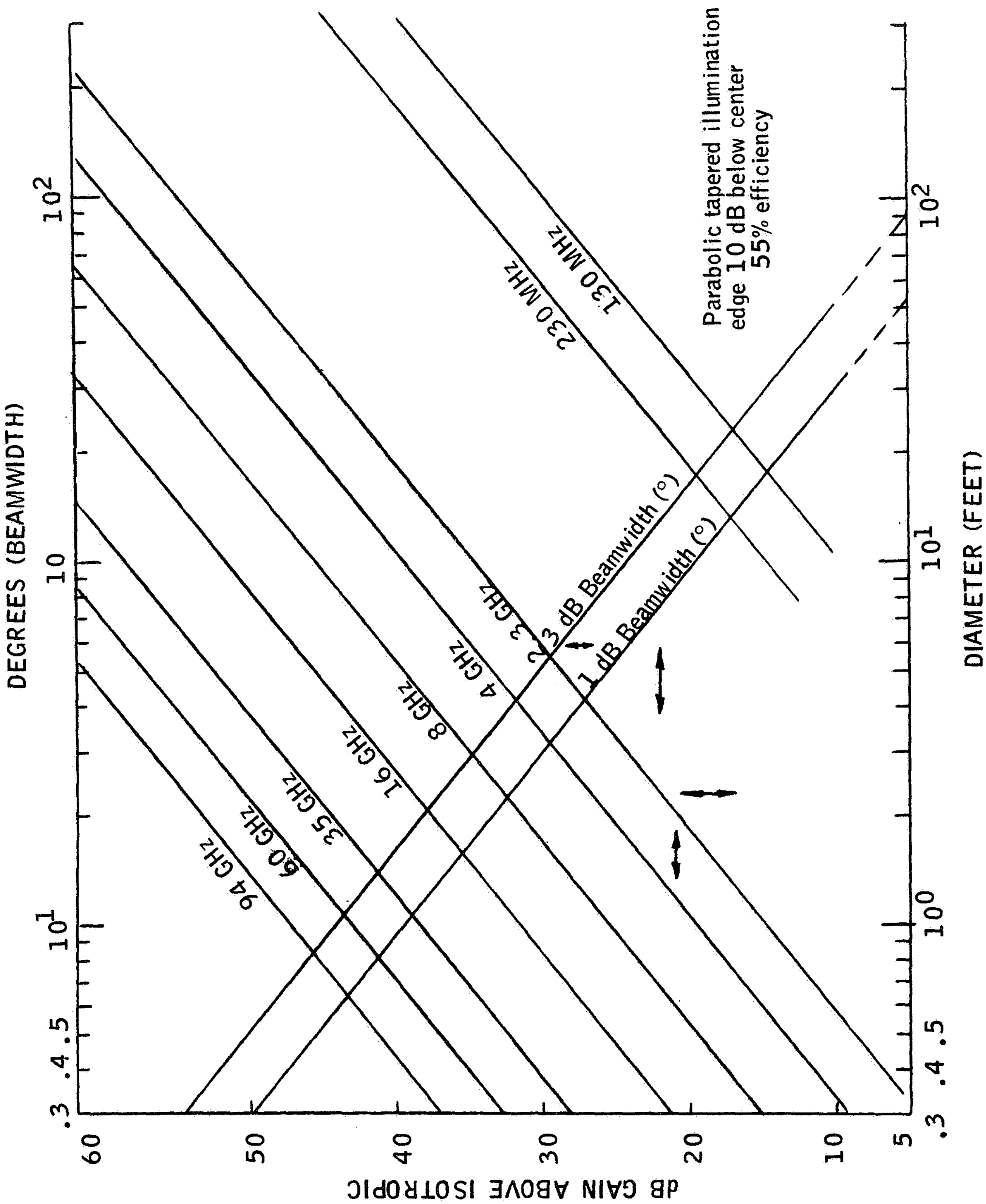


Figure 6.2-2. Parabolic Antenna Characteristics

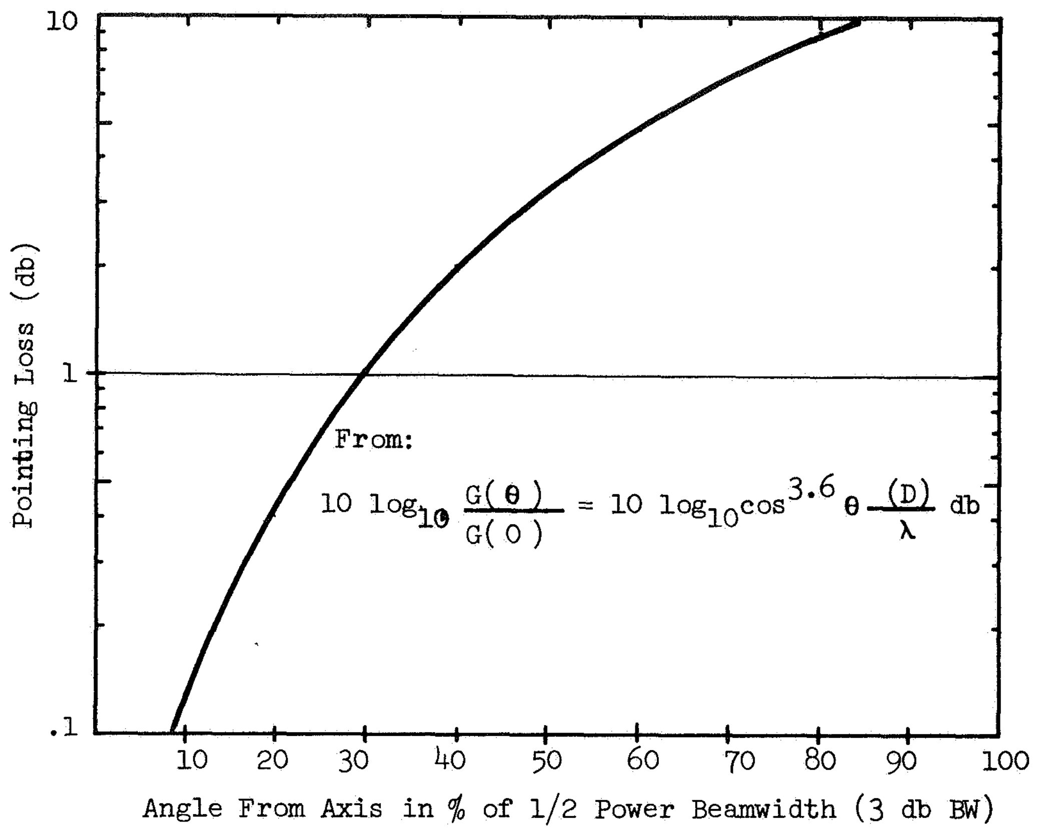


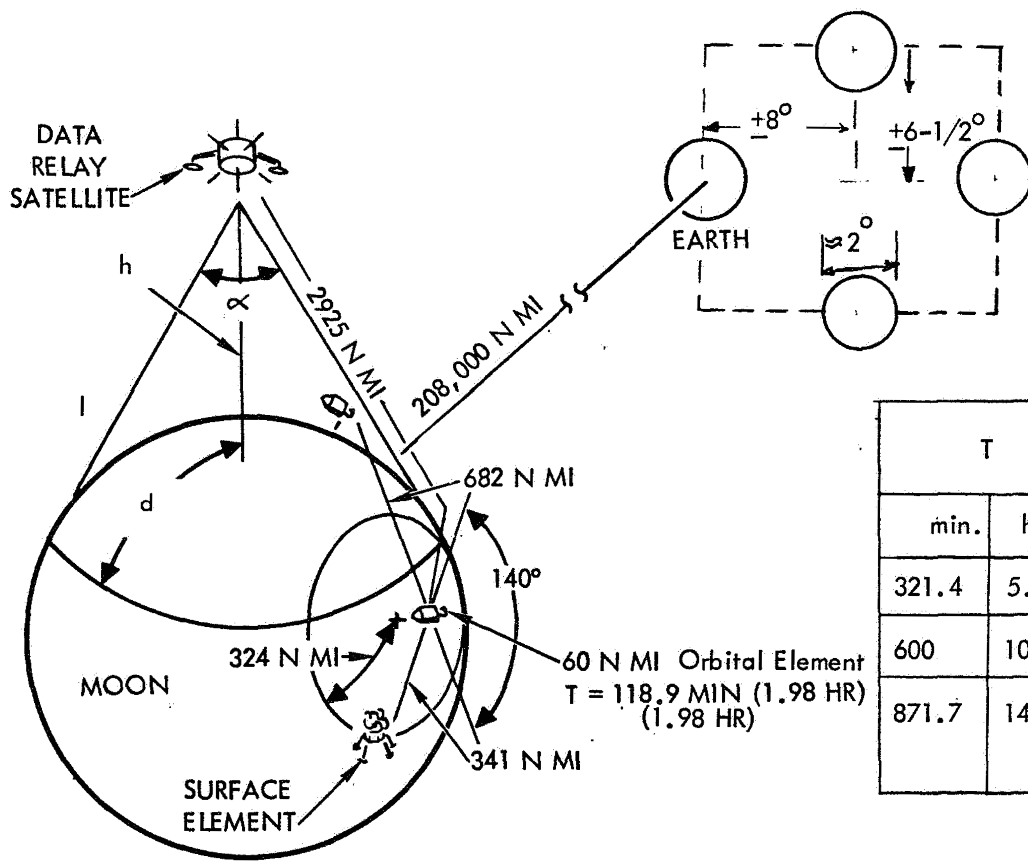
Figure 6.2-3. Parabolic Antenna Pointing Loss

outlined above would tend to negate the gain and show little effect on the LSB. The weight, volume, and power parameters are competitive for most options.

The earth link will require a high-gain antenna. Both phased array designs and conventional parabolas can be considered. Essentially, arrays pay a high penalty in complexity of feeds and radiating elements for its unique features. The array beam may be steered electronically, with no mechanical motion involved and is very useful where high slew rates are needed, or mechanical movement requires compensation, such as in a spacecraft. Arrays may be designed to allow multiple beams from the same antenna, and to some extent more efficiency is realized from a given area of antenna. The only feature which might apply to the LSB operation would be the lack of mechanical motion, and the LSB motion requirements are simple. The added complexity of the array does not appear warranted and conventional parabolic designs are recommended.

6.2.2 Earth Link - Performance

The link performance required is a function of the range and line of sight, or the geometry between the link terminals. The geometry for lunar elements as it affects the LSB space links are illustrated in Figure 6.2-4.



Range of Apparent Motions of Earth during One Month -- From Lunar Surface (Due to Motions of the Moon)

T		h	∝	l	d	Maximum Surface Track Rate (deg/min)
min.	hr	n mi	deg	n mi	n mi	
321.4	5.36	1000	57.9	1696	1000	2.17
600	10	2000	37.2	2784	1000	0.88
871.7	14.53	2800	30	3870	1000	0.55

Figure 6.2-4. Link Geometry - Lunar Elements

Link Geometry

The variation in the speed of the moon around the earth, due to ellipticity of the orbit, produces an apparent east-west motion (libration) of the moon about its axis. This motion causes an apparent movement of ±8 degrees in longitude in the position of the earth as viewed from a point on the lunar surface.

Also, the moon's axis is tilted 6-1/2 degrees from the plane of its orbit around the earth. As it makes one revolution each 28 days, the tilt causes an apparent motion of the earth of ±6-1/2 degrees in latitude to a lunar surface observer.

RF Path Loss

The RF path loss is the inverse square loss over a given distance in terms of wavelength, and is therefore a function of frequency. Path losses for a number of frequencies as a function of range is shown for reference in Figure 6.2-5. Earth-moon, lunar surface to orbit, and libration point (L_2) satellite ranges are indicated.

Link Gain

The base can exchange data directly with the earth when the location is in sight of earth. Figure 6.2-6 indicates power required at the shelter antenna as a function of information rate for antennas ranging from omni-directional to a 10-foot diameter parabolic. The receiving capability is indicated by a line across from the +30.4 dbw level. This assumes a 10-kilowatt earth transmitter, and a 930 K shelter receiving noise temperature. Values are given for MSFN 30-foot and 85-foot antennas. Use of a 210-foot earth antenna would improve performance by almost 7.8 db. The power is that required at the antenna, with no allowance for polarization, pointing or system loss. As an example of the calculations in Figure 6.2-6:

Path loss	211.2 db		(2.3 GHz)
Receiving noise	25.0 db		(315 K)
S/N	10.0 db		($\approx 10^{-5} P_E$, coherent PSK)
Modulation loss	1.0 db		(for coherent PSK ref.)
Baseline bits/sec	30.0 db		(1k b/s base)
0 dbw reference		228.6 db-Hz/ K	
	277.2 db	228.6 db	

So +48.6 dbw required if both antennas are isotropic. For a 30-foot MSFN antenna with 44 db gain, +4.6 dbw would be required from a shelter omni antenna for a 1k b/s rate, or for an 85-foot MSFN antenna with 53 db gain, -4.4 dbw would be required from a shelter omni antenna for the same 1k b/s rate.

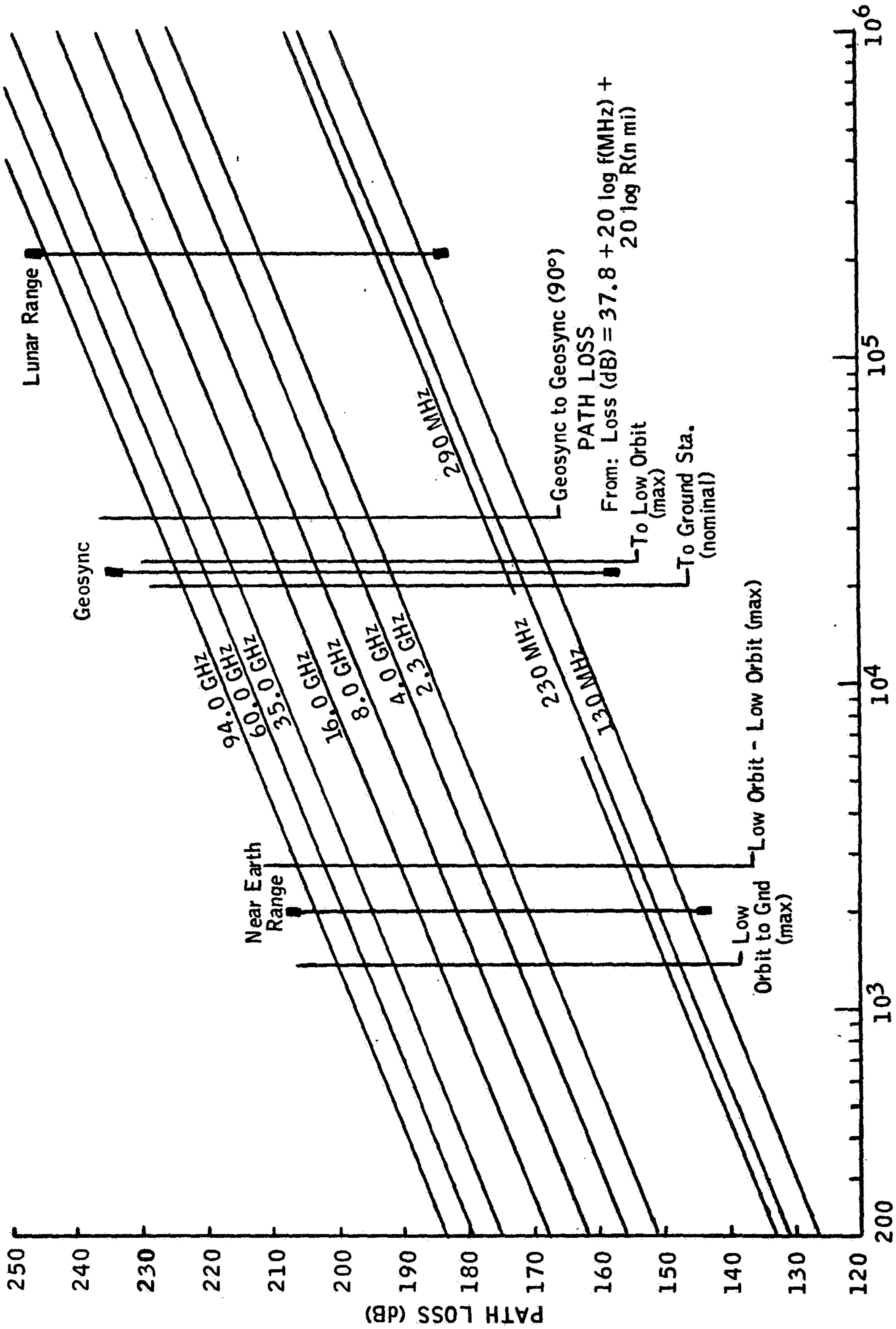


Figure 6.2-5. Path Loss

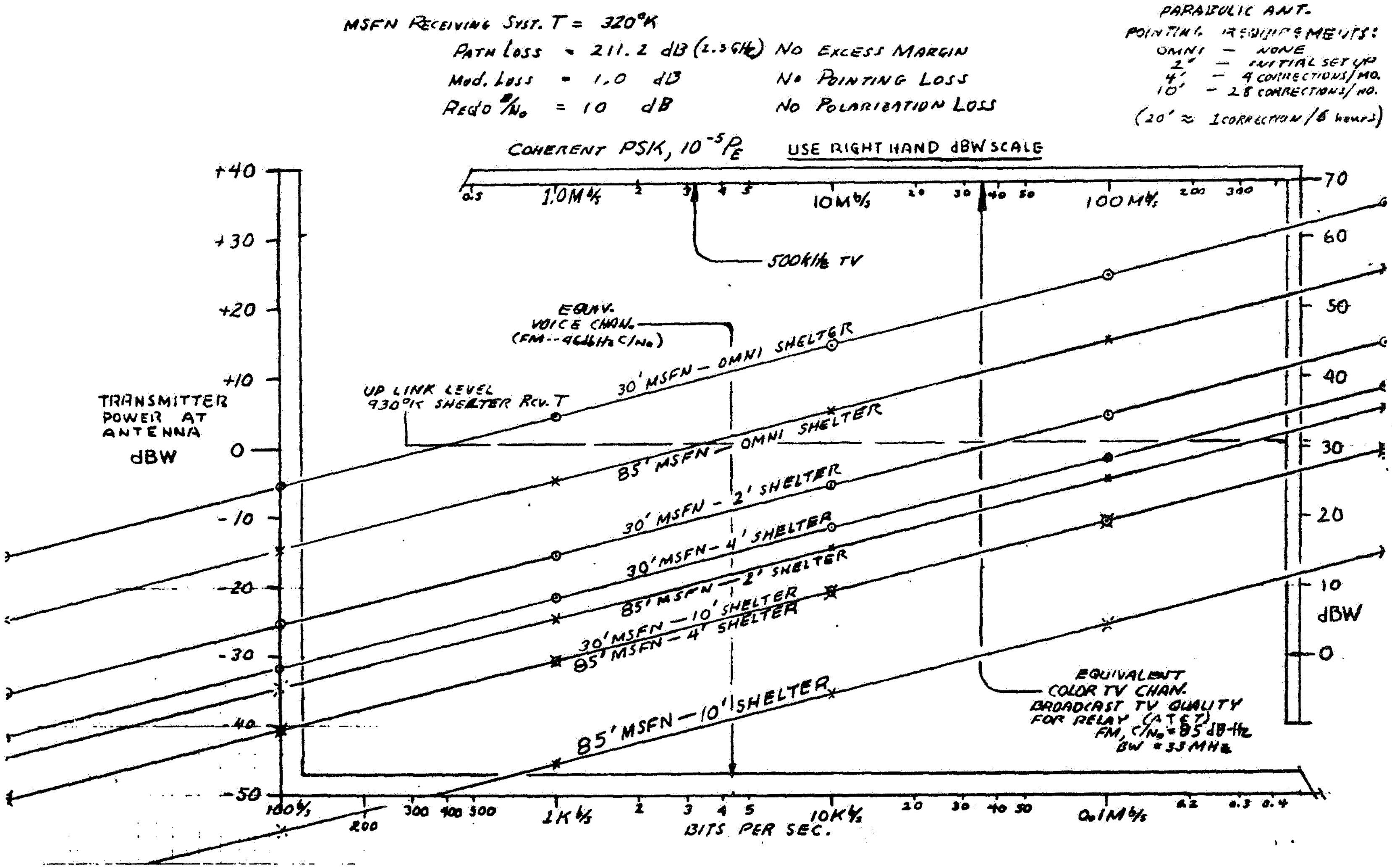


Figure 6.2-6. S-Band Power Required At Antenna for Transmission Data Rates to MSFN

The requirement increases with the data rate by $10 \log \frac{(\text{data rate})}{(1 \text{ k b/s})}$ Shelter antennas, in addition to the omni, are shown with the following performance gains:

2-foot	+20 db gain
4-foot	+26 db gain
10-foot	+35 db gain

Figure 6.2-7 illustrates the power required for the color TV link for specific antenna diameters. As an estimate of bus power required, a system efficiency of 25 percent is assumed for S-band transmission for the LSB time period. It should be noted that power greater than 75 watts of RF may not be available in space designs without a major jump in transmitter and feed system weight.

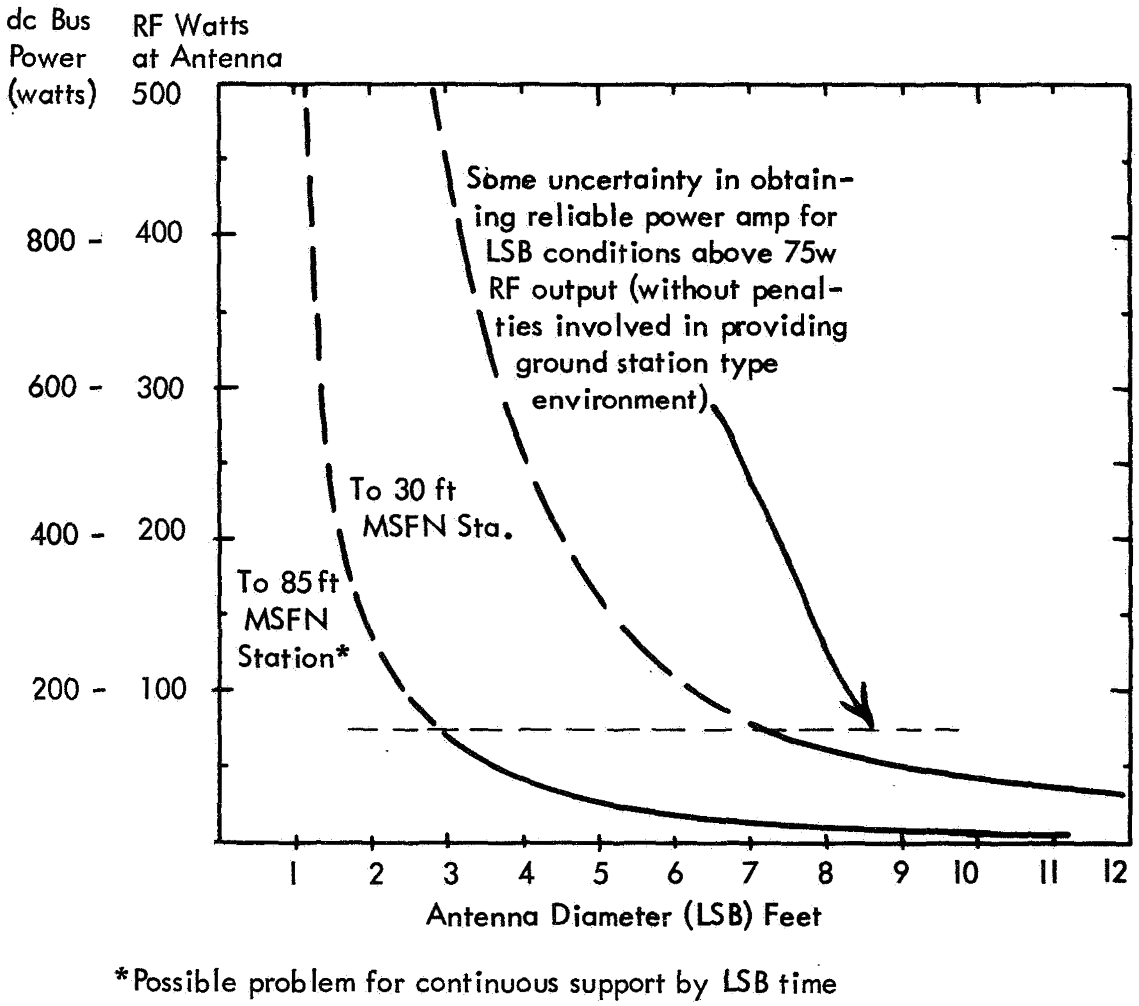


Figure 6.2-7. LSB Power for Commercial Grade Color TV to MSFN (Critical Link)

Figure 6.2-8 indicates weight as a function of diameter for space-qualified parabolic antennas and tracking systems. The earth link would not be an autotrack since even a 10-foot antenna requires only one correction each 24 hours. Links to lunar orbit will require tracking, and in both cases supporting structure must be considered unless the antennas are mounted on base structure.

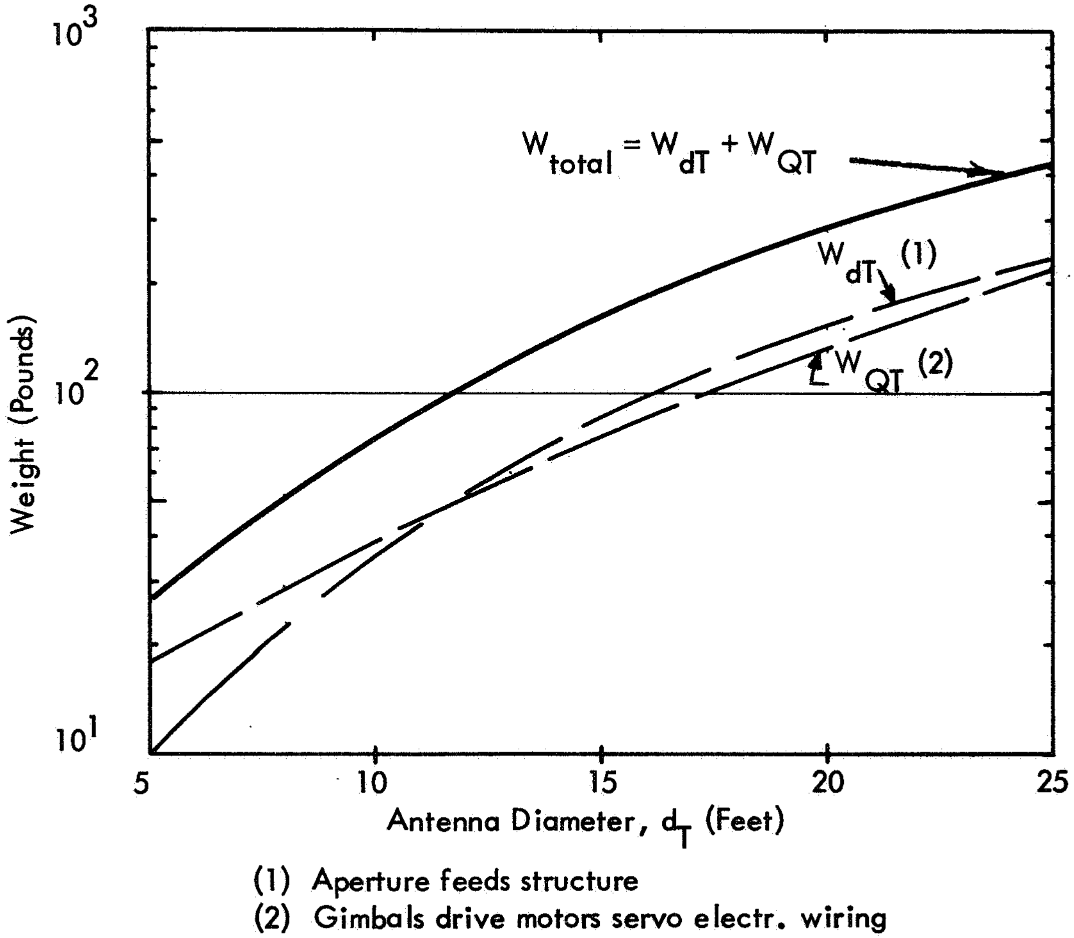


Figure 6.2-8. Antenna Subsystem Weight Versus Antenna Diameter

Comparative system weights are shown in Figure 6.2-9 for the MSFN link, and electrical power requirements in Figure 6.2-10. Eight-five-foot MSFN antennas will probably be available for initial LSB operations; however, long-term communications with MSFN and potential Principal Investigator (PI) stations will probably be supported with 30-foot antennas. An initial recommendation is therefore a 10-foot parabola for the earth link. Omni antennas will support voice communication as a backup and, with an 85-foot earth antenna, will allow 50,000 bps data during the initial buildup.

6.2.3 Space Links - Options

Space links potentially share the same options as the earth links (Figure 6.2-1). The selection criteria are essentially the same as the trades. The major problem shows up in the effects of the link geometry on the antenna selection. These geometric situations are illustrated by Figure 6.2-4 where view angles to the horizon from 60 nautical miles orbiting elements are shown along with the range to the horizon and the radius of the circle of vision. Two orbiting elements are shown to illustrate the maximum sight range between two such elements at 60 nautical miles. Lunar satellites are also shown at three other altitudes above the surface. One-thousand nautical miles is a nominal value used in prior studies. Two-thousand nautical miles is the altitude from which is is possible to see a 60-nautical mile orbit vehicle displaced 90 degrees from the radius to the satellite. Twenty-eight thousand nautical miles is the altitude for the same conditions allowing a 5-degree horizon clearance margin. Periods (T) are indicated, and maximum angular rates from the surface for tracking. The maximum rates occur directly overhead.

A satellite at the L_2 libration point would be nearly stationary and at a range of 35,000 nautical miles the path loss is less than the link to earth. At maximum slant range, the gain is 55.7 db (from Figure 6.2-5). Since the gain of the 85-foot antenna above an omni is 53 db, the orbit link is 2.7 db better than the 85-foot MSFN link assuming an omni on the orbital vehicle. These parabolic antennas do require auto tracking, which is not required for the earth link.

The comparison of weights in Figure 6.2-11 and electrical power in Figure 6.2-12 shows that the omni will be adequate for data somewhat in excess of 50,000 bps. The color TV link appears to require a two-foot antenna from a weight standpoint, but comparisons of the required power indicate that power demand is high and would drive system design. The use of a four-foot antenna would also provide backup to the 10-foot antenna for color TV to an 85-foot MSFN station. Since it is unlikely that circuit quality equivalent to that required for color TV (4.5 MHz) is required, the S-band system designed for the earth link but working through an omni antenna will probably satisfy the requirements and provide a much less complex system for both operations and maintenance. See Reference 3.

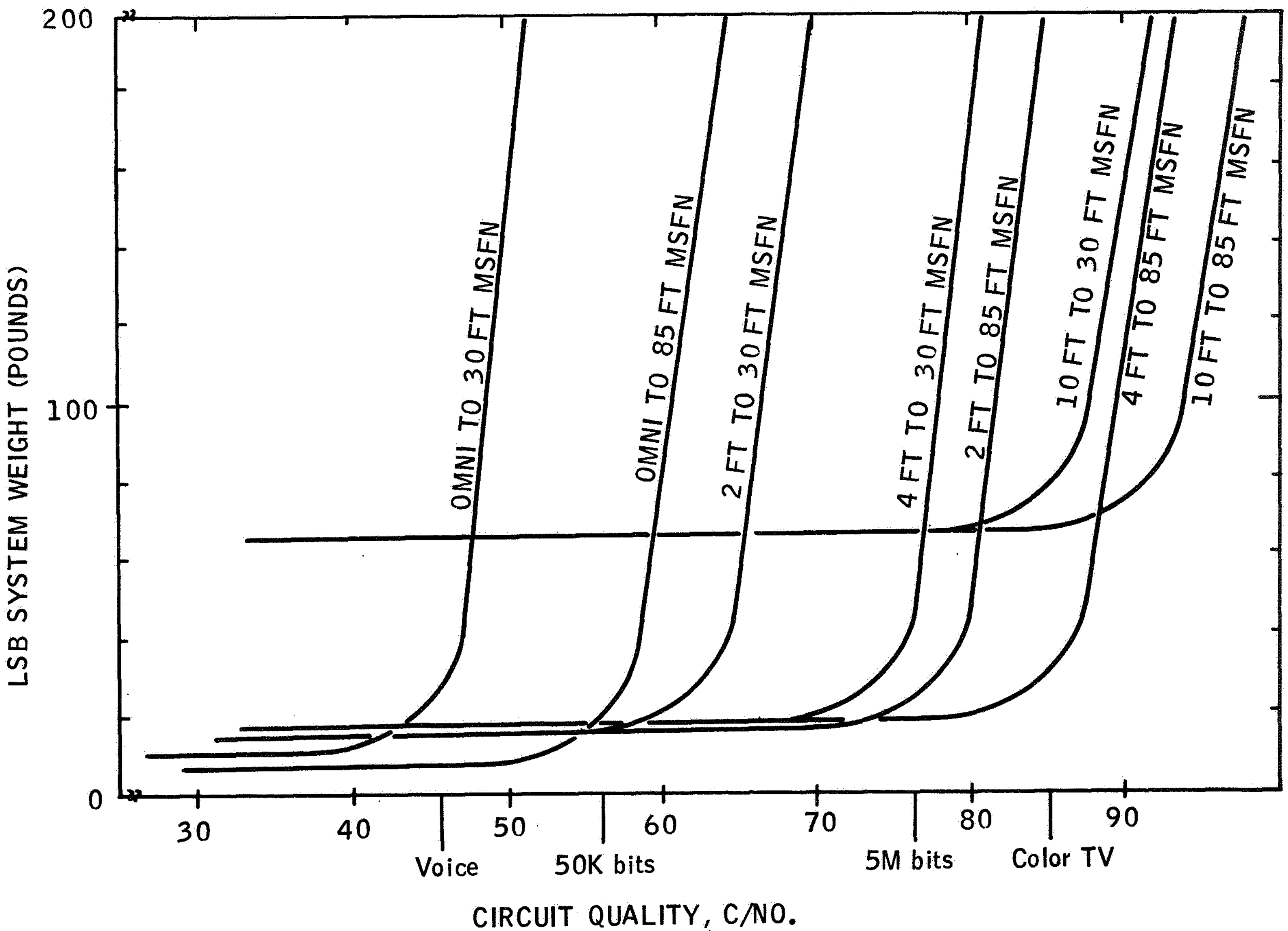


Figure 6.2-9. LSB to MSFN Link - System Trades, Weight

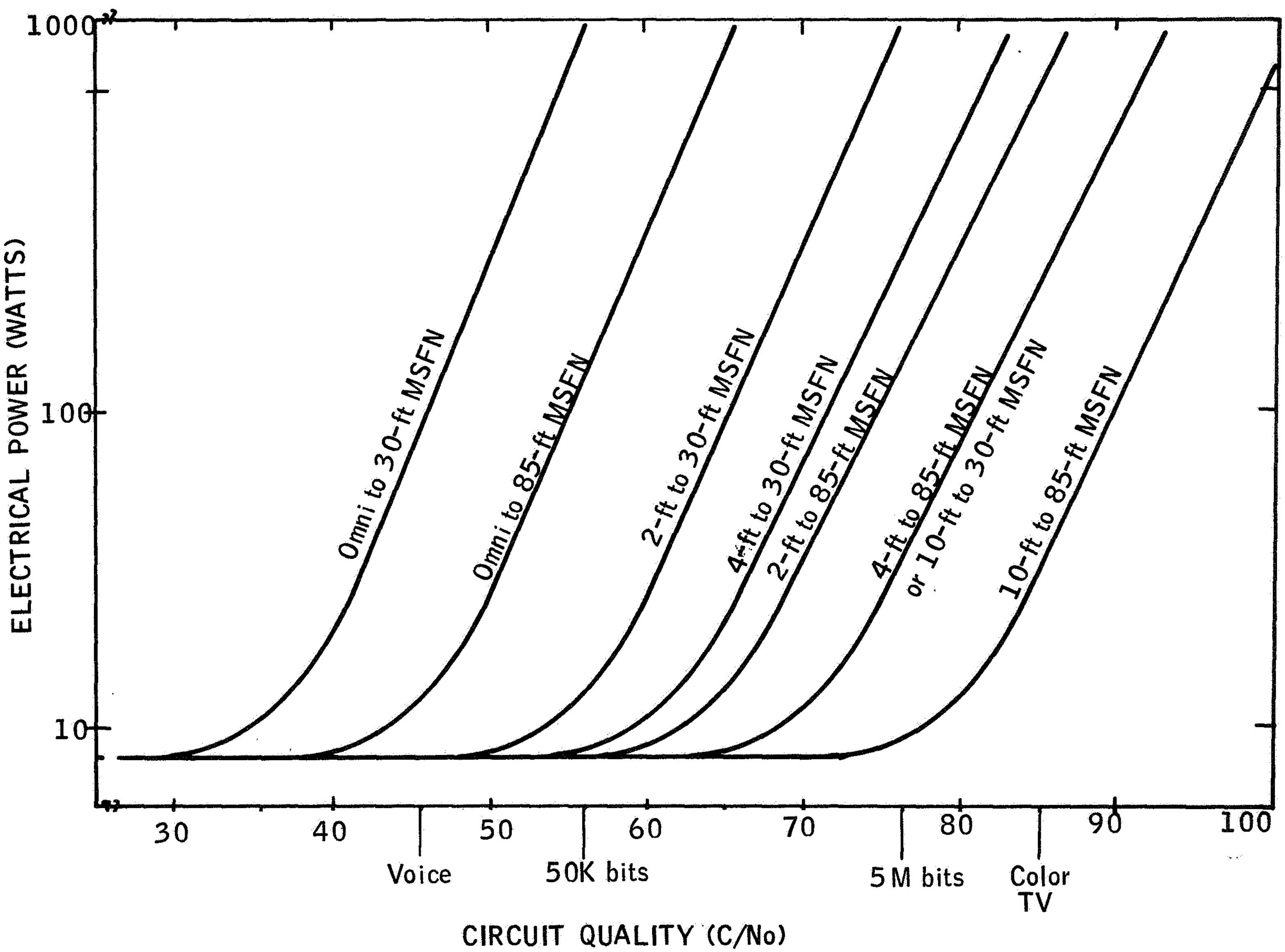


Figure 6.2-10. LSB to MSFN Link - System Trades, Power

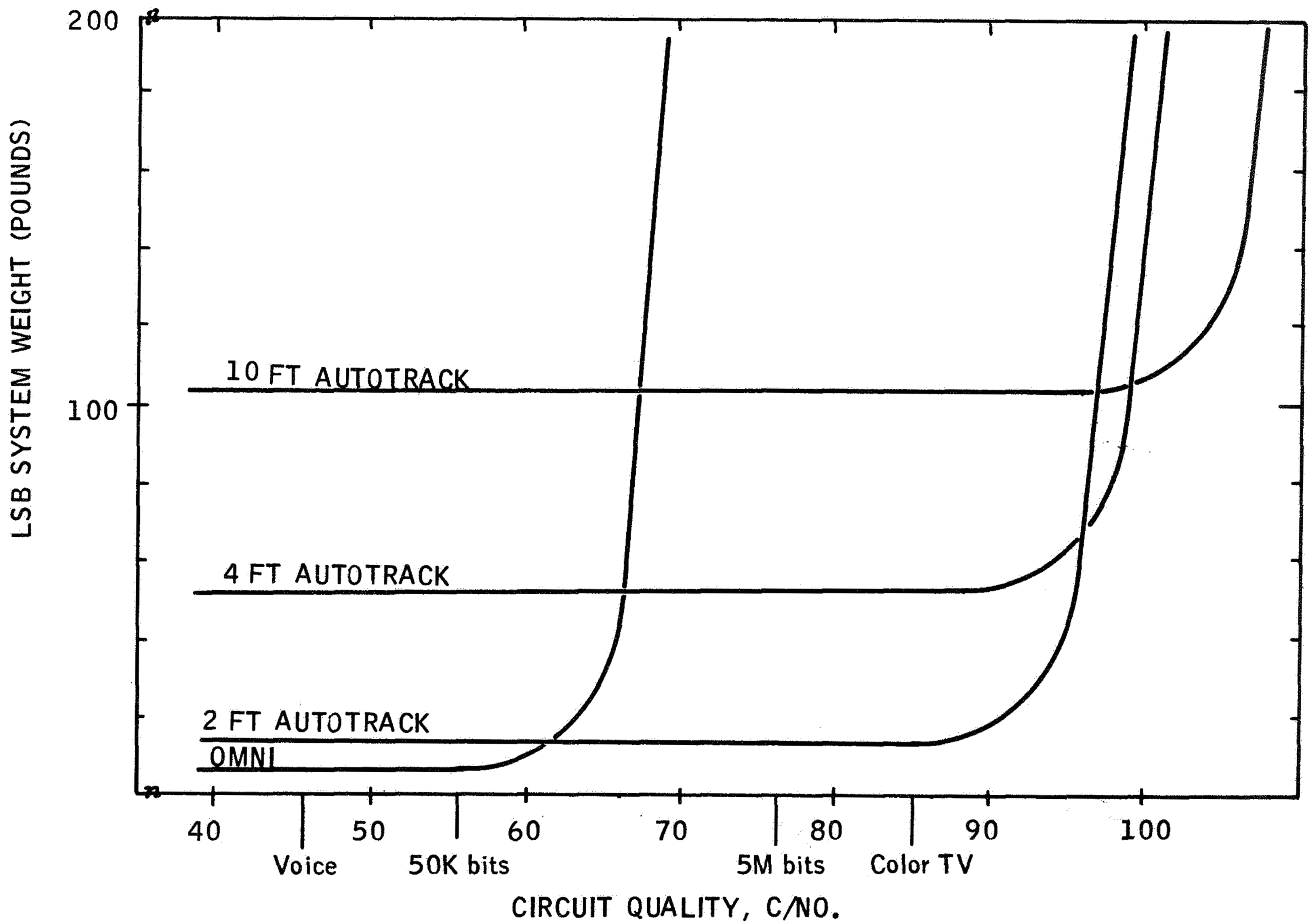


Figure 6.2-11. LSB to Orbit Link - System Trades, Weight

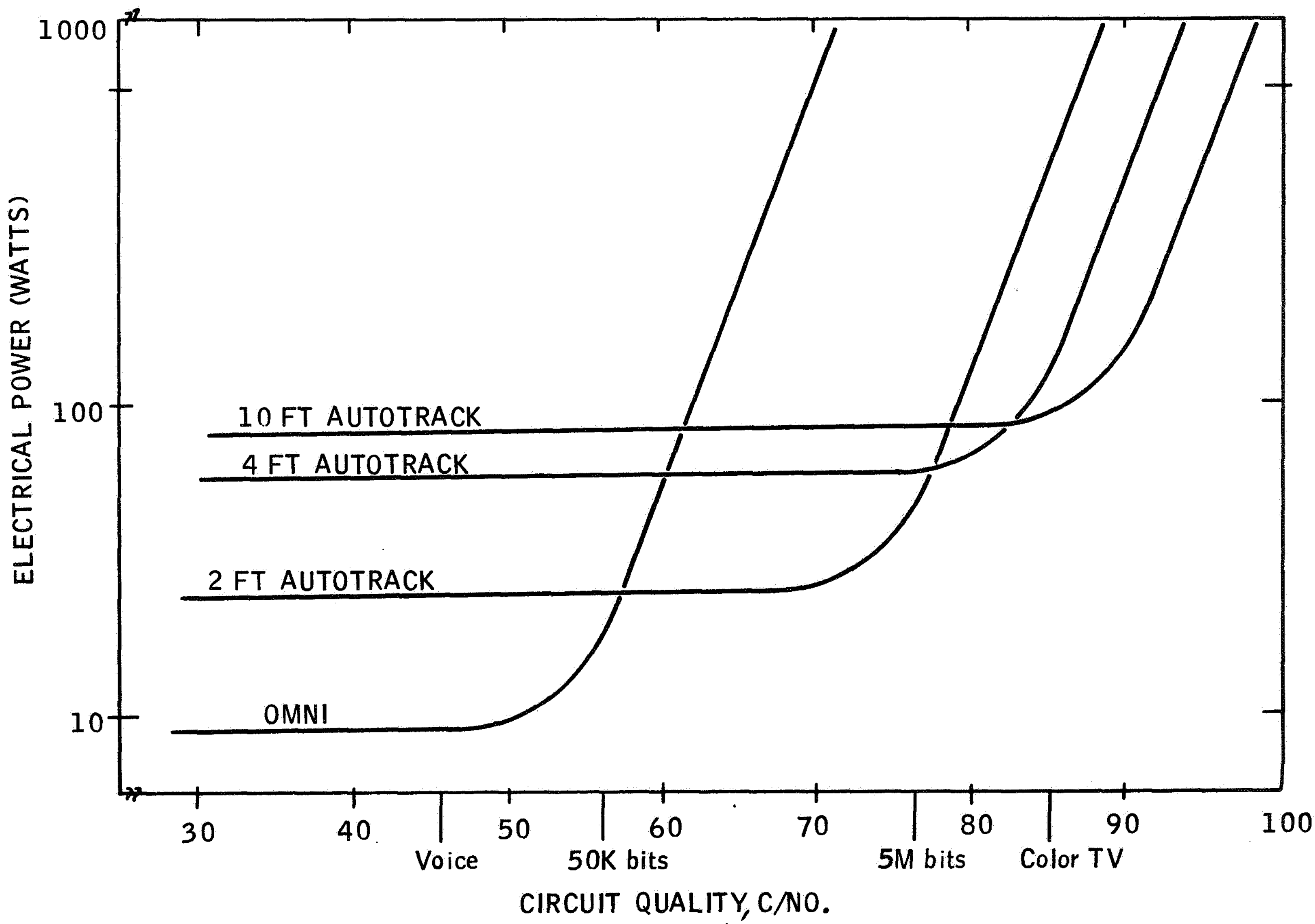


Figure 6.2-12. LSB to Orbit Link - System Trades, Power

6.2.4 Surface Links - Options

The surface links present a major communication problem due to the short line of sight to the lunar horizon. As indicated in Figure 6.2-1, the options considered were hardline, LF, and radio relays via earth, lunar satellite, and via deployed surface radio relays. All options are valid for specific applications.

LF links offer a means of over-the-horizon communications by ground wave propragation. Inherent limitations are information bandwidths on the order of 3 kHz, large power requirements, and some uncertainty in link performance due to possible variations in the lunar surface conductivity. Primary use for an LF link would be for the base to broadcast a signal to small receivers in surface elements with antennas for beaming on the base and for voice and/or code broadcasts of general interest, recalls, and general alarms.

Earth relays are advantageous for frontside operations. Disadvantages are the continuous support required from earth stations, the inherent delay of over five seconds to earth and back, and the loss of capability if the earth is out of sight due to libration motions.

Satellite relays offer some advantages in support of surface operations. A significant effort in an independent study would be required to define the satellite systems requirements and impact. The total lunar program operations, orbital and surface, would have to be evaluated to establish the cost effectiveness of the satellite program.

Hardlines are useful for short range but as the range is extended it becomes difficult to maintain wide bandwidths through the line amplifiers required. Further, the associated weight, power and operations implications associated with the deployment make them unattractive as a communications medium beyond a few hundred yards. The following characteristics were identified as characteristics of the hardline options:

Audio - to 3 kHz
- Assumptions:
  - 600 ohm pair of 24-gauge copper wire
  - Insulation weight negligible
  - 1.5-pound amplifier each 20 miles + 10 pounds for RTG power
- Total weight 13.8 pounds per mile

Video Cable - to 6 MHz Bandwidth
- Assumptions:
  - Improved coax similar to RG-62B/U
  - 1.5-pound amplifier at 2-mile intervals + 10 pounds for RTG power
- Total weight 138 pounds per mile

Surface relays deployment and operation would be a direct part of the surface operations and provide independence of both earth as well as other program implications. The relays would be deployed as a work or exploration crew moves out from the base, at points required to maintain the line-of-sight communications. Relays in the operating range of 150 to 300 MHz were selected since the bandwidths requirement could be easily achieved and the equipment would be simpler in comparison to microwave relays. Microwave is a possible alternate, but would require directional antennas, and would not cover the immediate area round the relays. The gross weight parameters would be similar. Surface relays are a viable concept and are perhaps the most practical option for limb locations. Channelization is required to avoid ringaround, with terminals alternating in receive and transmit frequencies. Table 6.2-1 presents some preliminary characteristics of a VHF surface relay concept.

Table 6.2-1. VHF Surface Relays

Voice through 5 M bps Data		
Transmitter/Receiver	4 lb	7 watts
100-ft mast and antennas	20 lb	
Mast supports	3 lb	
RTG for self-contained power	10 lb	
Total terminal weight	37 lb	
Relay Spacing ~ 20 miles		
Color TV		
Shorten spacing to 15 miles		
For 10 to 20 relays, add 3 pounds per relay to overcome relay noise		
For 20 to 40 relays, add 10 pounds per relay		

These surface radio links are severely constrained by the ability to radiate energy over the horizon as indicated by Figure 6.2-13. If a spherical moon is assumed and an antenna is elevated 10 feet above the surface, a radius of 10 miles is covered. Use of these data to determine total communication distances by adding the horizon distances of two elevated antennas must be approached with care, since the grazing path is appreciably affected by fresnel zones at frequencies below X-band. Either large power margins must be used, or 10 to 20 percent must be subtracted from the coverage.

6.2.5 Surface Link Recommendations

Comparison of the potential surface link concepts indicates that for distances significantly greater than 200 miles, all but the earth or satellite relays become very heavy.

In the area of the base, hardlines are recommended for distances on the order of 0.5 mile and VHF for longer links. The Westinghouse LESA studies indicated that 200 to 300 MHz is an optimum frequency for local covera, with a power advantage greater than 100 over S-band.

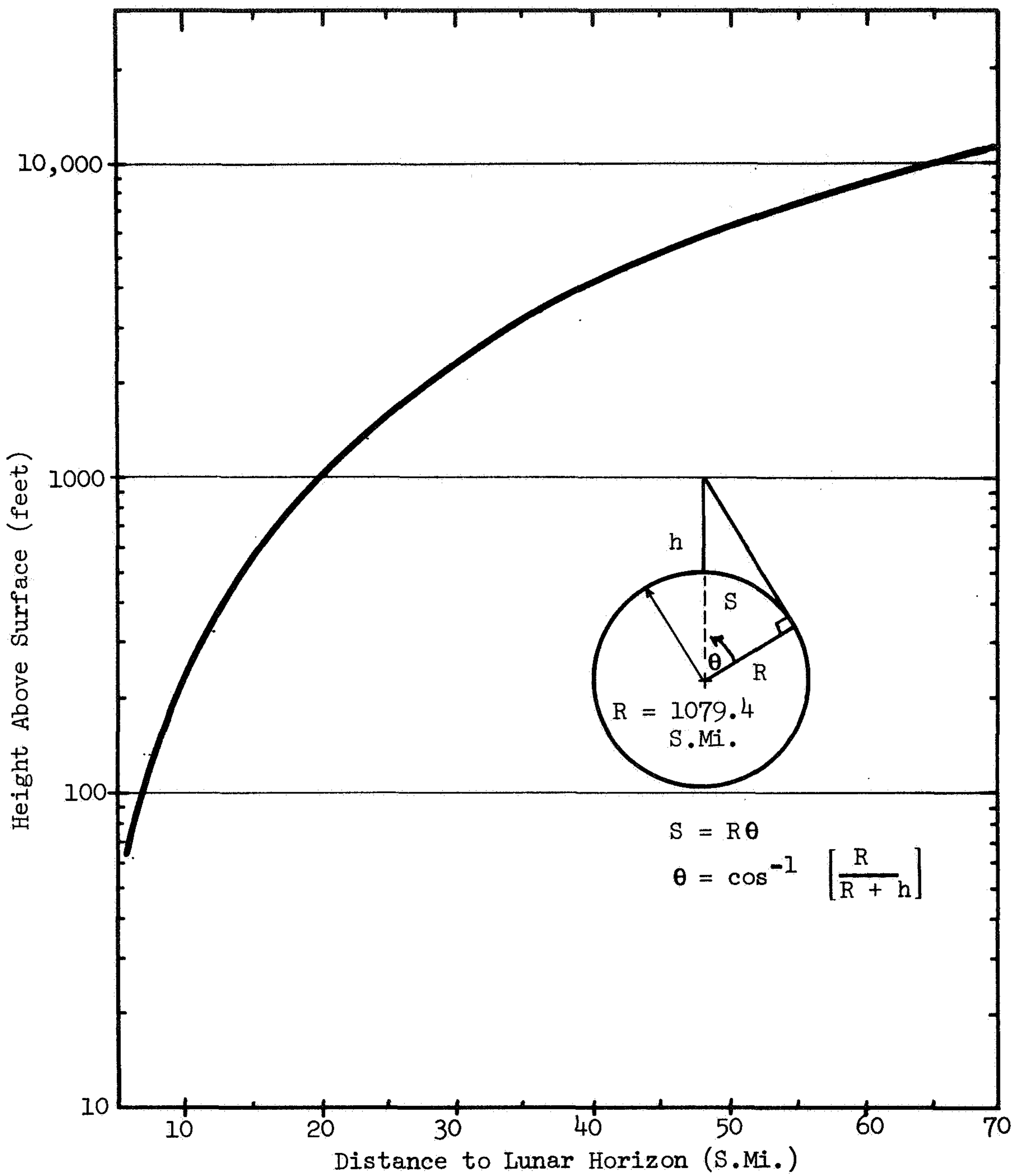


Figure 6.2-13. Distance to Lunar Horizon

Links over the horizon are somewhat more complex. LF range is a function primarily of power and is bandwidth limited. Earth relay, assuming the earth transmitter compensates for relay noise, requires essentially the same equipment as the base on both terminals for a given quality link but the earth must be in view of both terminals. In addition, a 5-second delay in transmission time must be tolerated. VHF relays require deployment and cover only the areas in view of their antennas. Satellites are a system themselves, and require the same or greater surface capability as the earth relay. Hardlines are prohibitive in power and weight, although they are independent of line of sight.

An optimum concept is not obvious and is highly dependent on base location and the scope of operations. The backside complications are discussed more fully in the following section. The LSB will require hardline for close terminals, VHF for mobile units and S-band for space links; any or all of these could also be used for surface links.

6.3 BACKSIDE LSB INFLUENCE

The LSB could be situated on the backside of the moon or on the limb and be out of sight of earth for all or part of the siderieal month. The primary effect is experienced in the communications concept. The direct line of sight S-band space link system cannot be implemented and some form of relay is required.

Use of the Orbiting Lunar Station (OLS) as a relay was considered. Figure 6.3-1 shows the times that a polar orbit OLS would be in sight of an LSB located at various latitudes. Since near equatorial sites are preferred for LSB astronomical operations, direct contacts with an OLS provide no significant benefits to LSB communications. An OLS with a complete satellite system essentially is similar to just the satellite system and is discussed below.

An LSB located on the limb could utilized VHF or S-band relays to carry all signals to a 10-foot antenna and transceiver located in view of the earth. Crossing the libration area could require a relay system over 300 miles long. It was estimated that the relay system would weigh 550 pounds and require approximately 20 days for installation. Revisits to the antenna site would be required approximately every 120 days to service the antenna and transceivers. No firm trade has been performed on the use of smaller, non-tracking antennas and multiple redundant higher power transmitters, but a large weight and power penalty could be accepted in order to eliminate the service trips.

A full backside site would require a satellite relay system. The concept of a relay satellite in HALO orbit around the L_2 libration point was recommended by R. W. Farquhar of NASA Goddard which would allow relay to earth as well as coverage of lunar elements away from the base. A system employing this concept was estimated to weigh about 2600 pounds at translunar injection.

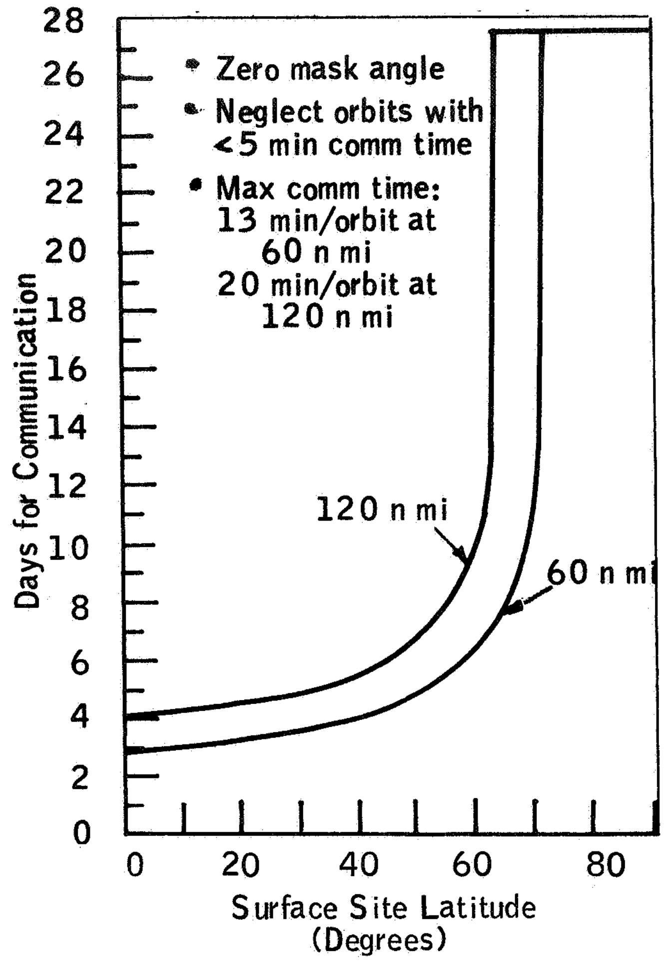


Figure 6.3-1. Polar Orbit Relay

For lunar orbiting communication satellites, Figure 6.3-2 illustrates an equatorial satellite system at a minimum altitude. All surface locations are covered with the exception of the immediate polar regions which may be covered intermittently by the OLS. Table 6.3-1 presents link calculations for S- and K-band up and downlinks. A potential satellite-to-satellite relay concept is shown in Figure 6.3-3 with S-band used for surface links and K-band for satellite-to-satellite links. Table 6.3-2 presents the link calculations. Figure 6.3-4 shows that if 40-watt power amplifiers were used at the LSB, the 10-foot antenna would be marginal, and a 12-foot antenna would be required fo for the relay of quality color TV. It should be noted that dumps up to 20 Mbps would still be satisfactory, and color TV would be only slightly degraded if the 10-foot antenna and the 40-watt power amplifiers were used.

For the low altitude satellites, an additional 30 pounds of tracking system would be required for the surface system and tracking power would be continuous, rather than the once every 24 hours, as on the frontside. Otherwise, the operation would be similar to earth contact and early relay to the surface, but without the 5-second delay.

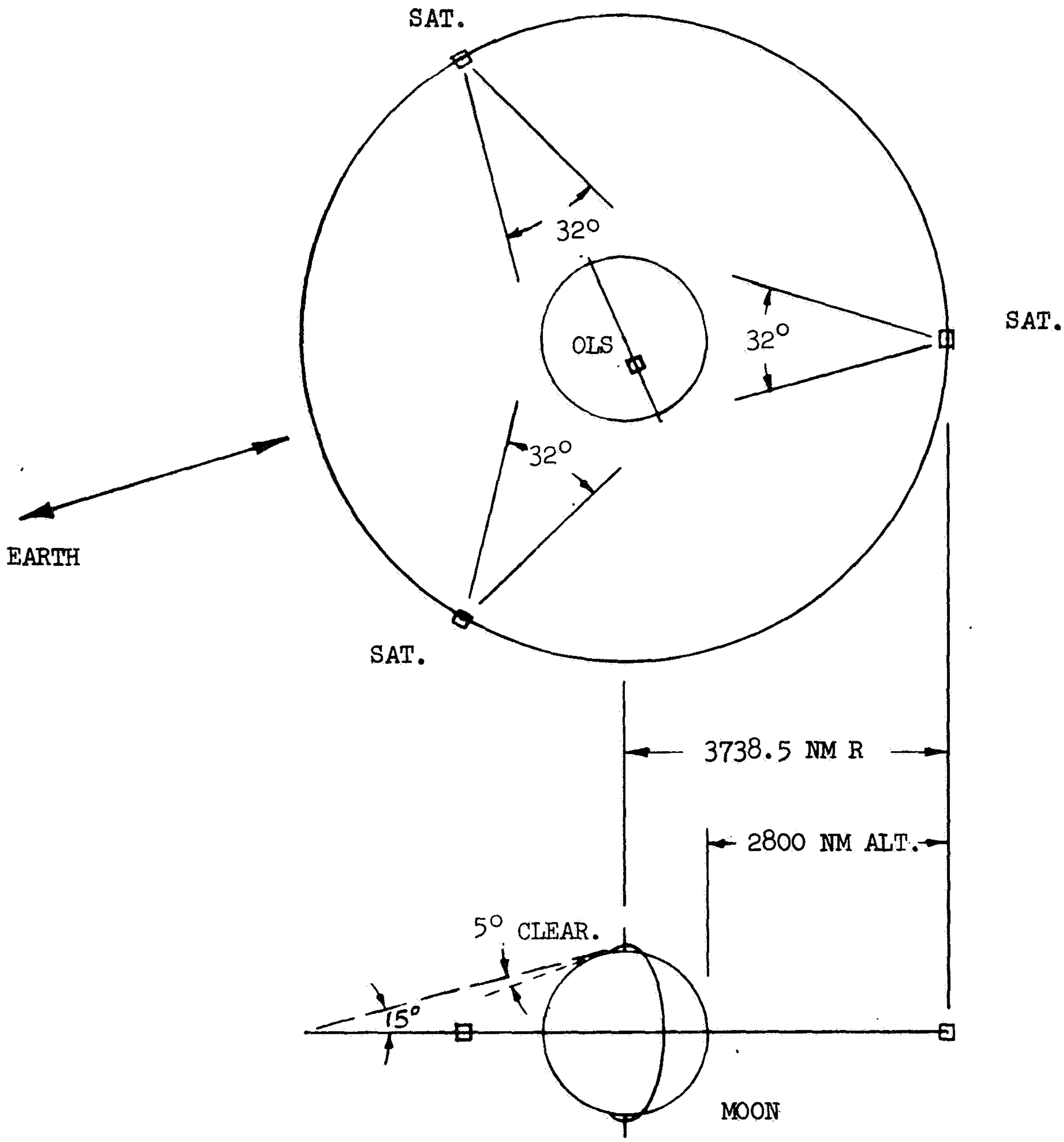


Figure 6.3-2. Lunar Orbit Satellite Relay Concept

Table 6.3-1. Lunar Orbit Satellite Relay
(see Figure 6.3-2)

Maximum satellite antenna gain for 30° coverage (no pointing loss) is 14.5 db at any frequency. Subtracting 3 db for edge loss gives:

	S-Band	K-Band
Antenna effective gain	11.5 db	11.5 db
Antenna diameter	1 foot	2 inches
Sat. RCVR Temp (200 K Moon)	500 K	800 K
Surface RCVR Temp	300 K	600 K

UP LINK	S-Band	K-Band
Path loss (3870 n mi max. range)	-176.8	-191.9
Receiver temperatures	- 27.8	- 29.0
Relay margin	- 3.0	- 3.0
0 - dbw reference	228.6	228.6
Antenna effective gain	11.5	11.5
C/No	33.3 dbw-Hz	16.2 dbw-Hz

DOWN LINK

Same as up link with:	S-Band	K-Band
Correction for antenna system temp	2.2 db	1.2 db
C/No	35.5 dbw-Hz	17.4 dbw-Hz

Required C/No (dbw-Hz)		S-Band ERP (dbw)		K-Band (dbw)	
		Up	Down	Up	Down
Voice/low data	- 46.0	12.7	10.5	29.8	28.6
50 K bits/sec	- 56.7	23.4	21.2	40.5	39.3
5 M bits/sec	- 76.7	43.4	41.2	60.5	59.3
Color TV	- 85.0	51.7	49.5	68.8	67.6

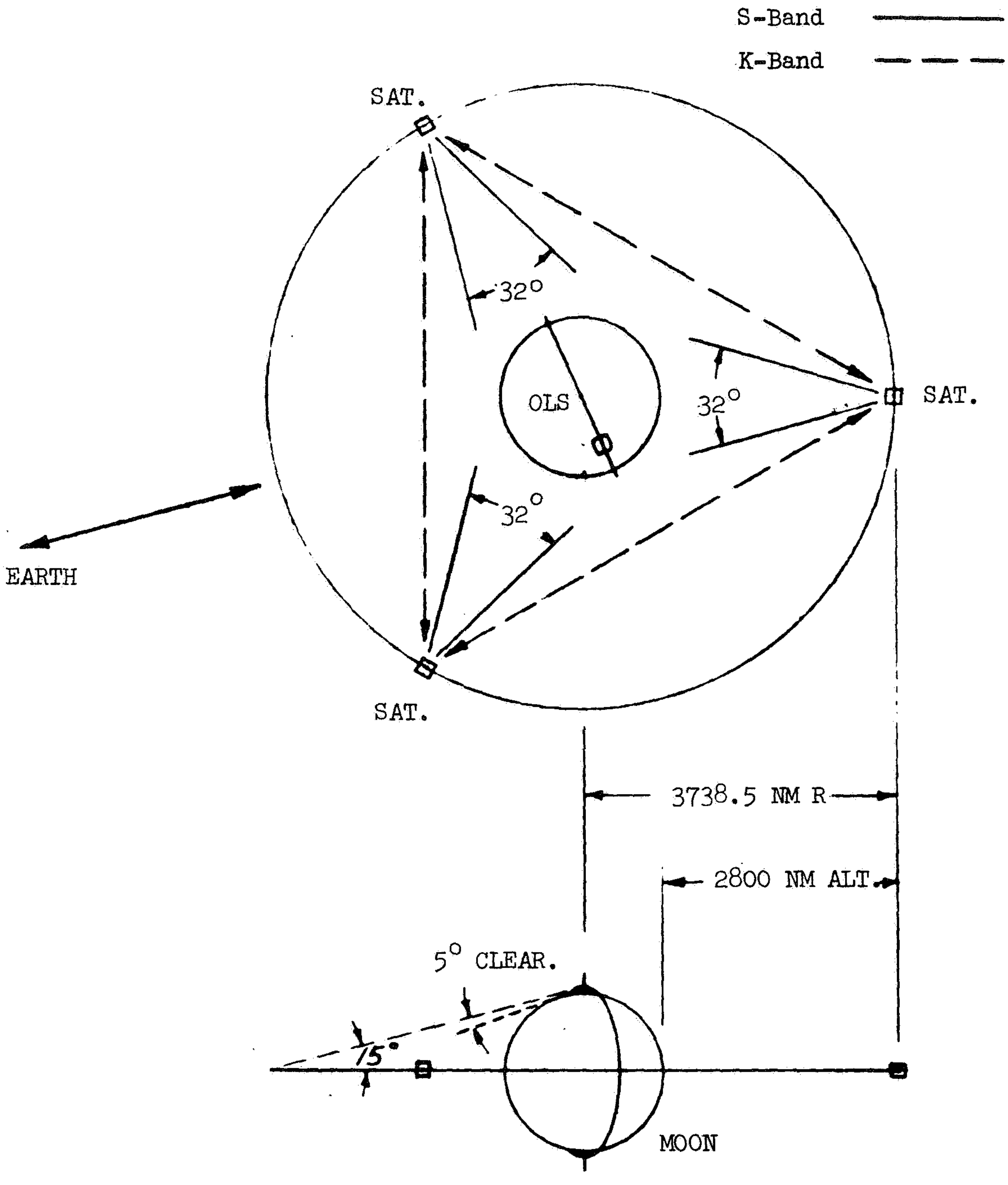


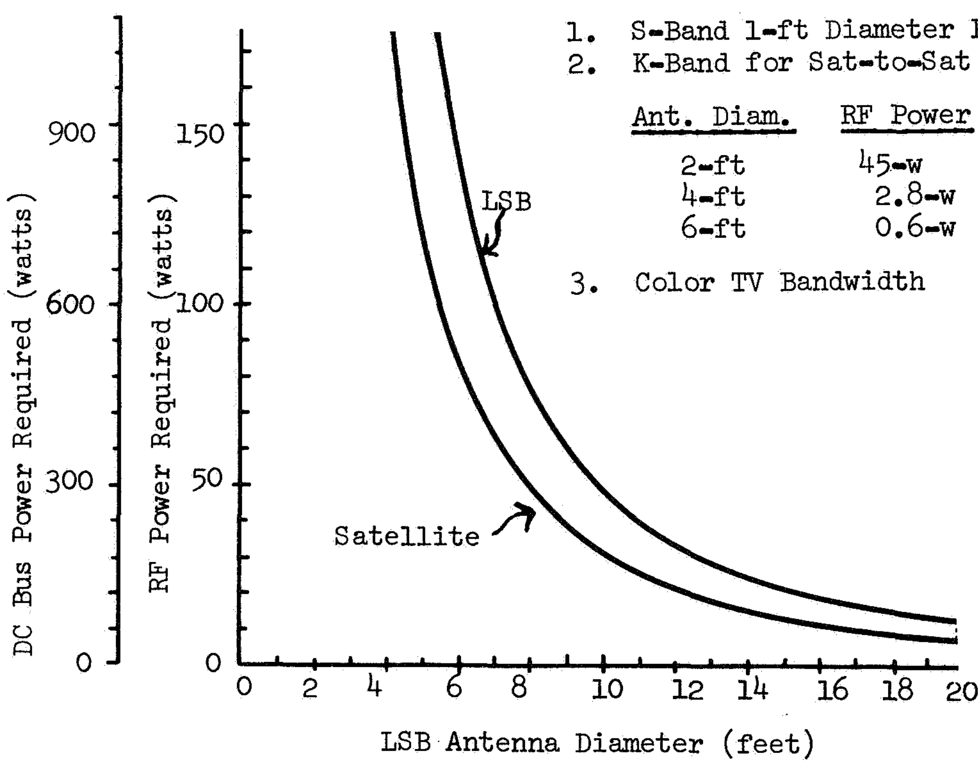
Figure 6.3-3. Lunar Orbit Satellite-to-Satellite Relay Concept

Table 6.3-2. Lunar Orbit Satellite-to-Satellite Relay
(see Figure 6.3-3)

	S-Band	K-Band
Path loss (6500 n mi)	-181.2 db	-196.3 db
Receiving system temp.	- 24.8 db (300 K)	- 27.8 db (600 K)
Relay margin	- 6.0 db	- 6.0 db
0 dbw reference	228.6	228.6
C/No (0 - dbw)	16.6 db-Hz	- 1.5 db-Hz

	C/No Req'd. (db-Hz)	S-Band Req'd. Link Gain* (dbw)	K-Band Req'd. Link Gain* (dbw)
Voice-Lo Data	46.0	29.4	47.5
50K b/s	56.7	40.1	58.2
S M b/s	76.7	60.1	78.2
Color TV	85.0	68.4	86.5

*Link Gain includes transmitting and receiving antenna gains plus transmitter power at antenna.



1. S-Band 1-ft Diameter Parabola for Lunar Link
2. K-Band for Sat-to-Sat Relay

Ant. Diam.	RF Power	Bus Power	Pointing
2-ft	45-w	315-w	± 1.5°
4-ft	2.8-w	25-w	± 0.8°
6-ft	0.6-w	12-w	± 0.5°

3. Color TV Bandwidth

Figure 6.3-4. Lunar Orbit Satellite-to-Satellite Relay

Table 6.3-3 presents link calculations for an L_2 satellite for the lunar and earth relay links assuming a HALO orbit or other displacement to place the satellite in the view of earth. The results are indicated in Figure 6.3-5. Similar performance factors hold as did for the low altitude case with the 40-watt amplifiers, the antenna size required is closer to 13 feet, but slightly degraded operation is possible with a 10-foot antenna or a higher gain power amplifier could be developed. The larger antenna is recommended because of the lower power consumption.

These concepts are general cases; large satellites with multiple tracking antennas could drastically reduce the surface requirement. However, the simpler area coverage concept seems more practical.

6.4 RECOMMENDED LSB COMMUNICATION CONCEPT

The recommended complement of communications equipment is presented in Table 6.4-1. Parabolic antennas are shown for communicating with the earth and with orbital and landing elements at S-band. Two S-band omni antennas are recommended for additional back up to the high gain antennas, for initial contacts from space elements such as a tug or cislunar shuttle, and for checkout of surface equipment external to the base. The antennas would be mounted on or as near the base structure as feasible.

VHF antennas include a turnstile with an overhead pattern for covering landing or other flying vehicles and as backup to orbital communications, and a vertical whip for area coverage of EVA and mobile vehicles in the area. The vertical also serves as the base element for VHF surface relays. The turnstile is mounted on a 20-foot mast to clear the immediate area. The whip is mounted on a 100-foot mast for maximum surface range.

The LF antenna consists of a 100-foot mast and a 100-foot ballast (ground) wire. The mast should be reasonably near the base shelter, with the ballast attached to the shelter, and extending away from the antenna on or under the surface. This provides an emergency bleeper and direction finder service for any unit within a 300-mile radius of the LSB proper.

The X-band antennas are part of the transponder located at the landing sites and are used for logistics mission support.

S-band transceivers (transmitter-receivers) are similar to the Earth Orbit Space Station designs, and provide transmitter, power amplifier, receiver and diplexer elements for 1, 5 or 30 watts of RF output. One unit is colocated with each of the parabolic antennas and each omni antenna. Some problems are anticipated with thermal control during the lunar day, but lightweight shields to minimize heat input from the lunar surface reflections should eliminate any problem. The transmitters provide a maximum simultaneous capability of a color channel to earth (one way), high bit rate data, and up to four-voice channels, when operating with a 30-foot MSFN antenna.

Table 6.3-3. L_2 Satellite Relay (see Figure 6.3-4)

EARTH LINK

Path loss (242k n mi)	-212.7
30' MSFN (S-band)	24.0
Relay margin	- 3.0
0 dbw reference	228.6
C/No (0 dbw)	36.9

	C/No Req'd. (db-Hz)	S-Band ERP Req'd. (dbw)
Voice/low data	46.0	9.1
50 K bits/sec	56.7	19.8
5 M bits/sec	76.7	39.8
Color TV	85.0	48.1

LUNAR LINK

UP LINK

	S-Band	K-Band
Path loss (35k n mi)	-195.9	-211.0
Sat. G/T (3.5° beamwidth)	6.0	4.0
Pointing loss	- 3.0	- 3.0
Relay margin	- 3.0	- 3.0
0 dbw reference	228.6	228.6
C/No (0 dbw)	32.7 db-Hz	15.6 db-Hz

	C/No Req'd. (db-Hz)	S-Band Req'd. ERP (dbw)	K-Band Req'd. ERP (dbw)
Voice/low data	46.0	13.3	30.4
50 K bits/sec	56.7	24.0	41.1
5 M bits/sec	76.7	44.0	61.1
Color TV	85.0	52.3	69.4

DOWN LINK

Power required will equal Up Link minus correction for lower antenna system temperature

-2.2 db	S-Band
-1.2 db	K-Band

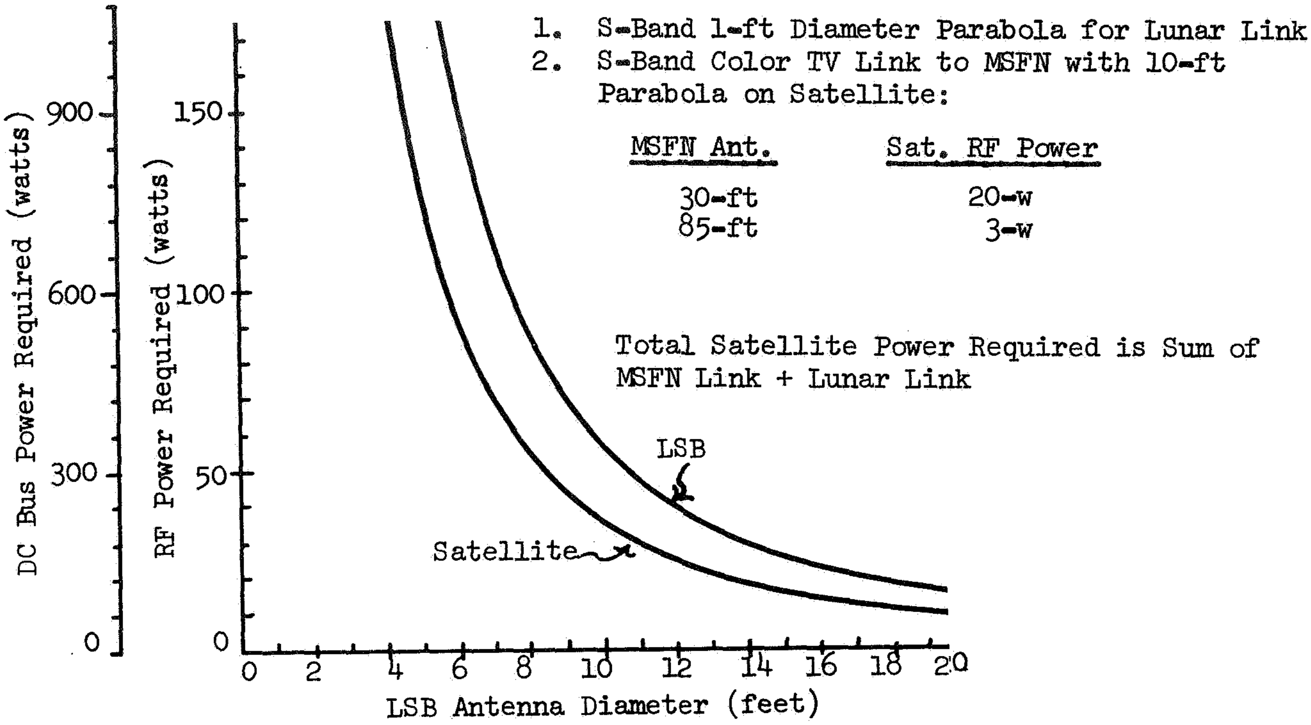


Figure 6.3-5. L_2 Satellite Lunar Relay

Three VHF sets allow communication on two VHF links plus a multiplexed link for relay operation to remote sites and/or a sortie.

The LF set provides the 100 to 200 mile voice or code broadcast capability and provides a homing carrier for external crew who may need bearings to the base. Operation would be at the power level and times appropriate to the personnel away from the base on foot or in vehicles.

Radar beacons are tentatively X-band, but would be compatible with logistics vehicle radars. Two units are assumed for alignment on one or two landing sites. Additional beacons would be required for any additional sites. Each beacon transmits only when interrogated by a radar, and is considered to be on in a 5-watt standby condition between interrogations.

The premodulation processor contains modems for conditioning the digital, audio, and video signals into formats or frequencies suitable for modulation of any of the transmitters. Signals from all receivers are separated and routed to appropriate locations for internal distribution. The selection of internal and external modes, and routing of signals is performed by the central switching unit. Internal communications test routines also originate in this unit.

Audio/video stations allow access by cameras and monitors, as well as intercom sets to the audio/visual bus. These units are located in all modules, with two exterior locations provided. A master unit is provided at the primary and backup control areas. These units are additional access points and also control the selection of camera and monitor stations.

Table 6.4-1. LSB Communications Equipment

Item	Unit Weight (lb)	Dimensions	Bus Power Peak (Avg) (watts)	Qty.	Total Weight (lb)	Total Power Peak (Avg) (watts)	Location and Note
S-band parabolic ant. (10 ft)	36	10 ft dia	-	1	36	-	On or near shelter
Limited drive	25	≈ 24 in. sq.	60 (-)	1	25	60 (-)	On 10 ft antenna; power 10 min/day annual maint.
S-band parabolic ant. (4 ft)	10	4 ft dia	-	1	10	-	On or near shelter
Tracking drive	15	20 in. sq.	30 (10)	1	15	30 (10)	On 4 ft antenna; power during veh. track , 4000 hour replacement
S-band omni antenna	1.5	6 in. spiral	-	2	3	-	Close above shelter
VHF overhead omni	2	20 in. cross	-	1	2	-	20 ft mast near shelter area
VHF surface omni	1.2	20 in. whip	-	1	1.2	-	On 100 ft mast near shelter
20-foot mast	3	20 ft mast	-	1	3	-	} masts above
100-foot mast	20	100 ft mast	-	1	20	-	
LF antenna	20	100 ft mast	-	1	20	-	Near shelter
LF ballast	10	100 ft wire	-	1	10	-	Base of LF antenna - away from antenna on surface
X-band overhead omni	1	2 in. spiral	-	2	2	-	One on each X-band beacon - each landing site
S-band transceiver	29	20 x 12 x 8	120 (36)	4	116	480 (144)	Ea. antenna, 1/5/30 w; 1 replacement per year
VHF transmitter-receiver	3.5	4 x 4 x 6	20 (2)	2	7	40 (4)	Inside module, near antenna feed through
VHF relay set	7	4 x 8 x 6	20 (20)	1	7	20 (20)	Inside module near antenna feed through; 1 replacement/2 yrs
LF 1 kw set	35	10 x 10 x 18	1250 (200)	1	35	1250(200)	Control area - on for broadcast/homing; 1 replacement/5 yrs
Radar beacon	10	5 x 5 x 6	40 (5)	2	80	80 (10)	Ea. landing site - on for location only
Premod. processor (MODEM)	50	12 x 12 x 14	50 (50)	1	50	50 (50)	Control area - redundant unit 1 replacement/3 years
Central switching/test	40	9 x 13 x 14	25 (20)	1	40	25 (20)	Control area; 1 repl./4 years
Audio/video station	6	6 x 6 x 2	9 (5)	10	60	90 (50)	One per module, external; 1 replacement/4 years
Master audio/video station	18	6 x 10 x 2	12 (12)	2	36	24 (24)	Primary and secondary control 1 replacement/4 years
Paging amplifier	10	6 x 6 x 8	50 (5)	1	10	50 (5)	Control area (or any module) 1 replacement/4 years
Audio recorder	15	5 x 12 x 20	20 (10)	1	15	20 (10)	Control area; 6 mo. maintenance 1 replacement/2 years
Video cameras	10	5 x 6 x 20	50 (10)	8	80	400 (80)	At any audio/video station 1 replacement/year
Video monitor (9-in.)	15	10 x 10 x 15	50 (10)	6	90	300 (60)	Work areas; 1 replacement/year
Video monitor (14-in.)	40	24 x 24 x 22	75 (15)	1	40	75 (15)	Meeting area; 1 replacement/2 yrs
Total					813.2	2990(702)	

The paging amplifier is a redundant amplifier operating as a selection from the intercom system. The alarm system also operates through the amplifier.

The audio recorder is for voice and for entertainment. It should be noted that with a selection of holographic archival storage for the Data Management System, voice storage capability may not be available in the archival memory, and necessitates expansion of the audio recorder.

Video cameras are portable units and may be used for monitoring any area including external locations. The nine-inch TV monitors are for general use in work and control areas. The units may monitor any video on the bus, internal or external. The 14-inch unit is located in the assembly/recreation area and may support conferences or provide entertainment. The control areas include a CRT display which may be used for color TV when not in use as a primary display.

7.0 DATA MANAGEMENT

The Data Management Subsystem (DMS) is concerned with the processing of information, both at the point where it is generated and at the LSB proper prior to forwarding to the user on earth. The interface with the communications functions of Section 6.0 are defined therein by Figure 6.0-1.

7.1 REQUIREMENTS DEFINITION AND INFERENCES

Data handling includes the acquisition, processing, storage and distribution of data, as well as the displays and controls associated with this operation. Sources are associated with the subsystem measurements and with the experiments. These data may be acquired directly by hardware, crew inputs, or from external communications. Processing includes computer operations on the data from stored programs for generating control signals, supplying display information for status, alarm and fault isolation, and selecting or reducing data for storage or transmissions. The range of data types and locations are illustrated by Figure 7.1-1.

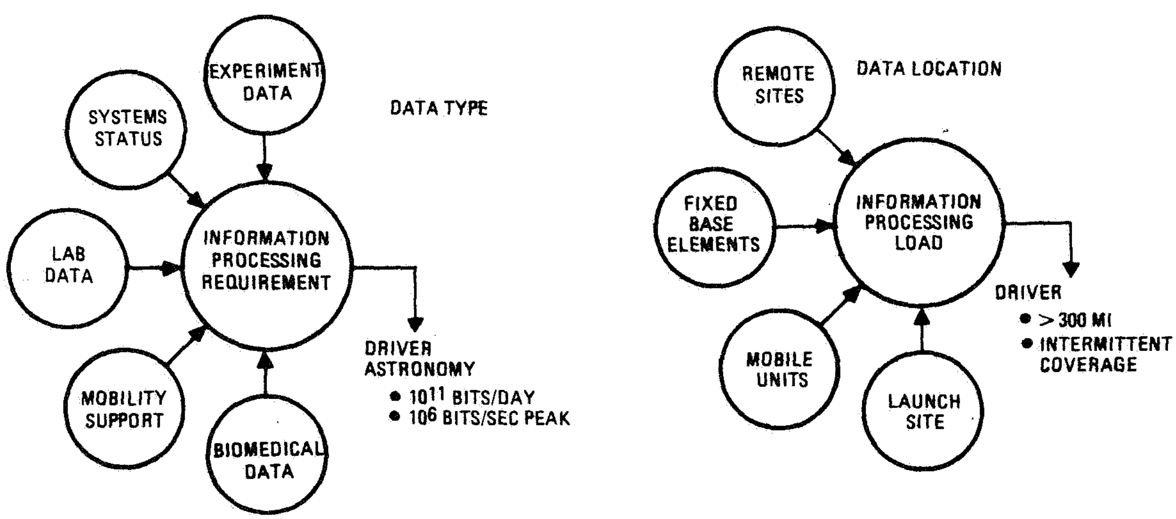


Figure 7.1-1. Data Management Requirements

Subsystem measurements will be required for monitoring and alarm generation (M&A), operational status monitoring (OSM), and for fault isolation (FI). In order to estimate this data load, measurement lists developed during EOSS studies have been extrapolated to the LSB subsystem. These estimates are listed in Table 7.1-1.

Table 7.1-1. LSB Subsystem Data Management
(Excludes Experiment Support)

Subsystem	Number of Measurements			Digitized Rates (K-bits/sec)		
	Analog	Event	Digital	Monitor & Alarm	Operational Status Monitor	Fault Isolation
Comm. & Data Management	500	220	110	3.5	13.2	10.0
Atmospheric & Crew Services	270	120	-	.1	.8	1.0
Electrical Power	520	100		3.4	1.5	5.0
Structural/Thermal	100	-	-	-	5.0	5.2
Crew Safety	150	20	10	20.0	2.0	45.0
TOTAL	1540	460	120	27.0	22.5	66.2

The experiments data have been estimated in terms of bits per day and peak data rates over the first three years of operation. These rates, along with the subsystem rates, are shown in Figure 7.1-2.

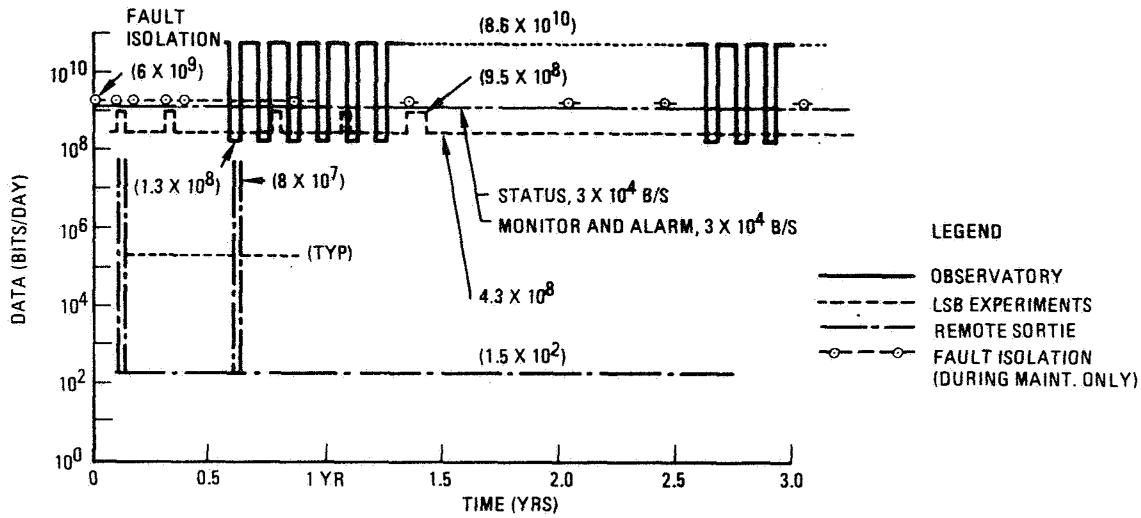


Figure 7.1-2. LSB Data Rate Estimates

7.1.1 LSB Subsystem Processing and Storage

EOSS studies of the program storage required for station operations and support have been applied to the LSB configuration to estimate processing and storage requirements.

Programs are classified as requiring operational memory or mass memory. The operational memory is a high speed extension of the memory in the processor itself. Mass memory has slower access times, mesured in milliseconds, than the operational memory and is suitable for operations not requiring an immediate digital decision or control response.

The program storage requirements are summarized in Table 7.1-2 in terms of 40-bit word storage. Table 7.1-3 lists the detailed assessments made in sizing the programs.

An additional type of data storage is archival. This system would provide slow access (several minutes) to information stored for evaluation of long term trends, little used programs which could be loaded into main or operational memory for special operations, and data to be transmitted at a later time or physically returned to earth. The actual requirements will depend to a large extent upon the processed level of data, and the available dumps. Without periodic data dumps or other reduction or discard of data, the archival memory could required on the order of 10^9 bits per day storage.

Table 7.1-2. Program Storage Summary Requirements

	Operational Memory (40-bit words)	Mass Memory (40-bit words)
Supervisory	58,000	8,000
Logistics inventory control	2,000	13,000
Operations control	11,000	22,000
Onboard checkout - M&A	16,000	7,000
Base control	32,000	4,000

7.1.2 Experiments Processing and Storage Inferences

The capability to provide automatic monitoring and control for experiments is considered an LSB requirement. The program storage established for similar functions in EOSS studies is considered a reasonable initial estimate for LSB. The estimated storage capacity for experiment control programs is:

Operational memory	18k words
Mass memory	42k words

The addition of a more conventional scientific computer capability will allow on-site evaluation of experiment trends, calibrations and performance to determine validity of data and allow modifications to the experiment set ups. The scientific routines are estimated to require a mass memory of 130k words for a scientific computer routine library.

Special routines to allow comparison, search, and evaluation of experimental and theoretical data may be expected to be reserved for earth-based operations. However consideration of autonomous operations for any period of time will require some degree of special routine capability. Such a requirement would exist, for example, where time varying events are being observed by the astronomy experiments and immediate decisions are needed as to the type of data to be taken and sources to be observed. Such operations in earth-based computers are occasionally plagued by the problem of running out of core memory in specific computers. The basic capability may be added by a small increase in operational memory and additional mass memory compatible with the basic configurations such as an operational memory of 13k words and a mass memory of 2000 words as an upper limit for special routines.

Table 7.1-3. Program Storage (Memory) Detailed Assumptions

	Operational Memory (40-bit words)	Mass Memory (40-bit words)
Supervisor Program	(58K)	(8K)
I/O Schedule and Control	8K	
Multiproc./Mult. Program	18K	
Int. Timing	2K	
Task Sched.	10K	
Program Load and Actuate		8K
Resource Handling	8K	
Interrupt Handling	12K	
Logistics Inventory Control	(2K)	(13K)
Onboard Inventory Update	2K	3K
Status Planning		10K
Ops. Control - Station and Remotes	(11K)	(22K)
Remote Term. Phase (Flt. Veh. Only)	5K	2K
Event Generation	6K	4K
Command Assembly		16K
Message Generation	10K	
Onboard Checkout; M & A	(16K)	(7K)
Exec. Programs	15K	
Fault Detection	1K	
Fault Isolation		2K
Fault Prediction		2K
Recertification		2K
Calibration		1K
Operations Data Management	(32K)	(4K)
Antenna Pointing	8K	
Command Execution/Verification	4K	2K
Subsystems Operations	8K	
Tracking and Ranging	7K	
Communications Control	5K	2K
Total Memory Reqmts - Station Operations	119K words	54K words

Archival storage would be required for scientific data awaiting reduction, dump via the communications link, or physical transport to earth. Pure storage of all raw data could require 10^{11} bits per day capacity. Actual requirements will result from further analysis of reduction and dump possibilities.

7.1.3 Peripheral Equipment

A printer and microfilm viewer capability is required for general support of both subsystems and experiment data management. The printer would provide the ability to review computer data without monopolizing the display console. The microfilm records would provide compact information in support of subsystems and experiment maintenance and operations.

Display and control requirements have been identified in terms of types and parameters for the LSB. Specific details will require waiting for more complete design of the base and subsystems. However, the display and control concept and typical approach may be developed from general criteria.

Table 7.1-4 identifies the types of display required for base operations management and the associated control requirements are indicated in Table 7.1-5. Similar information related to planning and scheduling functions are shown in Table 7.1-6. Display and control parameters for both the base operations and experiment operations are indicated in Table 7.1-7.

7.2 SYSTEM OPTIONS AND TRADE DATA

Figure 7.2-1 presents the system options considered. Table 7.2-1 lists the basic trade data used in selecting a data management subsystem for base services. General purpose computers are favored over special purpose due to a greater flexibility in being able to alter functions without designing and installing a new unit. In addition, the system can gracefully degrade by the processor dropping less critical functions in order to replace a failed critical unit. Hardware development, test and logistics are simplified, although software is more complex.

The power and weight data shown represent a sample system and favor the multiprocessor approach. The hardware units will have been developed commercially and applied by such space programs as EOS, EOSS, and possibly OLS. Further, the software programs will probably be substantially developed as well, which would be of major benefit since software development has become more expensive than the related hardware for many programs.

The data storage selections in other space study programs have selected plated wire for operating and mass memories, and tape for archival. The thin film requires greater power and the development is further in the future. For the LSB, the lower potential weight was considered to be a stronger factor than the increased power, and the additional development time required is also available considering the LSB time frame. This choice is not clear-cut though and is subject to the direction taken by the state-of-the-art.

Table 7.1-4. Display Requirements for Base Operations Management

	Display Required																								
	Status	Monitor and Alarm	Equipment Modes	Failure Modes	Configuration	Failed IFRU	Trend Information	Spare Parts	Quantities	Schedules	Emergency Identification	Calculation Results	Name	Location	Duty Status (Crew)	Tasks	BioMedical	Events	Voltages	Currents	Frequencies	Pressures	Partial Pressures	Flow Rates	Temperatures
Subsystems	X	X			X	X	X	X				X						X	X	X	X	X	X	X	X
Emergencies		X	X	X	X	X		X			X		X	X	X	X									
EVA		X											X	X		X	X	X				X	X	X	X
Personnel	X												X	X	X	X	X								
Consumables	X			X	X		X		X	X		X										X		X	X
Maintenance	X	X	X	X	X	X	X	X	X	X		X						X	X	X	X	X	X	X	X

Table 7.1-5. Control Requirements for Base Operations Management

Control Required	Control Function											
	Mode Control	Selection of Control	Inquiry	Events	Start Sequence	Crew Alert	Malfunction Correction	Communications	Video	Data File	Monitor and Alarm	
Subsystems	X	X	X	X	X		X	X	X	X	X	
Emergency	X				X	X	X	X	X		X	
EVA	X	X			X	X		X	X		X	
Maintenance	X	X	X	X	X	X	X	X	X	X	X	
Consumables												

Table 7.1-6. Control and Display Requirements for Planning and Scheduling

	Display Required								Control Required			
	Command Modes	Schedules	Data File	Personnel Status	Location of Experiments	Expendables	Spares	Maintenance Scheduling	Modes	Inquiry	Events	Start Sequences
Experiments	X	X	X	X	X	X	X	X	X	X	X	X
Logistics and Inventory		X	X			X	X	X	X	X	X	X
Personnel		X	X	X				X	X	X	X	X

Table 7.1-7. Display and Control Parameters

Operations	Parameters
Base	
Display	Experiment schedule Operational mode Operating status Data bank information EVA status Caution/warning advisory Three-axis attitude Remote vehicles under LSB control Three-axis rates of motion Remote vehicles under LSB control Video (intra) Video (extra) External visibility
Control	Operating modes Caution, warning, and advisory communications
Experiment - Experiment operation is subdivided into two areas of performance - general purpose and dedicated. Dedicated displays and controls are supplied by the experiment.	
General Purpose Displays and Controls	
Display	Visual monitor Data displays (Alpha-numeric, analog, and digital, X-Y graphic) Position and status indicators Time and timing indicators Communication modes Video (intra) Video (extra) Exterior visibility Calibration and checkout Emergency Airlock status Contamination monitor Computation parameters
Control	Controls for the above displays

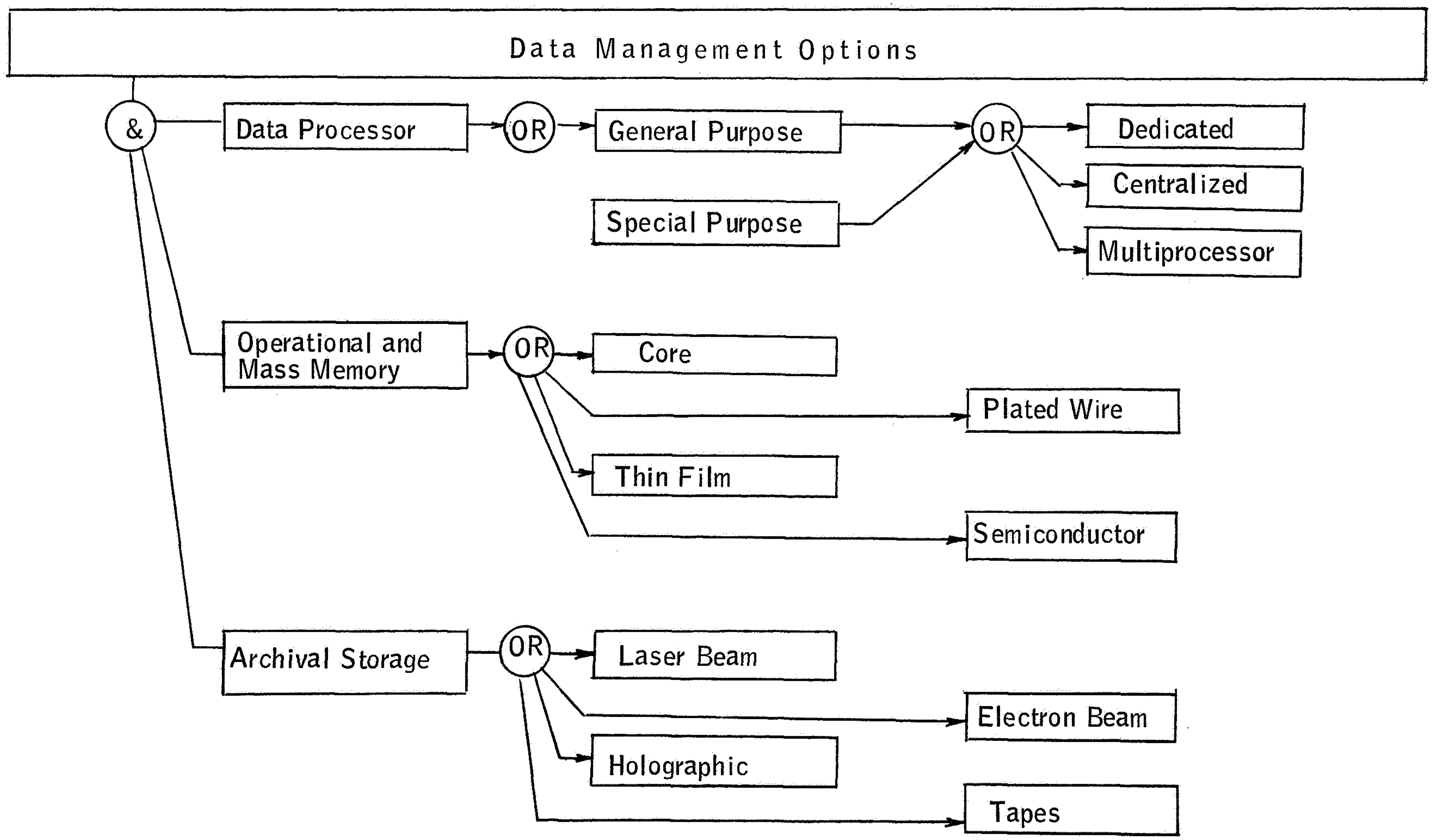


Figure 7.2-1. Data Management Options

Table 7.2-1. Base Services Data Management Trades

FUNCTION CLASS	OPTION	WEIGHT (LB)	POWER (AV. WATTS)	OTHER CONSIDERATIONS
General or Special Purpose Processors	Dedicated	830	600	Min. development
	Centralized	670	600	Some flexibility Some expansion
	Multiprocessor	500	450	Growth capability Flexible Self-healing
Operational and Mass Memory	Cores	600	840	Qualified Low cost
	Plated Wire	360	280	Small Development required
	Thin Film	250	400	Fast access Development required
	Semiconductor	1200	1400	Simultaneous read/write Fast access
Archival Storage	Laser and Elec. Beam	$1/1.2 \times 10^8$ bit	$1/10^9$ bits	Very fast access Development required
	Holographic	$1/1.2 \times 10^9$ bit	$1/10^9$ bits	Very fast access Development required
	Tapes	$1/1.2 \times 10^5$ bit	$1/10^8$ bits	Available

The archival storage is driven towards the holographic memory by the dense storage potential, approximately 1.2 x 10^9 bits per pound. The importance of this density results from the potential observatory data requirements. Raw storage of the observatory data could amount to over 21,000 pounds of tape per month. If the estimated density projected for the holographic memory is realized, the same storage capability reduces to a little over 2 pounds a month. These data are uncertain since the holographic systems are presently still in the very early stages of development. A driver for probable development of the process is cost since the holographic memory is expected to cost about the same as disc storage (0.01 cents per bit). Commercial systems are anticipated to be in operation by the time period of the LSB.

Figure 7.2-2 presents the required operating and mass memory storage based on plated wire stacks. Thin film may be expected to reduce weight and increase power to some extent; however, these values should provide an early estimate of these memories, and the weights involved in implementing scientific functions.

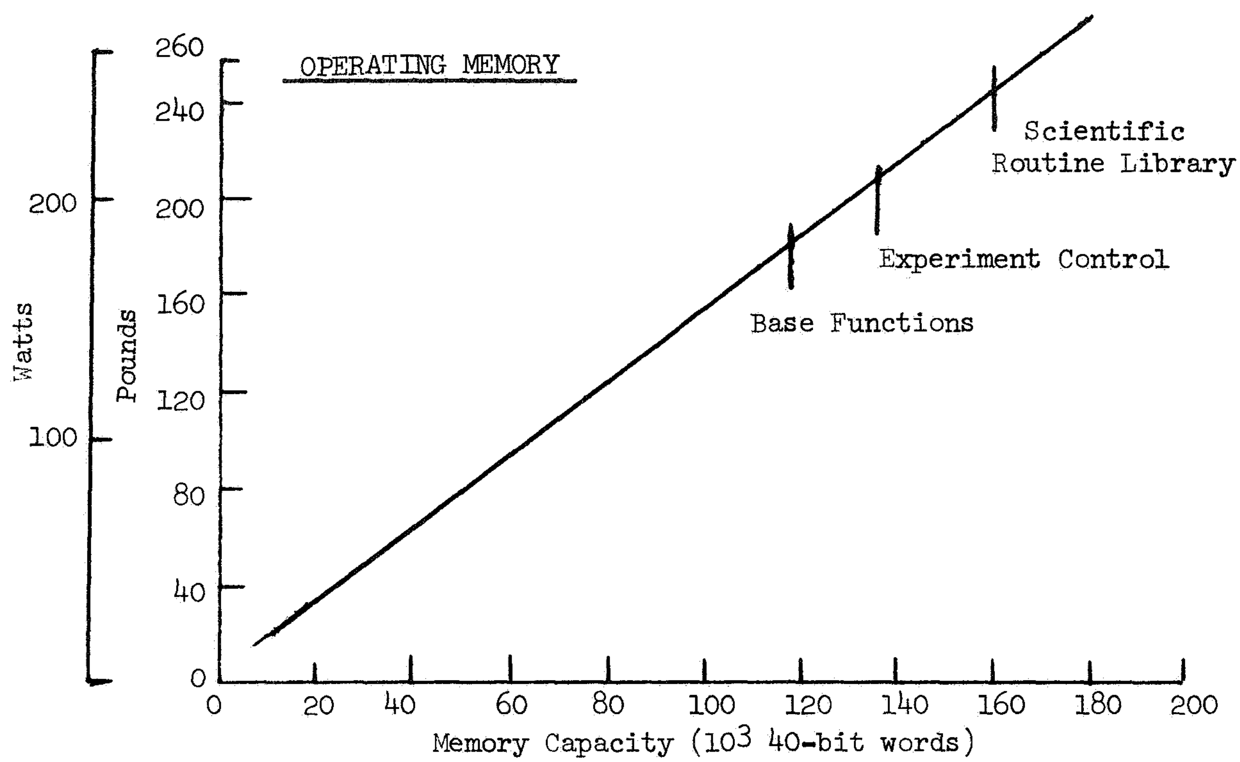
The weight for implementing experiment control is shown to be about 50 pounds in total memory. Without specific analysis, a rough estimate is that special purpose sequencers and controls for operation and monitoring will considerably outweigh this value if it is delted from the basic memory capability. The cost in memory is an additional 80 pounds to allow a scientific routine library and independent access to the program. The display and control capabilities will exist as a requirement for backup control of base functions.

Complete detailed processing capability could add 600 pounds to the memory, and require additional consoles. Some diminishing returns are present also, in that evaluation of data at this level is likely to add to the total information stored, due to correlations with known facts, rather than reduce the amount to be returned. It may also be questioned whether the LSB crew will contain the level of personnel to perform this level of investigation.

Minimal capability, less than that represented by the scientific routines, requires a large number of overhead functions related to the setting up and control of experiments, processing and selection of data to be returned to earth, evaluation by a Principal Investigator, and feedback of suggestions for re-adjusting and operating experiments. A basic example associated with the astronomy data is summarized in the next section.

7.3 SYSTEM OPTIONS AND TRADES, ASTRONOMY

The potential impact of the astronomical experiments and the associated data handling options can be seen from Table 7.3-1 where the options and trades are presented. These data indicate that the LSB system weight (or power) are not the key factors but rather the consumables cost and/or the impact on other elements of the space community. The consumables estimates were based on the use of tape for storage. If the holographic memory becomes available, option 2 may be the best; otherwise a form of option 4 is most reasonable. There is a trade here which cannot be resolved until the experiment requirements become better defined.



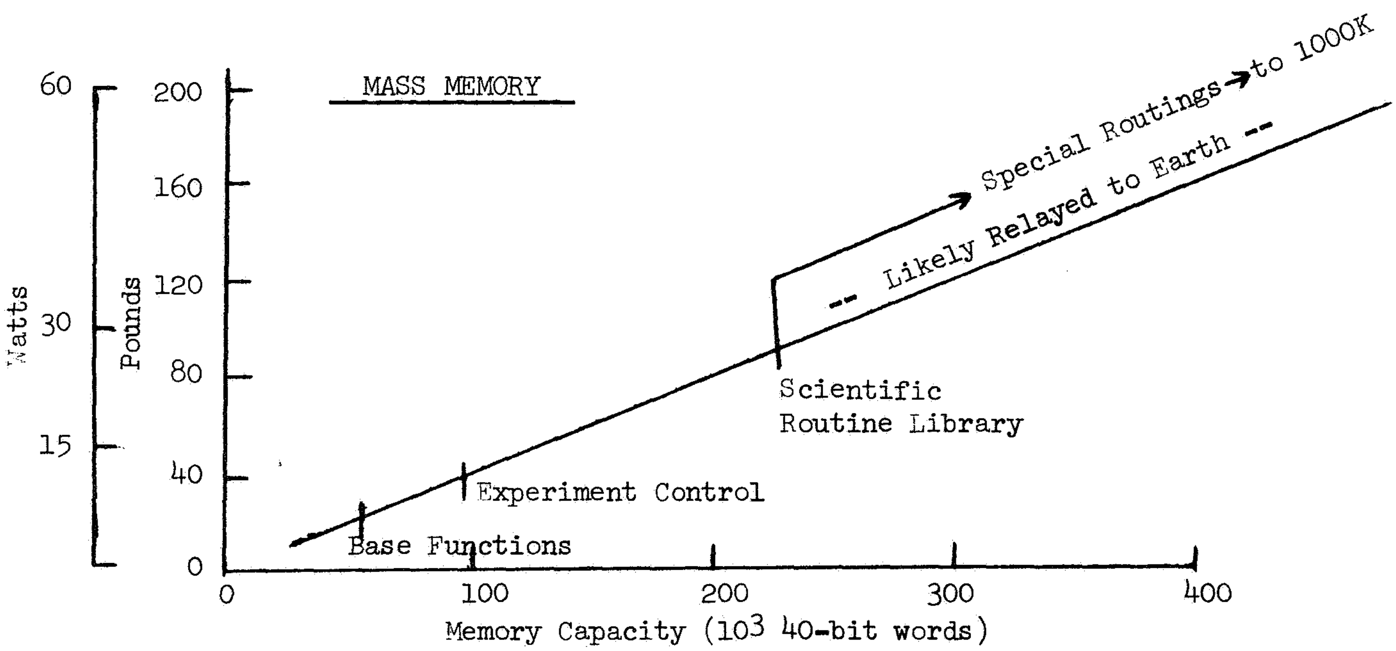


Figure 7.2-2. Processing Memory Parametrics

Table 7.3-1. Data Handling Options - Astronomy

CONCEPT	SYSTEM REQUIREMENTS	WEIGHT (LB)	CONSUMABLES IMPACT (LB/MO) *	OPERATIONAL CONSIDERATIONS
(1) ON-SITE PROCESSING	• Dedicated Data Processor • Display Systems • Replay System • Computer Memory	600	Up = 600 Dn = 600	• Principal investigator on site • Useful data lost • Additional manpower
(2) RECORD ON SITE SHIP TO EARTH P.I.	• On-Site Recorder • Massive Tape Storage • Active Maintenance	360	Up = 21.6K Dn = 21.6K	• Tape replacement and maintenance ~120 M-hr/mo • 100% time coverage
(3) REAL TIME TRANSMITTAL TO EARTH	• Autonomous Data Link to MSFN 1 M b/s continuously	220	-0-	• Requires unbroken LOS contact with P.I. stations on earth - dedicated wideband radio channel
	12 hrs storage plus above	+360	Up = 800 Dn = 0	• 12 hr store/12 hr dump to MSFN • Replace tapes weekly
(4) HYBRID OF ABOVE WITH DATA PRESELECTION	• Data Processor • Display Systems • Memory	400	Up = 180 Dn = 180	• Data dumps may be scheduled with specific earth stations • P.I. can be on earth • Preselection criteria required
* Based on use of tape storage				

7.4 RECOMMENDED DATA MANAGEMENT CONCEPT

The LSB Data Management components are listed in Table 7.4-1.

Four data processors are utilized, with the one committed normally for scientific support being available for backup. Conventional general purpose operations are performed in these units utilizing a built-in scratch pad memory, and the operating memory as a high-speed extension. The Input-Output Controller interfaces each processor with the digital line carrying control, response, and timing signals. Mass and archival memories are also accessed and controlled through the input-output units.

Five 32,000-word operational memory modules are used to provide a basic scientific library in addition to base operational functions, and some margin for a limited number of special science routines.

Archival memory is identified as a "set" in the basic list. Assuming advanced tape machines, the set consists of three cartridge recorders with 40 minutes of 5 Mbps plus voice capacity each. The holographic alternate might contain anywhere from 4000 to 10,000 hours of storage capacity.

The Remote Acquisition and Control Units (RACU) are the interface between systems and the digital lines. The number assigned indicates the number of channels carried. The units incorporate memory and mission processing as well as conversion capabilities across the analog and digital interfaces. They are controlled by the processing unit through the digital line.

Central timing provides the main timing line with accurate signals for support to processing and for time identification of stored data.

The display and control assembly is nominally configured in a 4 ft x 4 ft x 2 ft console. This contains the components that follow to make up a complete control station. The Light Emitting Diodes are graphic displays of characters which may be used for display of any computer data called up by the keyboards. Major control of subsystems, except for direct emergency controls, is through the keyboards and selectors. The color CRT may be used for text, graphic symbols for status or control, and for display of color TV.

The microfilm viewer is for stored or newly arrived records and instructions. The hand controller is a plug-in unit to allow control of antennas or remote controlled vehicles from the consoles or from a remote terminal unit.

The monitor and alarm units display alerts, status, and identification of primary causes of caution or alarm indications.

The remote terminal unit is essentially the CRT display and control and could be anywhere on the data bus. The keyboard and monitor and alarm are to provide complete backup primary control, as well as permit use of the science capability of the computer. The assembly can be partially activated when at least a remote terminal unit is connected to a processor-memory combination.

Table 7.4-1. LSB Data Management Equipment

Item	Unit Weight (lb)	Dimensions (in.)	Bus Power Peak (Avg.) watts	Qty.	Total Weight (lb)	Total Watts Peak (Avg.) watts	Location	Notes
DATA PROCESSOR ASSY.								
Processor	10	9 x 3.6 x 14	30 (3)	4	40	120 (12)	2 in control center, 2 in backup	1 replacement/2 yr
I/O controller	10	9 x 3.6 x 14	25 (15)	4	40	100 (60)	1 w/ea. processor	1 replacement/2 yr
32K-word op. memory	50	9 x 9 x 14	50 (20)	5	250	250 (100)	3 in control; 2 in backup	1 replacement/2 yr
256K-word mass memory	100	9 x 18 x 14	30 (15)	2	200	60 (30)	1 ea control area	1 replacement/2 yr
Archival memory set	120	18 x 18 x 14	135 (33)	1	120	135 (33)	In either control room	180 lb/mo IF tape
RACU 256 channel	6	3 x 3 x 8	8 (6)	12	72	96 (72)	Distrib. in subsyst.	1 replacement/8 yr
128 channel	5	3 x 3 x 4	4 (3)	4	12	16 (12)	Distrib. in subsyst.	1 replacement/8 yr
64 channel	1.5	3 x 3 x 2	2 (1.5)	4	6	8 (6)	Distrib. in subsyst.	1 replacement/8 yr
Central timing unit	18	9 x 6 x 14	30 (30)	2	36	60 (60)	Noncritical - inside	1 replacement/5 yr
DISPLAY & CONTROL ASSY.								
Console structural fittings	83	48 x 48 x 24		1	83		Prime control	Total - 1 per 4 years
Printer	40		100 (20)	1	40	100 (20)	In console	
Disp. address keyboard	6		7 (1.75)	2	12	14 (3.5)	"	
Function selection	15		5 (1.25)	2	30	10 (2.5)	"	
Light emitting diode display (LED)	10		20 (10)	2	20	40 (20)	"	
LED electronics	20		30 (15)	2	40	60 (30)	"	
CRT	25		50 (50)	1	25	50 (50)	"	
CRT electronics	20		10 (10)	1	20	10 (10)	"	
Microfilm viewer	35		50 (25)	1	35	50 (25)	"	
Hand controller	20		1 (.15)	2	40	2 (.3)	"	
Monitor and alarm assy.	30		89 (45)	1	30	89 (45)	"	
Remote terminal unit	40	12 x 12 x 8	250 (25)	2	80	500 (50)	Backup control	1 per 2 years
Display address keyboard	6		7 (1.75)	2	12	14 (3.5)	With backup control	1 per 4 years
Monitor and alarm assy.	30		89 (45)	1	30	89 (45)	Backup control	1 per 4 years
Total					1273	1873 (720)		

8.0 LSB BASELINE DEFINITION

Trade studies have been described in the previous sections which were performed to identify both the optimum module configuration and its subsystems. These data have permitted the selection of a lunar base shelter system concept that will satisfy the comprehensive criteria. This section identifies that lunar base shelter system.

8.1 BASELINE SHELTER DESIGN

The baseline shelter design, illustrated by the artist's conception in Figure 8.1-1 is composed of eight of the baseline modules arranged in a close-loop or "circular" floor plan. Any of the modules may be coupled at either end or at a hatch on one side. Two of the modules have provisions for opening the bulkhead to provide vehicular access. The single central floor in each module was selected to provide the maximum free floor space on one level. All equipment, tanks, ducts, wires, pipes/tubing and fixtures not normally requiring access are installed above the ceiling or below the floor, resulting in a larger proportion of free space and clear floor area in each module. The eight-module shelter complex provides over 26,000 cubic feet of free space and nearly 2500 square feet of clear floor area.

The modules are designed to operate autonomously, but in pairs to improve efficiency. The three crew modules provide atmospheric and crew services (A&CS) subsystems support to the lab module, the assembly and recreation module, and the base maintenance module. The garage and warehouse modules are designed to operate as part of the base providing only a minimum amount of atmospheric management. Specific identification of the module hardware elements may be found in the mass properties descrption in Section 8.4. Drawing 2284-7B provides a more detailed description of the Baseline Shelter arrangement.

The individual module descriptions are as follows:

1. The crew modules, three of which are used, are designed to house four crewmen plus one other major function. The crew quarters provide individual staterooms for four men of approximately 40 square feet each. They contain a bunk, desk, chair, and storage closets. The major functions which are distributed among the three modules are:

    a. command and control center
    b. medical facility
    c. backup galley and backup control center

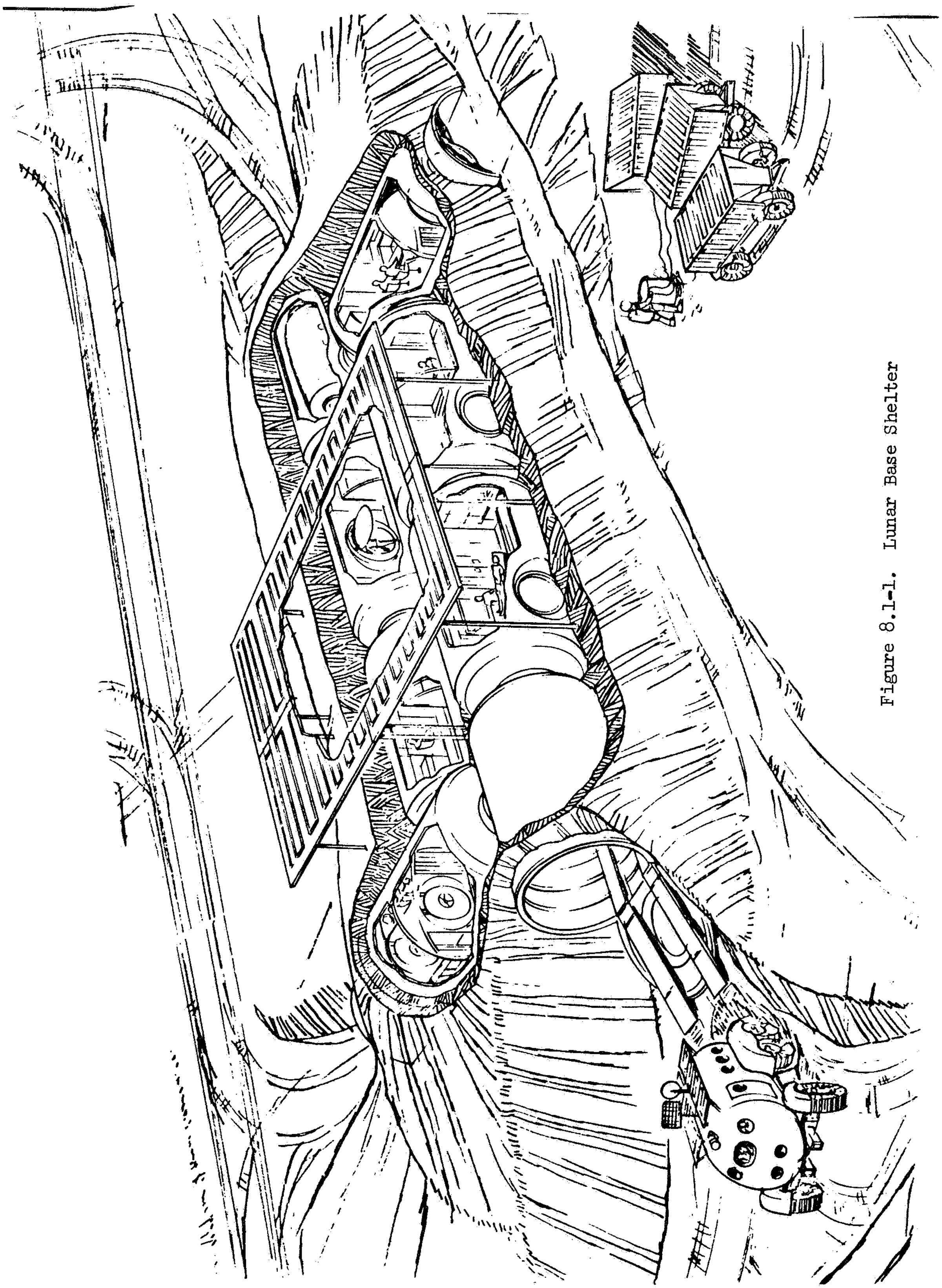
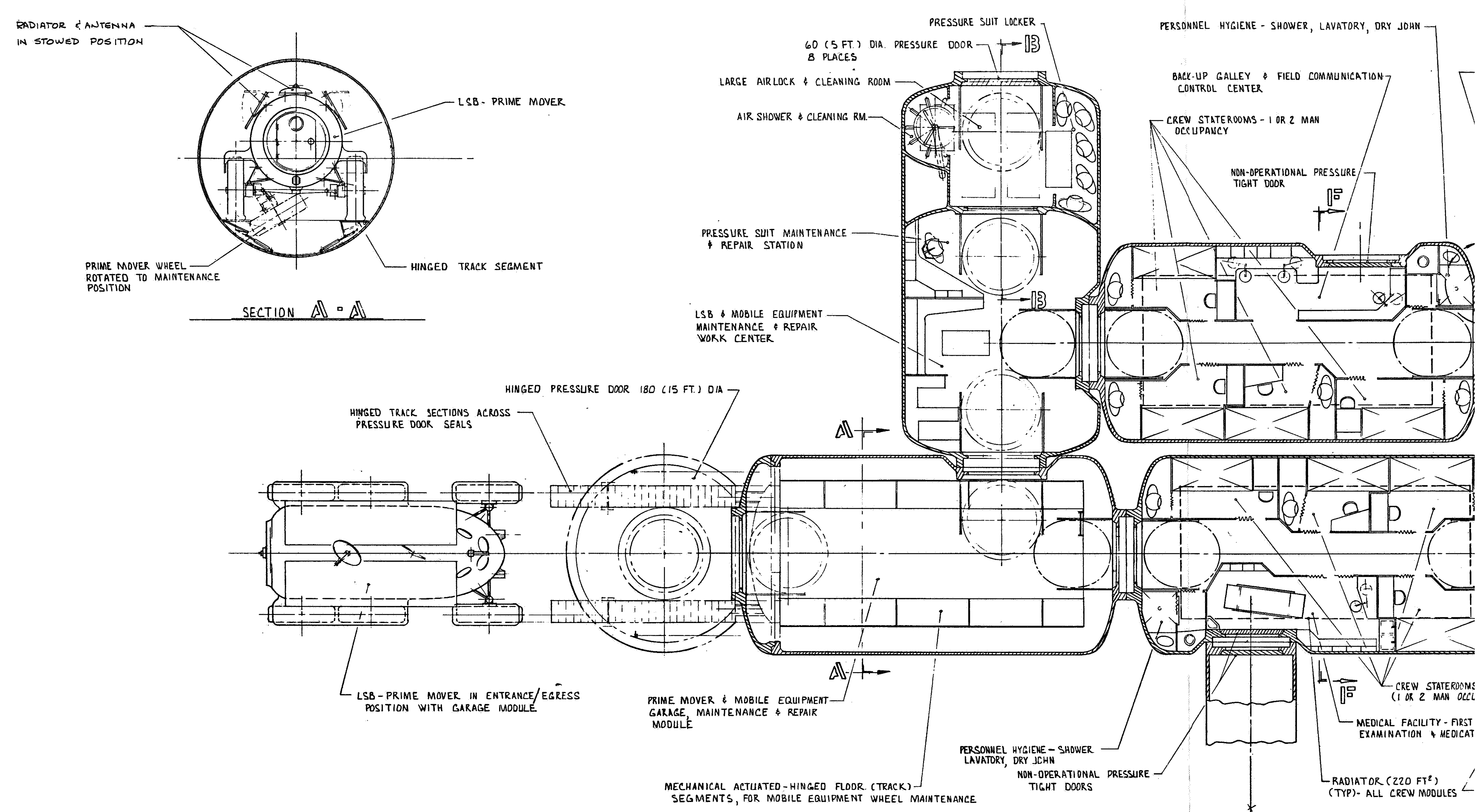


Figure 8.1-1. Lunar Base Shelter

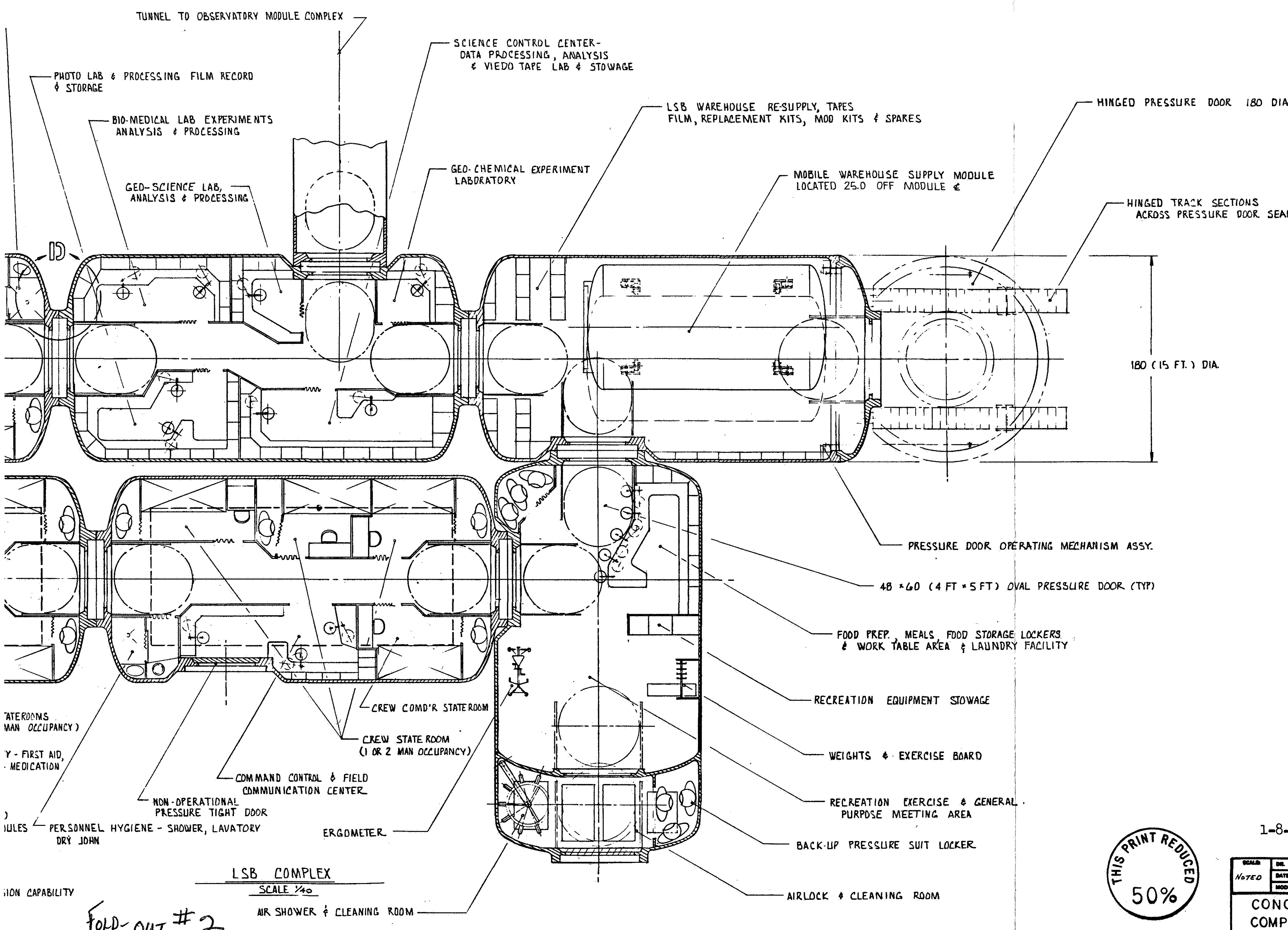


RADIATOR & ANTENNA IN STOWED POSITION
LSB- PRIME MOVER
PRIME MOVER WHEEL ROTATED TO MAINTENANCE POSITION
HINGED TRACK SEGMENT
SECTION A - A
PRESSURE SUIT LOCKER
60 (5 FT.) DIA. PRESSURE DOOR 8 PLACES
LARGE AIRLOCK & CLEANING ROOM
AIR SHOWER & CLEANING RM.
PRESSURE SUIT MAINTENANCE & REPAIR STATION
LSB & MOBILE EQUIPMENT MAINTENANCE & REPAIR WORK CENTER
PERSONNEL HYGIENE - SHOWER, LAVATORY, DRY JOHN
BACK-UP GALLEY & FIELD COMMUNICATION CONTROL CENTER
CREW STATEROOMS - 1 OR 2 MAN OCCUPANCY
NON-OPERATIONAL PRESSURE TIGHT DOOR
HINGED PRESSURE DOOR 180 (15 FT.) DIA
HINGED TRACK SECTIONS ACROSS PRESSURE DOOR SEALS
LSB-PRIME MOVER IN ENTRANCE/EGRESS POSITION WITH GARAGE MODULE
PRIME MOVER & MOBILE EQUIPMENT GARAGE, MAINTENANCE & REPAIR MODULE
MECHANICAL ACTUATED-HINGED FLOOR (TRACK) SEGMENTS, FOR MOBILE EQUIPMENT WHEEL MAINTENANCE
PERSONNEL HYGIENE - SHOWER LAVATORY, DRY JOHN
NON-OPERATIONAL PRESSURE TIGHT DOORS
CREW STATEROOMS (1 OR 2 MAN OCCL
MEDICAL FACILITY - FIRST EXAMINATION & MEDICAT
RADIATOR (220 FT²) (TYP)- ALL CREW MODULES
TUNNEL FOR FUTURE EXPANSION CAPA

FOLD-OUT #1

CHG	REVISIONS	DATE	CHG BY
A	1. REDRAWN & RECONFIGURED	1-20-71	R.T.
B	1. ADDED SECTION B, C, D, E & F	2-5-71	K.T.

Space Division
North American Rockwell



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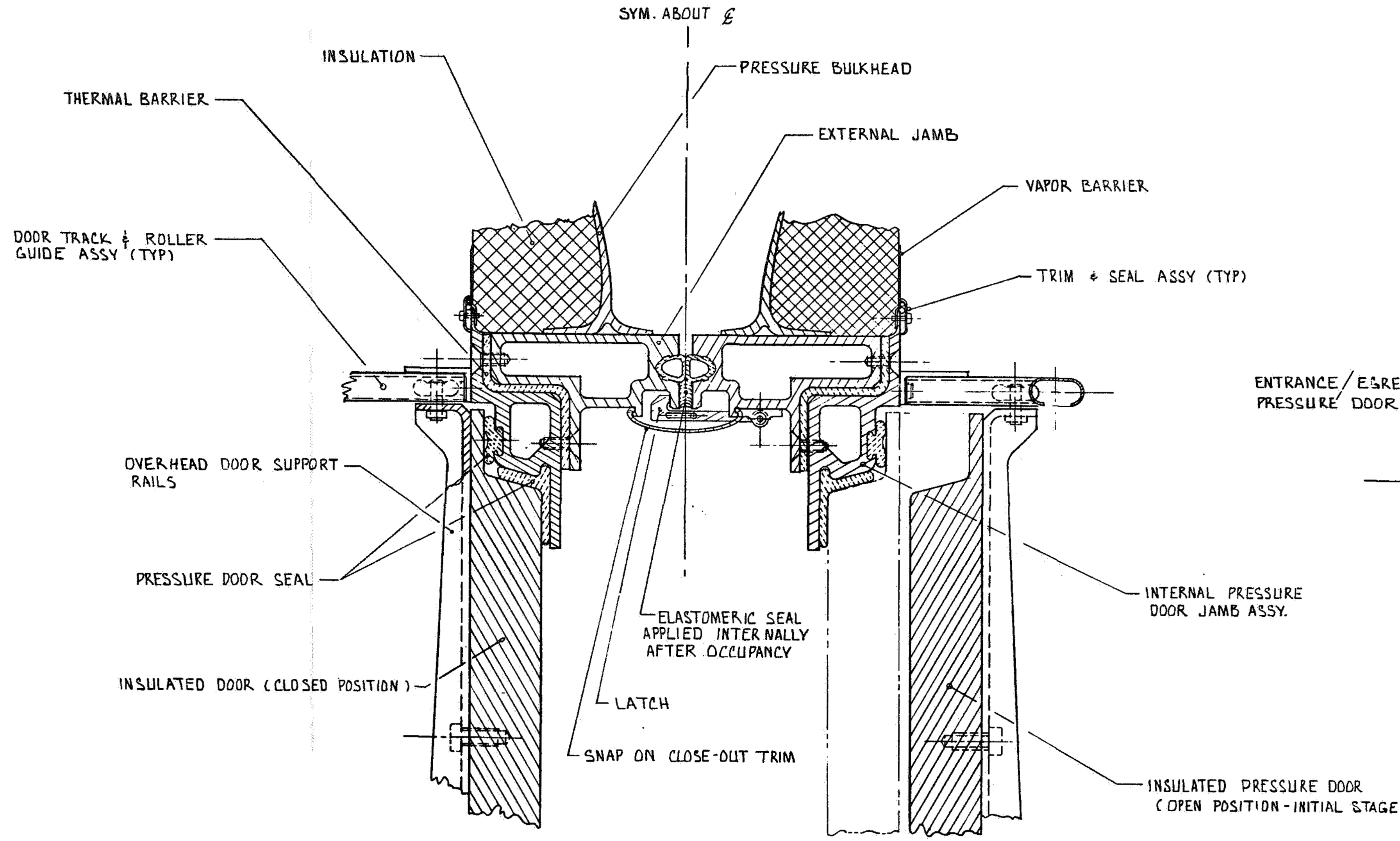
CONCEPT LAYOUT - LUNAR BASE COMPLEX, CONFIGURATION STUDY

2284-7B

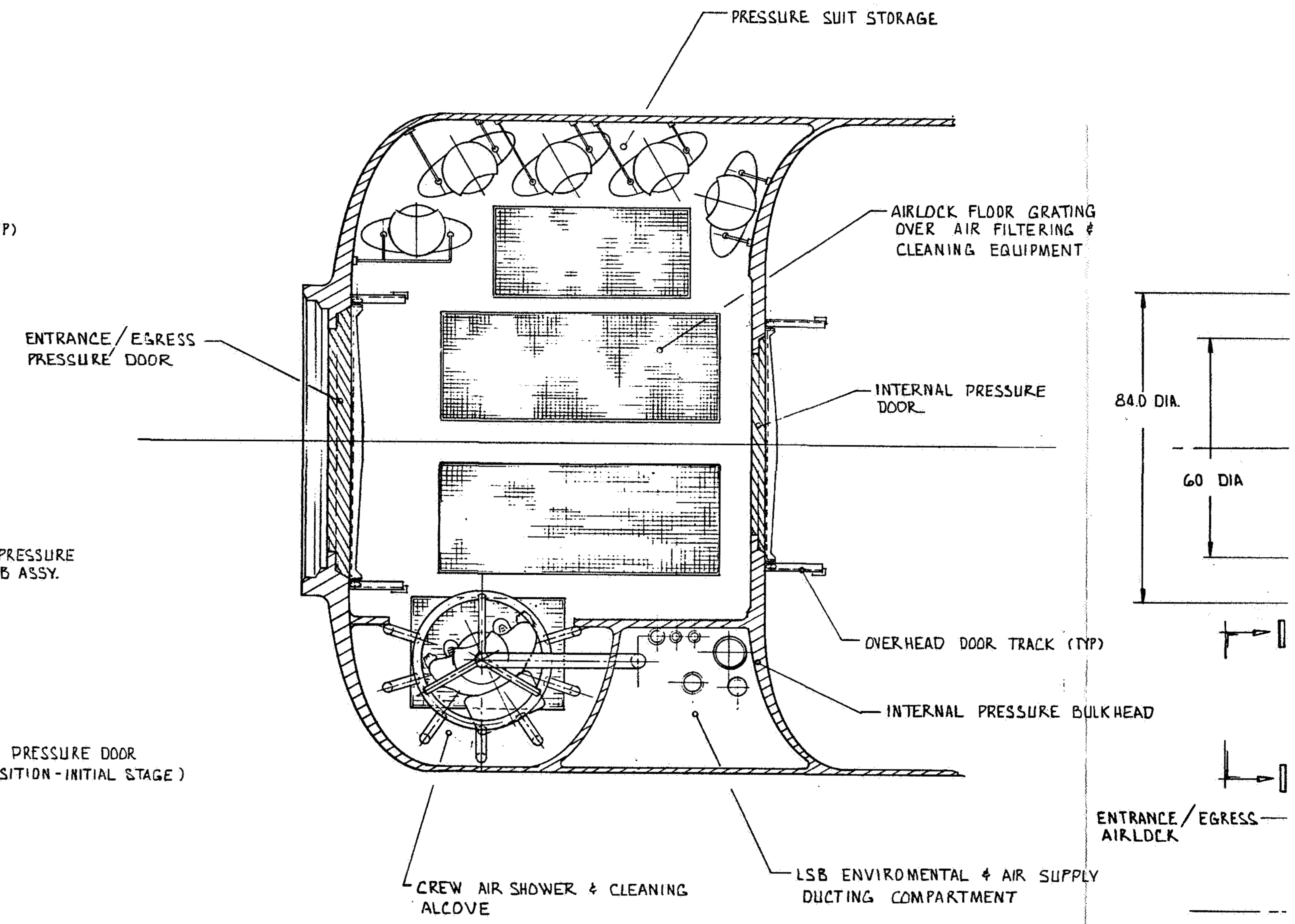
SHT 1 OF 2



(B) SECTION D

SCALE 1/4

(TYPICAL JOINT & DOOR DETAIL FOR ADJACENT MODULES)



(B) SECTION C - C

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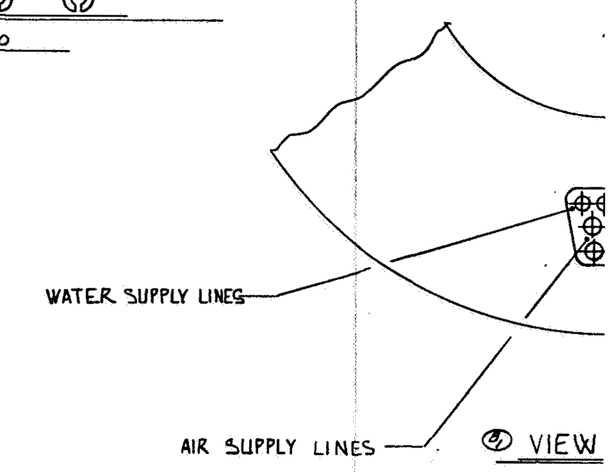

(B) VIEW

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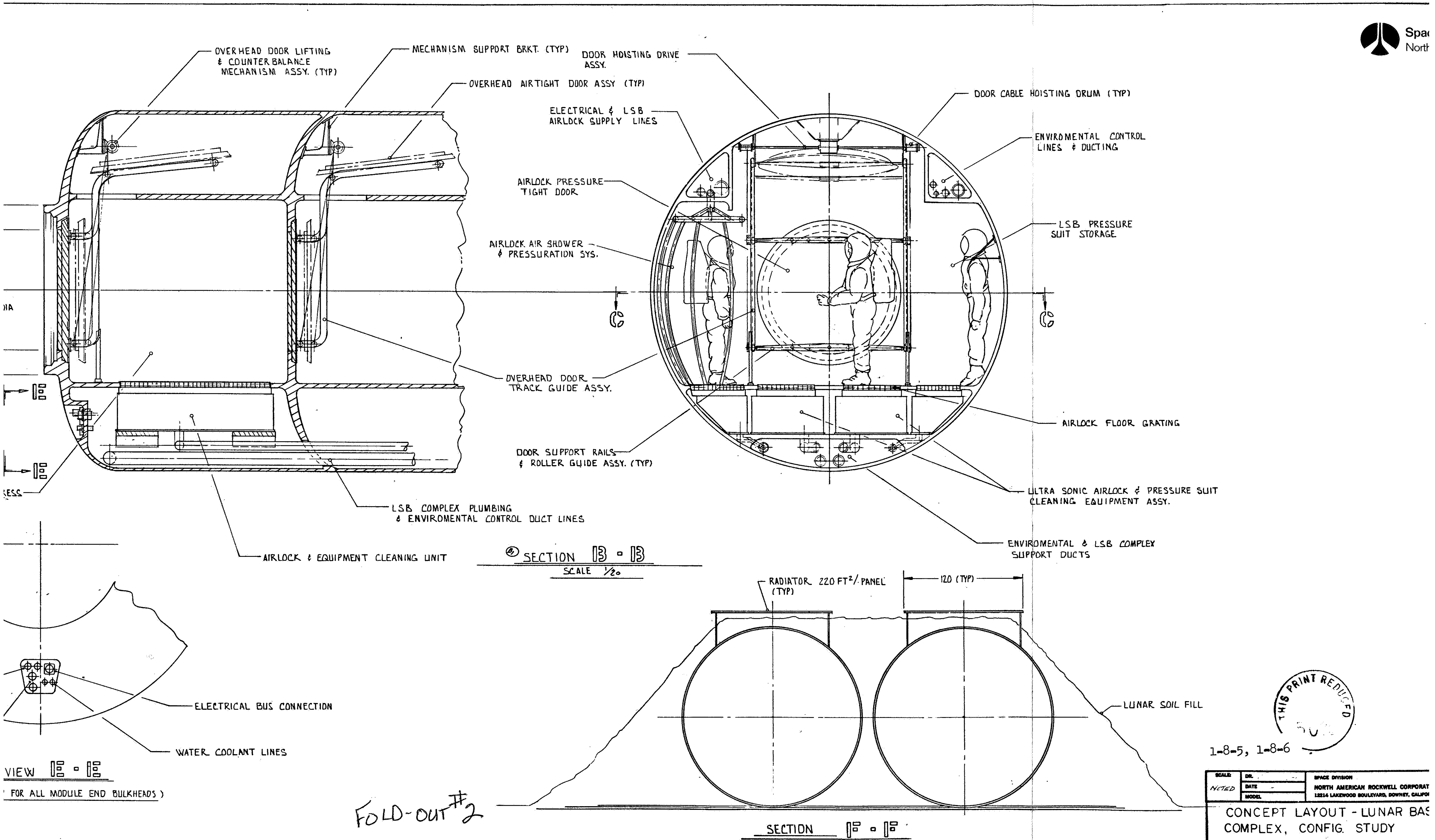

OVERHEAD DOOR LIFTING & COUNTERBALANCE MECHANISM ASSY. (TYP)
MECHANISM SUPPORT BRKT. (TYP)
OVERHEAD AIRTIGHT DOOR ASSY (TYP)
DOOR HOISTING DRIVE ASSY.
ELECTRICAL & LSB AIRLOCK SUPPLY LINES
DOOR CABLE HOISTING DRUM (TYP)
ENVIROMENTAL CONTROL LINES & DUCTING
AIRLOCK PRESSURE TIGHT DOOR
AIRLOCK AIR SHOWER & PRESSURATION SYS.
LSB PRESSURE SUIT STORAGE
OVERHEAD DOOR TRACK GUIDE ASSY.
AIRLOCK FLOOR GRATING
DOOR SUPPORT RAILS & ROLLER GUIDE ASSY. (TYP)
ULTRA SONIC AIRLOCK & PRESSURE SUIT CLEANING EQUIPMENT ASSY.
LSB COMPLEX PLUMBING & ENVIROMENTAL CONTROL DUCT LINES
ENVIROMENTAL & LSB COMPLEX SUPPORT DUCTS
AIRLOCK & EQUIPMENT CLEANING UNIT
SECTION B - B
SCALE 1/20
RADIATOR 220 FT²/PANEL (TYP)
120 (TYP)
ELECTRICAL BUS CONNECTION
LUNAR SOIL FILL
WATER COOLANT LINES
VIEW E - E
FOR ALL MODULE END BULKHEADS)
FOLD-OUT #2
SECTION F - F
1-8-5, 1-8-6
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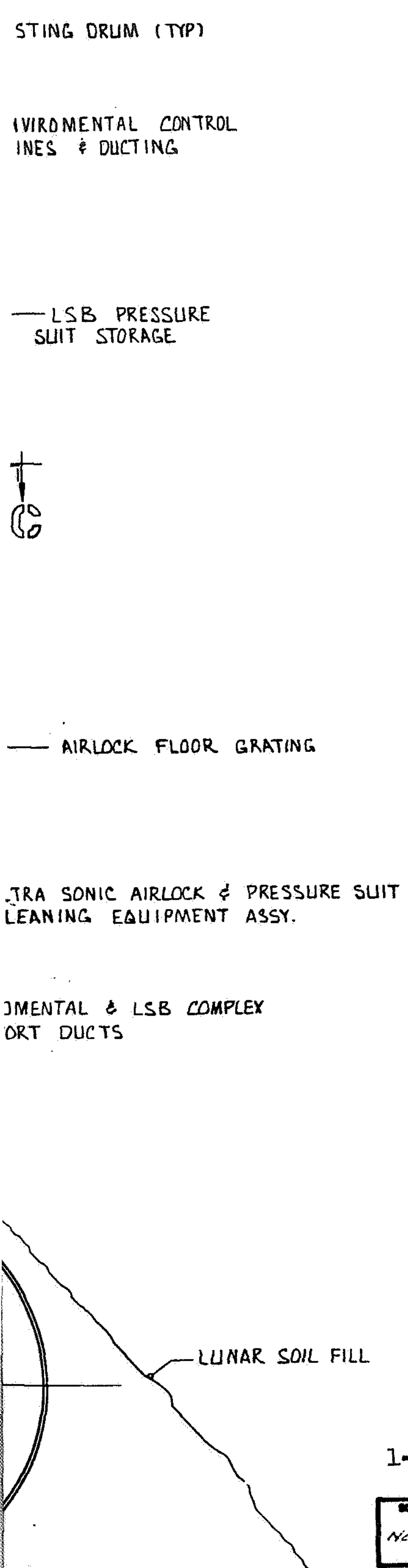

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	CONCEPT LAYOUT - LUNAR BASE COMPLEX, CONFIG. STUDY		2284-7B SHT 2 OF 2

FOLD-OUT #3

2. The garage module is designed to accommodate the prime mover or any of the mobile elements to permit repair of their exterior features. As indicated by section A-A of the drawing, the tracks are designed to permit replacement of the wheels or the drive units. Other facilities are limited due to space constraints. This same module is used as a shipping container for one of the mobility elements. The full bulkhead opens up and tracks are deployed to facilitiate loading and unloading the vehicle as indicated. Docking provisions are included to facilitate shirtsleeve transfer when required.

3. The warehouse module is much like the garage module; it also is first used as a mobility shipping container and subsequently as a warehouse. A limited number of shelves and bins are deployed after integration into the base. The docking capability may be used to couple a resupply module when and if required.

4. The maintenance module provides facilities for the repair and maintenance of all base systems. It has an electronic area, a mechanical area and a suit area. One of its primary function is to provide facilities for the ingress and egress of the EVA worker. It provides an airlock large enough to handle six workers at a time. This includes the air shower and multifiltration systems. The airlock pumpdown system is shared with the garage module, providing fast pumpdown for the airlock and a slower rate for the garage. Facilities are provided for docking a prime mover to the airlock door to permit shirtsleeve transfer to and from the vehicle without cycling the airlock.

5. The assembly and recreation module includes the main galley with its food preparation and preservation facilities. It also contains an airlock; however, its capacity is limited to four men. The dust control capability is the same as the larger one. Facilities are provided for docking to the airlock door for shirtsleeve transfer operations when vehicles are in use.

8.2 MISSION FLEXIBILITY AND GROWTH POTENTIAL

The modular concept proposed provides an extended growth capability as well as design and mission flexibility. It is apparent that at this point in time, it is impractical to attempt to fix a design for a mission in the 1980's. However, the following features have been identified in the module and shelter complex to support the objectives of mission flexibility and growth:

1. A standardized module with handling/docking fixtures on each end and one side.

2. Provisions for holding additional modules in the shelter complex by:

   a. coupling to an unused side hatch
   b. coupling to an end hatch
   c. removing an end module and extending the shelter complex as required

3. Provisions for integrating other mission elements into the shelter complex can be provided through use of a connector such as the option shown in Figure 8.2-1. The sections are designed to couple to an LSB docking port at one end and a mission system interface, such as astronomy observatory, at the other. Sections can be designed to be packaged in small elements which can expand by a factor of over 3 to 1. The clear height would be about 5 feet. Three wall options were considered, a pressurized stabilized soft structure, a rigid bellows and a self-stabilizing soft structure. Table 8.2-1 presents the associated trade data. All options are proposed to be covered by soil for environmental protection so that the performance characteristics are essentially the same. The indications are that the lightest is the choice since it also occupies less volume in the shipping condition. The rigid bellows may be eliminated on the basis of weight and the fact it would require use of smaller sections, imposing a still greater penalty.

Table 8.2-1. Connector Options

Option	Wall Structure	Weight (lb)
Pressure Stabilized		
3 - 10 ft	Dual wall nylon with neoprene and mylar	300
1 - 30 ft		160
Expendable		
3 - 10 ft	Foam with fiberglass on nylon and steel messh or spun wire	660
1 - 30 ft		520
Rigid Bellows		
3 - 10 only	Steel bellows	800

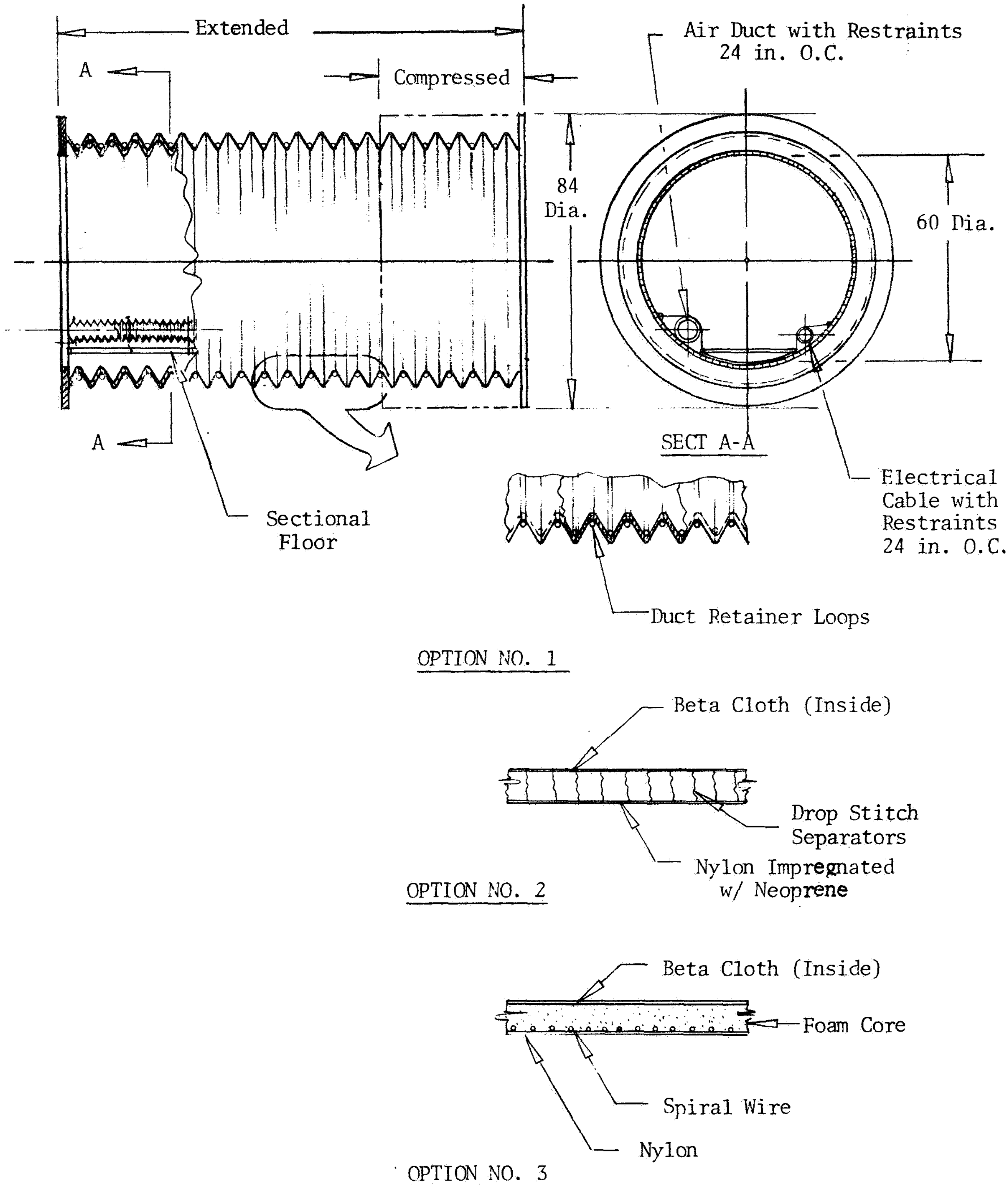


Figure 8.2-1. Shelter and Outpost Connector Options

8.3 LUNAR SURFACE BASE COMPLEX

Figure 8.3-1 presents an artist's concept of what the LSB complex may look like. The sketch satisfies the design criteria defined within this study and embodies all of the mission/system requirements. The radio astronomy antenna in the background provides some feeling for scale. The total complex is approximately 7 by 2 miles and occupies some 14 square miles of area.

The 100-inch optical observatory can be integrated into the shelter complex through a tunnel, which will minimize time lost in EVA. The observatory is located so as to eliminate blockage of its field of view and maximize separation from the logistics operations. The logistic vehicle landing site is located over one mile from the base and added protection from the dust ejecta is assumed to be provided by intervening topography or a man-made ridge.

8.4 BASELINE LSB MASS PROPERTIES

The estimated weights for the baseline LSB concept have been developed and are summarized by module in Table 8.4-1. The base shelter complex, without supplies, is estimated to weigh about 59.5K pounds. The individual modules were held to a weight less than 9.5K pounds to facilitate handling.

Table 8.4-2 presents a weight breakdown by module and major subsystem.

Table 8.4-3 presents the weight breakdown for the structural subsystems by individual module.

Table 8.4-4 presents the weight breakdown for the atmospheric management subsystem by individual module.

Table 8.4-5 presents the weight breakdown for the electrical power distribution and control subsystem and intercommunication function by module. Note that the electrical power source is assumed to be in mobile units and is not included here. The J-box and external controls for combining mobile units are included as support operation equipment hardware and are listed in Table 8.4-2.

Table 8.4-6 presents the weight breakdown for the communications and data management subsystems as they apply to the primary and backup command and control centers. Only intercommunication functions are in the other modules. The external communications equipment, relays, and antennas are included as support operations equipment hardware and are listed in Table 8.4-2.

Table 8.4-7 presents the weight breakdown for the medical center, galley, backup galley and laboratory subsystems, indicating the modules in which they are installed.

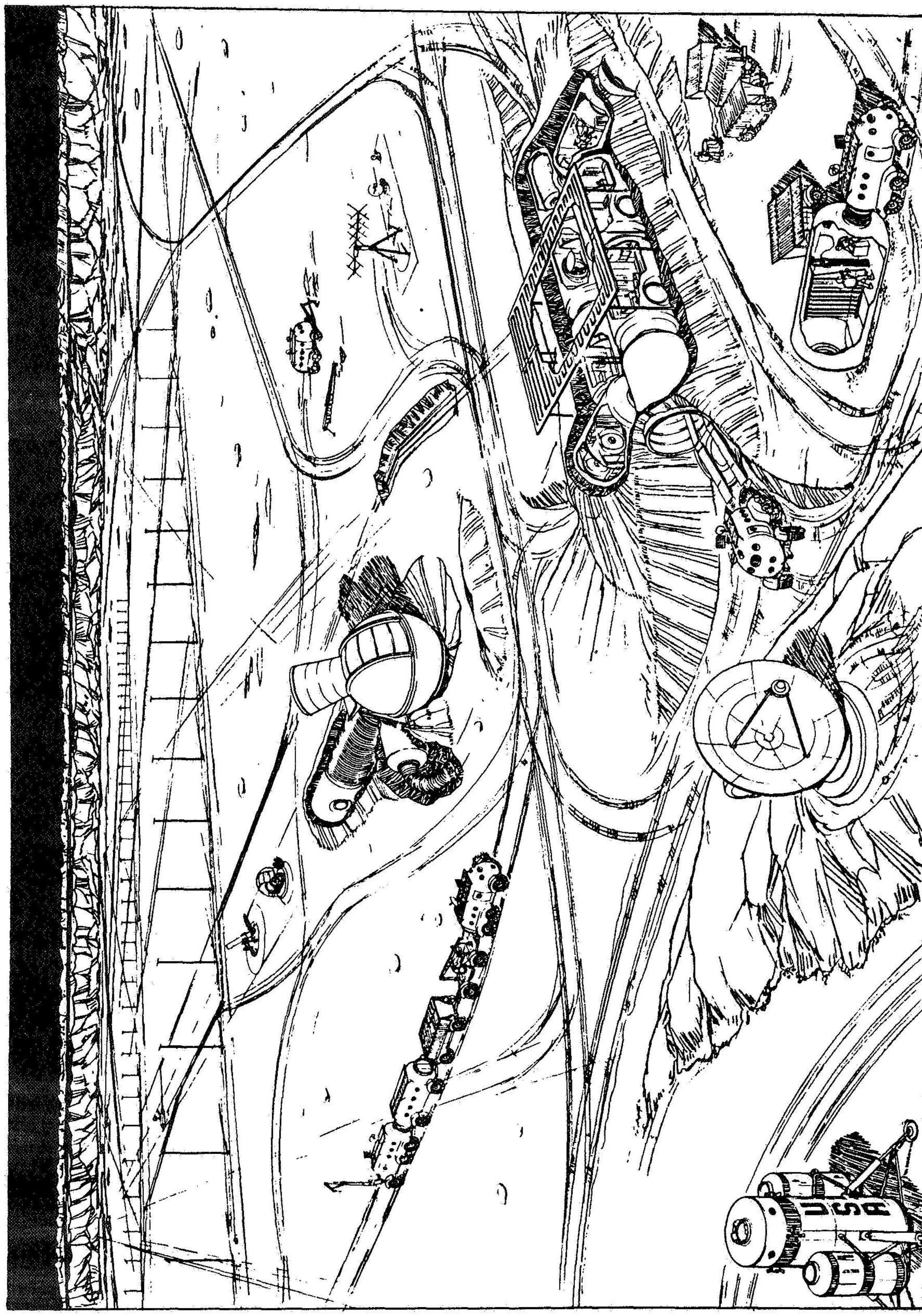


Figure 8.3-1. Lunar Surface Base Complex

Table 8.4-1. Lunar Surface Base Shelter - Baseline

ID No.	Module - Core		Weight (lb)
1XX-01	Crew and medical module - C&MM		8,290
1XX-02	Crew and operations module - C&OM		9,420
1XX-03	Sortie and transient crew module - S&TCM		8,820
1XX-04	Lab and backup command module - L&BCM		9,220
1XX-05	Assembly and recreation module - A&RM		7,570
1XX-06	Base maintenance module - BMM		6,260
1XX-07	Drive-in garage module - DGM		4,830
1XX-08	Drive-in warehouse module - DWM		5,050
	Basic shelter - 8 modules	Total	59,460
Auxiliary Modules			
1XX-09	Mobile cargo supply module - MCSM		980
1XX-10	Deep drill cover module - DDCM		4,350
1XX-12	Observatory shell module - OSM		4,580
1XX-13	Mobility equipment transport module - METM		4,080
Equipment			
1XX-11	Support operations equipment hardware		3,635

Table 8.4-2. Baseline Module Weight Summary

	C&MM 1XX-01	C&OM 1XX-02	S&TCM 1XX-03	L&BuCM 1XX-04	A&RM 1XX-05	BMM 1XX-06	DGM 1XX-07	DWM 1XX-08	MCSM 1XX-09	DDCM 1XX-10	SEOH 1XX-11	OSM 1XX-12	METM 1XX-13
Primary structure	3595	3595	3595	3595	4095	4295	4470	4270	900	4035		4271	4035
Furnishings and secondary structure	720	730	760	1200	468	389	53	548	80	14		8	45
Atmospheric mgmt. and crew services	3230	3240	3875	1670	1215	375	101	101	-	101		101	
Intercommunications and monitoring	31	31	31	31	56	31	31	31					
Electrical power distribution and control	235	930	225	770	280	235	175	100		200		200	
Command and control		894		102									
Medical facility	479												
Galley and backup galley			334		1456								
Laboratories				1852									
Base maintenance and repair						935							
Electrical power system											150		
• Wiring and plugs													
• Distribution and control													
Reliquefaction system											1818		
• Mounting structure													
• H_2/O_2 refrigeration/compressor													
• H_2/O_2 accumulators													
Launch and landing facility equipment											1405		
• Beacon/lights													
• Landing aids													
External communications equipment											262		
• Remote commun. antennas													
Total	8290	9420	8820	9220	7570	6260	4830	5050	980	4350	3635	4580	4080

Table 8.4-3. Baseline Detail Weight Summary - Structure

	C&MM		C&OM		S&TCM		L&BuCM		A&RM		BMM		DGM		DWM		MCSM		DDCM		OSM		METM	
	*Q	-01	Q	-02	Q	-03	Q	-04	Q	-05	Q	-06	Q	-07	Q	-08	Q	1XX-09	Q	1XX-10	Q	1XX-12	Q	1XX-13
Primary Structure	-	3595	-	3595	-	3595	-	3595	-	4095	-	4295	-	4470	-	4270	-	900	-	4035	-	4270	-	4035
•Cylinder	1	1170	1	1170	1	1170	1	1170	1	1170	1	1170	1	1170	1	1170	1	305	1	1170	1	1170	1	1170
•Closing bulkheads	2	900	2	900	2	900	2	900	2	900	2	900	2	900	2	900	2	160	2	900	2	900	2	900
•Wall covering	1	235	1	235	1	235	1	235	1	235	1	235	1	235	1	235	1	90	-		1	235	-	
•Docking ports/rings	-		-		-		-		-		-		-		-		2	80	-		-		-	
•Pressure doors	3	930	3	930	3	930	3	930	3	930	3	930	3	930	3	930	2	200	3	930	3	930	3	930
•Ceiling & floors	1	360	1	360	1	360	1	360	1	360	1	360	1	360	1	360	1	65	1	360	1	360	1	360
•Airlock and aux.press. wall	-								1	500	1	700	-	-	-	-	-		-		-		-	
•Veh. entry door provisions	-												1	625	1	625			1	625	1	625	1	625
•Veh. support tracks	-												-	100		50			-	50	-	50	-	50
•Drop panels and jacks	-												-	150		-								
Furnishings & Secondary Struct.	-	720	-	730	-	760	-	1200	-	464		389	-	53		548		80		14		9		45
•Secondary struct., fittings and hdw.	-	-	-	-		-		-		-		-		-		-		-		-		-		-
•Equip. brackets and mounts		390		510		360		590		364		64		53		48		80		14		9		45
•Storage cabinets		50		-		50		480		-		285		-		450								
•Chairs, desks, bunks, etc.		200		160		270		130		100		40		-		50								
•Partitions and fixtures		80		60		80		-		-		-		-		-								

*Q = Quantity

Table 8.4-4. Baseline Detail Weight Summary - Atmospheric Management

	C&MM		C&OM		S&TCM		L&BuCM		A&RM		BMM		DGM		DWM		DOCM		OSM	
	Q*	-01	Q	-02	Q	-03	Q	-04	Q	-05	Q	-06	Q	-07	Q	-08	Q	-10	Q	-12
Atmospheric Management and Crew Services	-	3230	-	3240	-	3875	-	1670	-	1215	-	375	-	101	-	101	-	101	-	101
•H_2 depolarizing cell	1	200	1	200	1	200	1	200												
•Sabatier reactor	1	38	1	38	1	38														
•Electrolysis cell/N_2H_4 dissa.	1	140	1	140	1	140	-	-												
•$H_2/O_2/N_2/N_2H_4$ tanks	-	1661	-	1661	-	1661	-	833												
•Catalytic burner/regen. charcoal	1	62	1	62	1	62	1	62												
•Water tanks	-	115	-	115	-	415	-	115	-	415										
•Reverse osmosis	1	28	1	28	1	28	1	28	1	28										
•Vapor compression	-	-	-	-	1	397	-	-	1	397										
•Thermal control	-	101	-	101	-	101	-	101												
•External radiator	1	170	1	170	1	170	-	-												
•Pressure control	1	32	1	32	1	32	1	32												
•Circulation system	-	60	-	60	-	60		60	1	60	1	60	1	60	1	60	1	60	1	60
•Temp & humidity control	-	150	-	150	-	150														
•Urinal/Dry John/shower	-	370	-	370	-	370	-	-												
•Emergency repressur. assy.	1	41	1	41	1	41	1	41	1	41	1	41	1	41	1	41	1	41	1	41
•Food reconstitution/fountain	-	62	-	62	-															
•First aid kit	-	-	1	10		10		10												
•Air shower/dust management/ pumpdown & APLSS recharge	-	-							-	274	-	274								

*Q = Quantity

Table 8.4-5. Baseline Detail Weight Summary - Intercommunications and EPS

	C&MM		C&OM		S&TCM		L&BuCM		A&RM		BMM		DGM		DWM		MCSM		DDCM		OSM		METM	
	Q*	-01	Q	-02	Q	-03	Q	-04	Q	-05	Q	-06	Q	-07	Q	-08	Q	1XX-09	Q	1XX-10	Q	1XX-12	Q	1XX-13
Intercommunications and monitoring	-	31	-	31	-	31	-	31	-	56	-	31	-	31	-	31	-	-	-	-	-	-	-	-
•Audio-visual-unit and TV camera	1	16	1	16	1	16	1	16	1	16	1	16	1	16	1	16								
•Hardwire intercommunications																								
•Remote data station	1	15	1	15	1	15	1	15			1	15	1	15	1	15								
•Remote data terminal									1	40														
•Emer. fire control and detection																								
•Preprocessors and RACU																								
•A&CS monitors																								
Electrical Power Distr. & Control	-	235	-	930	-	225	-	770	-	280	-	235	-	175	-	100				200		200		
•Primary buss, cabling and plugs																								
•Power switching and breakers																								
•Lighting and emergency batteries																								

*Q = Quantity

Table 8.4-6. Baseline Detail Weight Summary - Communications and Control

	C&MM		C&OM		S&TCM		L&BuCM	
	Q*	-01	Q	-02	Q	-03	Q	-04
Command and Control				894				102
• Data management				(268)				(---)
Central processor				20				
Operating and mass memory				150				
Archival memory				50				
Central timing				18				
Map and status board				30				
• Communications				(250)				(86)
Modulator/processor			1	50				
Central switch/test			1	40				
Audio recorder			1	15				
Facsimile unit			-	-				
TV camera			1	10				10
AVU monitor			1	18				18
Paging amplifier			1	10				
S-band transceiver			2	58				58
VHF transceiver			2	7				
VHF relay			1	7				
LF set (1 kilowatt)			1	35				
• Displays and consoles				(376)				(16)

*Q = Quantity

Table 8.4-7. Baseline Detail Weight Summary - Medical, Galleys and Labs

	C&MM		C&OM		S&TCM		L&BuCM		A&RM		BMM	
	Q*	-01	Q	-02	Q	-03	Q	-04	Q	-05	Q	-06
Medical Facility	1	477										
Galley and Backup Galley					-	344			-	1456		
•Microwave Oven					1	75			1	89		
•Resistance oven									1	119		
•Hotplate						10			-	-		
•Freezer									1	802		
•Refrigerator						165			1	178		
•Food reconstitution						59			2	59		
•Sink/fountain					-	22			-	22		
•Prep. utensils/trays/inventory									-	97		
•Dishwasher-dryer									1	90		
Laboratories							-	1852				
•Geochemistry lab								705				
•Photo lab								670				
•Data analysis lab								40				
•Bioscience lab								437				
Base Maintenance and Repair Station											-	937

*Q = Quantity

1.0 REQUIREMENTS COMPARISON

The possible existence of a modular space station (MSS) prior to the implementation of an LSB, makes it desirable to consider use of the same modules for both applications. There are two ways of approaching the objective:

1. Wait until the MSS designs are complete and then modify them for the LSB

2. Design them for both applications and provide special kits where differences exist

The latter is obviously the preferred concept so long as the functional requirements and operating stresses are nearly alike and the resulting application kits do not compromise the performance severely.

This section contains a requirements comparison to determine the scope and nature of these differences and their influence on the potential designs.

1.1 FUNCTIONAL COMPARISON

Requirements for the lunar surface base shelter and modular space station were compared to identify differences in design which would preclude interchangeability of the module elements. Functional and performance requirements for the mission and shelter system are listed in Table 1.1-1, and compared with the requirements for the OLS and MSS. The OLS comparison was listed but not evaluated. Throughout this comparison, it is assumed that the MSS requirements are equivalent to MSS capabilities. This assumption was required because a preliminary design has not been completed at this time. The requirements utilized for the comparison were those documented in Reference 4 as a result of the studies by NR of the MSS concept. The advantages and disadvantages of the MSS requirements with respect to the LSB requirements are indicated in the "credits" and "debits" columns, while the final column lists the tasks necessary to evaluate the interchangeability of the modules.

The primary purpose of this comparison was to define the broad areas of differences to provide a basis for a detailed comparison of subsystems where the specific hardware modifications can be identified. The results of this analysis indicate the differences in the areas of vehicle interfaces, structural load magnitudes and load paths, natural environment, storage volume, experiment program support, and the subsystems.

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison

LSB Shelter Requirements (1)	Optimized Shelter Requirement	OLS (2) Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB (3)
1. Mission Functional Requirements						
1.1 Initial mission						
1.1.1 Boost shelter to earth orbit EOS	Yes	Yes	Yes	None		None
1.1.2 Mate shelter and cislunar shuttle (CS) in earth orbit	Yes	Yes	No	No CS interface		Interface to be defined; mechanical electrical, radiation, and thermal
1.1.3 Boost shelter on translunar trajectory	Yes	Yes	No	No TLI boost loads		Define worst case boost loads considering also 1.15, 1.17, and 1.18
1.1.4 Translunar coast	Yes	Yes	No	No cislunar environment		Define worst case natural environment considering also 1.1.8
1.1.5 Deboost shelter into lunar orbit	Yes	Yes	No	No retro loads		See 1.1.3
1.1.6 Mate shelter and tug in lunar orbit	Yes	No	No	No tug interface		Define interface; see 1.1.2
1.1.7 Deboost shelter from lunar orbit	Yes	No	No	No retro loads		See 1.1.3
1.1.8 Land shelter on lunar surface	Yes	No	No	No touchdown loads		See 1.1.3
1.2 Resupply Missions						
1.2.1 - 1.2.8 Same as 1.1.1 - 1.1.8 for shelter cargo and cargo modules	Yes	No	No	a. No loads b. No cislunar environment c. No CS or tug interface		a. Define worst case boost loads (see 2.1.5, 2.1.7, and 2.1.8) b. Define worst case environment c. Define interfaces
1.2.9 Load and return cargo aboard tug	Yes	No	No	a. No tug interface b. No surf. vehicle interface c. Reduced airlock utilization	d. Increased docking port utilization	a. Define tug interface b. Define surface vehicle interface c. Verify MSS airlocks suitable for shelter d. Analyze design for possible simplifications
1.2.10 Boost return cargo to lunar orbit	Yes	No	No	No boost loads		1.2.10 - 1.2.14; see 1.2.1 - 1.2.8
1.2.11 Transfer cargo to CS	Yes	Yes	No	No CS interface		
1.2.12 Boost cargo on transearth trajectory	Yes	Yes	No	No boost loads		
1.2.13 Transearth coast	Yes	Yes	No	No cislunar environment		
1.2.14 Deboost cargo to earth orbit	Yes	Yes	No	No retro loads		

(1) Final MSS Requirements = EOS/MSS Requirements + LSB/MSS Requirements (SD 70-546-1, January 1971)

(2) MSS concept - listed for reference and not evaluated

(3) MSS is 14 feet by 31 feet module

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
2. Shelter Functional Requirements						
2.1 Provide shelter support to surface operations						
2.1.1 Remote exploration sorties						
2.1.1.1 Provide support to remote exploration sorties by providing the following personnel, equipment, or operations: crew quarters and consumables, equipment storage, field communications, sample analysis, data reduction and transmission, technician support, sample return, and crew rotation	Yes	Yes	No	MSS has no specific provisions to support remote sorties		Analyze MSS structure and subsystems for capability to provide this support
2.1.1.2 Surface vehicle maintenance between sorties to be done as IVA operations	Yes	No	No	MSS has no interface with surface vehicles		Define structure and subsystems for MSS to perform this maintenance
2.1.1.3 Maximum overlap between remote sorties shall be two weeks	Yes	No	No	MSS not designed to this explicit requirement		Define LSB maintenance and mobility concepts to satisfy this requirement and crew scheduling, training, and rotation logistics operations
2.1.2 Observatory operations						
2.1.2.1 Provide support to observatory operations by providing the following personnel, equipment, or operations: crew quarters and consumables, data reduction and transmission, tech. support and crew rotation	Yes	No	Yes		MSS satisfies this requirement with different hardware than LSB	Analyze MSS subsystems for capability to satisfy this requirement
2.1.2.2 The shelter shall be located in close proximity to the observatory to provide maximum support	Yes	No	No		MSS trajectory designed to be remote for telescopes to minimize interference	Analyze MSS subsystems for unnecessary comm., guidance, and attitude controls and displays
2.1.2.3 The observatory shall be automated to minimize routine crew support requirements, but to utilize crew for complex operations	Yes	No	Yes		MSS designed to control more telescopes, each automated to a higher order than the LSB	Analyze MSS subsystems for unnecessary automated controls
2.1.3 Shelter experiments						
2.1.3.1 Provide support to the experiments program at the shelter by providing the following personnel, equipment, or operations: crew quarters and consumables, equipment storage, remote equip displays and controls, data reduction and transmission, expmt power, technician support, sample return, and crew rotation	Yes	Yes	Yes		MSS designed to support different but more extensive internal experiments	None

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
2.1.3.2 Provide a contamination-free area accessible to the shelter for external experiments	Yes	No	No			None - not a shelter configuration requirement, but included here as a site layout requirement
2.1.4 Deep drilling						
2.1.4.1 Provide support to the drilling operations by providing the following personnel, equipment or operations: crew quarters and consumables, equip storage, communications with field, sample analysis, drilling power, rig and crew transportation, data analysis and transmission, sample return, and crew rotation	Yes	No	No	MSS not designed to support these requirements		Analyze MSS subsystems and define changes necessary to satisfy this requirement
2.1.4.2 Deep drilling operations are to be conducted as IVA operations to reduce drilling time	Yes	No	No	MSS not designed to support IVA drilling		Define MSS changes required to meet this requirement
2.2 Shelter functions						
2.2.1 Up payloads						
2.2.1.1 Ingress personnel in shelter living quarters	Yes	Yes	Yes		MSS satisfies this requirement with different equipment than LSB	Verify MSS equipment satisfactory for LSB
2.2.1.2 Stow cargo in shelter warehouse	Yes	No	No	MSS does not transfer cargo from cargo module to warehouse		Analyze MSS cargo transfer system for applicability to LSB
2.2.2 Routine operations						
2.2.2.1 Perform housekeeping operations	Yes	Yes	Yes		"	Verify MSS equipment satisfactory for LSB
2.2.2.2 Inspect, maintain, repair and check out shelter subsystems	Yes	Yes	Yes		"	"
2.2.2.3 Assemble and check out post-buildup shelter modules for subsequent growth	Yes	No	Yes		"	"
2.2.2.4 Inspect, maintain, repair and check out mobility equipment, suits, and science and support equipment	Yes	Yes	Mobility equip--No Suits--Yes Science equip--Yes Support equip--Yes		"	"
2.2.2.5 Inspect, maintain, repair and check out tugs which support LSB	Yes	Yes	No	MSS not supported by tug -- uses EOS		Analyze MSS subsystems and crew support capabilities to satisfy this requirement

Table 1.1-1. Lunar Surface Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
2.2.2.6 Provide laboratories for geosciences, photography, and data analysis	Yes	Yes	Geosciences -- No Photography -- Yes Data analysis -- Yes		MSS satisfies this requirement with different equipment than LSB	Verify MSS equipment satisfactory for LSB
2.2.2.7 Provide living quarters, work-space, medical facilities, galley, recreation, and control center	Yes	Yes	Yes		"	"
2.2.2.8 Provide storage volume for scientific and support equipment, suits, and crew and equipment consumables	Yes	Yes	Yes		"	"
2.2.3 Management						
2.2.3.1 Monitor and control landing and launch operations . Timing . Flight parameters . Tracking . Communication	Yes	Yes ①	Yes ②		"	"
2.2.3.2 Monitor and control the experiments program . Sci. payload composition (in and out) . Experiment sequencing . Data evaluation	Yes	Yes	Yes		"	"
2.2.3.3 Monitor and control LSB operations . Support equipment payload composition (in and out) . Task scheduling	Yes	Yes	Yes		"	"
2.2.3.4 Perform autonomous operations. Shelter must be capable of 180 days operation without resupply . Increased spares requirements . Increased computer support requirements . Increased crew skills mix . Increased subsystems and experiment equipment and operations data bank . Increased surf. comm. requirements (no manned earth relay) . Increased req. for auto. on-board checkout and displays	Yes	180 days	120 days		"	"

① Assumes rendezvous and docking control functions similar to landing and launch functions

② Independent of earth assistance or control

Table 1.1-1. Lunar Surface Shelter and Modular Space Station Requirements Comparison Matrix (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirements	OLS Requirements	MSS Requirements	MSS Debits	MSS Credits	Action Required To Make MSS Compatible with LSB
2.2.3.5 (Ref. I.2.03) (1) Management of long-range general mission planning for the shelter will be done on the ground	Yes	Yes	Yes			None
2.2.3.6 Principal investigators will not, in general, be located at the LSB	Yes	Yes	Yes			None
2.2.4 Safety functions						
2.2.4.1 Protect personnel, cargo and equipment from lunar environment . Radiation . Meteoroids . Seismicity	Yes	No	No	MSS not optimized for lunar surface environment		Analyze MSS design for capability to satisfy this requirement
2.2.4.2 Provide alternate operational capabilities in event of equipment loss, malfunction, or failure	Yes	Yes	Yes		MSS satisfies this requirement with equipment and operations different than LSB	Analyze MSS failure modes and corrective action procedures and equipment for suitability to LSB requirements
2.2.4.3 (Ref. B 2.11) (1) Hazardous material, potentially explosive containers, or volatile gas containers shall be structurally isolated from crew living and operating quarters, and shall be protected so a failure of one will not propagate to another	Yes	Yes	Yes			None
2.2.4.4 (Ref. B 1.3) The shelter shall be divided into pressurized areas so that any damaged module can be isolated as required. Accessible modules will be equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action to repair or reduce the damaged module	Yes	Yes	Yes			None
2.2.4.5 (Ref. B 2.6) Two or more entry-access paths shall be provided to and from every compartment or other area with restricted access	Yes	Yes	Yes			None
2.2.4.6 (Ref. B 2.8) Primary pressure structure materials shall be nonflammable. Interior walls and secondary structure shall be self-extinguishing	Yes	Yes	Yes			None
2.2.4.7 Provide capability to rescue personnel and equipment from remote and inaccessible locations	Yes	Yes	Yes		MSS satisfies this requirement with equipment different than LSB	Analyze MSS rescue concepts and operations for applicability to LSB
2.2.4.8 All walls, bulkheads, hatches and seals whose integrity is required to maintain pressurization shall be readily accessible for inspection and repair by crewmen in pressurized suits	Yes	Yes	Yes			None
2.2.4.9 (Ref. B 2.14) All EVA and unpressurized compartment IVA shall be conducted using the "buddy system". The buddy system shall also be used during shirtsleeve operations in hazardous areas.	Yes	Yes	Yes			None

(1) MSS Guidelines and Constraints Document, MSC-03696, Rev. 1, 8 Feb. 1971

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
2.2.4.10 Contingency provisions and habitable facilities shall be adequate to sustain the primary crew plus a replacement crew for one CS minimum turnaround cycle (Ref. B 1.4)	Yes	Yes	2 days	Insufficient storage		Provide larger crew consumables and storage volume
2.2.4.11 (Ref. B 1.5) Atmospheric stores and subsystem capacity sufficient for one repressurization shall be maintained on the shelter to independently supply each pressurized volume to sustain the entire crew	Yes	Yes	Yes			None
2.2.4.12 (Ref. 1.110) As a goal, no single malfunction or credible combination of malfunctions and/or accidents shall result in serious injury to personnel or to crew abandonment of the shelter	Yes	Yes	Yes			None
2.2.5 Down payloads						
2.2.5.1 Package, store, and unload cargo from shelter for return flight	Yes	Yes	Yes		MSS satisfies this requirement with different equipment than LSB	Verify MSS equipment satisfactory for LSB
2.2.5.2 Egress personnel from shelter for return flight	Yes	Yes	Yes		"	"
3.0 Mission Performance Requirements						
3.1 Earth orbit parameters for EOS and CS shall be 258 n mi altitude at 31.6° inclination to equatorial plane	Yes	Yes	240-270 n mi 55°			None - Inclination not driver plus short stay in this orbit
3.2 Lunar orbit parameters for CS shall be 60 n mi altitude with inclination a function of site latitude	Yes	Yes	No			None - Short stay in this orbit
3.3 Shelter launch date shall be January, 1985	Yes	1982	1978			None
3.4 Shelter resupply interval shall be 164 days	Yes	109 days	30 days	MSS not designed for this resupply interval		Provide larger warehouse storage volume
3.5 Half of each crew will be rotated every resupply interval	Yes	Yes	Variable			None - will not affect design
3.6 Individual crew stay times will be 324 days	Yes	234 days	180 days			None - will not affect design
3.7 Shelter shall be capable of normal internal operations and external mission support throughout lunar day and night, particularly surface EVA	Yes	No	No		MSS satisfies this requirement with different equipment than LSB	Verify MSS equipment satisfactory for LSB. Also verify MSS compatible with LSB site lighting
3.8 Shelter will be delivered unmanned	Yes	Yes	Yes			None
3.9 Directional orientation of the shelter on the surface is not critical from a mission viewpoint and may be determined by the local terrain; therefore, no orientation restrictions shall be imposed by shelter subsystems	Yes	Yes	Yes			None
3.10 Shelter shall be capable of full operations for any accessible, nonhazardous location on the lunar surface	Yes	No	No	MSS not designed for surface environment		Analyze MSS structure and subsystems for compatibility with environment extremes at equator, poles, near side and far side

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirement	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
4.0 Shelter Performance Requirements						
4.1 Shelter useful life on lunar surface shall be 10 years with resupply of consumables and replaceable equipment	Yes	No	No	MSS operations and environment significantly different than LSB		Analyze MSS structure and subsystems for long life compatibility with lunar surface and subsurface environment, corrosion protection and dust accumulation (internal)
4.2 Shelter shall be designed for a normal crew complement of 12	Yes	8	Yes			None
4.3 The shelter and its resupply cargo modules and crew shall be delivered to the lunar surface via the EOS, CS and space tug. Crew and cargo will be returned to earth in reverse order	Yes	Yes	No	MSS primary interface is with EOS, not CS or tug		Analyze MSS structure and subsystems for interface capability with CS and tug
4.4 Maximum cargo module weight shall not exceed 20,000 pounds	Yes	Yes	Yes			None
4.5 Maximum integral shelter component dimensions are limited by EOS to a cylinder 15 ft dia x 60 ft long	Yes	Yes	Yes			None
4.6 Boost loads and attach points shall match EOS capabilities	Yes	Yes	Yes			Verify hard points do not affect module operations
4.7 The shelter shall be capable of quiescent operation; i.e., subsystem and equipment shutdown and subsequent restart for multiple period up to one year each	Yes	No	No	MSS designed for continuous manned operations		Analyze MSS subsystems for compatibility with restart requirement
4.8 The shelter reliability over the 10-year mission shall be sufficient to preclude premature termination of the mission, or serious injury to any crewman, or severe damage to equipment	Yes	Yes	Yes			None
4.9 Shelter design will not preclude growth to a larger size base	Yes	Yes	Yes			Verify MSS can be assembled into LSB config., and that config. expansion is possible
4.10 Solid and liquid waste material will be stowed in sealed, unpressurized containers and transported to a remote area for disposition	Yes	Return to earth or lunar surface	Yes		MSS designed to return solid wastes to earth	Define waste stowage concept and design for LSB
4.11 Shelter design will permit continuous shirtsleeve operations in a 3.5 psia O_2 - 6.5 psia N_2 atmosphere	Yes	14.7 psia	14.7 psia		MSS has 4.7 psia higher pressure loading	Verify MSS + subsystem compatible with lower pressure
4.12 Shelter hardware interchangeability with the modular space station hardware is a design goal to minimize development costs. Primary objective is common housing and cargo modules and subsystems	Yes	Yes	Yes			Verify MSS structure, subsystems and operations compatible with LSB
4.13 Continuous two-way voice communications capability will be maintained between the shelter and earth and between the shelter and remote exploration crews	Yes	No	No	MSS communications system performance requirement substantially different than LSB		Analyze MSS communications subsystem for capability to satisfy LSB requirements

Table 1.1-1. Lunar Surface Base Shelter and Modular Space Station Requirements Comparison (Cont'd)

LSB Shelter Requirements	Optimized Shelter Requirement	OLS Requirement	MSS Requirement	MSS Debits	MSS Credits	Action Required to Make MSS Compatible with LSB
4.14 Shelter buildup operations to the 12-man capability will be completed within 6 months from initial launch	Yes	No	No		MSS has much slower buildup	None - operational difference only
4.15 Shelter shall be firmly anchored to lunar surface to minimize relative motion of modules	Yes	No	No	MSS structural alignment and support through docking ring only		Analyze MSS docking ring for possible weight reductions. Analyze MSS structure for foundation attach and jacking points

1.2 DEFICIENCIES DEFINITION

The preceding requirements comparison identified areas where requirements differences could exist due to mission stress and functional differences. These data have been used to identify the subsystems selections to be compared. The tables in this section identify the potential subsystem deficiencies, a detailed discussion for which is presented in subsequent Sections 2.0 and 3.0 as referenced by paragraph number under the column labeled "impact" in the following tables. Additional details of the analyses are contained in Appendix D to this Volume.

Table 1.2-1 presents a comparison of the atmospheric management subsystem functions. Most functions are similar in the concept stage. See Section 2.1 for a detail comparison.

Table 1.2-2 presents a comparison of the crew services subsystem functions. Most of these functions are similar; see Section 2.2 for details.

Table 1.2-3 presents a comparison of the electrical power subsystem functional capabilities. These data indicate significant differences in both the source concept selection and the average power required. Only the ac and dc voltages and the impact on the distribution systems within the modules are similar. Section 2.3 discusses the resultant modification requirements.

Table 1.2-4 presents a comparison of the communications system functions. Although the functional usage varies considerably, the resulting hardware requirements are similar in many respects. Section 2.4 defines the modifications including the lack of some hardware requirements.

Table 1.2-5 compares the data management functions. The conceptual differences identified are numerous; however, the impact of an LSB derivative may be very slight since the functional capabilities are similar. See Section 2.5 for details.

Table 1.2-6 compares the structural aspects of the baseline modules. Many of the recommended characteristics are similar; however, the docking concept is a key issue since the proposed MSS concept may not satisfy the LSB requirement.

Table 1.2-1. Subsystem Comparative Analysis, MSS vs. LSB, Atmospheric Management Functions

SYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
Atmospheric Content			
Pressure	14.7 psia	10 psia	Para. 2.1.1
O_2 Content	3.1 psia	3.5 psia	2.1.1
N_2 Content	11.6 psia	6.5 psia	2.1.1
Leakage	30 #/day	12 #/day	None
Ingress/Egress			
Airlock Facility	Single one-man	Two multi-men	2.1.2
Dust Control	None	Integrated Airlock control	2.1.2
Trace Control			
Removal	Charcoal/Cat.burner	Same	None
Monitor	Mass spectrometer	Same	None
CO_2 Management			
Removal	H_2 Depolarized cell	Same	None
Recovery	Sabatier reactor	Same	None
Electrolysis	Solid polymer	Same	None
Atmospheric Source			
O_2	Water Elec.	Same	None
N_2	Cryogenic	Hydrazine elec.	2.1.3
H_2	Cryogenic	Hydrazine elec.	2.1.3
Humidity Control	Heat Exch. w/9" ducts	Same	None
Thermal Control			
Insulation	MLI	Lunar soil	2.1.4
Coolant Loop	Water inside	Same	None
	Freon outside	Same	None
Radiators	Integrated structure	Separate units	2.1.5
Fire Control	CO^2 extinguisher	Same	None

Table 1.2-2. Subsystem Comparative Analysis, MSS vs. LSB, Crew Services Functions

SYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
Water Management			
Urine Recovery	Vapor compressor	Same	None
Wash Recovery	Reverse osmosis	Same	None
Storage Containers	106°F, silver ions	Same	None
Resupply	"Wet" food	Same	None
Waste Management			
Biological	Dry John	Same	None
Trash	Dryer/compactor	Bury	2.2.1
Hygiene			
Wash	Chamber sink	Standard lavatory	2.2.2
Shower	Zero "g" design	Standard shower	2.2.2
Housekeeping	Portable vacuum cleaner	Same	None
Food Management			
Storage	Freezer/refrigerator	Same	None
Preparation	Microwave/resistance	Same	None
Cleanup	Recon. Unit	Same	None
Backup Provisions	Freeze dry foods	Same	None
Crew Provisions			
Cloths	Disposable	Same	None
Medical/Dental	Medical & dental fac.	Same	None
Crew Furnishing			
Design Criteria	Zero g	1/6 g	Insignificant
Consumables	120 days	180 days	2.2.3
Storage	Separate large modules	Same with increased capacity	2.2.4

Table 1.2-3. Subsystem Comparative Analysis, MSS Vs. LSB, Electrical Power Functions

SYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
Main Source	Solar Cells/Fuel Cells	Isotope organic rankine	FP 2.3.1
Backup Source	Fuel Cells	Thermoelectric	FP 2.3.2
Average Power	26 Kw - centralized	21 Kw - dispersed	None
Energy Storage	67 KAH - central	100 KAH - dispersed	FP 2.3.3
Power Levels			
. AC	120/208	Same	None
. DC	56	Same	None

Table 1.2-4. Subsystems Comparative Analysis, MSS Vs. LSB, Communications Functions

SYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
MSFN Link	S-band semi-direct*	S-band - hi gain	¶ 2.4.1
Log Vehicle Link	S-band omni	S-band omni	None
LSB to Surface	None	VHF omni and LF	¶ 2.4.2
Entertainment	Audio/video	Audio/video	None
Data Cont.	Modulation processor	Same	None
	Central timer	Same	None
	Audio & visual recorder	Same	None

*Early station. Later stations may use 13-ft high gain antenna for TDRS link.

Table 1.2-5. Subsystem Comparative Analysis, MSS vs. LSB, Data Management Functions

SYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
Data Processor	Central & local general purpose	Central general purpose	Insignificant
	Operation 1-10 psec	Operation 1-10 psec	2.5.1
Input/Output	10 MBPS/64 ch	Same	None
Operating Memory			
Type	Plated wire	Thin film	Insignificant
Word length	32 Bits	Same	None
Capacity	32 K words/unit	186 K words/unit	2.5.2
Mass Memory			
Type	Plated wire	Thin film	Insignificant
Word length	32 Bits	Same	None
Capacity	128 K words/unit	> 226 K words/units	2.5.3
Archival Memory			
Type	Tape	Holographic	2.5.4
Word Length	32 Bits	Same	None
Capacity	2.4×10^9 bits/Cart.	Unlimited	2.5.4
Remote Terminals	1000 characters, B&W on color TV	Same	None
Commercial Console	Color CRT, Alpha-numeric display, hand controls, monitor & alarm	Essentially the same	2.5.5

Table 1.2-6. Subsystem Comparative Analysis, MSS Vs. LSB, Structural Components

SUBSYSTEM FUNCTION	MSS BASELINE	LSB BASELINE	IMPACT
Baseline Module Size	14 ft. dia. x 31 ft. long	15 ft. dia. x 30 ft. long	₱ 3.1.1
Meteoroid Protection	External bumper	Lunar soil	₱ 3.1.2
Deck Arrangement	Single longitudinal with lower level aisle	Single longitudinal with center aisle	₱ 3.1.3
Docking Adapter	Male/female concept	Neuter concept	₱ 3.1.4
Wall Construction	Glass/foam/.040 Al.	Same	None
Floor Construction	Honeycomb Sandwich	Same	None
Hatch Mechanism	Overhead rail storage	Same	None

1.3 SAFETY INFERENCES

A review of the MSS and LSB safety criteria indicates that the requirements are similar in nature, although the method of implementation changes in some areas. These differences are associated with the differences in location and environment. For example, while the meteoroid and solar flare environments are more severe on the lunar surface, the use of lunar soil with the MSS derivative will solve the problem without impacting the design.

The required consumables margin and its impact on storage facilities must be increased from the MSS 48-hour limit to the LSB 28-day limit as set by the minimum turnaround time for the logistic systems. Further, these consumables must be limited to those that will survive room temperature/pressure conditions, such as freeze dry foods and water. This requirement stems from the from the long logistic lines between the earth and moon systems.

One major difference exists in the safety philosophy. The earth orbit missions depend on an abort capability to relieve some emergencies. For the LSB the difficulty of providing a readily available return link all the way to earth and the relatively safer lunar shelter environment makes it more desirable to remain on the surface and plan around the emergency.

2.0 SUBSYSTEM MODIFICATION DEFINITION

This section discusses the impact of the subsystem differences identified by Tables 1.2-1 through 1.2-6 of Section 1.0. Where a function is not discussed, the MSS subsystems are identical to those selected for the baseline LSB and the rationale for selection has been covered in Sections 4.0 through 7.0 of Part 1, Volume III.

2.1 ATMOSPHERIC MANAGEMENT SUBSYSTEM MODIFICATIONS

The following factors influence the MSS atmospheric management subsystem if it were to be used as an LSB subsystem.

2.1.1 Atmospheric Content

The atmospheric content should be reduced to the 10 psia (3.5 O_2) recommended LSB level because of the impact on personnel safety. The large EVA budget necessitates many ingress/egress operations and crew embolism is a very real possibility if the base were operated at an N_2 pressure higher than recommended. This should not impact the hardware; but rather be a simple adjustment, particularly if the hardware were designed for it.

2.1.2 Ingress/Egress

The ingress/egress provisions for the MSS are inadequate for an LSB operation. The LSB application requires provisions for from four to six men to enter and leave together and to deal with the lunar dust during each ingress operation. Provisions are also required for shirtsleeve vehicle maintenance and a drive-in warehouse.

An examination of the MSS modules indicates that there are no modules proposed that would meet these LSB requirements and any modifications would be so extensive as to involve a complete redesign. These requirements, probably necessitate a new module over and beyond those designed specifically for the MSS.

2.1.3 Atmospheric Source

The nitrogen and hydrogen gas resupply requirements for the LSB are modest but important. The recommended LSB concept involves disassociation of hydrazine rather than cryogenics as the MSS proposes. Cryogens could be used for the LSB, but are not recommended because of the long supply line and the attendant handling problems. Conversely, MSS trades could result in using hydrazine since it is also a good Reaction Control System propellant. It is, therefore, recommended that hydrazine disassociation be added to the MSS derivative shelter and the shipping containers in the cargo modules be designed accordingly.

2.1.4 Thermal Control - Insulation

Insulation for the LSB modules is primarily provided by covering them with lunar soil. This will eliminate the need for multi-layer internal insulation. The influences of exposed surfaces such as the hatches for the airlocks and the garage doors remain to be considered. These must be treated as a heat loss during the lunar night but can be shielded during the day so that minimum heat would be gained. Elimination of the MLI eliminates a construction problem and an internal handling problem. Use of an externally deployed insulation such as soil provides a uniform insulation media, completely independent mounting points with the only "penetration" being those required for access.

2.1.5 Thermal Control - Radiators

The space radiators for LSB applications must be deployed horizontally and parallel to the lunar surface so that they will not "see" the lurain. Any other orientation can result in a heat gain rather than loss during the lunar day.

The MSS modules, when used for LSB application must be modified to use separately deployed radiator sections. These sections form an additional design requirement.

2.2 CREW SERVICES SYSTEMS MODIFICATIONS

The major portion of the crew service functions defined for MSS will satisfy the LSB mission requirements. The following modifications are proposed to optimize the resulting mission system concept.

2.2.1 Trash Disposal

Trash disposal for an LSB mission could best be handled through use of a "lunar dump", utilizing one of the local craters or one of the empty cargo modules. Either concept eliminates a function from an MSS module, simplifying its design and manufacturing.

2.2.2 Hygiene

Hygiene on the lunar surface is simplified by the low but significant gravitational force, as opposed to the zero-gravity MSS situations. The MSS systems are designed for zero-g operations but will work better under the influence of a gravitational field. However, the potential designs make them heavier and more complex than optimum for the LSB situation. Some modifications or a common design would optimize the concept; however, modifications are not essential to their use in the LSB.

2.2.3 Consumables Storage

Consumables storage must be increased from a 12-man capability for 120 days to at least 180 days capability. Further, the emergency stores capability must be increased from the MSS 48-hour limit to the 28 days for the LSB established by the estimated turnaround time for the logistics system. This requirement does not necessarily impact the use of MSS shelter modules, but rather the warehousing size.

2.2.4 Cargo Modules

Both the MSS and the LSB use separate cargo modules. The MSS mission concept involves use of two cargo modules, a manned and unmanned version. Both provide the same contained volume, much of which is dedicated to the cryogenic storage and systems. The unmanned version can carry 8000 pounds of dry bulk cargo and 4200 pounds of cryogens; the passenger version can carry only 4500 pounds of dry bulk cargo plus 2400 pounds each of cryogens and passengers. Since the LSB concept does not require cryogens and at the recommended resupply interval, requires delivery of more than twice these amounts, the MSS cargo modules not suffice as presently designed. Increased packing densities and/or modified tanks may make this use feasible.

2.3 ELECTRICAL POWER SUBSYSTEM (EPS) MODIFICATIONS

A comparison of the MSS and LSB electrical power system requirements indicates differences that are difficult to reconcile. The LSB requires large amounts of power at widely dispersed locations while the MSS requirements are centralized. These factors lead to rejection of the MSS power source for the LSB application. However, the individual module distribution and control systems may be compatible.

2.3.1 Main Source

The MSS EPS source involves use of a solar array for primary power with nickel-cadmium batteries for storage on the dark side. The concept is impractical for LSB applications as indicated in Section 5.0, Part 1 of this report. The batteries required for storage of energy for the 14 days of darkness compared the 45 minutes for MSS would necessitate a vast increase of batteries. Obviously, another approach is required and the mobile modular isotope organic Rankine concept selected for the LSB, is also recommended for the MSS derivative by virtue of the same reasoning previously described.

2.3.2 Backup Source

The backup EPS proposed for MSS involves use of fuel cells which require the resupply of cryogens. Since the MSS derivative will use the mobile isotope organic Rankine as its main source, use of the backup thermoelectric converter is more desirable. It adds only 150 pounds per modular unit, requires no maintenance, and provides 1.2 kwe per unit for a total of 7.2 kwe for the LSB. Since it utilizes the same heat source as the main power source, it requires no resupply beyond that for the main source. The fuel cell-cryogenic concept would add over 150 pounds to the system and require one pound of reactants per hour of operation per system, or about 4032 pounds for cryogens plus tankage for the 28-day emergency cycle.

2.3.3 Energy Storage

The energy storage capability of the MSS is provided by 672 hundred ampere-hour batteries. In tandem, they provide a total of 67k ampere-hours. The selection of the nickel-cadmium type is compatible with the large number of charge-discharge cycles required to satisfy the LSB mobility requirement. The LSB planned capability for the baseline is a total of 100k ampere-hours distributed between the mobile power units and the base modules. Although the capacity required for the LSB application will increase to a total of 1000 hundred ampere-hour batteries, the type of cell need not.

2.4 COMMUNICATIONS SUBSYSTEM MODIFICATIONS

The MSS communication system is centered around a low power S-band concept. While the LSB requirements are more diverse, and some require more power, the differences are relatively minor in the detailed hardware and for the most part can be rectified by some additional components to provide the additional radiated power.

2.4.1 MSFN Link

The MSFN link requires an effective system gain of over +39 db while the early MSS gain is limited to about -31 db for the same bandwidth (4.5 MHz). Although this MSS system will not satisfy the LSB mission requirement, the addition of a power amplifier and a high-gain directional antenna (with a 10 to 13-foot dish) will provide the capability. The 13-foot dish may be incorporated in a later version of the MSS to provide a link through the TDRS system. This antenna system may be too sophisticated for the LSB requirements.

2.4.2 LSB Surface Links

The LSB surface links do not have a counterpart in the MSS concept. This deficiency results in the need to add several VHF transceivers to both the command center and the backup center. The LF emergency link is not essential but is desirable for safety and should also be added.

The resulting modifications required to the MSS communications facilities are identified by Table 2.4-1. A close examination indicates that as many elements are deleted as are added.

2.5 DATA MANAGEMENT SUBSYSTEM MODIFICATIONS

The data management functional requirements for the MSS are better defined than are those for the LSB. The wide variation in potential LSB requirements make it difficult to identify any potential deficiencies in the selected MSS concepts. From Table 1.2-5 and Figure 2.5-1, it may be seen that on a conceptual basis the proposed system functions are very similar. The following exceptions are noted, but do not necessarily infer a design change.

Table 2.4-1. Communication Systems Comparison - MSS and MSS Derivative LSB

System Component	Module Location - MSS Has/LSB Requires						Total Required (for LSB)
	Core	Crew #1	Crew #3	Galley	Control #1	Control #2	
Semi Dir. Antenna	3/0				2/0	2/0	0
High Gain Antenna					0/2	0/2	4
Approach Radar					2/0	2/0	1*
VHF Omni					0/2	0/2	4
Transponder (S-Band)	3/0				2/2	2/2	4
Power Amp "					0/2	0/2	4
Modulators Processor					1/1	1/1	2
VHF Tranceiver					0/2	0/2	4
Central Switch Unit					1/1	1/1	2
Hard Wire Intercom	1/1	1/1	1/1		1/1	0/0	4
Audio Visual Unit	4/4	4/4	4/4	4/4	5/5	5/5	26
Rock					1/1	1/1	2
Video Recorder					1/1	1/1	2
Audio Recorder					1/1	1/1	2
Facsimile Unit					1/1	1/1	2
TV Camera					1/1	1/1	2
TV Monitor		4/4	4/4	2/2	1/1	1/1	12
Paging Amplifier					1/1	1/1	2

*At landing site not in LSB

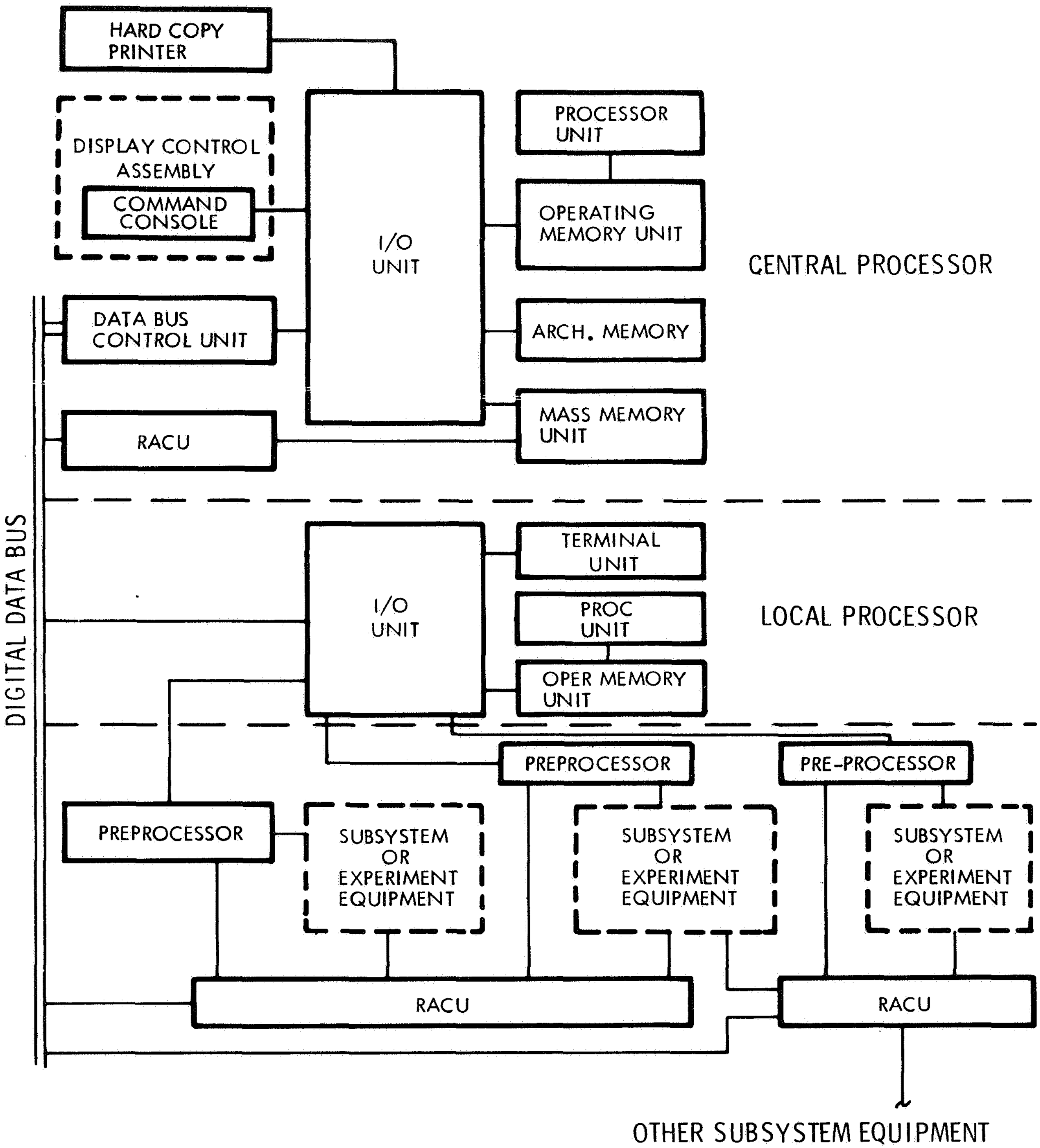


Figure 2.5-1. MSS Derivative LSB Mechanization Diagram, Data Processing

2.5.1 Data Processor

The data processor concept for the MSS involves use of three levels of processing. This concept divides the workload and permits simple functions such as systems control to be performed locally by a preprocessor, which weighs only three pounds, requires about ten watts of power, and requires no special cooling. The local processor has a larger memory plus a software assembly, permitting it to perform more detailed operations. It weighs 12 pounds and requires about 15 watts. It is a dedicated processor, designed to facilitate the functions of the particular module and, therefore, may require modifications. The central processor is similar to the one proposed for the baseline LSB. The differences in the processors are in the complexity factor alone. The MSS concept should perform the LSB functions with changes in software alone since it is a more sophisticated approach.

2.5.2 Operating Memory

The operating memory proposed for the MSS is plated wire in contrast to the thin film recommended for the baseline LSB. However, either one will meet the LSB requirements. The thin film memory may require a longer development cycle, but results in a lighter weight per unit bit and should be less costly overall. The storage capacity of an MSS single unit central processor is 32k words as contrasted to the LSB 186k words (both are based on a 32-bit word). However, the MSS system with its three levels of processing actually provides about 380k words of operating memory, some of which is convertible into mass memory. As a result, the decentralized MSS concept will more than satisfy the projected LSB requirement.

2.5.3 Mass Memory

The mass memory proposed for the MSS is also a plated wire concept versus the thin film proposed for the LSB; however, either is considered acceptable for both applications. The storage capacity is also lower than that specified for the LSB central processor, but use of the decentralized concept and the resulting division of storage requirements to the local and preprocessors appear to compensate completely for the difference.

2.5.4 Archival Memory

The archival memory concept proposed for the MSS uses conventional tapes. The recommendation for the baseline LSB was the advanced holographic concept because of the substantial reduction in weight, over two orders of magnitude less per bit. The tape concept can be used for the LSB mission but it may impact the logistic system if large amounts of data are required to be returned to earth.

2.5.5 Command Console

The command console provides the ability to control station operations and experimentation. Since both the station operations and the character of the experiment programs are quite different, it is reasonable to assume that extensive modifications of both the hardware and associated software will be required. The specific nature of these modifications are unknown since the console is not defined in sufficient detail. However, modifications will include deletion of any vehicle control functions and the additional of outpost and sortie systems monitor functions. The approximate size and complexity of both the command center console and the backup or experiment control console are expected to be similar to the corresponding MSS units.

3.0 MSS MODULE APPLICATIONS POTENTIAL

Use of the MSS structure for LSB applications appears to be feasible. The analysis of the potential differences reflected in Table 1.2-6 indicates that the differences are not difficult to resolve and should not impose a compromise to either mission if they were designed for both.

3.1 MSS STRUCTURAL INFERENCES AND MODIFICATIONS

The baseline structural concepts envisioned for the MSS and the LSB employ many similar features. The cylindrical shape, similar length and diameter, docking provisions, and use of ellipsoidal bulkheads are examples. The module size, meteoroid protection, deck arrangement, and docking adapter concept were examined in some detail and are major factors affecting the use of these modules for the LSB. The conclusion reached is that the structural modifications required are relatively minor and involve only the removal of the meteoroid bumper and provision of a suitable docking/handling interface. Some additional changes are recommended for the MSS baseline concept which would enhance the subsequent adaptation for an LSB shelter but are not essential.

3.1.1 Module Size

The MSS baseline module concept as defined in Reference 4, is illustrated by Figure 3.1-1. All of the various functional modules of the MSS except the core module utilize the same structural arrangement: a module 14 feet in diameter by 31 feet, 9 inches long from docking interface to docking interface. The exterior of the module is enclosed by an environmental shield, which includes the radiators when required for a specific module. The primary structure consists of the pressure wall, a longitudinal deck, and two heavy frames. The majority of the internal equipment, especially all heavy equipment, is mounted on the longitudinal deck. The module is supported during launch at two side attachment points which react longitudinal and lateral loads, and at one forward attachment point which only reacts lateral loads.

Each of the functional modules is a single pressurizable volume, with a longitudinal deck (providing 298 square feet of usable area) positioned 14 inches below the centerline. A false ceiling 82 inches above the deck extends the full length of the module. The volume between the deck and the false ceiling is used for all functional activities and provides deck area or functional volume as required. All distribution utilities are installed above the false ceiling. The storage volume used for system equipment, spares or storage is below the deck.

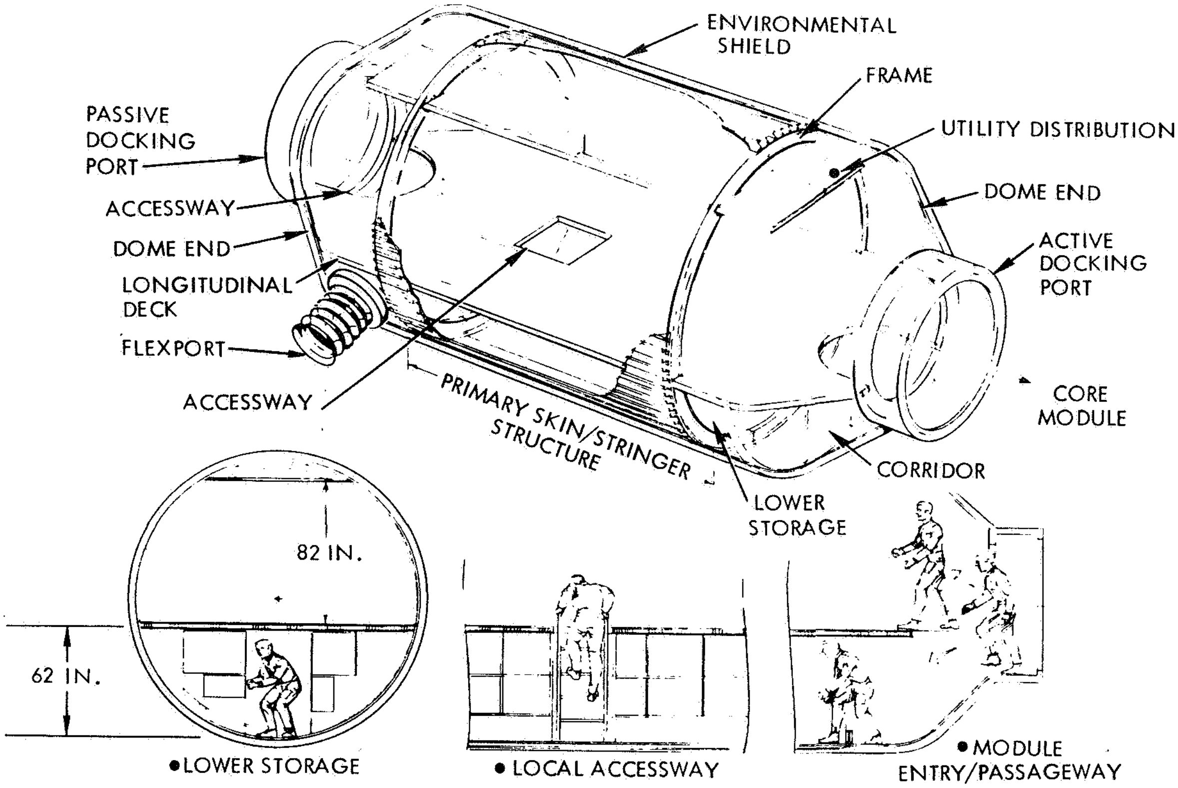


Figure 3.1-1. Basic Structural Arrangement

The differences between this concept and the baseline LSB lie primarily in the layout or cross-sectional concept. The 14-foot diameter results in the corridor providing only 62 inches of headroom. This is entirely adequate for zero-g passage but is considered extremely marginal for lunar surface operations. Increasing the overal diameter to 15-feet would be of considerable benefit if the added dimension were reflected in the lower passage headroom, although even 72 inches is less than optimum. As discussed below, the LSB baseline involves a single deck concept featuring a greater amount of open area with all subsystems below deck, except those requiring constant access. The 31-foot, 9-inch overall length impacts the use of the EOS since the 60-foot bay would permit only one module per flight when two could potentially be carried within the weight constraint. If the overal length were reduced to 30 feet, the recommended LSB criteria would be satisfied.

3.1.2 Meteoroid Protection

The meteoroid protection concept for the MSS involves use of an external bumper fastened to the primary structure. This bumper is not required for the LSB concept since meteoroid protection is provided by lunar soil and would be eliminated from the fabrication process.

3.1.3 Deck Arrangement

The deck arrangements are quite different in that the LSB uses a central aisle concept with facilities off to one side, while the MSS uses a below deck aisle with low headroom. The MSS modules can be used in the sense that they provide the space and facilities; however, it must be recognized that the lack of headroom in the aisles do compromise the headroom requirements established for LSB applications. The compromise may not be as severe if the MSS utilizes 15-foot diameter modules.

3.1.4 Docking Adapter Concept

The docking arrangement are also different. The MSS baseline module presently features an active port on one end and a passive port on the other. This may not satisfy the LSB mission requirements as presently configured. The modules used for LSB applications must have a true neuter concept on both ends. This requirement is established by the need for transferring the modules between the vehicles in space. During the logistic operations both ends are actively used. See Section 3.0 of Part 3 for further discussion of this requirement. Additional study is required of this area.

3.2 CORE MODULE APPLICATION

The MSS concept is designed around the use of a core or central module which connects all of the functional modules. Two core module designs are required for the completed configuration. Figure 3.2-1 illustrates the first and larger of the two along with its key design features. Of particular interest for LSB application are the locations of the ten docking ports. There are four on the X plane, four on the Y plane, and one at each end. The structural design is different than the MSS baseline being 41-1/2 feet long and 12 feet in diameter for most of its length. A short 14-foot diameter section is included for control moment gyros which are not needed for the LSB version.

The large core module (CM 1) was found to be satisfactory for use in an MSS derivative LSB configuration, with the modifications noted on Table 3.2-1. Its total weight as modified will be about 9900 pounds. The baseline LSB concept does not involve a core so that this may be considered a penalty.

3.3 CREW MODULE APPLICATION

The MSS crew modules (CQM 1, CQM 2, and CQM 3) were designed to the same basic habitability criteria as the LSB modules except for the influences of the gravitational field. A typical crew module is illustrated by Figure 3.3-1 including a backup galley for early manning and emergencies. The influence of gravity on systems design was defined under the subsystem discussion and has little influence on the architectural characteristics other than the aisle height. The 62-inch ceiling is satisfactory for zero gravity, but inconvenient for even low gravitational situations and does compromise the human factors criteria. Nevertheless, it will satisfy the functional requirements at some lower performance level.

DESIGN FEATURES

1 10 DOCKING PORTS (PASSIVE)
2 IVA/EVA AIRLOCK
3 2 SEPARATE VOLUMES
4 G&N EQUIPMENT
5 MAIN UTILITY DISTRIBUTION
6 ELECTRICAL POWER SYSTEM
7 OVAL HATCH UTILIZATION
8 RCS QUADS
9 HIGH-PRESSURE TANKS
10 BATTERIES

• SPECIAL DESIGN

CORE MODULE		STANDARD MODULE	
LENGTH	41'6"	LENGTH	31'9"
DIAMETER	12'	DIAMETER	14'
DOCKING PORTS	10	DOCKING PORTS	2

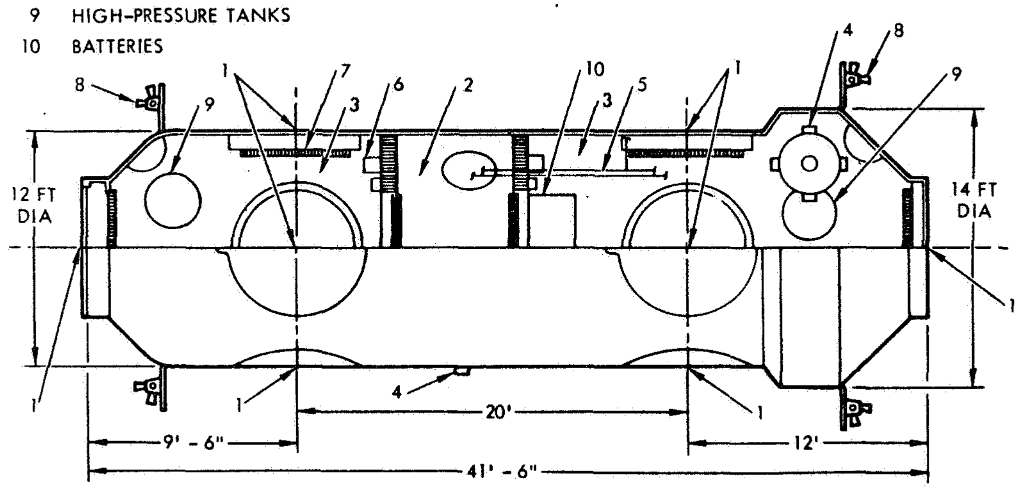


Figure 3.2-1. MSS Core Module

There are two basic crew module options in addition to the galley version of CQM 2. CQM 1 features four standard size crew staterooms, about 7 x 8-1/2 feet, with a bunk, closet, desk, and chair each. In addition, it has the backup galley facility. CQM 3 is quite similar but in place of the backup galley, one of the staterooms is expanded for the base commander and/or chief scientist to give him additional facilities.

These MSS crew modules will satisfy all the LSB functional requirements for crew module with very little modifications. Table 3.3-1 identifies the modifications recommended for these modules. One each CQM 1 and CQM 2 are required, plus two CQM 3's for the LSB configuration.

3.4 CONTROL MODULE APPLICATION

There are two versions of control and laboratory modules designed for the MSS, CCM 1 and CCM 2. Figure 3.4-1 illustrates CCM 1 in its MSS configuration. The basic differences from the LSB requirements are found in the laboratory facilities planned for each. The MSS laboratories are designed for earth orbit/zero-g missions and the equipments are not applicable to the LSB. The substructural elements may remain unchanged. Each module provides an an autonomous status assessment and control capability so that one provides the primary command facilities and the other, a backup command capability. This concept would be maintained for the LSB mission.

Table 3.2-1. MSS Core Module Modification for LSB Applications

Function Influenced	Modifications Required
Docking Ports	Plug 4 in "Y" plane
Meteoroid Protection	Eliminate
Reaction Control System	Eliminate and plug hole
Fuel Cell System	Eliminate
Battery Pack	Eliminate all but 1-100 amp-hr.
Control Moment Gyro	Eliminate
Control Electronics	Eliminate
Near-Earth Communications	Eliminate
Radiator	Eliminate and couple coolant loop into the central system.
Other Hardware	Eliminate all zero-g cargo handling aides.
Floors	Add floor assembly
Crew System	Add water tanks
Atmosphere Management	Add $H_2/O_2/N_2$ tanks and emergency repressurization.

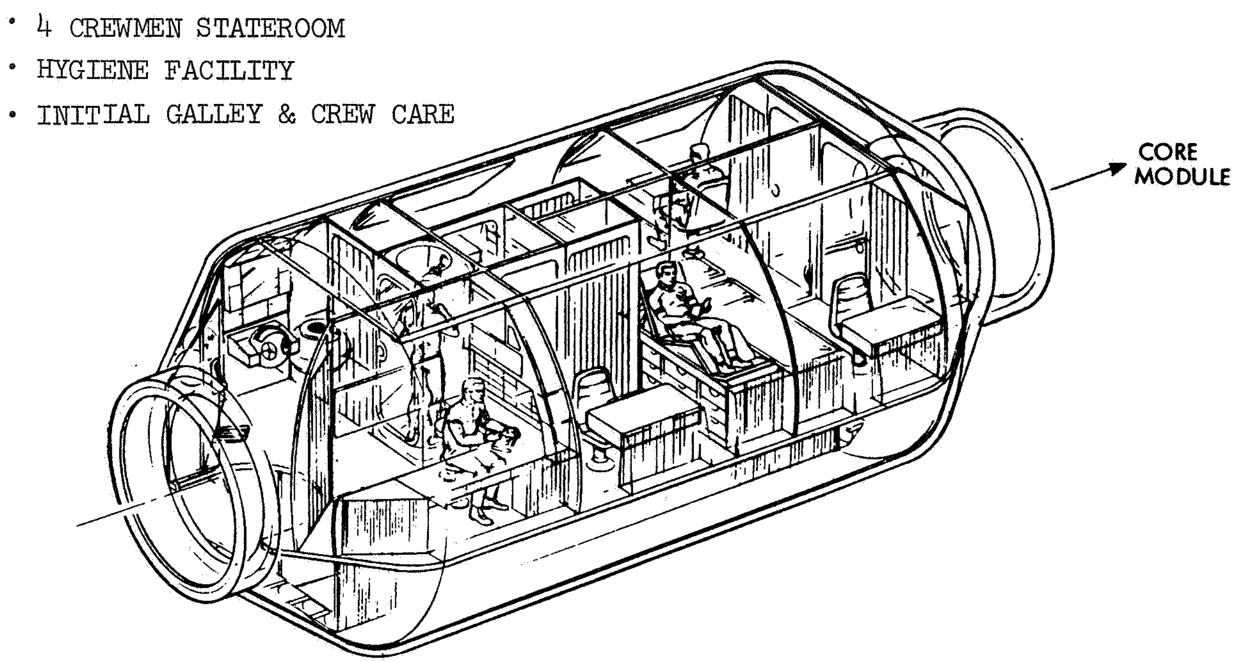


Figure 3.3-1. Typical MSS Crew Module

Table 3.3-1. MSS Crew Module (All) Modifications for LSB Application

FUNCTIONS INFLUENCED	MODIFICATION REQUIRED
Structure	Eliminate cargo rails and meteoroid bumper. Provide dual neuter docking adaptor.
Guidance	Eliminate docking aids.
Atmospheric Management	Eliminate MSS radiator and modify for LSB baseline radiator design. Eliminate MLI.

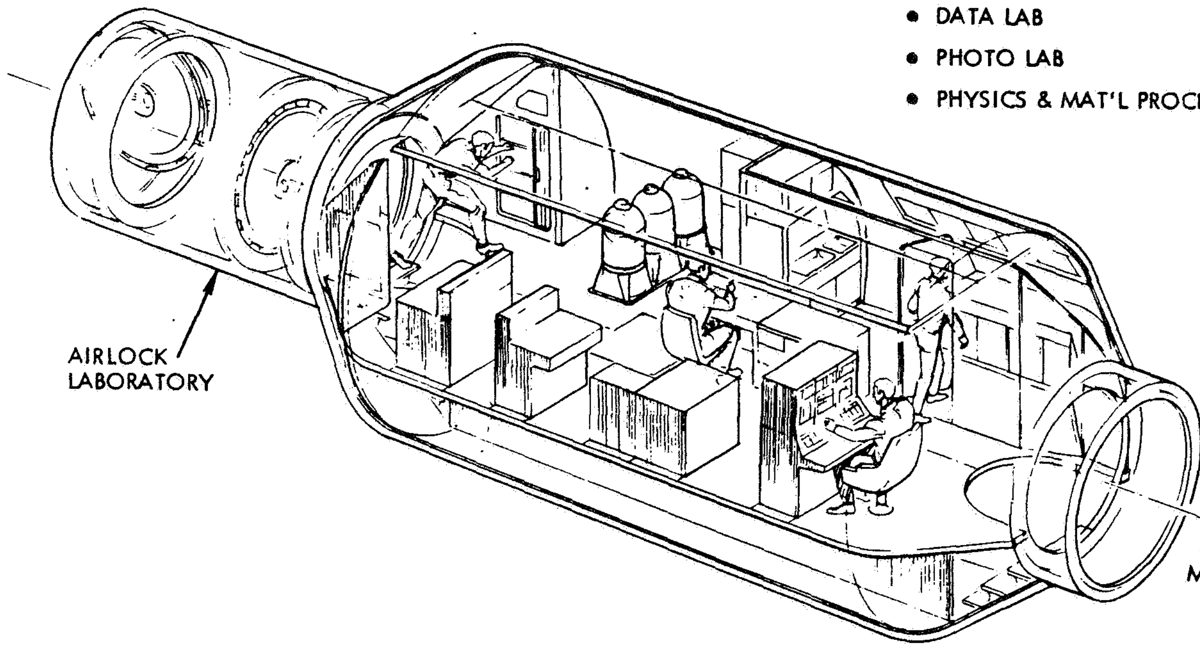


Figure 3.4-1. Typical MSS Control Module - CCM 1

An analysis of the laboratory facilities provided for MSS versus those required for the LSB indicated that using one each of these modules would satisfy the LSB requirements with minimum modifications. It was found that CCM 2 could be modified as indicated in Table 3.4-1 and would thereby satisfy the main command center functions in addition to providing necessary medical and maintenance facilities. CCM 1 can be modified to provide both the backup command center and the laboratory facilities required for the LSB. These modifications are identified in Table 3.4-2.

In summary, these modules can be used as modified and will provide the required functions satisfactorily.

3.5 CARGO MODULE APPLICATION

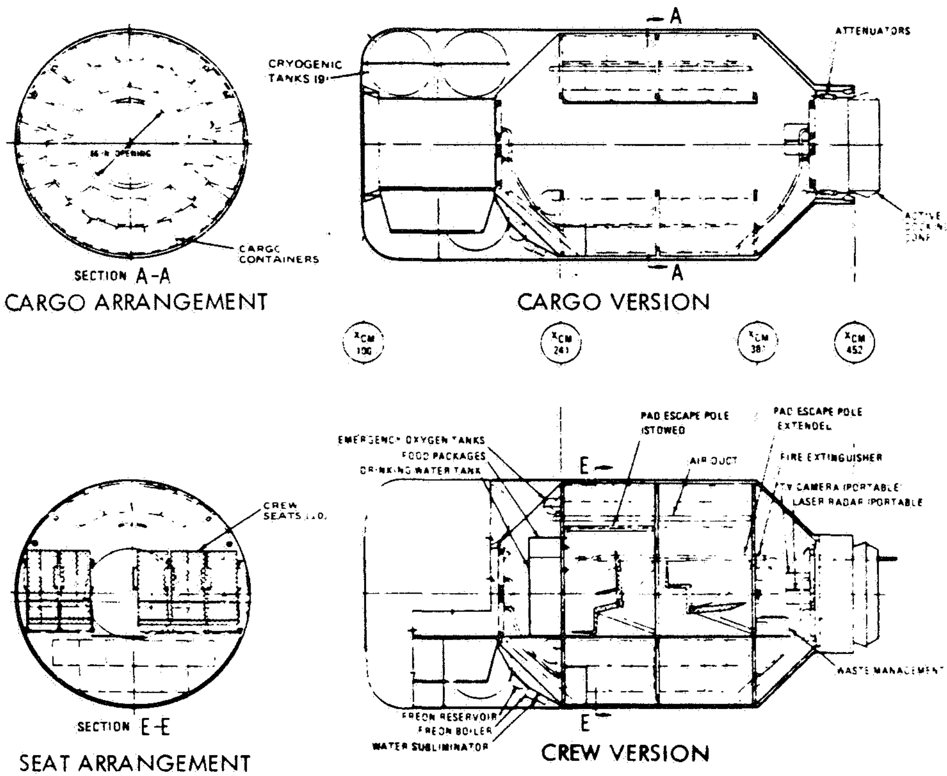
There are two versions of cargo modules designed for use with the EOS for the MSS program. These, the cargo version and the crew version, are identified in Figure 3.5-1. The crew version is not applicable to the LSB program since the LSB crew will be enroute between three and five days and will require the more complete quarters planned for the cislunar shuttle crew module.

Table 3.4-1. MSS Control Module (CCM 2) Modifications for LSB Control Center

FUNCTION INFLUENCED	MODIFICATION REQUIRED
Structure	Eliminate cargo rails and meteoroid bumper. Provide dual neuter docking adapter.
Guidance	Eliminate docking aids.
Atmospheric Management	Replace MSS integral radiator with LSB independent radiator. Eliminate MLI.
Communications	Add: 2 S-band power amplifiers, high gain antenna and switch. Add: 2 VHF transceivers with pancake omni antenna. Eliminate: Semi-directional antenna and approach radar.
Data Management	Modify: Command center panel for LSB functions data processor software.
Laboratory	Replace: Fluid Mechanics Lab with Base Maintenance Facility. Electronics Lab with Suit Maintenance Facility. Modify: Medical and Optical Labs for Medical and Dental Facility.

Table 3.4-2. MSS Control Module (CCM I) Modifications for LSB Backup Control and Lab

Function Influenced	Modifications Required
Structure	Eliminate cargo rails and meteoroid bumper. Provide dual neuter docking adapter.
Guidance and Control	Eliminate docking aids.
Atmosphere Management	Replace MSS integral radiator with LSB independent radiator. Eliminate MLI.
Communications	Add: 2 S-band power amplifiers 2 Hi-gain antenna 2 VHF transceivers with pancake omni antenna 1 LF transceiver Eliminate: Semi-directional antenna and approach radar
Data Management	Modify: Command center panel for LSB functions data processor software
Laboratory	Eliminate Airlock lab and experiments Replace: Physics lab with Geoscience lab Materials lab with Bioscience lab Add: Photo lab Data analysis lab



Dry Wt.	8,400 lb
Cargo	12,200 lb
	20,600 lb

Dry Wt.	9,500 lb
Crew (10)	2,000 lb
Cargo	6,900 lb
	18,400 lb

Figure 3.5-1. MSS Cargo Module Versions

As indicated, the MSS cargo module version is designed to carry 12,200 pounds of which 8000 pounds may be bulk cargo and 4200 pounds are cryogens. The gross volume of the cargo bay is 2600 cubic feet and the average density is less than 3 pounds per cubic foot. The LSB requires delivery of about 37,000 pounds of crew and cargo per cycle, none of which is cryogens. If the hydrazine and crew are factored out and the remainder divided between two modules in order to provide a balanced pair for the tug (see Section 3.3 of Part 3), the packing density for the LSB application would increase to just over 6 pounds per cubic foot, which is well below what is expected to be achievable.

These data indicate that the MSS cargo version module could conceptually meet the LSB requirement in transporting the required cargo, exclusive of the crew. The operations might be somewhat different in that it may preclude use of a drive-in warehouse. However, the drive-in warehouse is proposed at 15-foot diameter and the present MSS cargo modules are 14 feet so that it may be possible to slide them in. The cargo module, if used, would require fairly extensive modifications as indicated on Table 3.5-1.

Table 3.5-1. MSS Cargo Version Module Modifications for LSB Applications

FUNCTION INFLUENCED	MODIFICATION DESCRIPTION
Structure	Eliminate meteoroid bumper, cargo rails, cryo tank supports, tunnel and fittings. Provide dual neuter docking adaptor.
Orientation Cont.	Eliminate
Plumbing	Replace cryogen system with hydrazines storage
Atmospheric Management	Eliminate subsystems and MLI
Personnel Provisions	Eliminate
Cargo Provisions	Expand bulk storage facilities

4.0 MSS DERIVATIVE LSB

The preceding sections have defined the subsystem and module modifications required to be compatible with the individual LSB module requirements. These modified modules must now be configured into a usable base which will satisfy both the mission objectives and the safety criteria.

4.1 CONFIGURATION OPTIONS

A large number of combinations are possible in configuring the MSS modules for an LSB; however, they can be grouped into logical classes of combinations. Figure 4.1-1 presents eight of many potential configuration options. Figure 4.1-1 also presents a summary of trade data used in the selection process. The selection is based on both qualitative and quantitative factors as follows:

1. The number of joints are related to the assembly activity and the potential leak rate and therefore should be minimized.

2. The number of special modules influence the development costs and the manufacturing requirements.

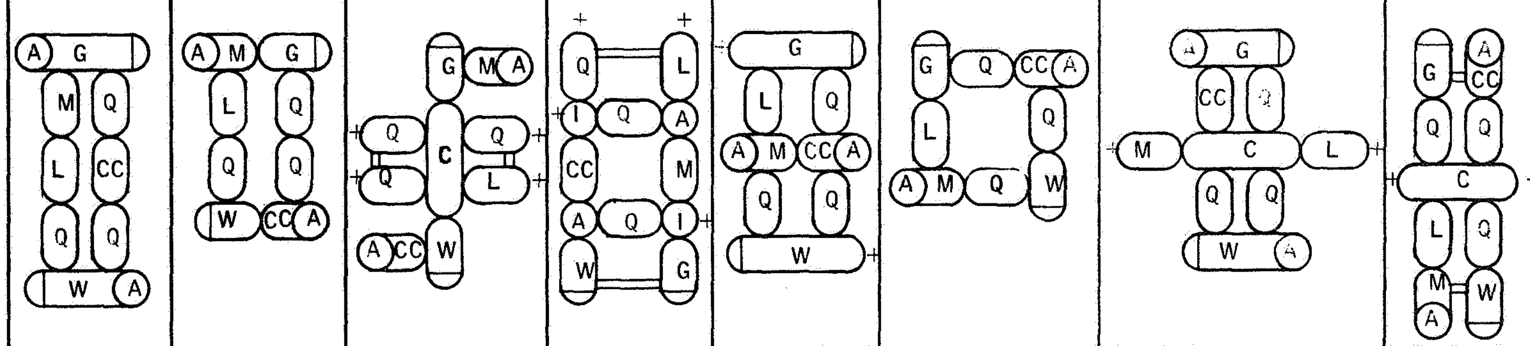
3. The number of readily available growth points directly influence the growth and flexibility of the base and, in particular, impact the ability to tie in close coupled outposts.

4. One of the safety criteria followed in the baseline LSB was to provide dual paths out of each module to escape an emergency. Not all arrangements provide this feature.

5. The number of MSS modules used is to some degree the inverse of the number of new modules. The ideal case would be a configuration where the LSB could be constructed completely from the available MSS modules. However, this objective cannot be met because of the airlock functions and the garage drive-in warehouse requirements. Because the garage and warehouse are also used as shipping containers for the mobility and other special equipment, they are multipurpose modules and are of a specialized design.

6. The alignment requirements can have a very significant influence on base deployment time. As each module is moved into place at the LSB site, the modules must be aligned to permit latching the connecting collar. Configurations that involve closing loops create difficult alignment problems and can greatly increase deployment time and effort.

	1	2	3	4	5	6	7	8
Joints	8	8	8	12	9	8	10	8
Alignment	Complex	Complex	Simple	Complex	Modest	Complex	Modest	Simple
Growth Paths	0	0	4	4	2	0	2	2
Dual Paths	All	All	Part	All	All	All	Part	All
MSS Modules	6	4	5	6	4	4	7	5
Spec. Modules	2	4	4	6	4	4	2	4
Total Modules	8	8	9	12	8	8	9	9



MODULE LEGEND:

M Maintenance
Q Crew Quarters
L Lab
CC Command Center
G Garage
W Warehouse
A Airlock
C Core
I Interconnect
+ Growth Points

Figure 4.1-1. MSS Derivative Shelter Options

7. The total number of modules are significant in that a minimum volume and floor area are required and the delivered weight should be minimized

A review of the eight configurations identified, in light of the factors assessed in Figure 4.1-1, plus the functional requirements, led to selection of concept seven for the MSS derivative shelter. It makes use of the maximum number of MSS modules and requires the least number of special modules. It is relatively easy to assemble and can be implemented in steps. The subsequent section described this configuration in more detail.

4.2 RECOMMENDED MSS DERIVATIVE CONFIGURATION

Drawing 2284-9A presents a conceptual layout of the complete recommended MSS derivative shelter. It is composed of seven MSS modules, modified as previously defined, and two special modules, designed to satisfy the functions not provided by the MSS modules. It is configured around the MSS core module. The configuration provides two independent loops with passage between outer modules provided by either the aisle-to-aisle flexports or on the upper level, the garage or warehouse modules. The core module also incorporates a small airlock and/or emergency escape hatch, up from the middle of the shelter complex (see Section C-C of the drawing).

The characteristics of the MSS modules were defined in Section 3.0 of this volume. The two new modules are used to close the ends off and provide additional functions. The major features of the MSS derivative shelter are its flexibility and the 3130 square feet of available floor area, plus the lower aisle space of over 540 square feet.

4.3 SPECIALIZED MODULE DESCRIPTION

Two specialized modules , a garage/airlock module and a warehouse/airlock module, were required to be incorporated to satisfy the functional requirements. These are also illustrated on Drawing 2284-9A. The modules resemble the corresponding baseline shelter modules except that an airlock with dust control facilities has been added to one end of each module. In addition, an additional docking collar has been added to the side to permit coupling with two MSS crew and/or control modules. The characteristics of these facilities are identical to those in the baseline concepts. The modules have been extended to the 45-1/2-foot length to accommodate either the garage or warehouse plus an airlock in one module, thereby minimizing the number of required modules.

4.4 MSS DERIVATIVE MASS PROPERTIES

The weight of the MSS derivative LSB shelter complex has been estimated from the NR-MSS data. The proposed modifications as identified in Tables 3.2-1, 3.3-1 through 3.4-1 and 3.4-2 were used as guidelines in determining the LSB configuration weight.

Table 4.4-1 presents a top-level summary of the derivative shelter weight. The total delivered shelter weight is estimated to be about

84,500 pounds, without consumables. This weight is about 24,000 pounds heavier than the baseline. The increase stems from the use of a core module and the extensions of the two specialized modules by over 15 feet. These two 15-foot lengths would make up for one additional module. These, together with the core module and the slightly heavier subsystems, account for the weight difference.

Table 4.4-2 presents the MSS derivative summary weight statement by module. Note that except for the garage and warehouse, they average around 9,800 pounds, which is below the maximum weight handling capability of the LSB hoist concept.

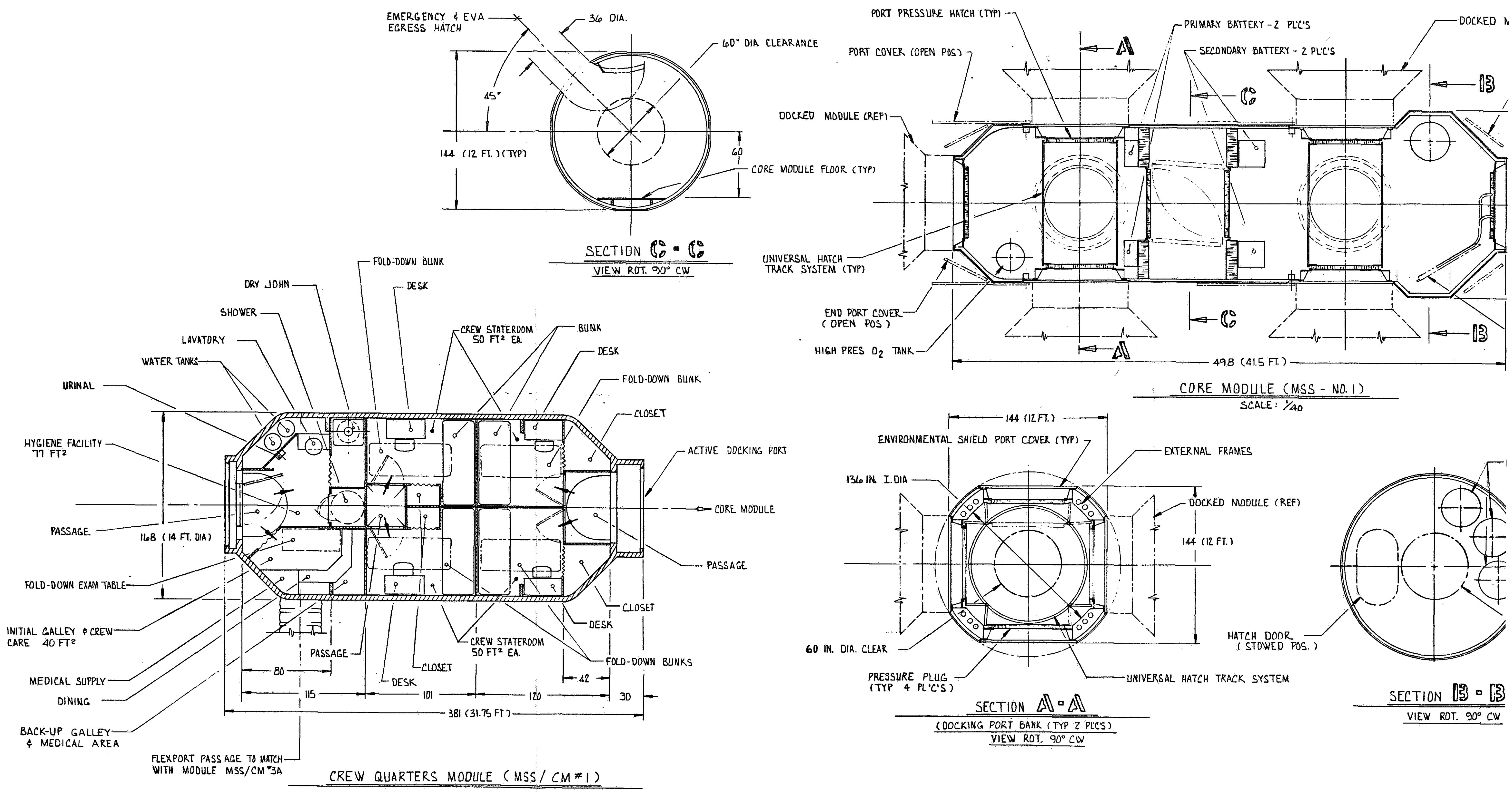
Table 4.4-3 presents a detailed weight summary for the MSS derivative shelter structure after modification for LSB application.

Table 4.4-4 presents the weight estimates for the atmospheric management subsystem as modified for LSB application.

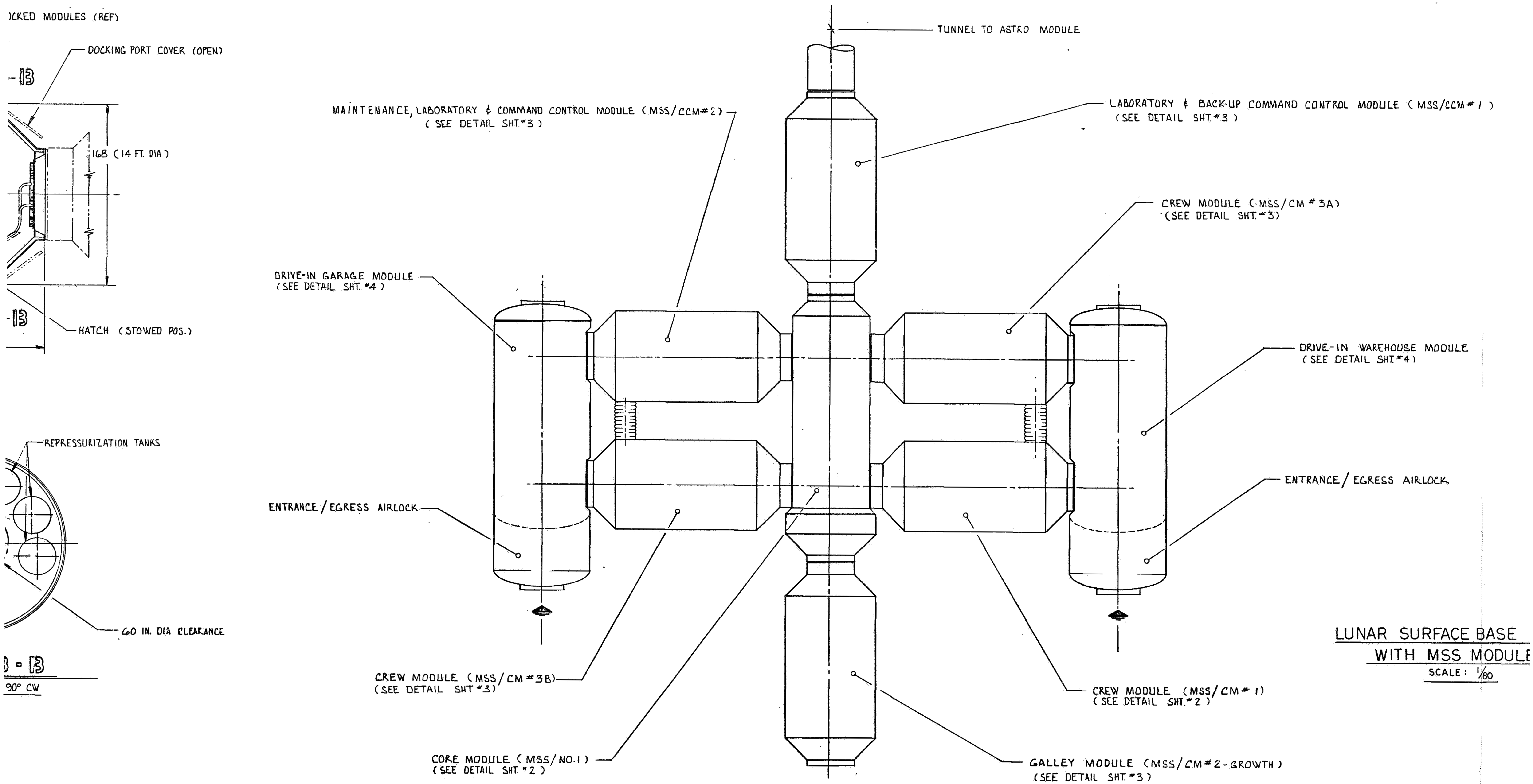
Table 4.4-5 presents the weight estimate for the communications and electrical power subsystems as modified for the LSB

Table 4.4-6 presents the weight estimate for the data management/command and control subsystem as modified for LSB application.

Table 4.4-7 presents the weight estimate for the laboratory facilities, medical and galley subsystems. These elements required extensive changes in the installed functions but little or no change in the primary or secondary structural components.


EMERGENCY & EVA EGRESS HATCH
36 DIA.
60" DIA. CLEARANCE
45°
144 (12 FT.) (TYP)
60
CORE MODULE FLOOR (TYP)
SECTION C - C
VIEW ROT. 90° CW
PORT PRESSURE HATCH (TYP)
PRIMARY BATTERY - 2 PL'C'S
SECONDARY BATTERY - 2 PL'C'S
DOCKED M
PORT COVER (OPEN POS)
DOCKED MODULE (REF)
UNIVERSAL HATCH TRACK SYSTEM (TYP)
END PORT COVER (OPEN POS)
HIGH PRES O_2 TANK
498 (41.5 FT.)
CORE MODULE (MSS - NO. 1)
SCALE: 1/40
FOLD-DOWN BUNK
DRY JOHN
DESK
SHOWER
CREW STATEROOM 50 FT² EA
BUNK
LAVATORY
DESK
WATER TANKS
FOLD-DOWN BUNK
URINAL
CLOSET
ACTIVE DOCKING PORT
HYGIENE FACILITY 77 FT²
CORE MODULE
PASSAGE
168 (14 FT. DIA)
PASSAGE
FOLD-DOWN EXAM TABLE
CLOSET
DESK
INITIAL GALLEY & CREW CARE 40 FT²
CREW STATEROOM 50 FT² EA.
PASSAGE
FOLD-DOWN BUNKS
CLOSET
80
MEDICAL SUPPLY
DESK
42
DINING
115
101
120
30
381 (31.75 FT)
BACK-UP GALLEY & MEDICAL AREA
FLEXPORT PASSAGE TO MATCH WITH MODULE MSS/CM #3A
CREW QUARTERS MODULE (MSS/CM #1)
144 (12 FT.)
ENVIRONMENTAL SHIELD PORT COVER (TYP)
EXTERNAL FRAMES
136 IN. I. DIA
DOCKED MODULE (REF)
144 (12 FT.)
60 IN. DIA. CLEAR
HATCH DOOR (STOWED POS.)
PRESSURE PLUG (TYP 4 PL'C'S)
UNIVERSAL HATCH TRACK SYSTEM
SECTION A - A
(DOCKING PORT BANK (TYP 2 PL'C'S)
VIEW ROT. 90° CW
SECTION B - B
VIEW ROT. 90° CW

FOLD-OUT #1



)CKED MODULES (REF)
DOCKING PORT COVER (OPEN)
168 (14 FT. DIA)
HATCH (STOWED POS.)
REPRESSURIZATION TANKS
60 IN. DIA CLEARANCE
90° CW
TUNNEL TO ASTRO MODULE
MAINTENANCE, LABORATORY & COMMAND CONTROL MODULE (MSS/CCM#2)
(SEE DETAIL SHT.#3)
LABORATORY & BACK-UP COMMAND CONTROL MODULE (MSS/CCM#1)
(SEE DETAIL SHT.#3)
CREW MODULE (MSS/CM#3A)
(SEE DETAIL SHT.#3)
DRIVE-IN GARAGE MODULE
(SEE DETAIL SHT.#4)
DRIVE-IN WAREHOUSE MODULE
(SEE DETAIL SHT.#4)
ENTRANCE/EGRESS AIRLOCK
ENTRANCE/EGRESS AIRLOCK
CREW MODULE (MSS/CM#3B)
(SEE DETAIL SHT#3)
CREW MODULE (MSS/CM#1)
(SEE DETAIL SHT.#2)
CORE MODULE (MSS/NO.1)
(SEE DETAIL SHT.#2)
GALLEY MODULE (MSS/CM#2-GROWTH)
(SEE DETAIL SHT.#3)
LUNAR SURFACE BASE
WITH MSS MODULE
SCALE: 1/80

FOLD-OUT #2

ASE CONFIGURATION
DDULES
o

FOLD-OUT #3

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2-4-5, 2-4-6

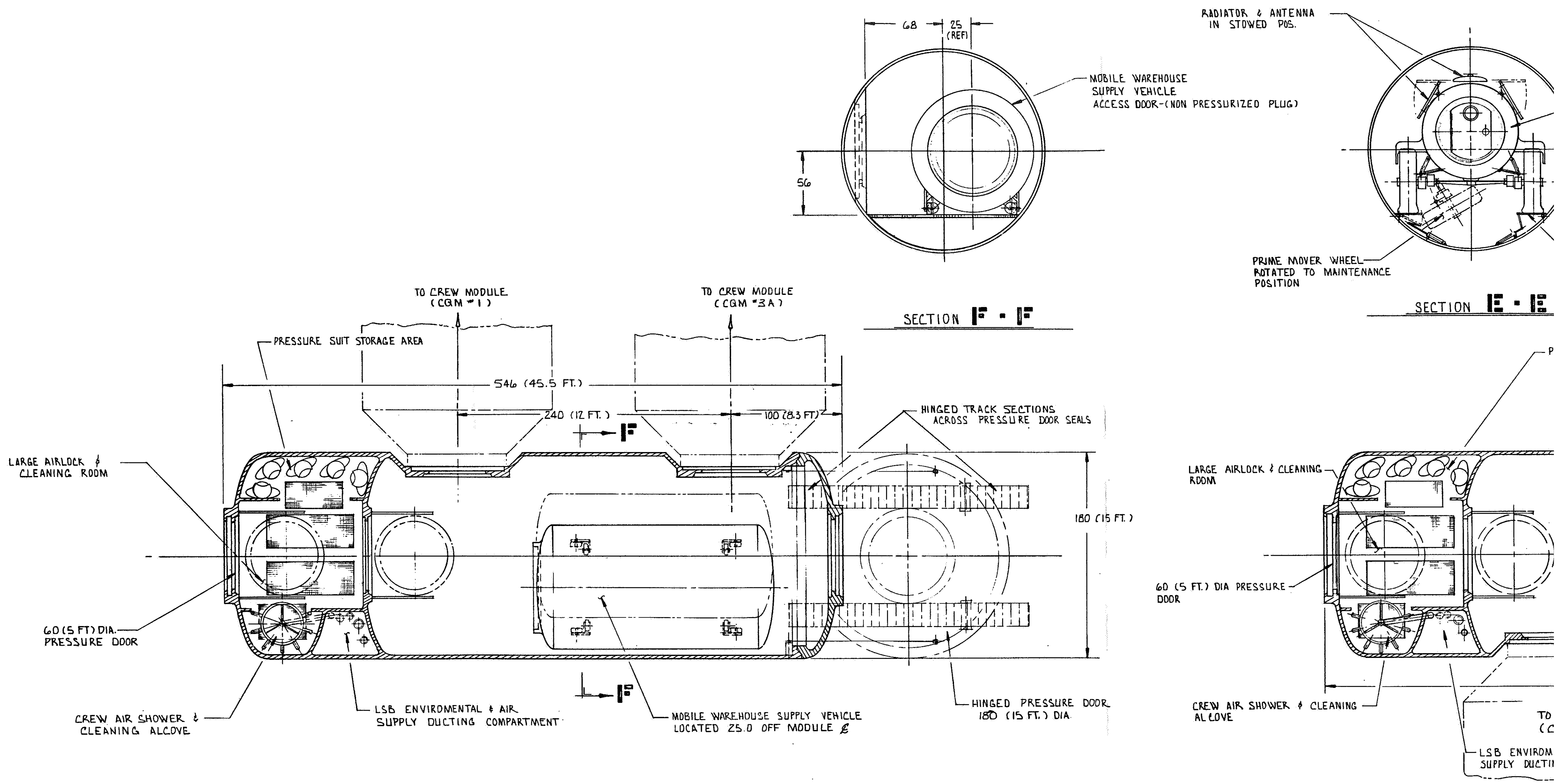
SD 71-477

SCALE	DR.	SPACE DIVISION
1/40 & NOTED	DATE 3-9-71	NORTH AMERICAN ROCKWELL CORPORATION
	MODEL	12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA

CONCEPT LAYOUT—LUNAR BASE COMPLEX, LSB/MSS CONFIG. STUDY

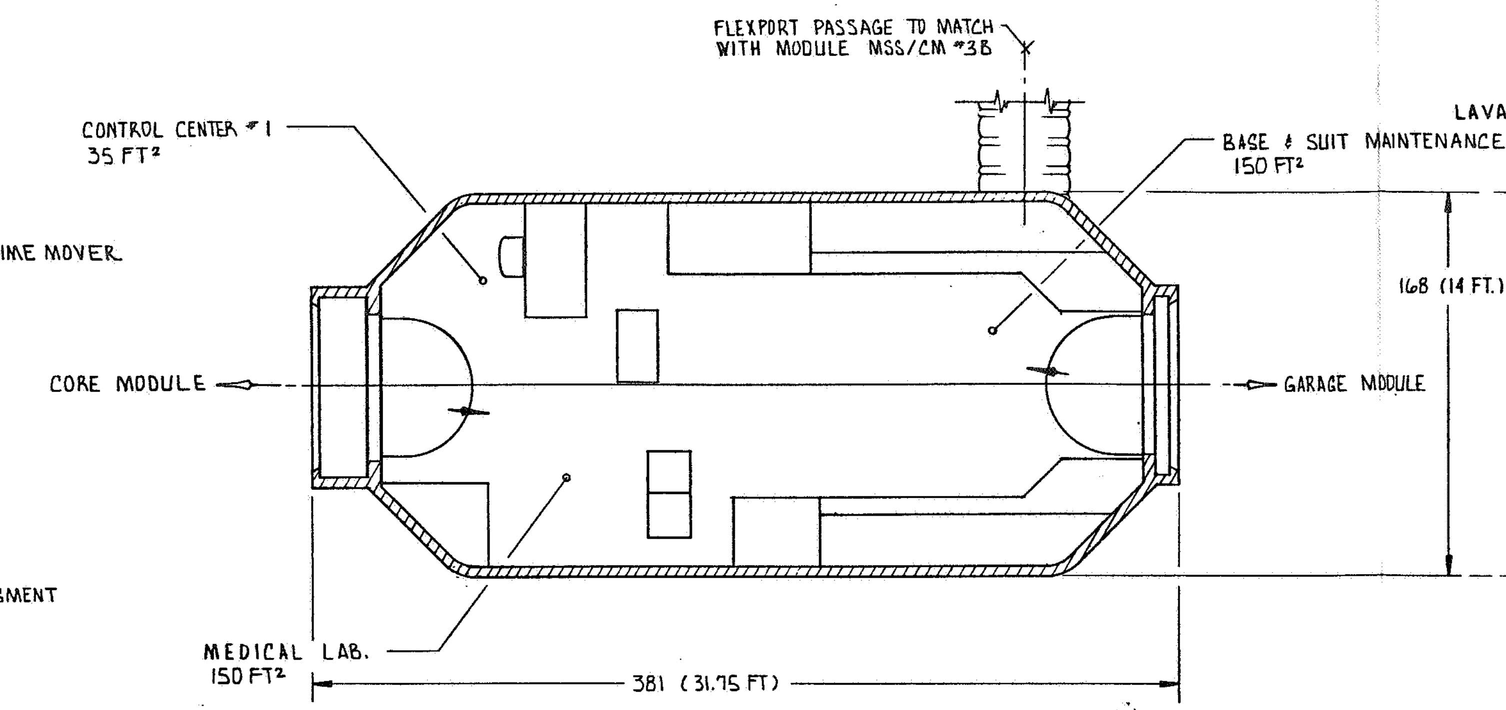
2284-9A

SHEET 1 OF 2

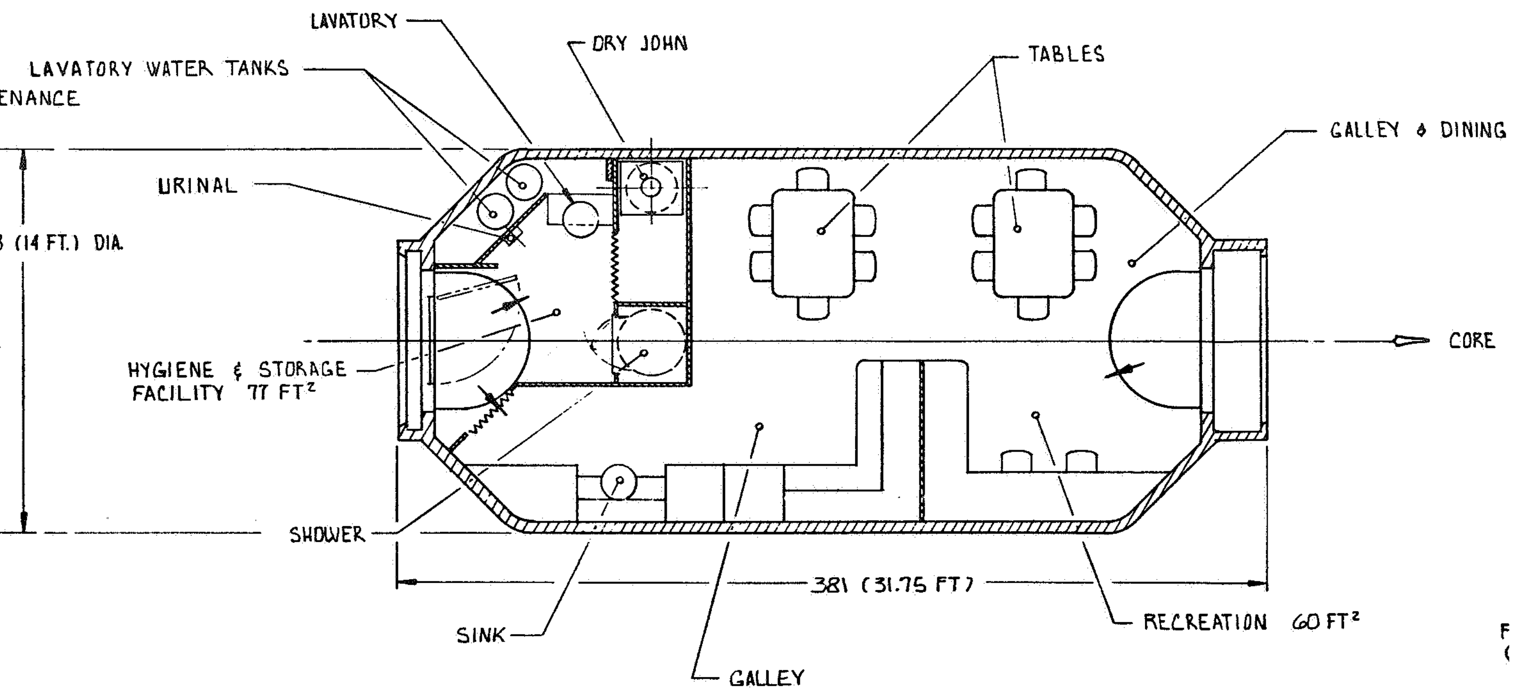


AIRLOCK & DRIVE-IN WAREHOUSE MODULE

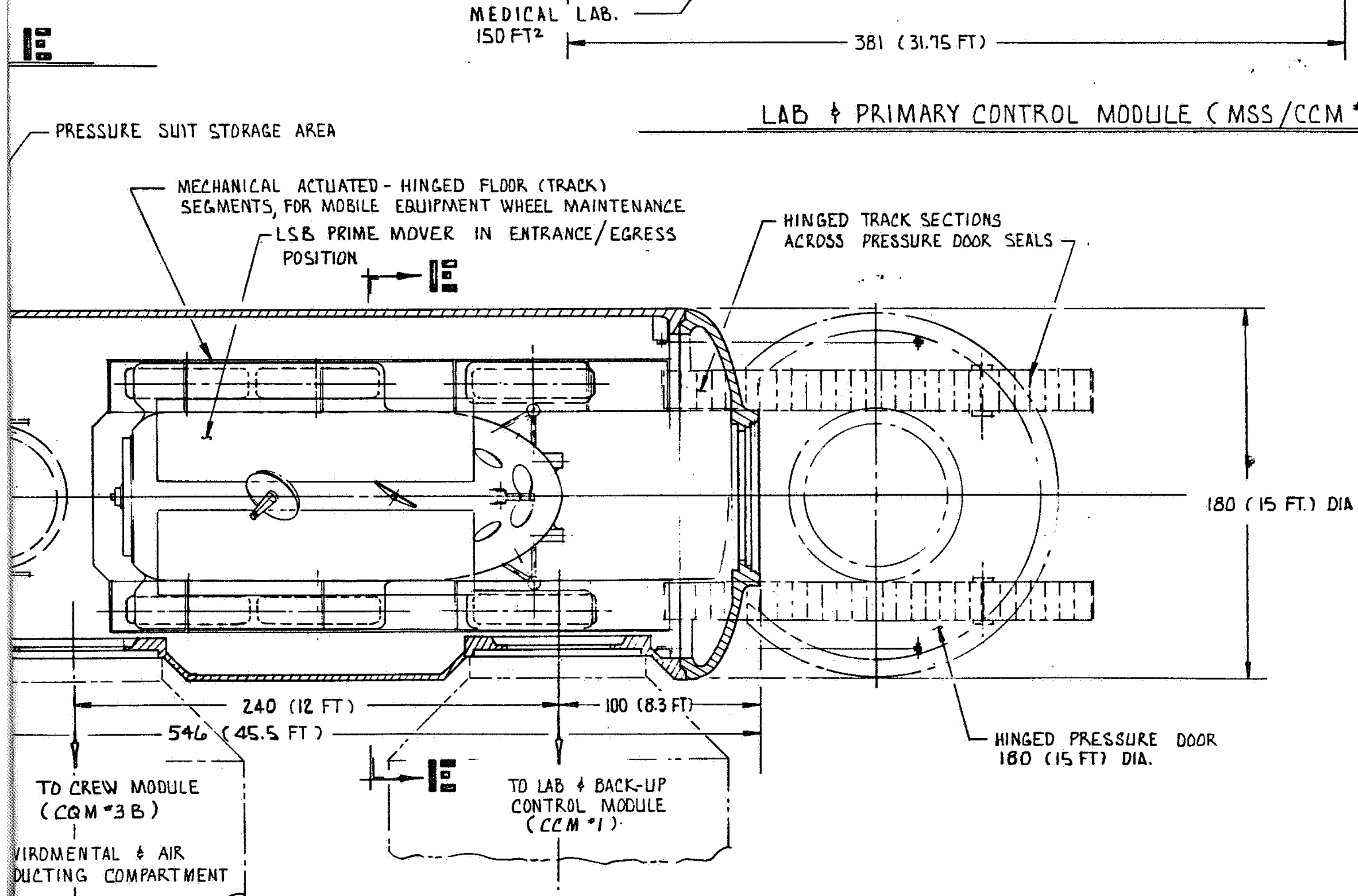
FOLD-OUT #1



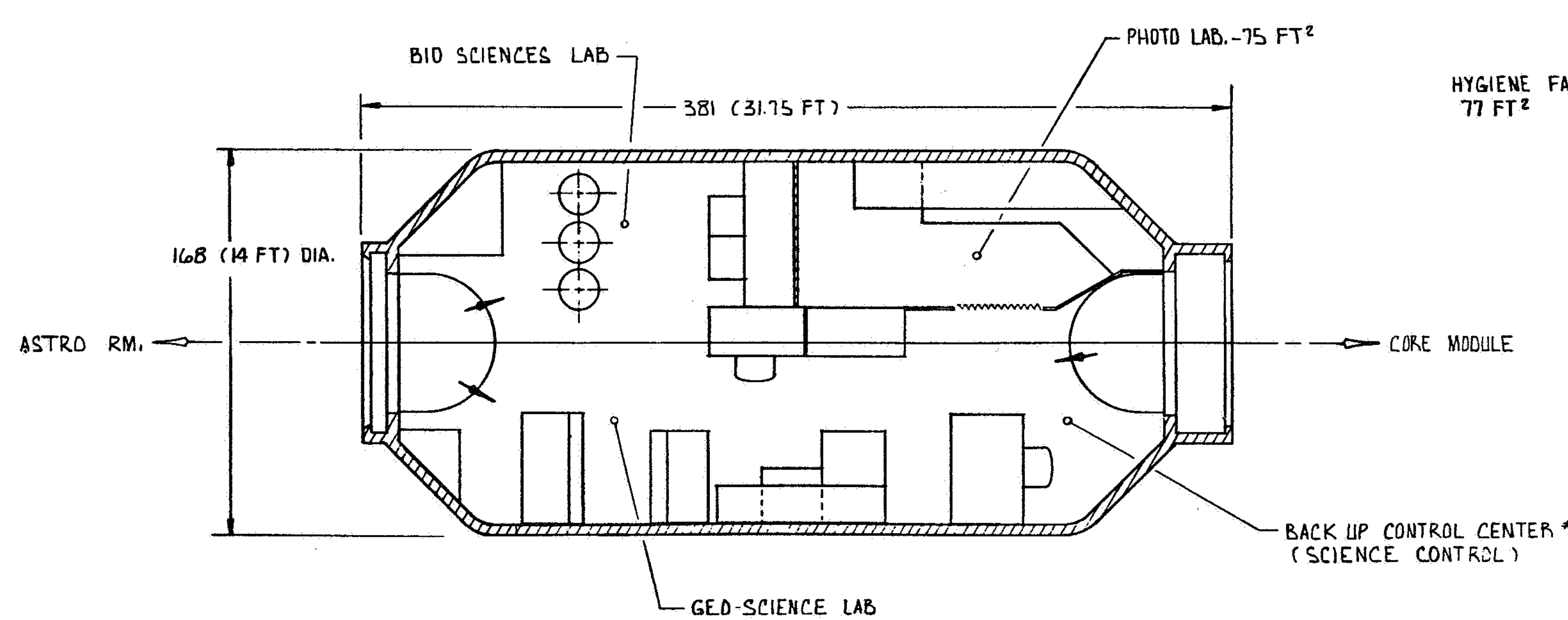
LAB & PRIMARY CONTROL MODULE (MSS/CCM #2)



GALLEY MODULE (MSS/ CM #2 - GROWTH)



AIRLOCK & MOBILE EQUIPMENT MAINTENANCE GARAGE & REPAIR MODULE



LAB & BACK-UP CONTROL MODULE (MSS/CCM #1)

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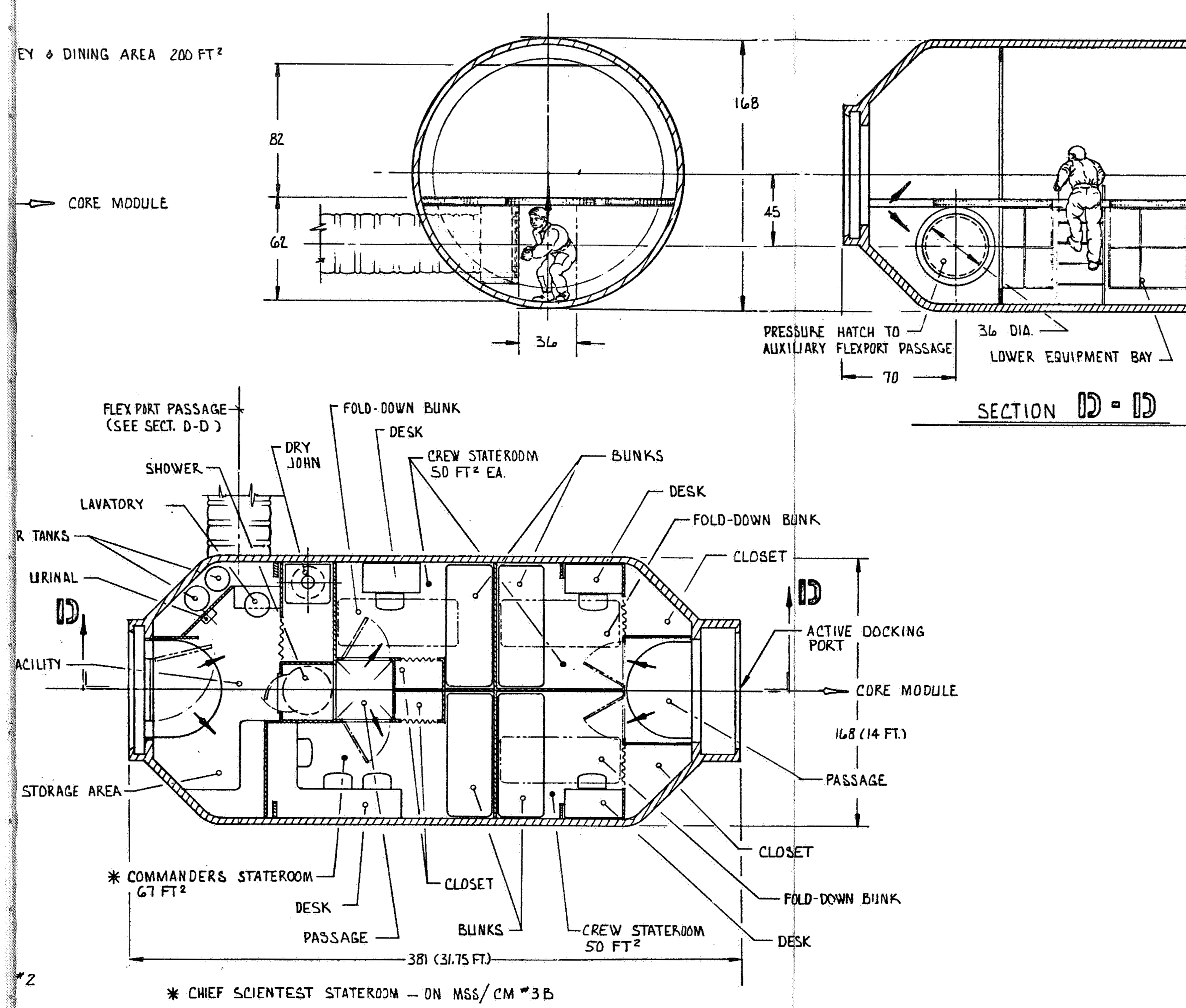
Space Division
North American Rockwell



CREW QUARTERS MODULE (MSS/CM #3A)-SHOWN
CREW QUARTERS MODULE (MSS/CM #3B)-IDENTICAL EXCEPT AS NOTED

FOLD-OUT #3

2-4-7, 2-4-8

SD 71-477

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SPACE DIVISION
NORTH AMERICAN ROCKWELL CORPORATION
12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA

CONCEPT LAYOUT-LUNAR BASE COMPLEX, LSB/MSS CONFIG STUDY

2284-9A
SHT 2 OF 2

Table 4.4-1. Summary Weight Statement, MSS - Derivative Shelter

CODE	MODULE	WEIGHT (lb)
CM1	Core Module	9,906
CCM1	Control Center Module (Incl. Labs)	9,852
CCM2	Control Center Module (Incl. Med.)	10,851
CQM1	Crew Quarters Module (Incl. B.U. Galley)	9,914
CQM3	Crew Quarters Module - 4 Man	9,904
CQM3	Crew Quarters Module - 4 Man	9,904
GM	Galley Module	9,728
DWM	Drive-In Warehouse Module	7,330
DGM	Drive-In Garage Module	6,906
	Total - Basic Shelter, 9 Modules	84,495

Table 4.4-2. MSS - Module Weight Summary

	CM1	CCM1	CCM2	CQM1	CQM3	GM	DWM	DGM
Primary structure	5955	3937	4152	4212	4212	3937	5965	6015
Furnishings and secondary structure	1015	1331	1437	1428	1430	1484	541	67
Atmospheric management and crew services	1636	903	1364	3182	3282	2737	558	558
Intercommunications and monitoring	52	93	83	250	240	168	31	31
Electrical power distribution and control	1248	740	740	740	740	740	235	235
Command and control		1290	1390					
Medical facility			750					
Galley				102		662		
Laboratories		1558						
Base maintenance and repair			935					
Total	9906	9852	10,851	9914	9904	9728	7330	1906

Table 4.4-3. MSS - Detail Weight Summary - Structure

	Q*	CM1	Q	CCM1	Q	CCM2	Q	CQM1	Q	CQM3	Q	GM	Q	DWM	Q	DGM
Primary Structure		5955		3937		4152		4212		4212		3937		5965		6015
Cylinder	1	1749	1	1163	1	1163	1	1163	1	1163	1	1163	1	1805	1	1805
Closing bulkheads	2	350	2	380	2	380	2	380	2	380	2	380	2	900	2	900
Wall covering	-	315	-	253	-	253	-	253	-	253	-	253	-	240	-	240
Docking ports/rings	6	1580	2	870	2	870	2	870	2	870	2	870	-	-	-	-
Pressure doors	6	1188	2	396	2	396	2	396	2	396	2	396	4	1240	4	1240
Ceiling and floors	-	350	-	875	-	875	-	875	-	875	-	875	-	405	-	405
Airlock and auxiliary pressure wall	1	423											1	700	1	500
Vehicle entry door provisions													1	625		625
Vehicle support tracks													-	50		50
Flex. tunnel provisions					1	215		275	1	275						
Furnishings and Secondary Structure		1015		1331		1437		1428		1430		1484		541		67
Secondary structure, fittings, and hardware		457		329		325		333		327		328		-		-
Equipment brackets and mounts		308		189		206		297		281		279		41		67
Storage cabinets				200		200								450		
Chairs, desks, bunks, etc.				74		140		244		268		448		50		
Partitions and fixtures		250		539		566		554		554		429				

*Q = Quantity

Table 4.4-4. MSS - Detail Weight Summary - Atmospheric Management

*	Q	CM1	Q	CCM1	Q	CCM2	Q	CQM1	Q	CQM3	Q	GM	Q	DWM	Q	DGM
Atmospheric Management and Crew Services		1636		903		1364		3182		3282		2737		558		558
H_2 depolarized cell								330		330		330				
Sabatier reactor								40		40		40				
Electrolysis cell/N_2H_4 dissa.								444		444		444				
$H_2/O_2/N_2/N_2H_4$ tanks		1366		600		1000		750		850		400				
Catalytic burner/regen char.								65		65		65				
Water tanks		40		50		105		200		200		200				
Reverse osmosis								50		50		50				
Vapor compression								270		270		270				
Thermal control		110		75		75		170		170		170				
External radiator								170		170		-				
Pressure control								32		32		32	1	32		32
Circulation system		120		120		120		120		120		120		60		60
Temp. and humidity control				58		64		150		150		150		150		150
Urinal/Dry John/shower								391		391		466				
Emergency represur. assy														41		41
Food reconstitution/fountain								-		-		-				
First aid kit																
Air shower/dust management/ pumpdown and APLSS recharge														275		275

* Q = Quantity

Table 4.4-5. MSS - Detail Weight Summary - Intercommunications and EPS

*	Q	CM1	Q	CCM1	Q	CCM2	Q	CQM1	Q	CQM3	Q	GM	Q	DWM	Q	DGM
Intercommunications and Monitoring		52		92		83		250		240		168		31		31
Audio-visual unit	4	36	5	45	5	45	4	36	4	36	4	36	1	16	1	16
Hardwire intercomm.	1	10	5	10	-	-	1	10								
Remote data station	1	6														
Remote data terminal							1	40	1	40			1	15	1	15
Emergency fire control and detection			1	38	1	38										
Preprocessors and RACU							8	24	8	24	4	12				
A&CS monitors							1	100	1	100	1	100				
TV monitor							4	40	4	40	2	20				
Electrical Power Distribution and Control		1248		740		740		740		740		740		235		235
Primary buss, cabling and plugs		868		590		590		590		590		590				
Power switching and breakers		245		15		15		15		15		15				
Lighting and emergency batteries		135		135		135		135		135		135				

*Q = Quantity

Table 4.4-6. Detail Weight Summary - Communications and Control

	CCM 1		CCM2	
	Qty.		Qty.	
Command and Control	-	1290	-	1390
• Data management		(524)		(524)
Central processor	1	390	1	390
Operating and mass memory	-	-	-	-
Archival memory	1	80	1	80
Central timing	1	18	1	18
Map and status board	-	-	-	-
RACU	12	36	12	36
• Communications		(326)		(416)
Modulator/processor	1	50		50
Central switch/test	1	120		120
Video recorder and audio	-	75	-	75
Facsimile unit	-	-	1	40
TV camera	1	3	1	3
TV monitor	1	10	1	10
Paging amplifier	1	10	1	10
S-band transceiver	2	58	2	58
VHF transceiver			2	7
VHF relay			1	7
LF set (1 kilowatt)	-	-	1	36
• Displays and consoles		(440)		(450)

Table 4.4-7. MSS - Detail Weight Summary - Medical, Galleys and Labs

*	CM1 Q	CM1	CCM1 Q	CCM1	CCM2 Q	CCM2	CQM1 Q	CQM1	CQM3 Q	CQM3	GM Q	GM	DWH Q	DWH	DGM Q	DGM
Medical Facility						750										
Galley and Backup Galley								102				662				
Microwave oven							1	75				75				
Resistance oven												80				
Hotplate												-				
Freezer												300				
Refrigerator												120				
Food reconstitution							1	27				27				
Sink/fountain												22				
Prep. utensils/trays/ inventory												38				
Dishwasher-dryer												-				
Laboratories				1558												
Geochemistry lab				705												
Photo lab				416												
Data analysis lab				-												
Bioscience lab				437												
Base Maintenance and Repair Station																

*Q = Quantity

1.0 RECOMMENDED MOBILITY CONCEPT

It was not an objective of this study to design any vehicles. However, because of the importance of the mobility concept in the analysis of the potential LSB mission systems, the assistance of a noted consultant in the mobility field, Dr. M. G. Beckker of Santa Barbara, California, was sought to assist in the definition of the elements of important influence on the vehicle/LSB interface. This activity culminated in mobility systems design criteria which were applied in the synthesis of several mobility system elements. These are not necessarily recommended designs but rather, serve to indicate the conceptual feature requirements.

1.1 MOBILITY SYSTEMS REQUIREMENTS

The LSB mission requirements on the mobility systems can be grouped in three areas:

1. Mission Functional Requirements
2. Sortie Scientific Activities
3. LSB Interface Influences

These are obviously interrelated and for that reason the selection process must consider all in concert.

1.1.1 Mission Functional Requirements

The mobility systems functional requirements can be determined from the requirements of the individual missions planned to be conducted from the LSB. This analysis was described in Volume II and is summarized in Table 1.1-1. Analysis of seven LSB mission elements involving mobility resulted in a requirement for five surface vehicle types: a prime mover and four powered trailers, and a small lunar flyer.

1.1.2 Sortie Scientific Activities

The scientific sortie mobility requirements derived in Volume II are summarized in Table 1.1-2. From these requirements the following design factors were developed for the vehicles and prime mover in particular.

Table 1.1-1. Mobility Systems Utilization

LSB MISSION ELEMENTS	PRIME MOVER	POWER TRAILER	SUPPLY TRAILER	MOBILE SHELTER	MODULE TRANSPORTER	LUNAR FLYER
Local Sorties	1	-	*	-	-	2
Remote Sorties	2	1	1	1	-	2
Base Support	2	-	*	-	*	-
Local Drilling	1	1	-	-	*	-
Remote Drilling	2	1	1	1	1	-
Local Logistics	1	-	1	-	-	-
Remote Logistics	1	1	1	-	-	-

*Occasional or one time use only.

Table 1.1-2. Science Sortie Mobility Requirements Summary

Sortie Duration	< 90 days
Travel Distance	
. To and from sites	< 855 SM
. At site	< 100 SM
Terrain	
. Surface	Ranging from Maria to Uplands
. Slopes	96% on 0-10° slopes
	3% on 10-30° slopes
	1% on 30° + slopes
Science-Payload Characteristics	
. Weight	
. . Fixed	1,468 lbm
. . Consumables	238 lbm
. . Return samples	703 lbm
. Power	
. . Drilling	3 Kw while drilling
. . Other	100 watts daily average
. Volume	123 ft^3
. Drilling Mission	< 12 10-ft. holes & 2 100-ft holes
. Flyer Missions	8 per LSB site; each consisting of 2 20-SM round trip flights
. Sensing Data Rate	10^4 BPS
Manpower	
. Traverses	2 crewmen minimum
. Site exploration	4 crewmen optimum

1. A prime mover with an enclosed cab is desirable because of the autonomous operations requirements and the resulting saving in crew time.

2. The cumulative free volume, distributed between the prime mover and a mobile shelter should equal or exceed 1330 cubic feet for the extended sorties.

3. A docking adapter is required on the prime mover to permit shirtsleeve transfer between the mobile shelter or LSB and the prime mover.

4. The prime mover chassis design must have a low c.g. and include six or more powered wheels on an articulating frame, flexible wheels with a wide wheel base and wide track.

5. Exterior mounted closed circuit TV with light intensification is required for night driving.

6. Dust cleaning facilities similar to the base are required on any extended sortie.

7. The prime mover should have a capability for autonomous operation for up to 48 hours for sortie on site traverses and local mission support.

8. Storage for up to 4,850 pounds or 248 cubic feet of supplies are required.

9. Powered and articulating connections are required between the prime mover and trailers or between trailers.

1.1.3 LSB Interface Influences

The LSB interface influences are found in the subsystem performance requirements. The LSB complex and all of its constituent elements must be considered as a unit. Consumables used in one mission element must not differ from those in another or a compensating interface subsystem function is required. Each of mission systems element or vehicles are required to be designed to match at some compatible interface point.

The atmospheric management and crew services subsystem design requirements are defined in Part I of this Volume and the resulting consumables budget is presented in Table 1.1-3.

The electrical power system design requirements were assessed in Section 5.1 of Part I and the resulting EPS budget for a mobile power unit on a sortie (extended trip) is presented in Table 1.1-4. The EPS subsystem design is defined in Section 5.3. The trailer is defined in a subsequent paragraph.

Table 1.1-3. A&CS Consumables Budget - Sortie Missions

Crew Consumables		
. Food & Supplies	2.11	lbm/man-day
. Water	8.50	lbm/man-day
. Oxygen	2.70	lbm/man-day
System Consumables		
. Oxygen	0.3	lbm/day
. Hydrogen	.0375	lbm/day
	<	
	.338	lbm/man-day

The communications subsystems are defined and selected in Section 6.0 of Part 1. The use of a VHF relay together with S-band earth or satellite relays establish requirements for both capabilities on the prime mover, along with a backup LF voice system.

Navigation on the lunar surface is an area of concern. The LSB facility can provide very little support, except in its immediate vicinity. This, therefore, imposes a requirement on the vehicle/train that it possess a navigation system capable of operating without LSB support.

1.2 LSB MOBILITY SYSTEM ELEMENTS

As indicated in Table 1.1-1, the mobility systems are composed of five surface elements, a prime mover and four trailer concepts which can be used in various types of "train" concepts. An example of the configuration which might be utilized for an extended sortie with deep drilling is illustrated in Figure 1.2-1. The mobility elements are described below. The deep drill module is described in Section 7.2.

Table 1.1-4 EPS Budget - Sortie Missions

Mobility Consumption	0.1 Kwh/mi-Klbm
A&CS	0.55 Kw/man 24-Hr. Average
Communication, Navigation, Stationkeeping, Lighting	0.5 Kw 24-Hr. Average
Science	
. Nominal	0.1 Kw 24-Hr. Average
. W/Drill	3.0 Kw 24-Hr. Average

1.2.1 Prime Mover

Figure 1.2-2 illustrates the baseline prime mover as defined for this study. It embodies all of the features required by the LSB missions, the LSB interface and those recommended by the consultant, Dr. Beckker. In addition to incorporating all of the design factors listed in Section 1.1, it provides: 90-degree approach and 60-degree exit angles, a short turning radius, 10k ampere-hours of battery power, over 600 cubic feet of free volume, and weight just over 4,000 pounds. Additional design details are shown in Drawing 2284-4B including the use of attachments for construction and logistics operations. Further details of these interfaces are contained in Section 2.0 which follows. A weight breakdown for the prime mover is shown in Table 1.2-1.

The A&CS functions are defined in Section 3.3 and the communications subsystem in Section 6.0 of Part 1. A preliminary guidance and navigational system has been identified. Accurate navigation on the lunar surface may not be feasible with the present system concepts. NR conducted a preliminary analysis of four options. The results of these analyses are contained in the Appendix D to Volume II. The system requirements imposed on the prime mover are identified in Tables 1.2-2 and 1.2-3. The illumination subsystem is required to provide visibility at night and facilitate feature recognition and triangulation for navigation.

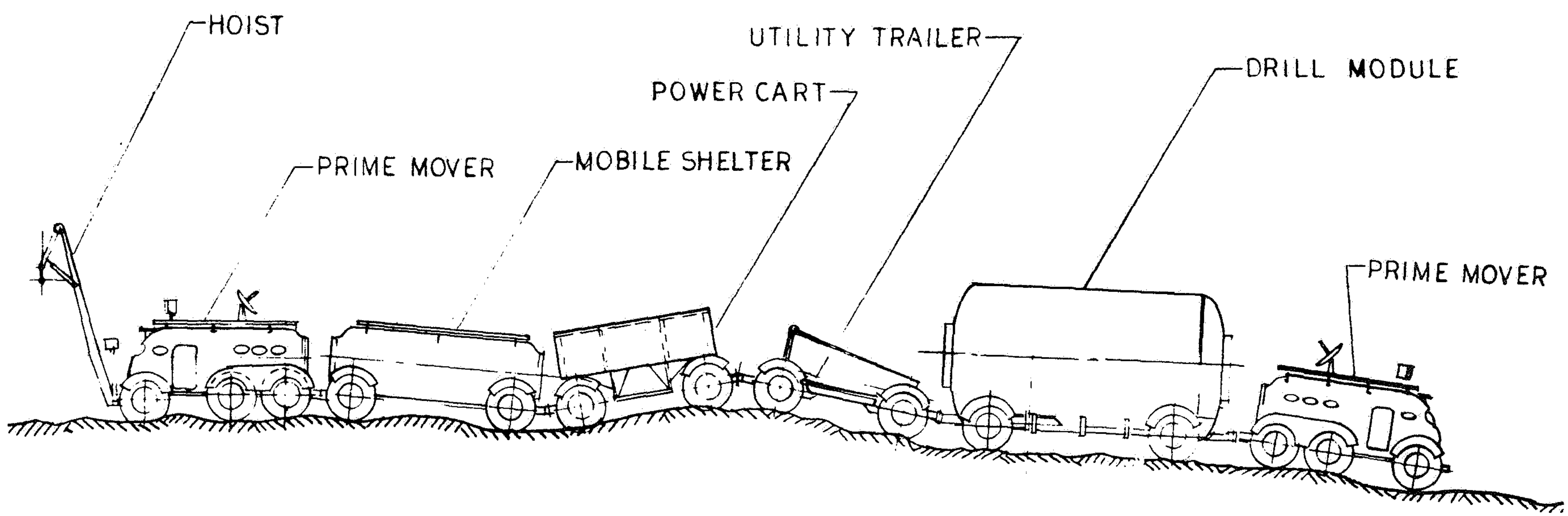


Figure 1.2-1. Sortie Mobility Elements

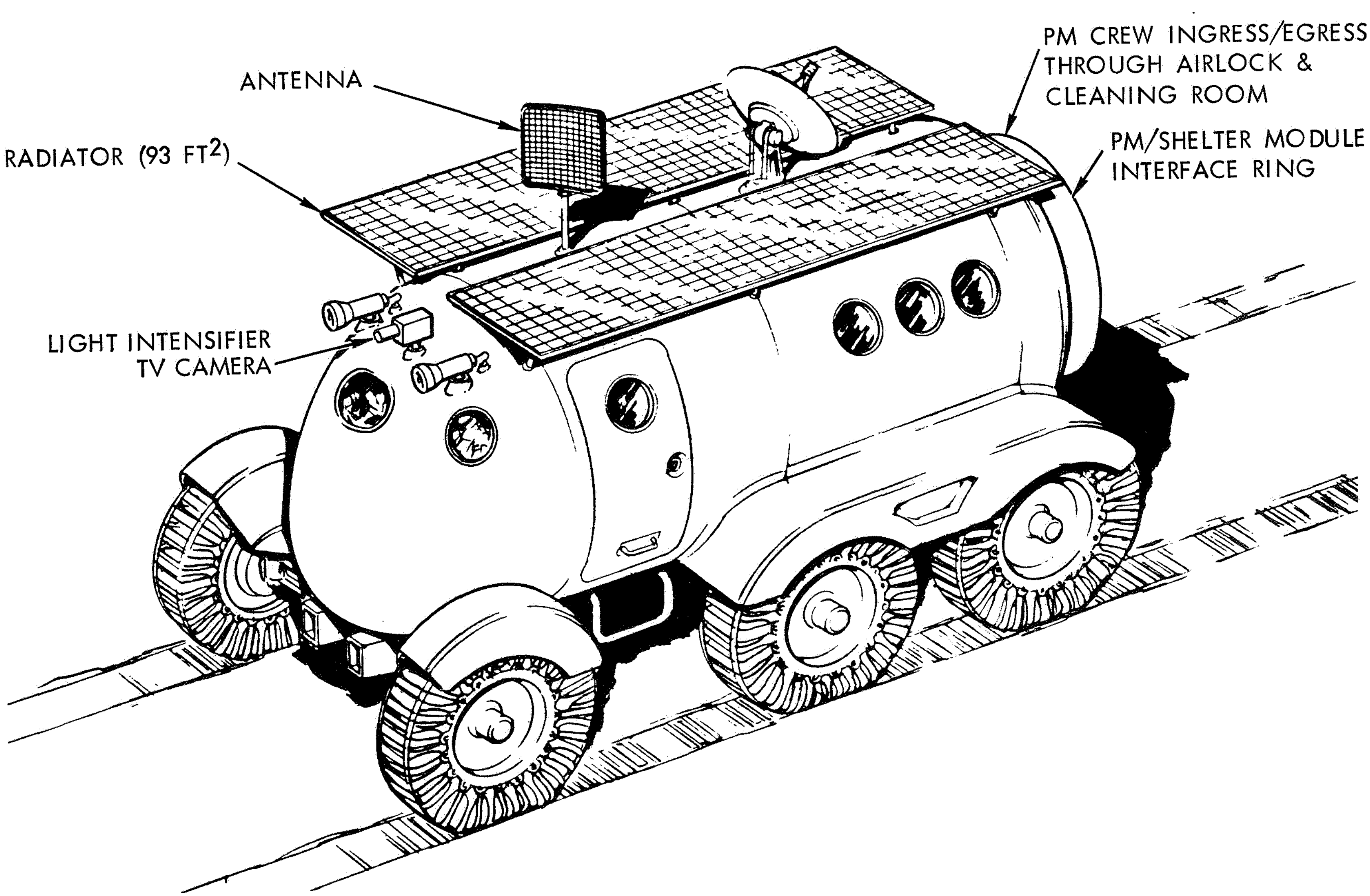
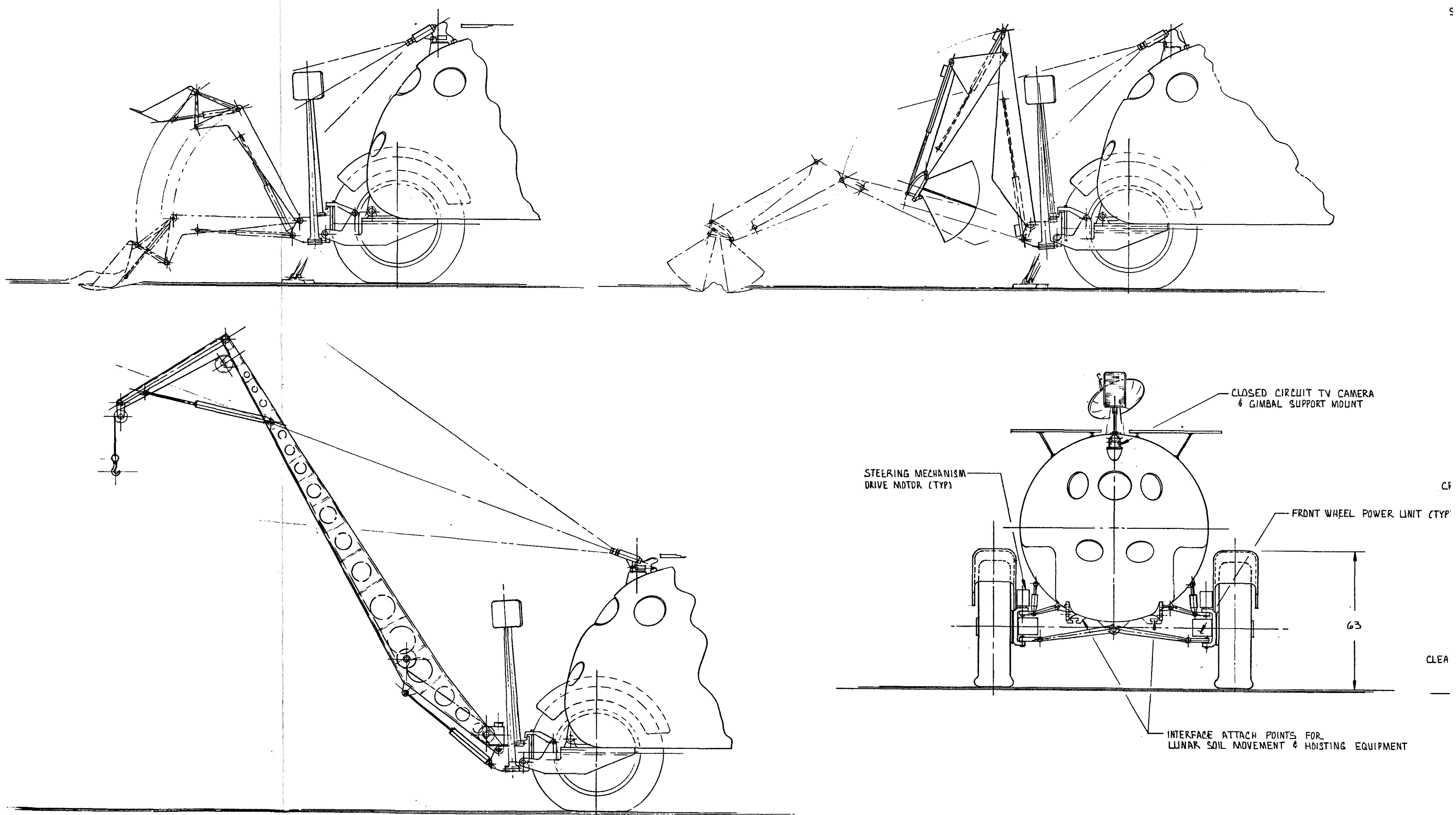


Figure 1.2-2. Prime Mover


CLOSED CIRCUIT TV CAMERA
& GIMBAL SUPPORT MOUNT
STEERING MECHANISM
DRIVE MOTOR (TYP)
FRONT WHEEL POWER UNIT (TYP
63
INTERFACE ATTACH POINTS FOR
LUNAR SOIL MOVEMENT & HOISTING EQUIPMENT

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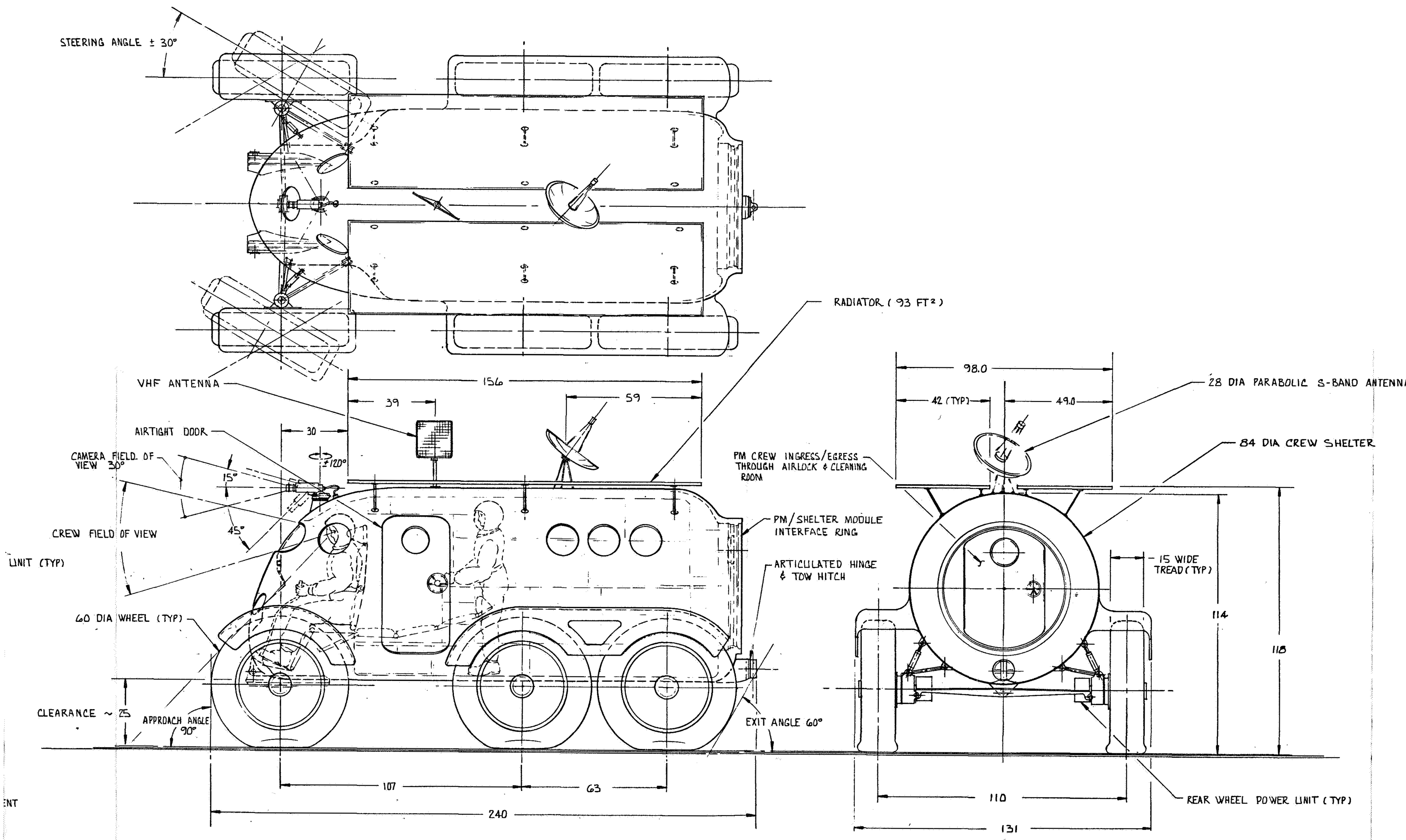

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A	1. REDRAWN & RECONFIGURED	12-15-70	R.T.
B	1. ADDED LSB UTILITY TRANSPORTER DELEATED MOBILE CREW SHELTER	3-16-71	R.T.

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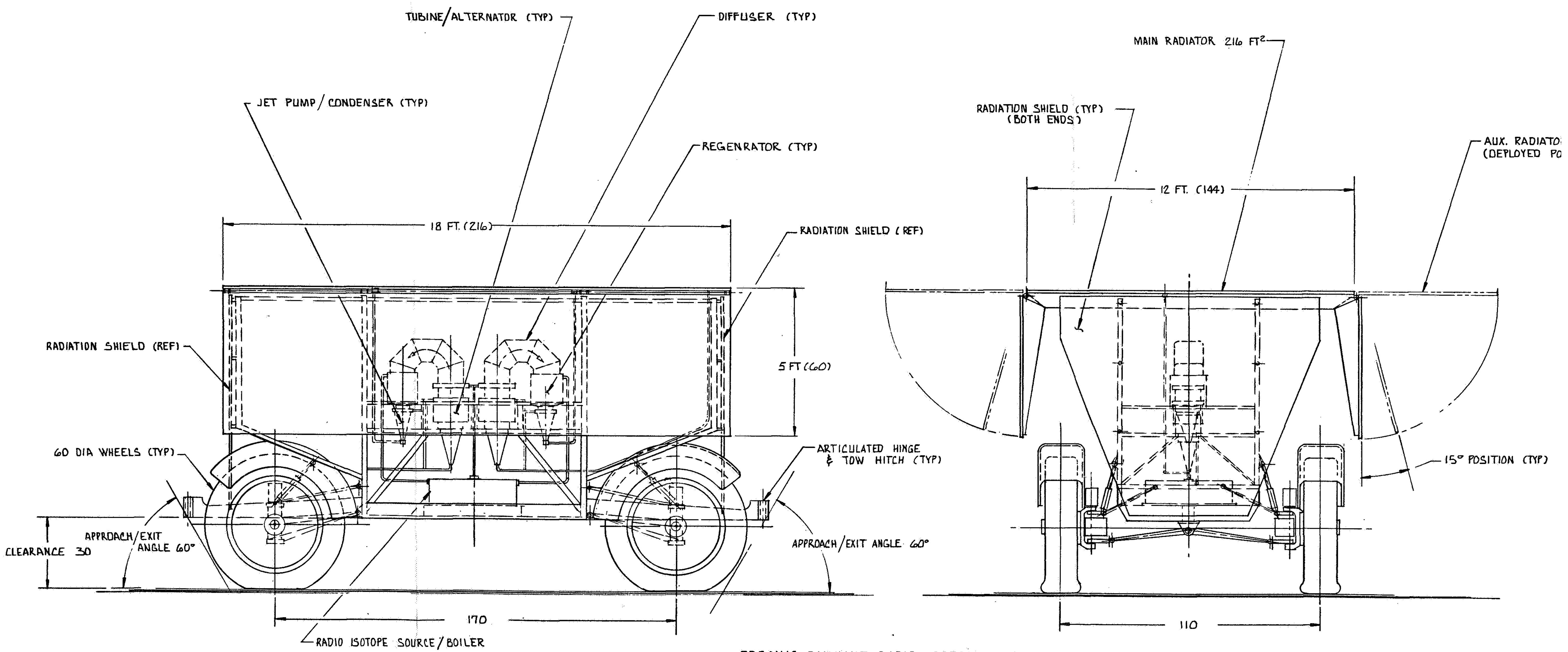
SCALE: 1/20	DR. [signature] DATE 12-16-70 MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
PRIME MOVER - LUNAR SURFACE BASED VEHICLE/SHELTER CONCEPT			2284-4B SHT 1 OF 2



ORGANIC RANKINE RADIO ISOTOPE EPS

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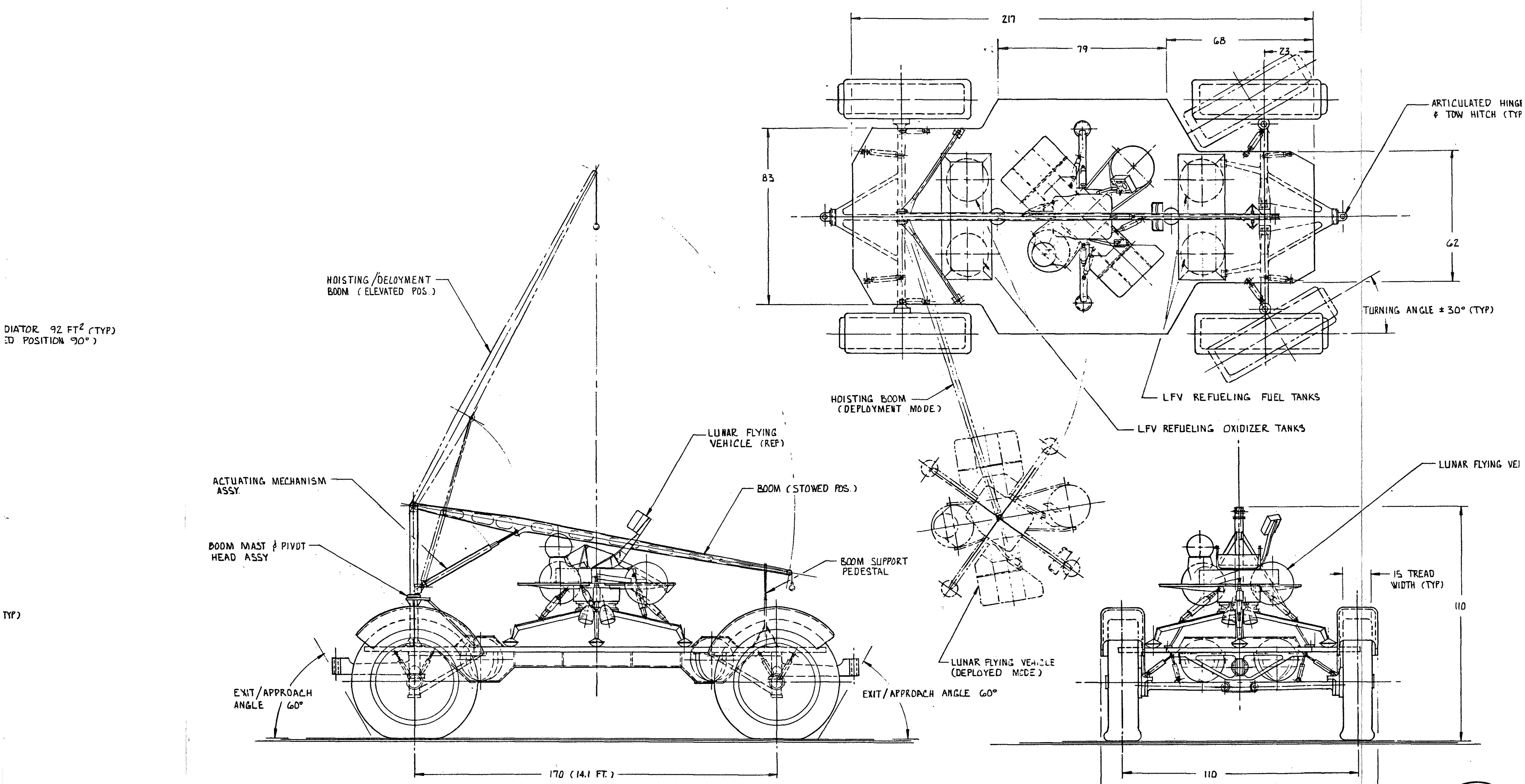

LSB UTILITY TRANSPORTER - WITH LFV PAYLOAD

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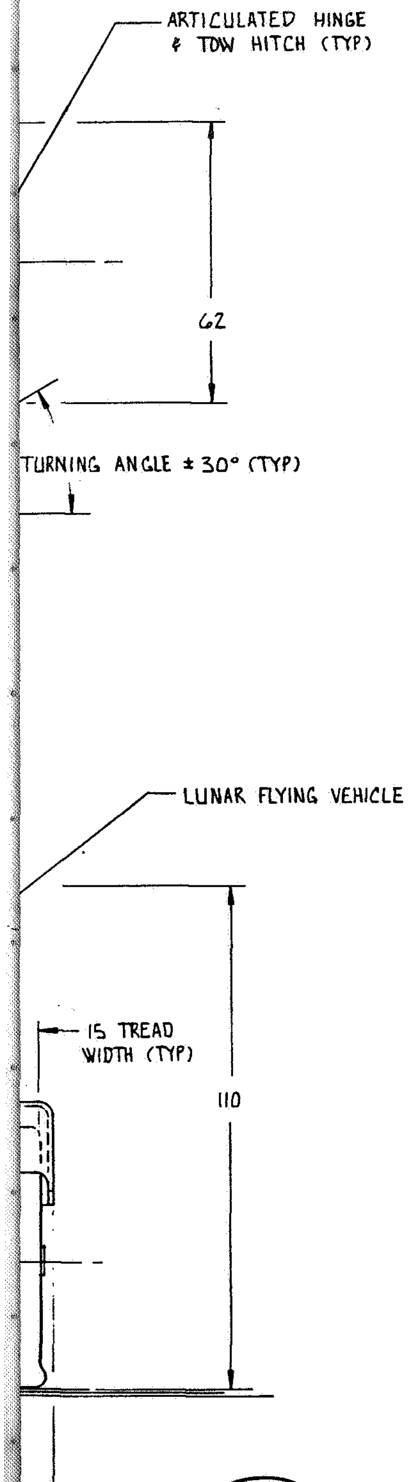

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PRIME MOVER - LUNAR SURFACE BASED VEHICLE/SHELTER CONCEPT			2284-4B SHT 2 OF 2

Table 1.2-1. LSB Mobility Elements Weight Data

System	Module				
	Prime Mover	EPS Cart	Crew Shelter	Flyer Cart	Utility Trailer
Structure	(1440)	(620)	(2010)	(500)	(1220)
Primary structure	480	620	630	500	410
Insulation	200		270		180
Meteor protection (90-day)	380		515		350
Door, frames, etc.	200		300		200
Airlock tunnel/bulkhead			45		
Furnishings	180		250		80
Equipment	(2075)	(2750)	(3190)	(1000)	(70)
A&CS - fixed equipment	695		1110		20
- tankage	30		930		
EPS and distribution	860	2510	400		50
Navigation	65				
TV assist	25				
Comm. and data	240		50		
Food prep. and water supply	60		570		
Radiators and support struct.	100	240	130		
Propellant tanks				1000	
Drive system	(555)	(400)	(400)	(400)	(400)
Front wheel assembly	175	175	175	175	175
Rear wheel assembly	330	175	175	175	175
Misc. fittings and attachment	50	50	50	50	50
Dry weight (pounds)	4070	3770	5600	1900	1690
Useful load	(1180)		(2280)	(1400)	(4810)
Flyer				400	
Flyer propellant				1000	
EVA support equipment	535		1280		
A&CS spares	125				1150
Consumables	150		1000		3660
Crew	370				
Gross weight (pounds)	5250	3770	7880	3300	6590

Table 1.2-2 Weight and Power Requirements for Navigation Subsystem

Components	Weight (lbs)	Power (Watts)
Periscopic Theodolite	18	3
Tilt Sensor	3	6
Directional Gyro	6	8
Odometer (in mobile system)	-	-
RDF Receiver	15	5
Navigation Computer	15	30
Steering Indicator	2	6
Maps	-	-
Sextant	5	-
	64	58

Table 1.2-3. Illumination Subsystem for Lunar Vehicles

Components	Weight (lbs)	Power (Watts)
TV Camera Assembly (2)	16	15
Illumination Source	5	40
A2-El Control	8	10
Combiner-Synchro	1	1
Television Monitor	7	15
Internal TV Cameras (2)	8	14
Total Illumination & TV	45	95

1.2.2 Mobile Power Unit

The power source for the mobile power unit has been defined in Section 5.0 of Part 1. The trailer, radiator and other functions are illustrated conceptually in Drawing 2284-4B. Each of the two organic Rankine converters will produce 3.5 kwe and in the emergency mode an integral thermoelectric converter will produce 1.3 kwe. The unit is designed to fit the same chassis as the other powered trailers and has an articulating chassis and a hitch to transfer loads forward and to the rear. At least 60 degrees clearance is provided to assure the required obstacle traversing capability for rough terrain. The mobile power unit weight breakdown is presented in Table 1.2-1.

1.2.3 Utility Trailer/Flyer Transporter

The LSB study has not identified postive mission requirements for a lunar flying vehicle. However, it was indicated that if a flyer is needed, the requirement would arise at a point some distance from the base. It could be flown from the base or carried out to the nearest point accessible on the surface and flown from there. The latter concept is recommended since the resulting saving in fuel consumption and flyer weight far surpass the potential advantages of direct flying.

The utility or supply trailer is a "standard" powered trailer chassis with a flat bed or a cargo module (not shown) for extended sorties. Its elements and estimated weight are identified in Table 1.2-1.

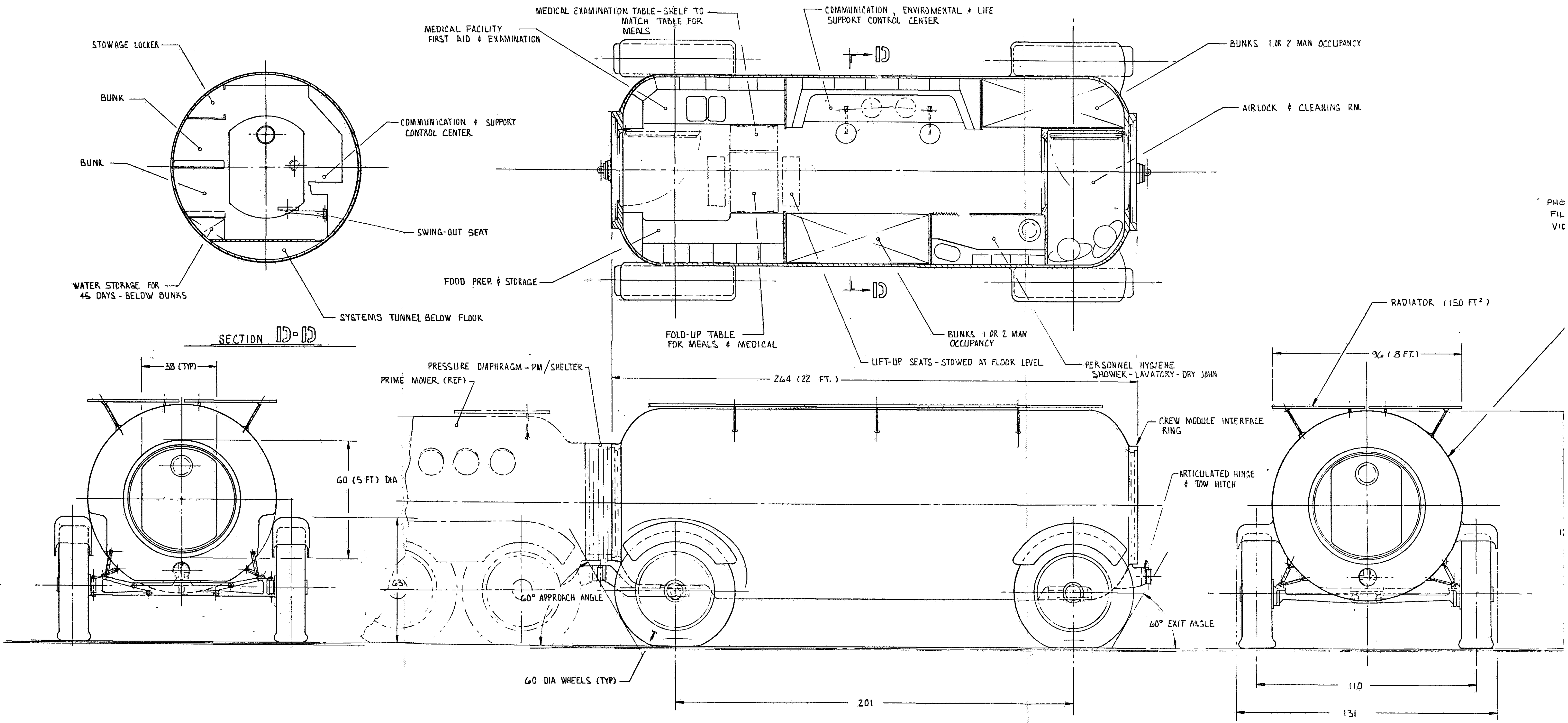
The adaptation of the utility trailer to transport the flyer is shown on Drawing 2284-4B. It is designed to carry the flyer and fuel for two flights, above that in the flyer tanks. It uses the same trailer as the other units, is self-powered and, therefore, has the same performance capability. The weight is also estimated in Table 1.2-1.

1.3 MOBILE SHELTER RECOMMENDATIONS

The requirements analysis indicated that both the sortie and some deep drilling operations would require 4 and 2-man crews to be away from the base for periods as long as 90 days.

Three shelter module options investigated for this purpose are illustrated on Drawing 2284-3A. The options involving the 15-foot modules had c.g.'s too high and were not easily coupled to the prime mover. The recommended 8-foot by 22-foot cylinder has more floor area for less weight and the c.g. is much lower. Again this concept is not necessarily a proposed design but provides a baseline for the mission plans and cost estimates.

The subsystems required are identified on the weight statement of Table 1.2-1. The subsystems operational concepts are defined in the mass balance discussion in Section 3.0 of Part 1. Communications and data functions are provided by the prime mover. Data handling capabilities are limited to the minimum requirements and approximate the capabilities of the MSS "Local Processor."



4 MAN MOBILE CREW SHELTER

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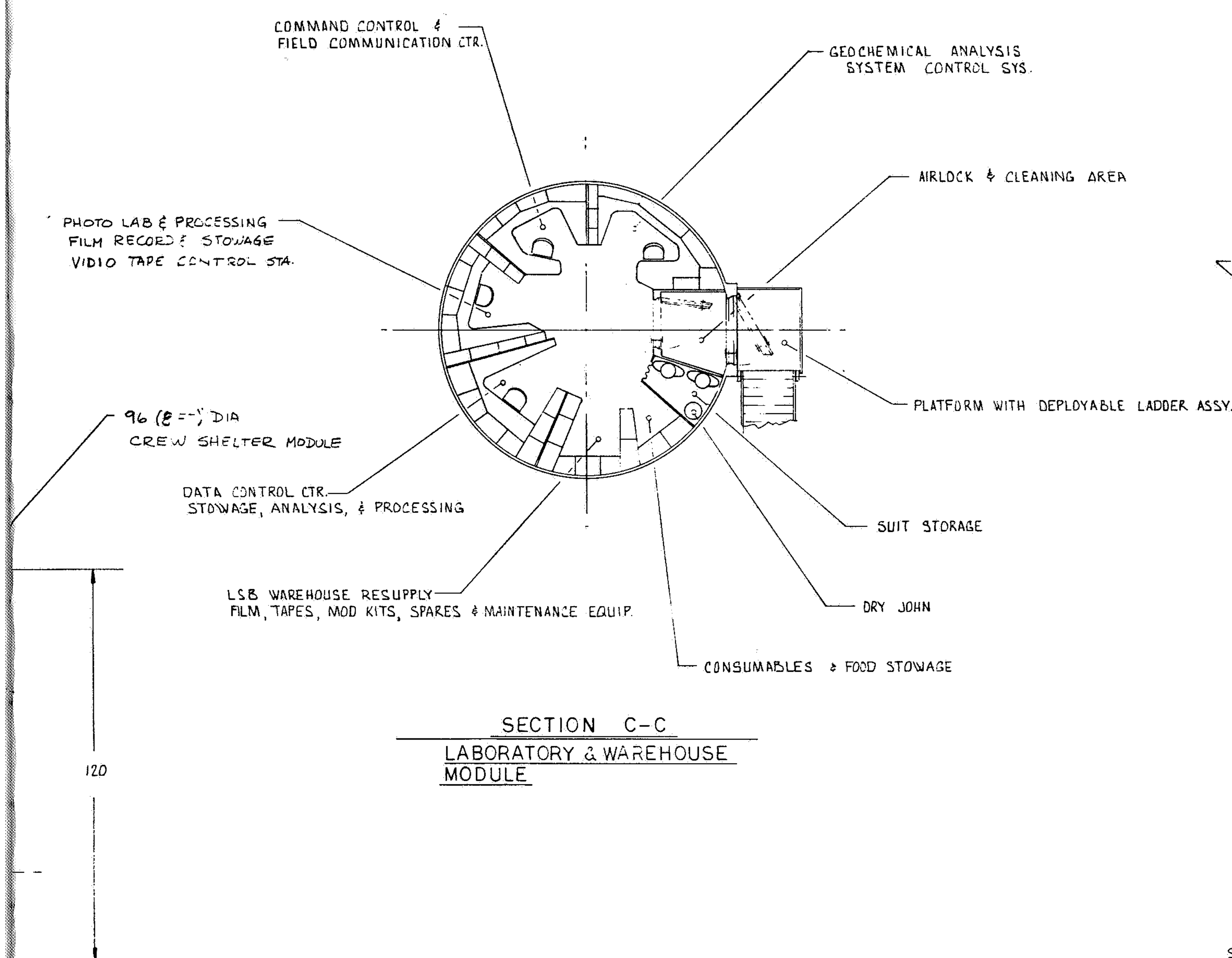
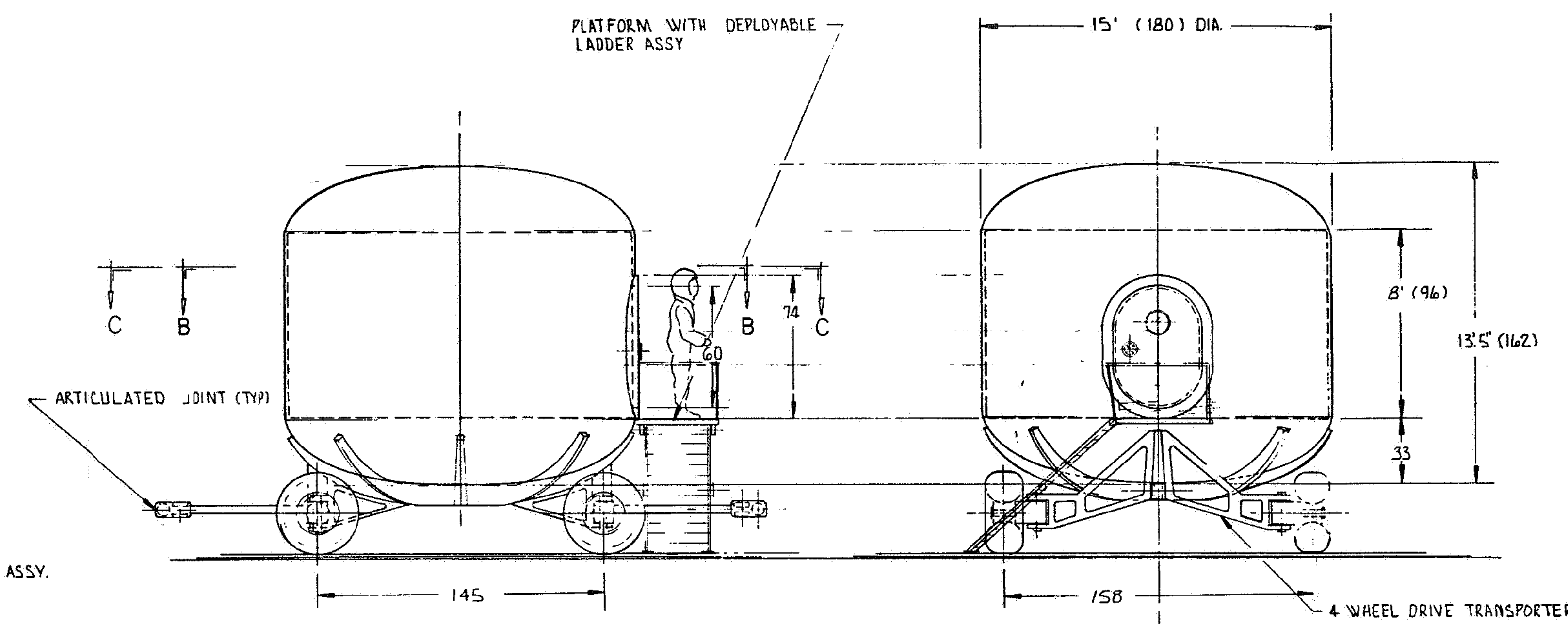
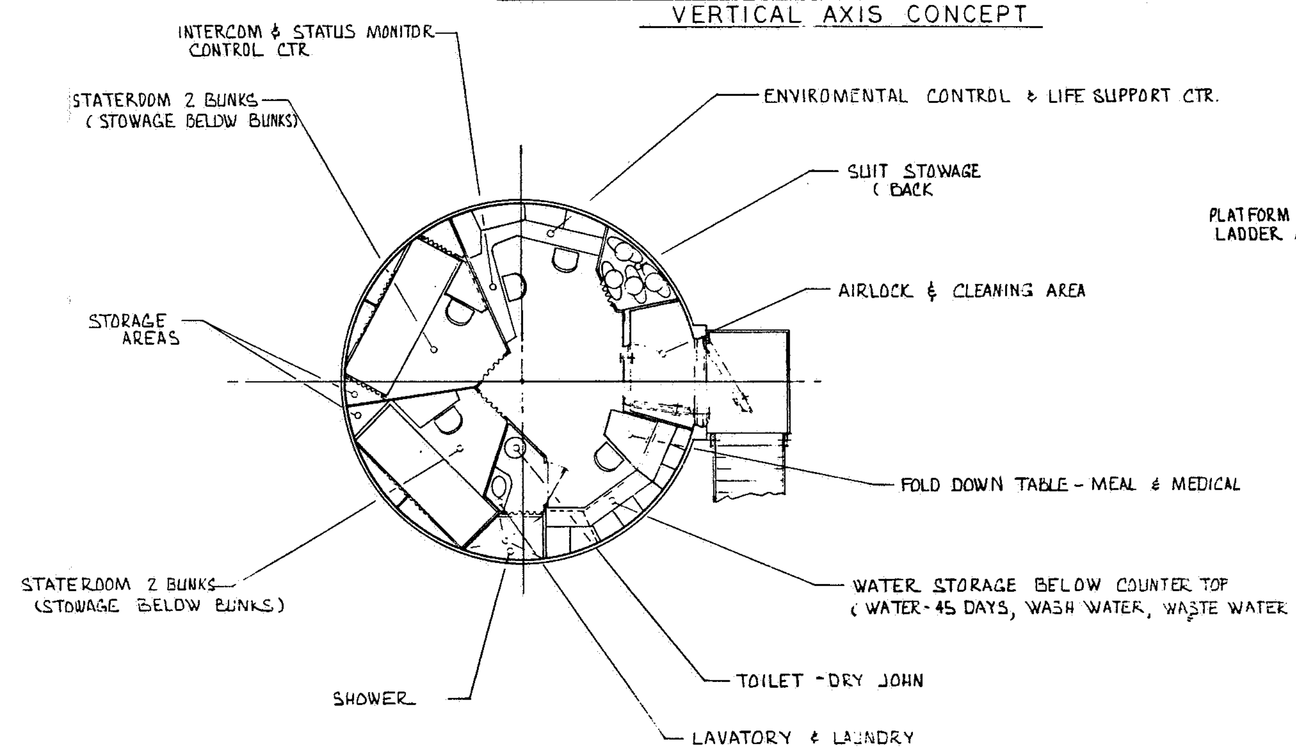


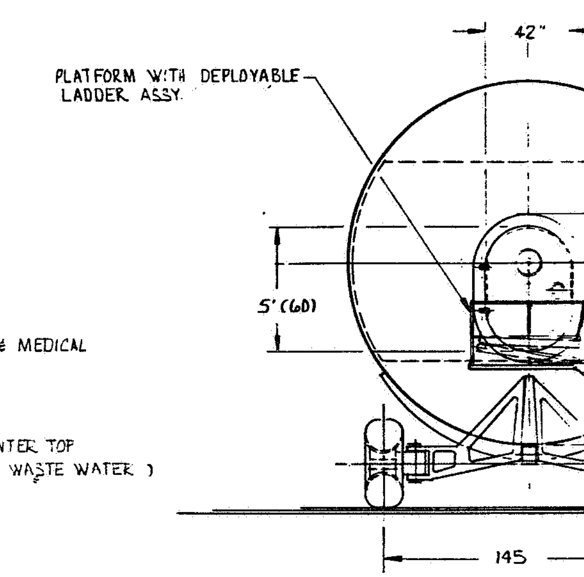
SECTION C-C
LABORATORY & WAREHOUSE MODULE



4 MAN MOBILE SHELTER & SUPPLIES
VERTICAL AXIS CONCEPT



SECTION B-B
(CREW MODULE)



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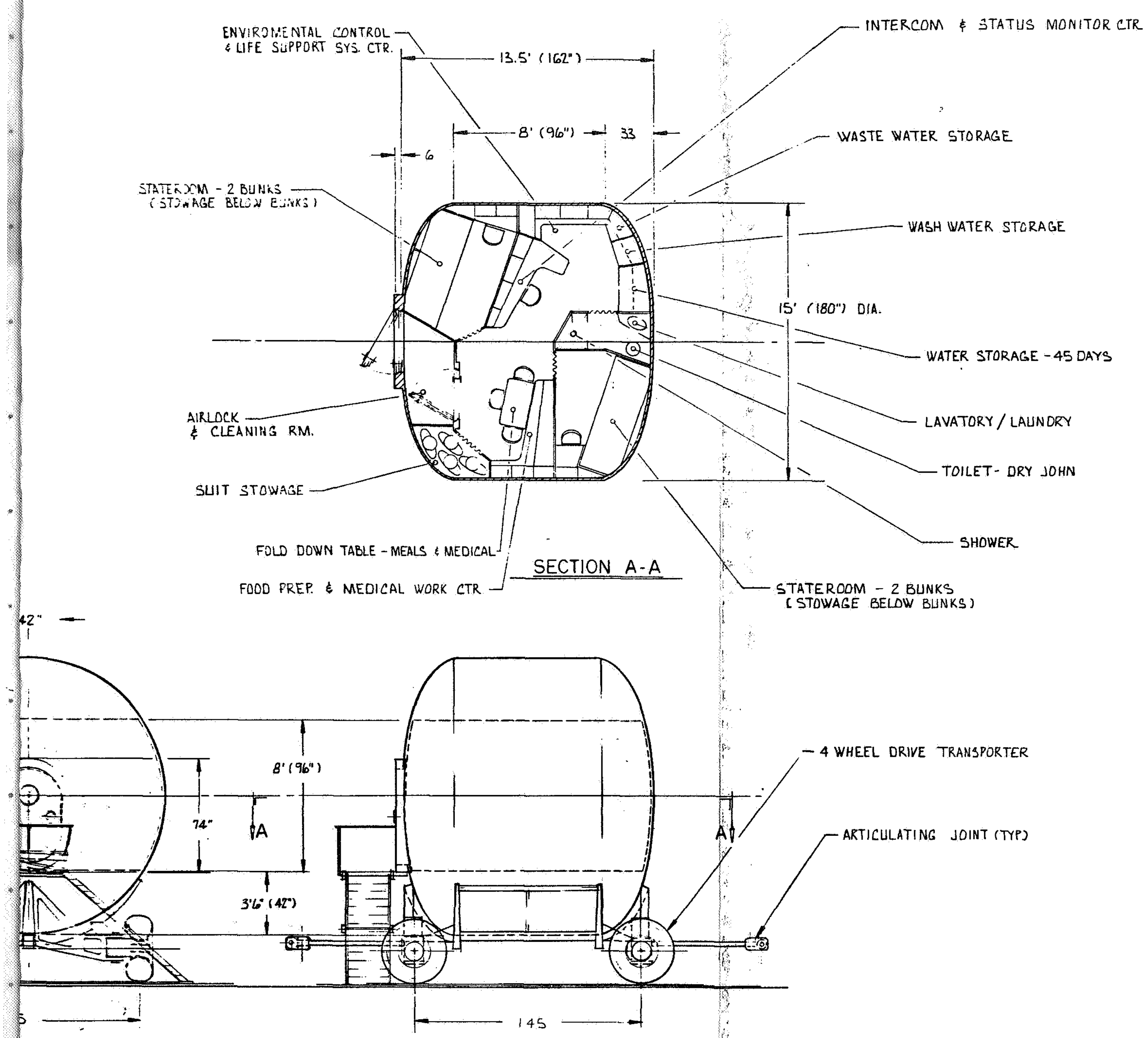
SHEET 2 OF 2



4 MAN MOBILE SHELTER & SUPPLIES

HORIZONTAL AXIS CONCEPT

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A	1. ADDED ALTERNATE SHELTER MODULE	1-27-71	R.T.

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North American Rockwell

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SCALE: 1/40 & NOTED | SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA

4 MAN MOBILE SHELTER MODULE, LUNAR SURFACE BASED VEHICLE

2284-3A

SHEET 1 OF 2

2.0 HANDLING SYSTEMS DEFINITION

Analysis of the base deployment and base operations has resulted in the definition of requirements for the following handling systems: soil moving and grading, heavy cargo handling, and cargo transfer. This section describes the requirements for each of these operations and the potential design solutions.

2.1 SOIL HANDLING REQUIREMENTS INFERENCES

The LSB mission requires the capability to:

1. Grade and maintain the tug landing sites

2. Prepare the frequently traveled surface vehicle routes

3. Grade the sites for the main base modules, the observatory(s), the drill, and other extra-base locations

4. Provide meteoroid/radiation/thermal protection by a soil cover over the main base module complex

Table 2.1-1, Soil Handling Requirements, estimates the capability required for typical LSB soil handling operations. In general, the tug landing sites and the main roads will be prepared by surface grading. The base location, however, would be prepared by cutting a trench about four or five feet, or as deep as the soil will permit, to reduce the amount of soil required for cover and provide a convenient source for the covering soil.

In addition to these known requirements, there exists the possibility of using a grader on the surface sorties. Although the lunar surface is relatively dormant and the weathering effects of the impacting meteorites have locally reduced major sharp features, a surface grader attached to one of the sortie vehicles may be of use in aiding the sortie through the rough areas. This requirement has not been established except in this sense, but it is reasonable to assume that the equipment developed for base work may be utilized on the sorties.

In implementing these requirements into a design solution, several points must be considered.

1. Lunar construction is inherently different than earth techniques in that the reduced gravity field decreases the traction capability of the prime mover affecting its overall performance in trying to handle the same mass. Lunar soil characteristics have been estimated (Reference 5) and have been substantiated by lunar exploration

Table 2.1-1 Soil Handling Requirements

Requirement	Area	Volume	Distance Moved
Grade Tug Landing Sites	Surface cut of 1 inch 7850 yd^2	218 yd^3	Effective dist. ∿ radius of site - 50 yards
Roads	Surface cut of twice the vehicle width - 20 ft length - 4 mi depth - 1 inch	-	Moved 1/2 the blade width - graded to the side continuously
Main Base Grading	Trench cut to floor level of modules - 3 to 5 ft base area - 600 yd^2	665 yd^3	Effectively moved 1/2 width of base - 20 ft
Covering Base	Cover to 6" min. on top of modules (side slopes ∿ 35°	980 yd^3	Effectively moved 1/2 width of base ∿ 20 ft
100-in observatory Site Grading	Surface cut ∿ 1 in area ∿ 4700 ft^2	14 yd^3	Effectively moved 1/2 width of area ∿ 10 ft
100-in Observatory Cover	Cover to 6" min on second reflector and experiments lab side slopes ∿ 35°	450 yd^3	Effectively moved 1/2 width of area covered ∿10 ft

programs through Apollo 14. Actual vehicle performance will be better determined from the planned Apollo 15 (and following) lunar rover vehicles.

2. The types of lunar material to be handled may vary from loose dust to moderately indurated breccia. The design solution must be capable of operating throughout this regime.

3. Since additional weight delivered to the lunar surface is extremely expensive, it is desirable to incorporate several functions in the same piece of equipment if only minor modification or minimal manpower efficiency loss is involved.

2.2 SOIL HANDLING OPTIONS AND RECOMMENDED CONFIGURATIONS

On the basis of handling requirements and the above considerations, several options are available for soil moving--dozer, grader, backhoe, power shovel, clam shell, or skiploader. Table 2.2-1 presents comparisons of soil handling options. From these data, the skiploader appears as the most universal tool for scooping, moving, and grading. Figure 2.2-1 illustrates this concept as attached to the prime mover. The equipment, in a dozing configuration with a 10-foot wide blade, can move about one-and-a-half cubic yards (range of 1 to 2 cubic yards) with no blade penetration. The maximum cut varies from 8 inches down to no penetration as the bucket accumulates the load. Scraping to the side, the dozer may make about half this cut or 3 to 4 inches deep. The dozing velocity is 1 to 1.5 mph and the prime mover specific energy is about 2 kwh per mile dozed for each cubic yard (or 2 kw per mph per cubic yard). Figure 2.2-2 illustrates a timeline analysis of skiploader operation as used in a cut and moving operation.

2.3 HOISTING OPERATIONS REQUIREMENTS

Hoisting requirements at the lunar base complex involve unloading the logistics vehicle, positioning the various modules on the transfer vehicle frame, unloading and positioning the base modules, science equipment and antenna arrays. Sortie support is not required; however, the deep drilling operations will involve hoisting operations.

The equipment to be handled may be categorized as:

1. Shelter modules

2. Surface mobility vehicles

3. Heavy machinery (construction/erection equipment)

4. Power source equipment

Table 2.2-1. Soil Handling Options

OPTION	ESTIMATED WEIGHT	VERSATILITY		
		Grading/Scraping	Cutting	Hauling
Dozer	325 lbm	X	X	
Grader	325 lbm	X		
Backhoe/Powershovel/Clamshell	675 lbm		X	X
Skiploader	450 lbm	X	X	X
Soil Transport Box	277 lbm			X

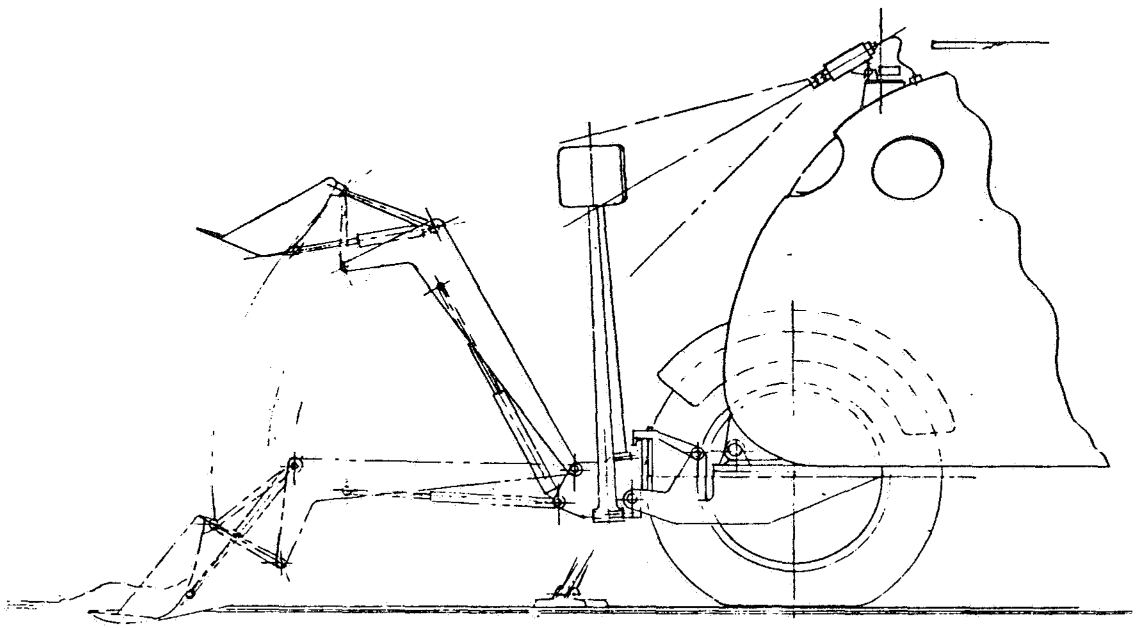


Figure 2.2-1. Recommended Soil Handling Concept

5. Communications equipment

6. Launch support equipment

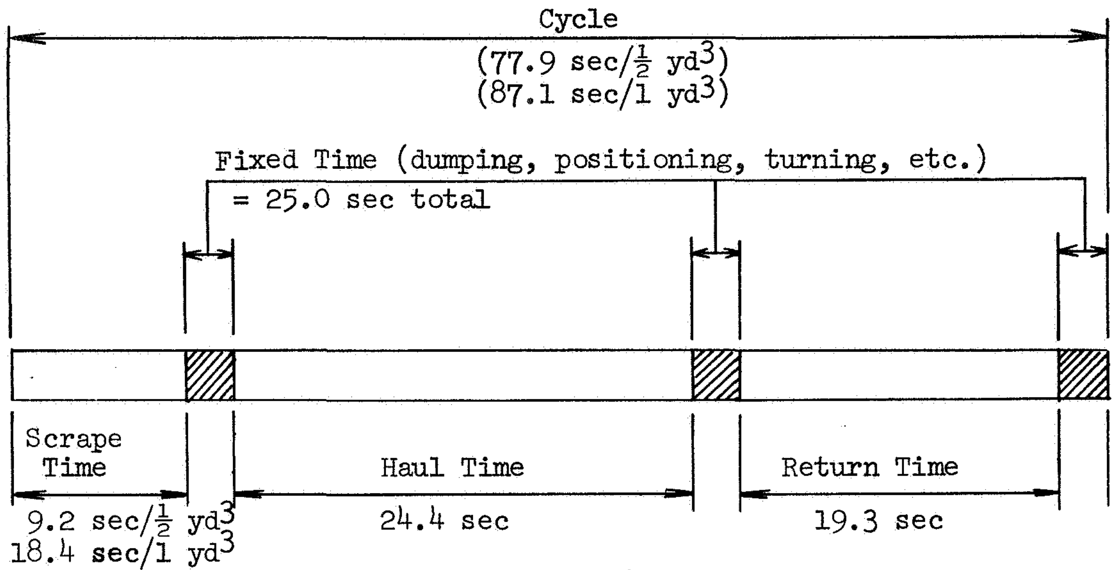
7. Science equipment (observatories, drill, antennas)

8. Consumables

Each item are configured to be delivered within an envelope of 15 feet diameter by 30 feet long. The dome and plane mirror for the 100-inch telescope optical observatory will be segmented to fit within this envelope.

The packing density of this equipment as delivered to the lunar surface varies from 3 to 5 pounds per cubic feet for base shelter modules and from 10 to 20 pounds per cubic foot for cargo resupply modules. The cylindrical module total mass as a function of its shape and packing density are presented in Figures 2.3-1 and 2.3-2 for delivered base modules and for cargo modules respectively. The baseline shelter maximum delivered weight is noted on Figure 2.3-1. Section 2.0 of Part 1 establishes the cargo module shape as shown on Figure 2.3-2.

Expected operations involving the prime mover and hoist consist of assisting the unloading of the logistics vehicle and transferring the load to the transporting cradle. After transporting the load to the shelter complex, the load will be removed and positioned for attachment. The hoist will also be used in constructing the observatories, drill, and the numerous antenna arrays.



NOTE: Avg. distance - 85 feet
Rates: Bulldozing 1 mph
Hauling 2 mph
Return 3 mph

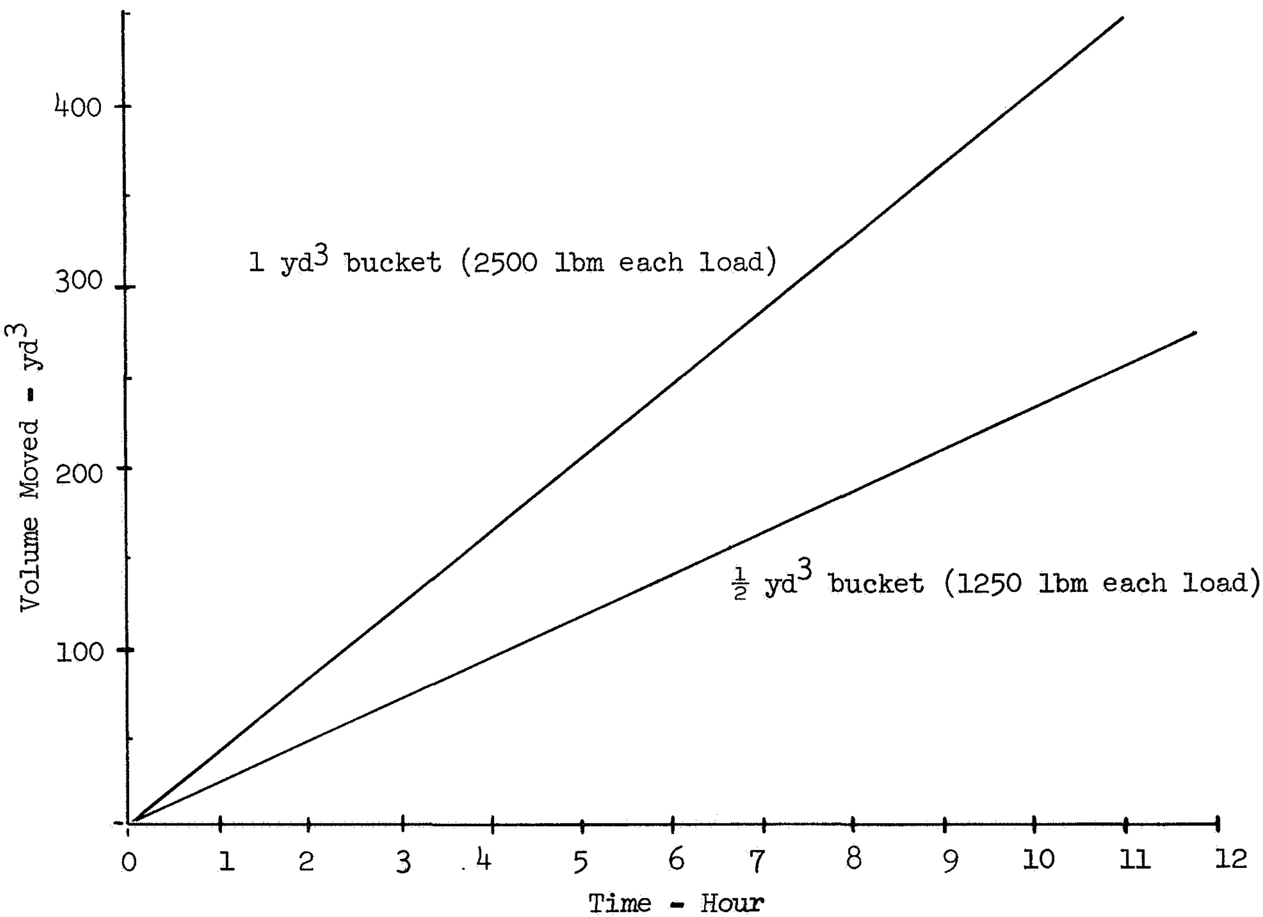


Figure 2.2- 2. Skip Loader Time Profile

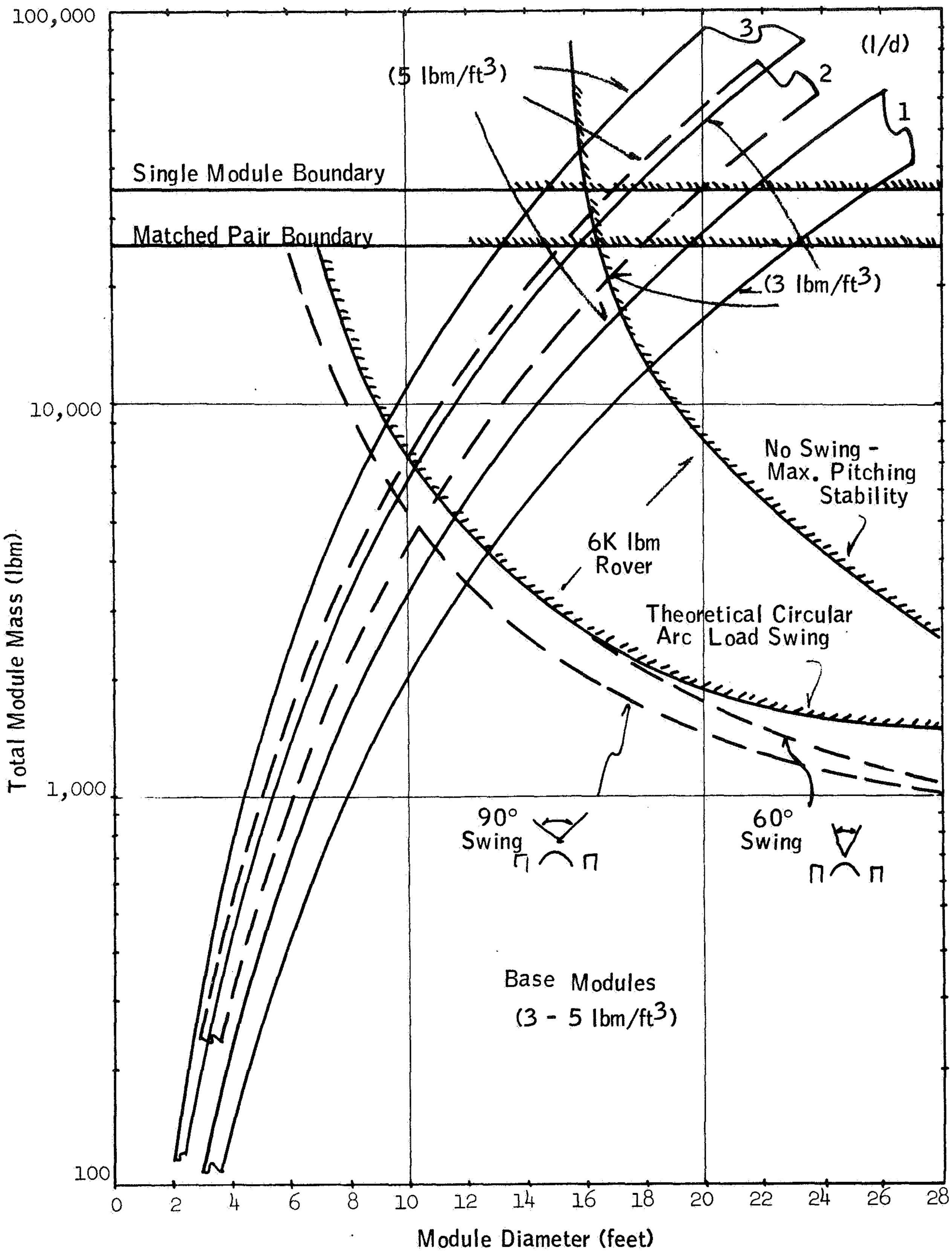


Figure 2.3-1. Base Module Handling

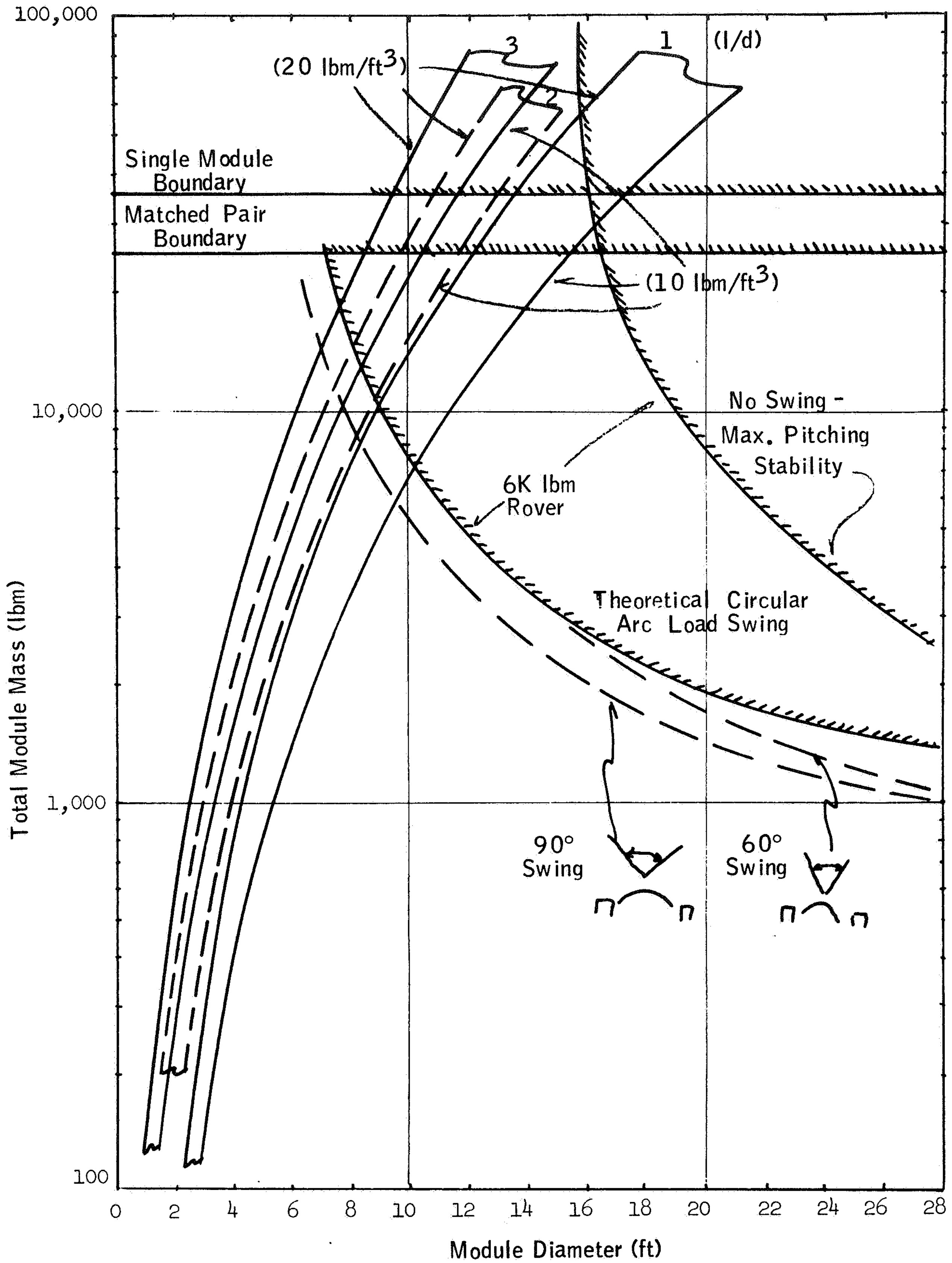


Figure 2.3-2. Cargo Module Handling

Figure 2.3-3 presents the hoist concept as attached to the prime mover. The capabilities with and without outriggers were determined for loads centered at a specified distance from the vehicle assuming that the critical load pitch and roll stability occurred when the rear (pitch) or outside (roll) wheel load was reduced to zero. The relationships are presented in Figure 2.3-4 and the summary results are superimposed on Figures 2.3-1 and 2.3-2. The hoisting capability varies as the maneuver limits range from no swing to a theoretical circular arc swing (load and vehicle wheel interference lowers the limit for various arc swings as shown).

Figures 2.3-1 and 2.3-2 indicate that the hoist with outriggers can easily lift both the base and cargo modules in a pure frontal lifting situation. In order to swing the load, however, the outriggers must be placed more to the side thus decreasing the frontal outrigger distance component and reducing the capability. This determination was made for a prime mover without trailers. With a power trailer attached, a much larger pitching moment arm is allowable and the circular arc swing boundary increases. Therefore, it appears that even the heaviest of these modules can be hoisted by the prime mover hoist as shown in Figure 2.3-3 and, with either attached trailers or ground anchors, may be moved to a new position.

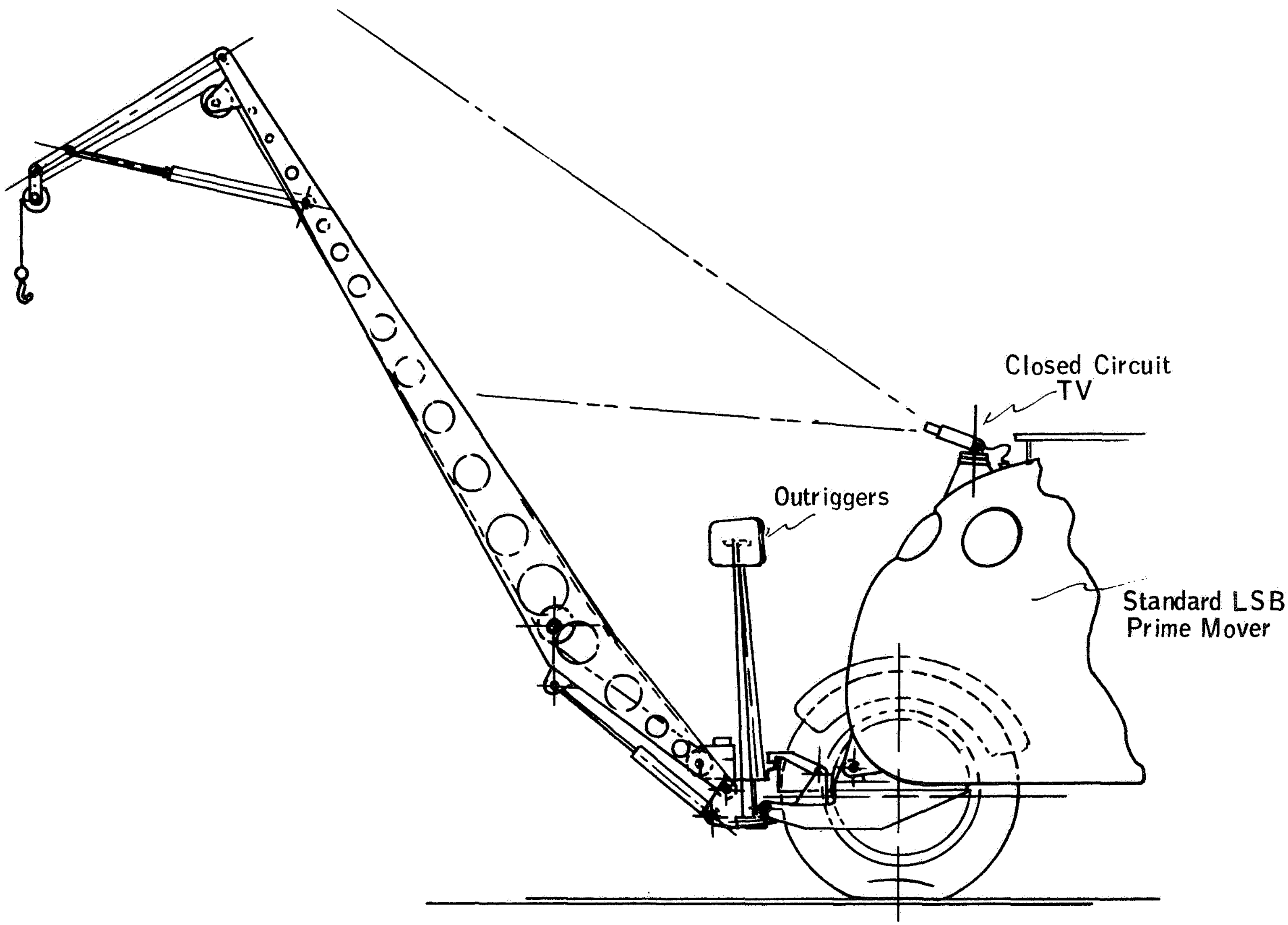


Figure 2.3-3. General Purpose Hoist, LSB Applications

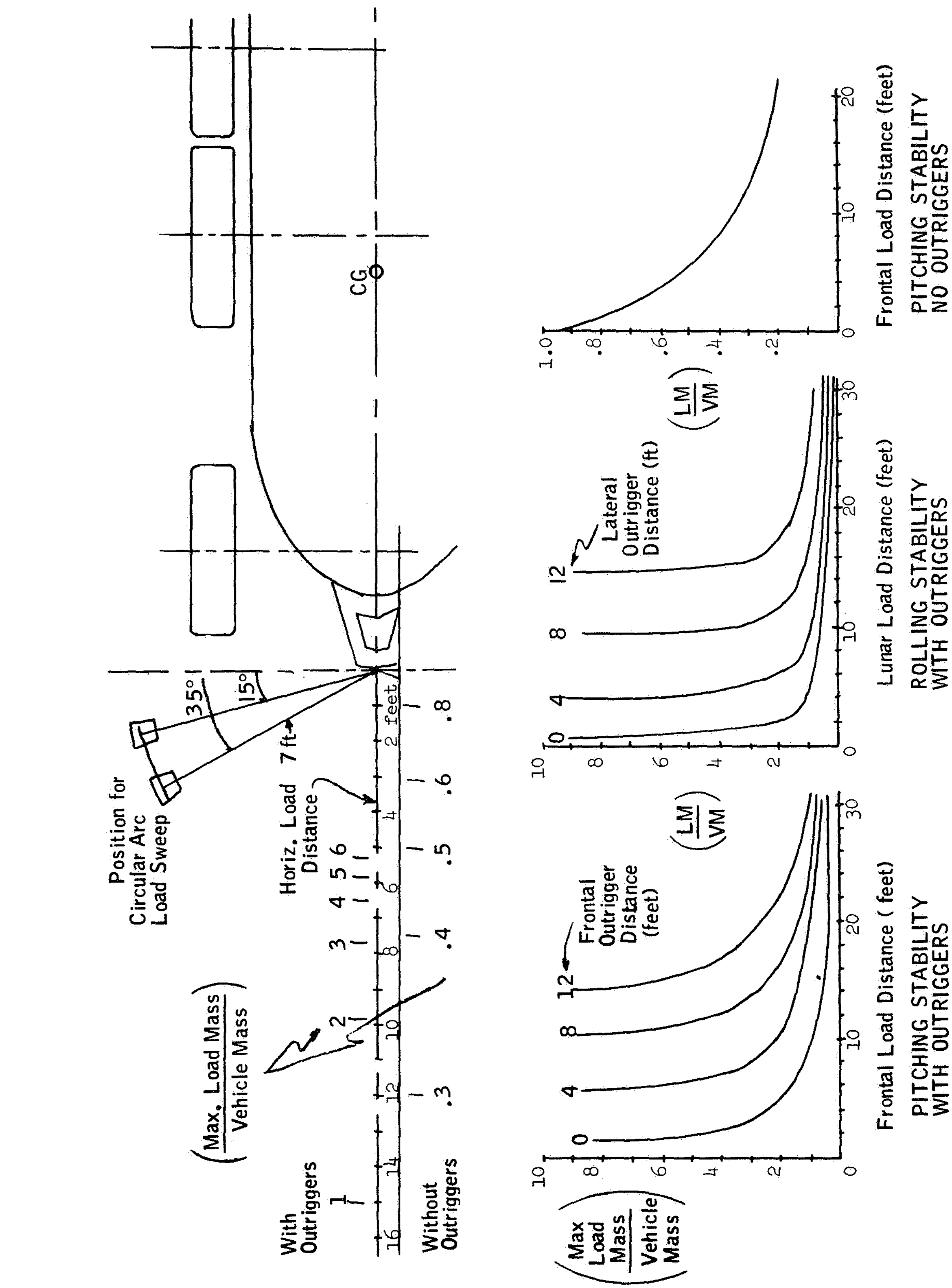


Figure 2.3-4. Handling Capabilities

3.0 MODULE TRANSIT OPERATIONS

The LSB baseline modules have been defined as cylinders with ellipsoidal bulkheads, thirty feet long and fifteen feet in diameter. They weigh approximately 10,000 pounds dry and incorporate a docking adapter on each end for handling and assembly. The modules will be delivered from the earth's surface to the selected site on the lunar surface, utilizing a series of up to three vehicles that are expected to make up the space transportation systems at that time. This section describes the physical interfaces with these vehicles. Drawing 2284-8 presents an illustration of the overall process.

3.1 EOS OPERATIONS

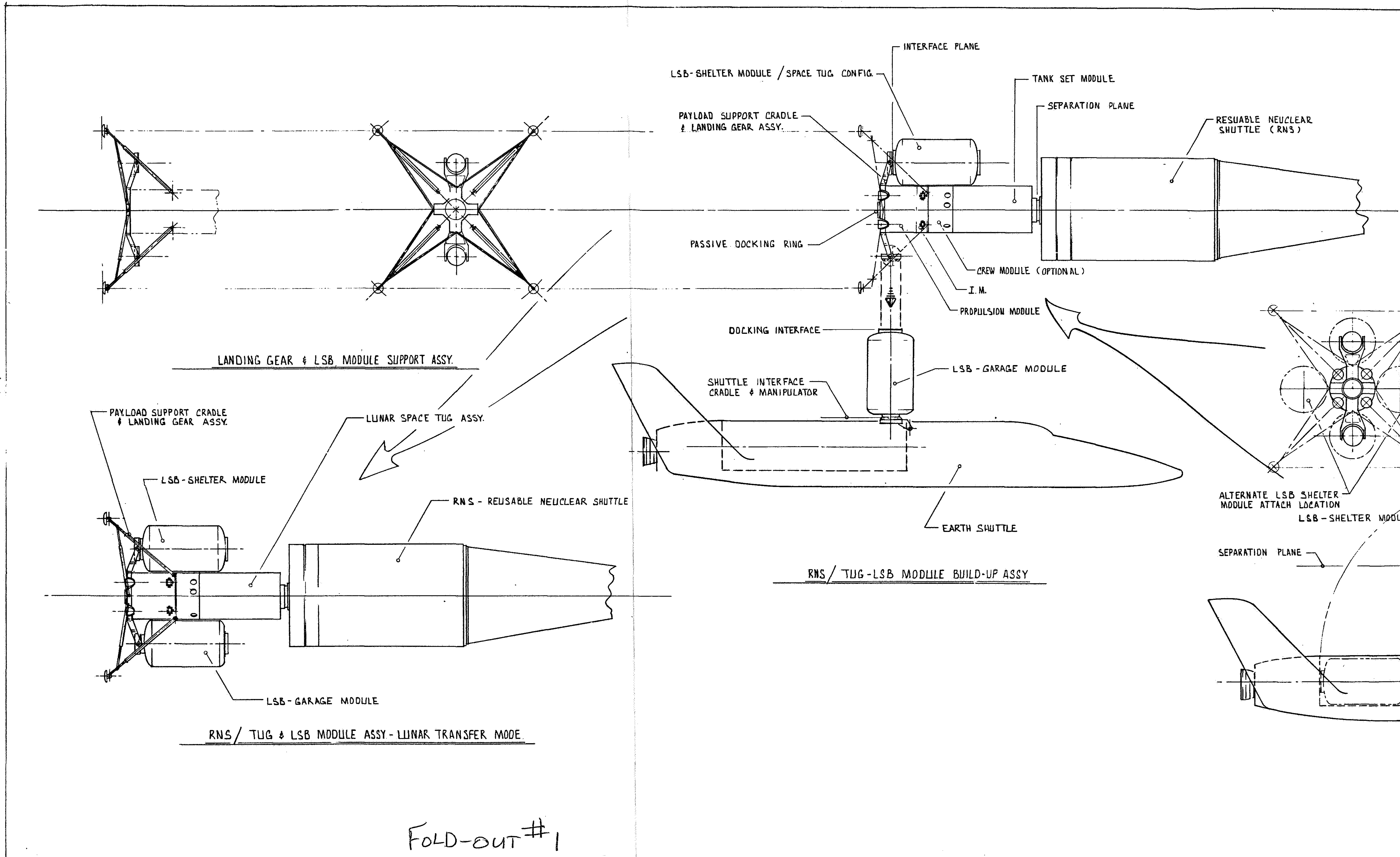
The upper stage of the Earth Orbit Shuttle (EOS) is assumed to deliver the modules to an earth orbit. The EOS has a cargo bay with usable dimensions of sixty feet in length and fifteen feet in diameter, which will, therefore, accommodate two LSB baseline modules. The EOS incorporates deployment mechanisms to which the payloads are docked. After arrival in earth orbit, the cargo bay doors are opened, the modules are deployed and transferred to the cislunar shuttle as shown in Drawing 2284-8. The same approach is shown for delivery of the lunar landing tug to earth orbit.

3.2 CISLUNAR SHUTTLE OPERATIONS

A cislunar shuttle will be used to move the modules from earth orbit to lunar orbit. The Reusable Nuclear Shuttle (RNS) is shown in the drawing as a baseline; however, any other cislunar shuttle option would function similarly. The operations shown on the drawing are illustrative of an initial delivery mode wherein the RNS delivers the manned version of the tug with the first increment of the crew and a set of LSB modules. The EOS first delivers the tug and subsequently a second EOS docks to a LSB module to one side of the tug and then a second module to the other. The tug module adapter is then tilted 90 degrees so that the modules are parallel to the tug where they are locked in place for translunar injections.

3.3 TUG CONFIGURATIONS AND OPERATIONS

Figure 3.3-1 illustrates the baseline space tug configuration selected for LSB operations. It is adapted from the NR Concept 11 (Reference). The landing gear assembly is attached by docking to the aft docking port of the tug and includes two or four docking adapters for coupling shelter modules or cargo to the tug. The docking operation is illustrated in Figure 3.3-1.


INTERFACE PLANE
LSB-SHELTER MODULE / SPACE TUG CONFIG.
TANK SET MODULE
SEPARATION PLANE
RESUABLE NEUCLEAR SHUTTLE (RNS)
PAYLOAD SUPPORT CRADLE & LANDING GEAR ASSY.
PASSIVE DOCKING RING
CREW MODULE (OPTIONAL)
I. M.
PROPULSION MODULE
DOCKING INTERFACE
LSB - GARAGE MODULE
SHUTTLE INTERFACE CRADLE & MANIPULATOR
EARTH SHUTTLE
RNS / TUG-LSB MODULE BUILD-UP ASSY
ALTERNATE LSB SHELTER MODULE ATTACH LOCATION
LSB - SHELTER MODULE
SEPARATION PLANE
LANDING GEAR & LSB MODULE SUPPORT ASSY.
PAYLOAD SUPPORT CRADLE & LANDING GEAR ASSY.
LUNAR SPACE TUG ASSY.
LSB - SHELTER MODULE
RNS - REUSABLE NEUCLEAR SHUTTLE
LSB - GARAGE MODULE
RNS / TUG & LSB MODULE ASSY - LUNAR TRANSFER MODE
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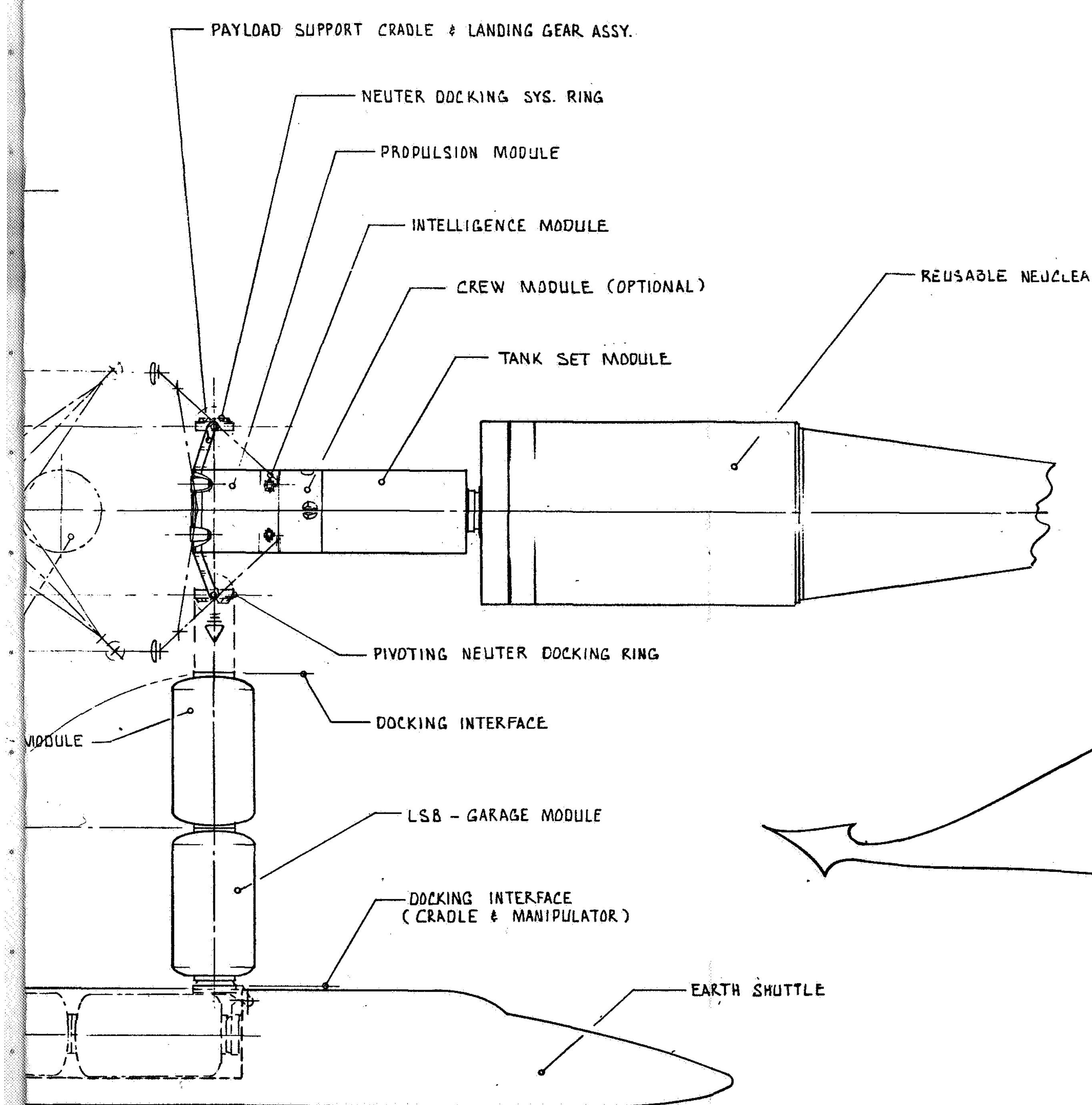
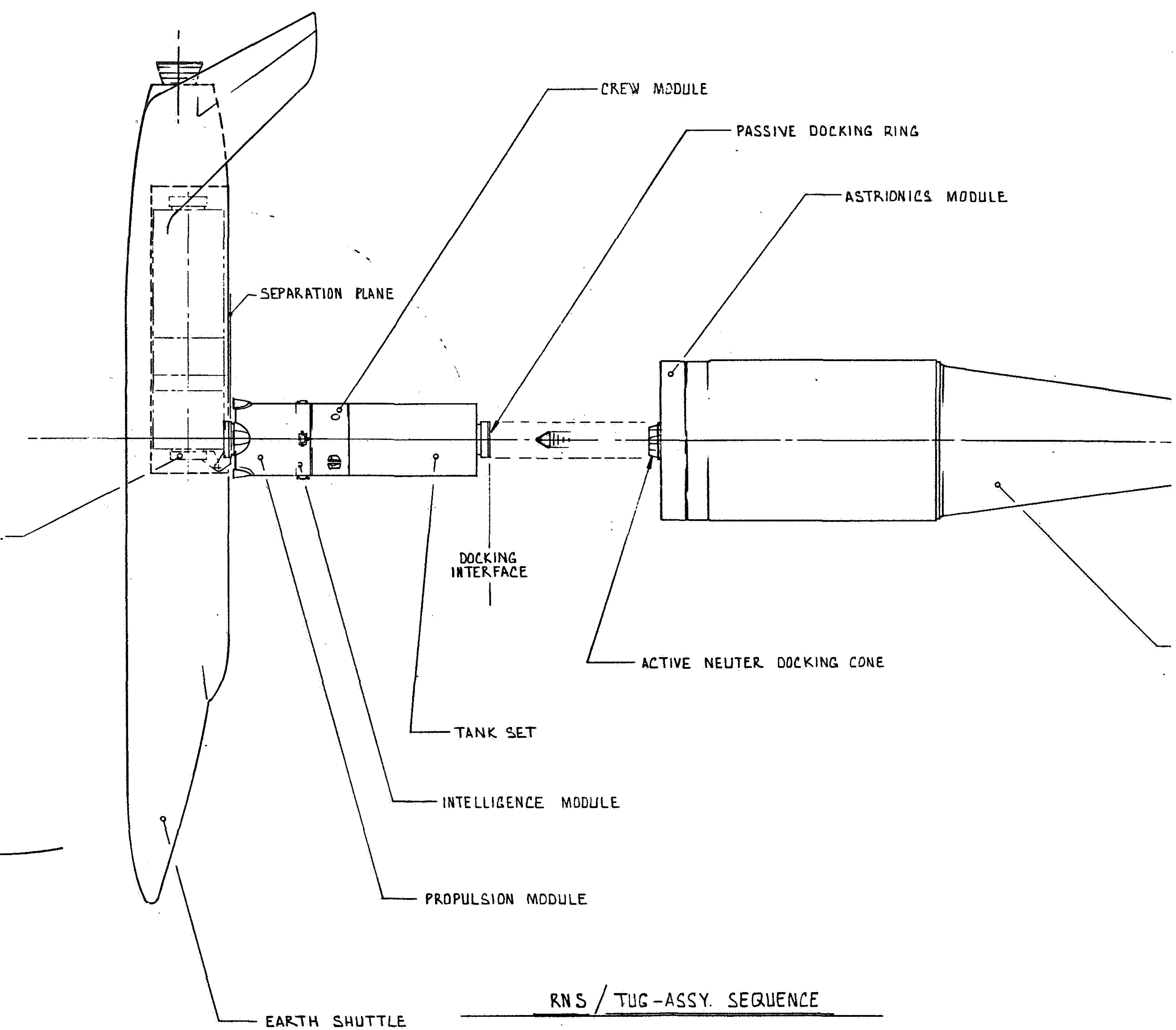
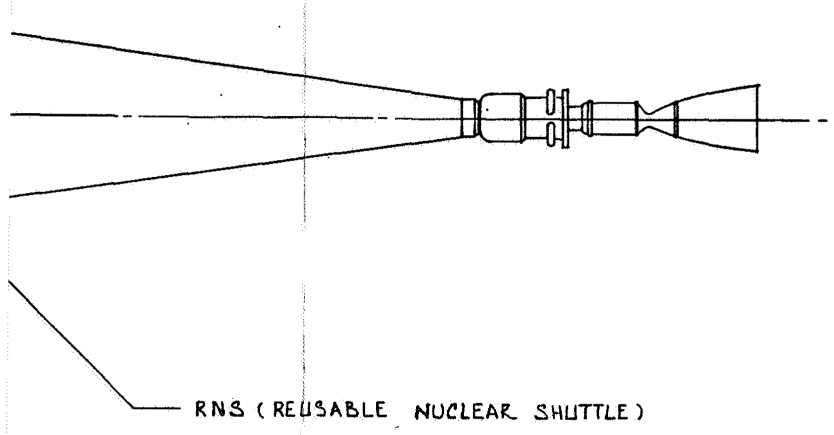


RNS/TUG-LSB MODULE BUILD-UP ASSY.



RNS/TUG-ASSY. SEQUENCE

FOLD-OUT #2



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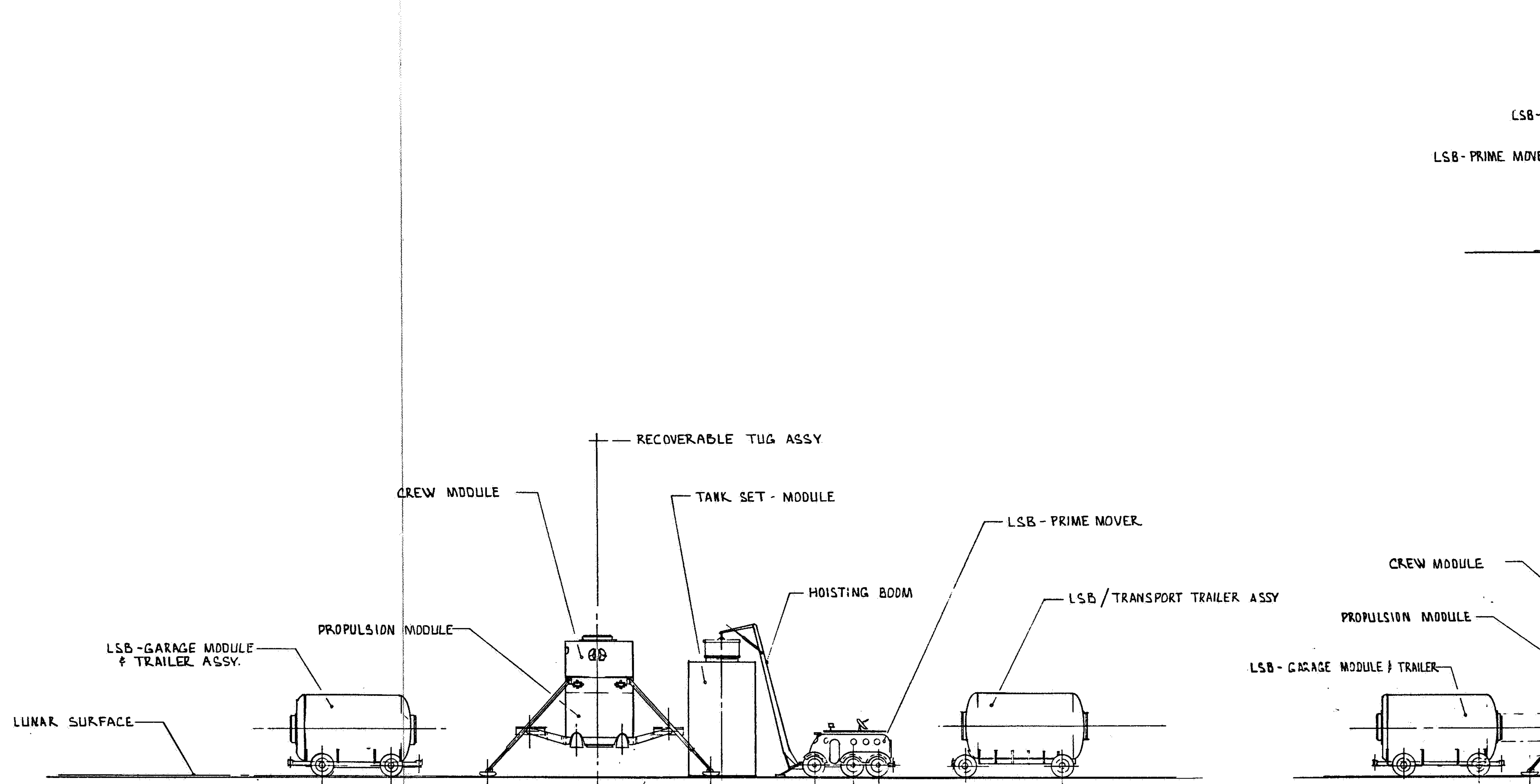
SD 71-477

SCALE 1/160	DR. Thompson / DATE 1-15-71 / MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
SPACE TUG & LSB MODULE ASSY.— RNS RENDEZVOUS & LUNAR DELIVERY CONFIG. CONCEPT			2284-8B SHT 1 OF 2



TUG / LSB DEPLOYMENT SEQUENCE - PHASE III

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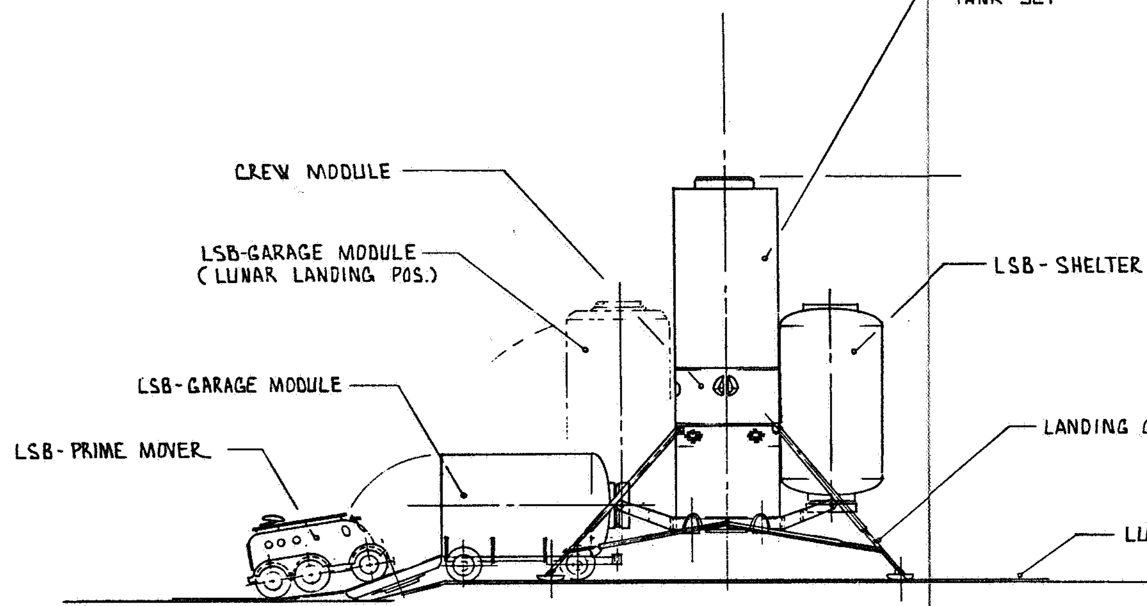
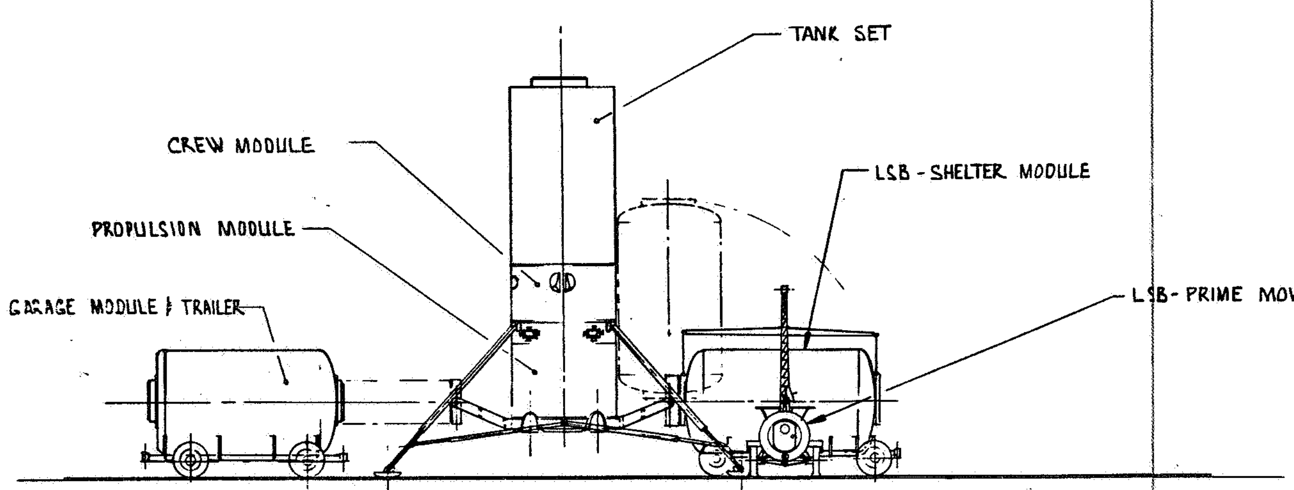
Space Division
North American Rockwell



TUG/LSB DEPLOYMENT SEQUENCE - PHASE I



TUG/LSB DEPLOYMENT SEQUENCE-PHASE II

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SD 71-477

SCALE 1/100	DR. / DATE / MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
SPACE TUG & LSB MODULE ASSY.- RNS RENDEZVOUS & LUNAR DELIVERY CONFIG. CONCEPT			2284-8 SHT 2 OF 2

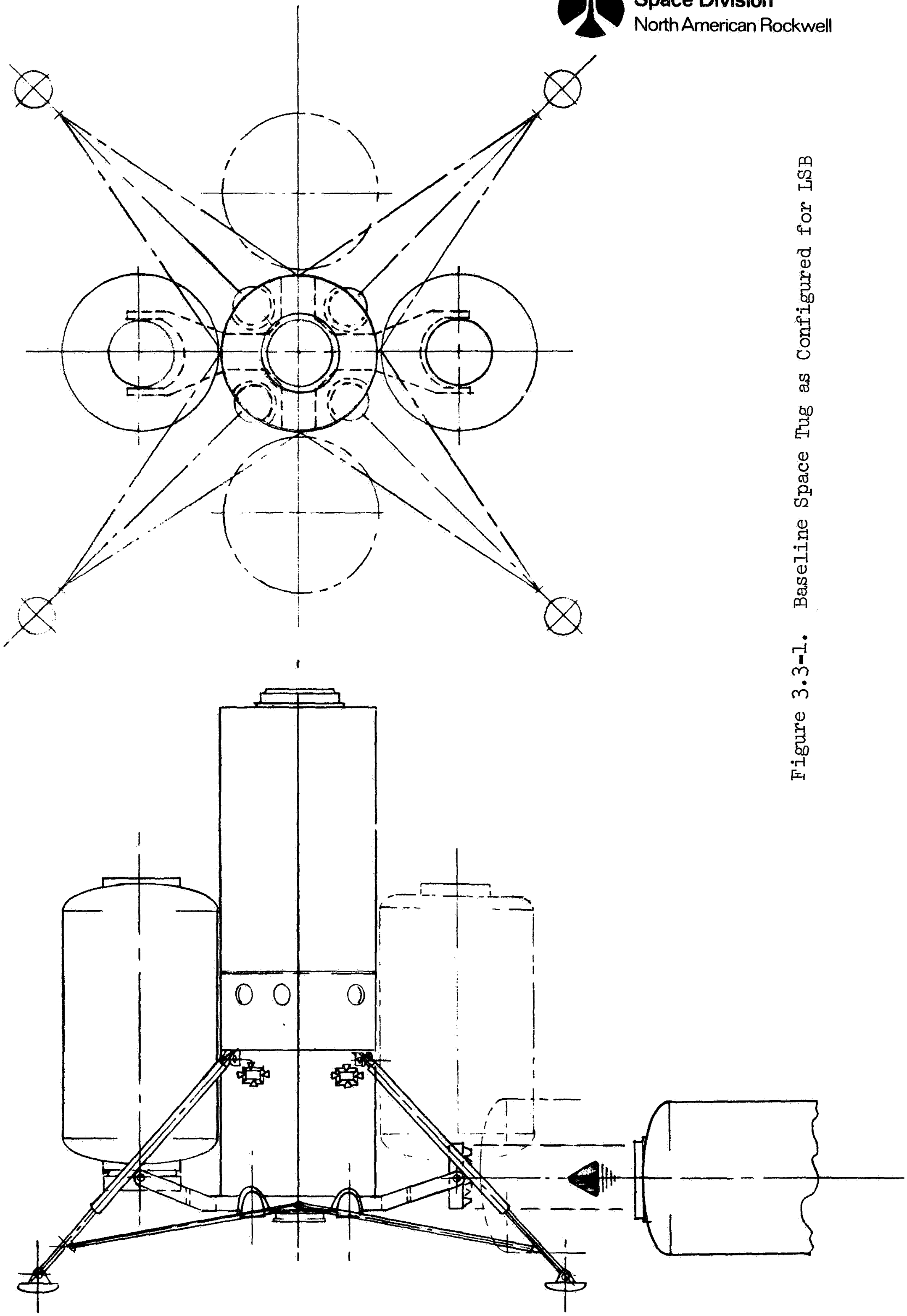


Figure 3.3-1. Baseline Space Tug as Configured for LSB

In lunar orbit the tug with the modules attached and personnel inside tug crew module, separates from the cislunar shuttle and descends to the lunar surface. The modules are unloaded as illustrated in Figure 3.3-2. A prime mover with hoist attachment moves the module transport trailer into position, then disconnects and turns around to assist in the lowering of the modules onto the trailer.

After a module is in position on the trailer, the docking collar is released, the trailer is driven to the LSB site where the module is lifted from the trailer by the hoist, lowered into its final position, and coupled to the other modules.

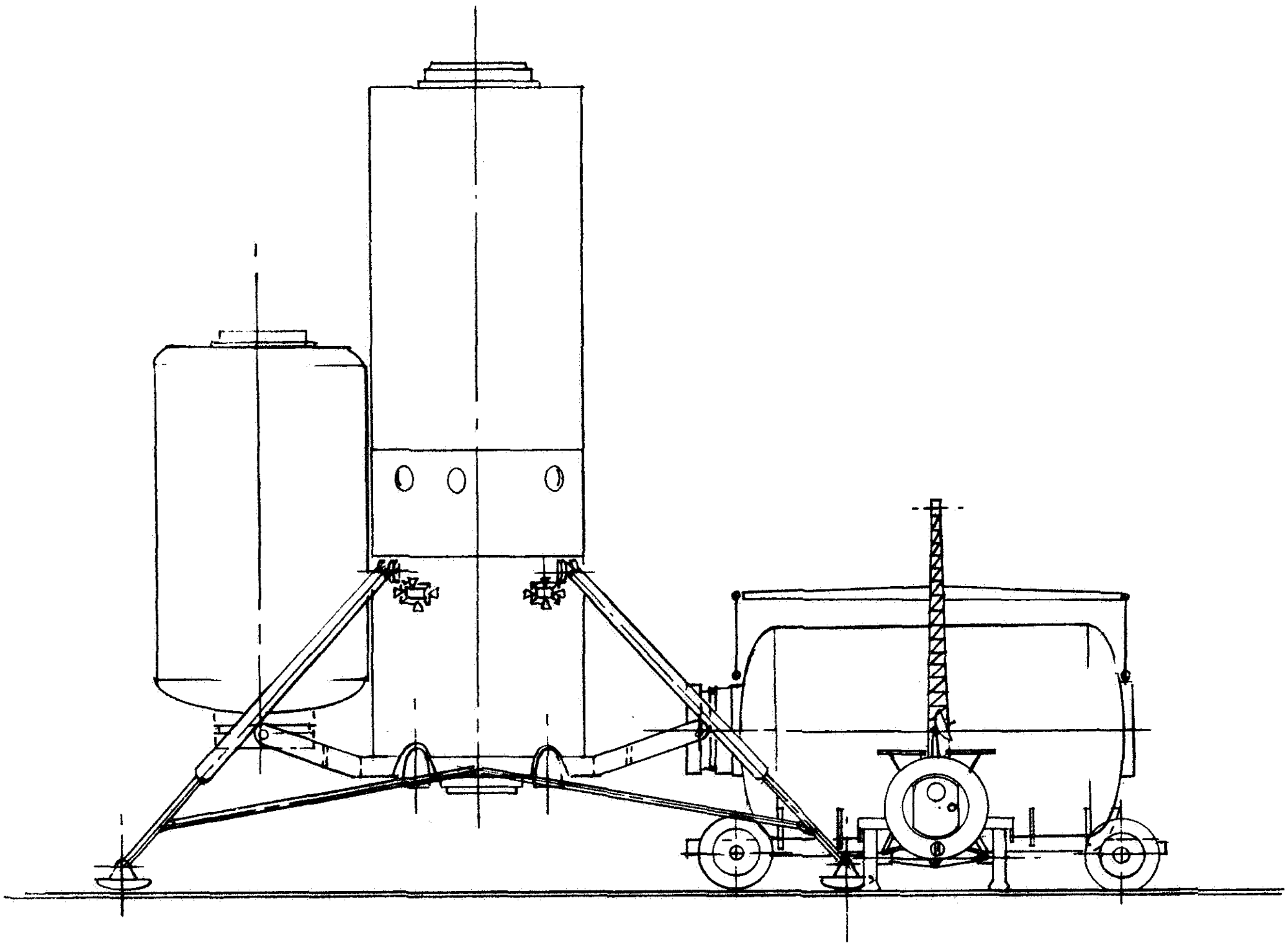


Figure 3.3-2. Module Removal from the Space Tug

4.0 BASE BUILDUP SEQUENCE

The LSB baseline shelter described in Part 1, Section 8.0, the logistics system developed in Volume II, and the handling systems definitions from the previous section have been integrated into an overall base buildup sequence. From a general buildup rationale and priority list, the base elements delivery schedule is developed. Some individual construction tasks are discussed and timelines for the complete base construction are related to the delivery schedule. Finally, normal base resupply requirements are described.

4.1 BUILDUP RATIONALE

A base buildup rationale involves a matching of priorities of equipment delivered with the assumed logistics system and the crew and power available. Many interfaces are involved, and only after several iterations will a consistent delivery scheme be determined. Figure 4.1-1 depicts the nature of the significant element interaction. The primary goal is to establish a base and to accomplish the scientific objectives. Since men are required, the first step is to deliver equipment to sustain life necessary for mission safety and assurance. Next is the delivery of the scientific equipment whose operation, in conjunction with the manned observations, completes the mission objectives.

The major influence on the entire buildup scheme is the assumed earth-moon logistics system. Volume II describes this system in some detail and Figure 4.1-2 summarizes the assumed logistics system capabilities used in this section. With the assumed logistics capability, a delivery philosophy was developed such that the base was built up at a logical rate, sufficient manpower was available at each stage to manage the equipment from each delivery, and electrical power was available to provide the energy as required.

4.2 CARGO DELIVERY SCHEDULE

Based on several iterations of a preliminary delivery scheme, an LSB cargo delivery schedule has been developed which fits the four considerations for each flight.

1. Is sufficient (or too much) manpower available to assemble the equipment as delivered?
2. Are crew supporting functions available (i.e., shelter, environmental control, mobility)?
3. Is enough power available?
4. Is the cargo delivered in the proper sequence?

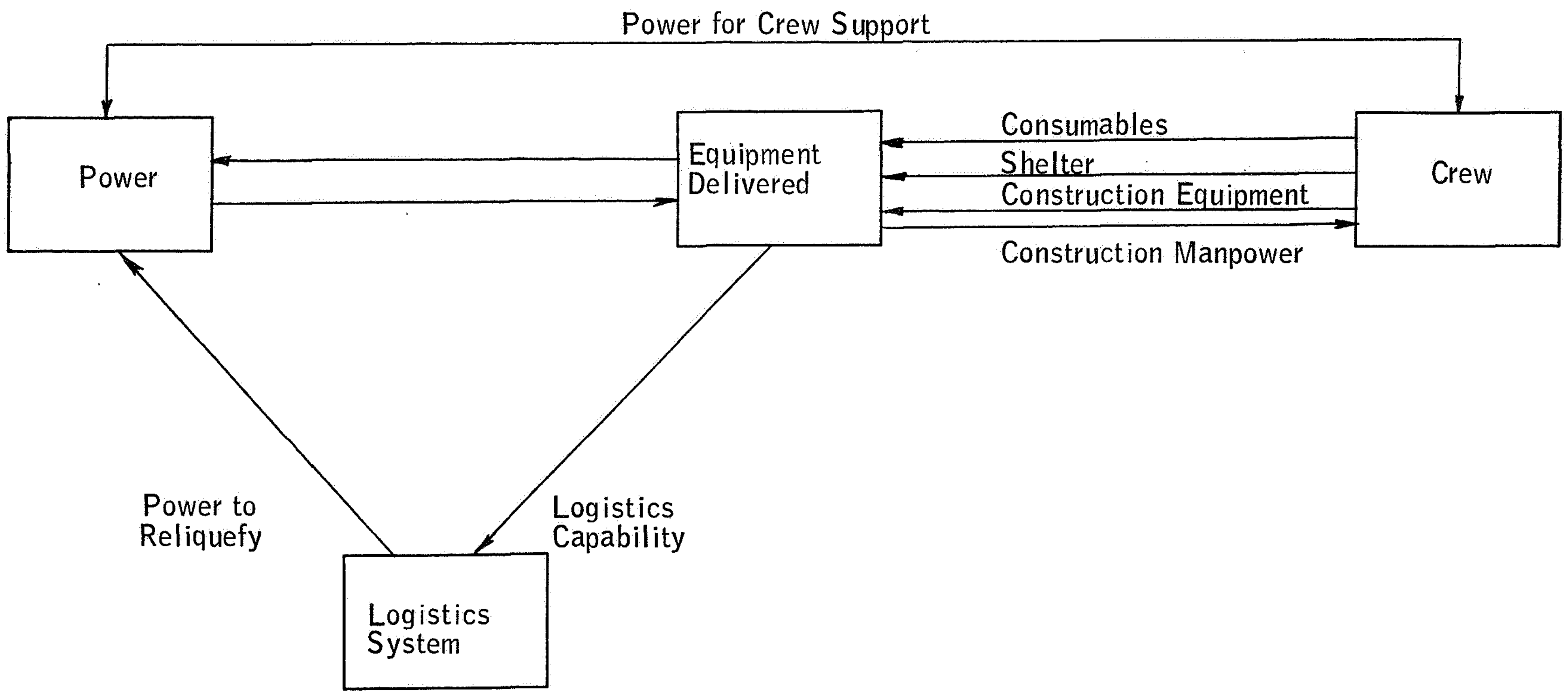
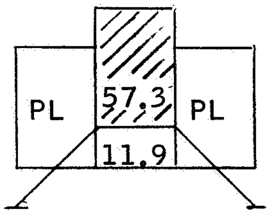


Figure 4.1-1. Buildup Element Interfaces

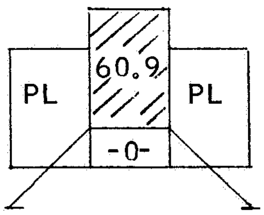
ON-ORBIT CONFIGURATION PROPELLANT WT-KLB	MODE	PAYLOAD - KLB

UNMANNED (RETURN PL = 0)



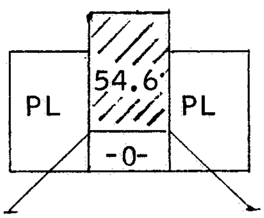
INITIAL DELIVERY
3-KLB BOILOFF
ALLOWANCE

68.3



RESUPPLY TANK SET
NO BOILOFF ALLOWANCE
RETURN TO ORBIT

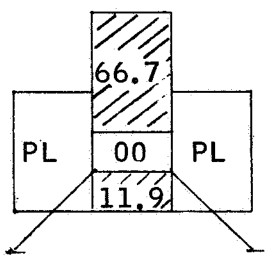
62.1



RESUPPLY TANK SET
EXPEND ON SURFACE

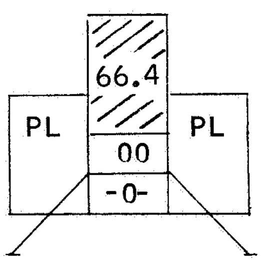
68.4

MANNED (RETURN PL = 4.25 KLB



INITIAL DELIVERY
ALLOWANCE FOR ABORT
W/O PL JETTISON

28.0



RESUPPLY TANK SET
NO BOILOFF ALLOWANCE
RETURN TO ORBIT

49.7

Figure 4.1-2. Logistics System Capabilities Assumed

Table 4.2-1 summarizes the projected delivery schedule. Additional details on the buildup flight sequence is contained in the paragraphs which follow.

The first flight, 1U (unmanned), lands at a site marked by the precursor. It will stay about 60 days before it must return to orbit, and an allowance has been included for boiloff of about three thousand pounds of propellant. It delivers the garage, crew and medical, crew and operations, and recreation and assembly modules. These modules, with the warehouse (delivered on the next flight), comprise the initial crew support facilities for the buildup crew. In addition, a power cart, handling equipment, reliquefaction unit, communications equipment, base and crew supplies, and miscellaneous observatory equipment are delivered.

The second flight, 1M (manned), occurs 28 days later and delivers the four-man base buildup crew. The first manned landing has reserve propellant capability to abort the landing sequence at any point up to and including touchdown without jettison of the payload. After a successful landing and unloading, this tug has an extra 16.6 k lbm of propellant over that required for subsequent return to orbit which may be used for fuel cell power, flyer fuel, and/or permit propellant boiloff losses. Delivered in this flight are a prime mover, power cart, drill and shell, warehouse module and supplies. This crew of four has sufficient equipment and power to erect the delivered shelter elements prior to the next flight.

The third flight, 2U (1U returned to orbit and mated with a tank set and payload), occurs 33 days later delivering power carts, a prime mover, observatory equipment and supplies. Unloading and support is provided by the buildup crew.

The fourth flight, 2M (1M returned to orbit unmanned and mated with a tank set and payload), occurs 28 days later, or 85 days after 1U, and brings six additional crewmen. A prime mover, power cart, mobile shelter, and 50-inch telescope are delivered.

The fifth flight, 3U (2U returned to orbit and mated with a tank set and payload), occurs 27 days later and brings the remainder of base modules, another prime mover, flyer and cart, observatory pieces and supplies. This tug may be expended on the surface at this point since it is no longer required for the LSB program.

Flight 3M (2M returned to orbit with buildup crew) and subsequent flights deliver six crewmen and the normal resupply complement (See Section 4.4 following).

The total equipment and crew weight delivered to the surface during the buildup phase amounts to 262.9k lbm. The estimated capability of these vehicles is about 276.5 k lbm for the modes described, indicating a growth allowable of about 5 percent. This growth figure may be increased by deleting the abort capability on 1M which would add 28 k lbm to the delivered weight capability of that flight. This would result in a growth allowance

Table 4.2-1. Cargo Delivery Schedule

Item	Unit Weight (k lbm)	Number Req'd.	Flight Number 1U	1M	2U	2M	3U
Drive-in garage	5.90	1	5.90				
Crew and medical mod.	8.91	1	8.91				
Crew and operations command module	9.01	1	9.01				
Rec., assembly, airlock	8.35	1	8.35				
Base maintenance and airlock	5.96	1					5.96
Sortie and transient crew	8.41	1					8.41
Drive-in warehouse	6.30	1		6.30			
Lab - data process - sci. cont.	9.01	1					9.01
Prime mover	4.03	4		4.03	4.03	4.03	4.03
Power unit (unpowered)	3.30	6	3.30	3.30	9.90	3.30	
Tug isotope, storeage and delivery	1.21	-	1.21	1.21	3.63	1.21	
Handling equipmet set	2.10	1	2.10				
Landing facilities	.10	2	.20				
Communications equipment set	.20	1	.20				
Liquefaction unit	.50	2	1.00				
Electrical power j-box and line	1.00	1	1.00				
VHF relay link sets	.30	2	.60				
Mobile shelter	5.64	1				5.64	
Utility trailer	.60	1	.60				
Lunar flyer	.40	2					.80
Flyer cart	1.90	1					1.90
Flyer propellant	3.00	-	(Tug residuals)				
Science:							
Drills, small and medium	.60	-	.60				
1000 ft	4.20	1		4.20			
Observatory, 100-in.	33.00	1			9.72		23.28
50-in.	11.55	1				11.55	
Other	15.50	-	8.03				7.47
Remote sortie equipment	3.40	-	2.20			.20	1.00
Drill cover	4.04	1		4.04			
Observatory cover (prime)	4.04	1			4.04		
Observatory cover (secondary)	4.27	1			4.27		
Supplies:	N/A	N/A					
EPS spares			.39		.45		
Prime mover spares			3.84		.45		.31
Crew consumables			6.23	.78	14.03	1.17	
EVA spares			.59		1.28		
A&CS spares			.50				
Comm. and data spares			.84				
Medical			.10		.22		
Crew				1.50		2.25	
Mobility equipment trans. mod.	4.04	7			8.08	16.16	4.04
Subtotal			65.70	25.36	60.10	45.51	66.21
Contingency Allowance			2.60	2.64	2.00	4.19	2.19
Total Capability			68.30	28.00	62.10	49.70	68.40

of 15 percent. Special logistics trajectory concepts may also increase the estimated capability as well as firmer payload capability definition. Finally, additional growth payload may be delivered on 3M and subsequent flights according to priority.

4.3 BASE CONSTRUCTION

Inherent in the cargo delivery philosophy are the base construction operations in that an estimation of the time, manpower, and assisting equipment necessary to erect the delivered cargo between landings provide an interface with the cargo and crew delivery sequence. The major construction tasks consist of site preparation, module deployment, soil cover, and science equipment emplacement. The equipment capability has been described in Section 2.0 and is applied to the anticipated base construction tasks in the following time estimates:

1. Site Preparation

Tug landing site

Survey	2 men	1 hour
Grade	2 men	8.2 hours
Emplacement beacon and marker	2 men	1.5 hours
	2 men	~ 3 days

LSB shelter site

Survey	2 men	2 days
Trench	2 men	4-1/2 days
Perimeter preparation	2 men	1 day
	2 men	7-1/2 days
Transfer rate (survey and grade)	2 men	1 day
Observatory location (survey and grade)	2 men	1 day
Drill location(survey and grade)	2 men	1/2 day

2. Module Deployment

Unload tug	2 men	1/2 hour
Transfer (1.5 mph)	2 men	1 hour
Position module (align and level)	2 men	1 hour
Connect module	4 men	1 hour
Power up		
Connect radiators	2 men	2 hours
Integrate A&CS and EPS and check out	4 men	2 hours
	4 men	1 day

3. EPS Cart Power Up

Fuel		
Pu 238 isotopes or	2 men	2-1/2 hr/cart
Po 210 isotopes	2 men	5 hour/cart
Power up	2 men	1/2 hour/cart

4. Soil Cover

Full base cover	2 men	1/2 hour/cart

5. Science Equipment Emplacement

Drill		
Module delivery and position	2 men	1 day
Experiment setup	2 men	15 days
100-inch telescope setup	2 men	30 days
50-inch telescope setup	2 men	8 days
X-ray telescope setup	2 men	12 days
Radio astronomy		
.3 - 1 MHz	2 men	22 days
1 - 5 MHz	2 men	11 days
.6 - 12 MHz	2 men	6 days
5 - 500 MHz	2 men	6 days

Utilizing the cargo delivery schedule and the base construction tasks time estimates, a base buildup timeline has been determined and is presented in Figure 4.3-1.

4.4 BASE RESUPPLY

Resupply requirements in the form of consumables, spares and expendables for a 12-man lunar surface base under normal operations are presented in Table 4.4-1. Under the assumption that half the crew are rotated each landing (so that each crew stays twice the resupply interval), these requirements can be presented as a function of logistics resupply interval as shown in Figure 4.4-1.

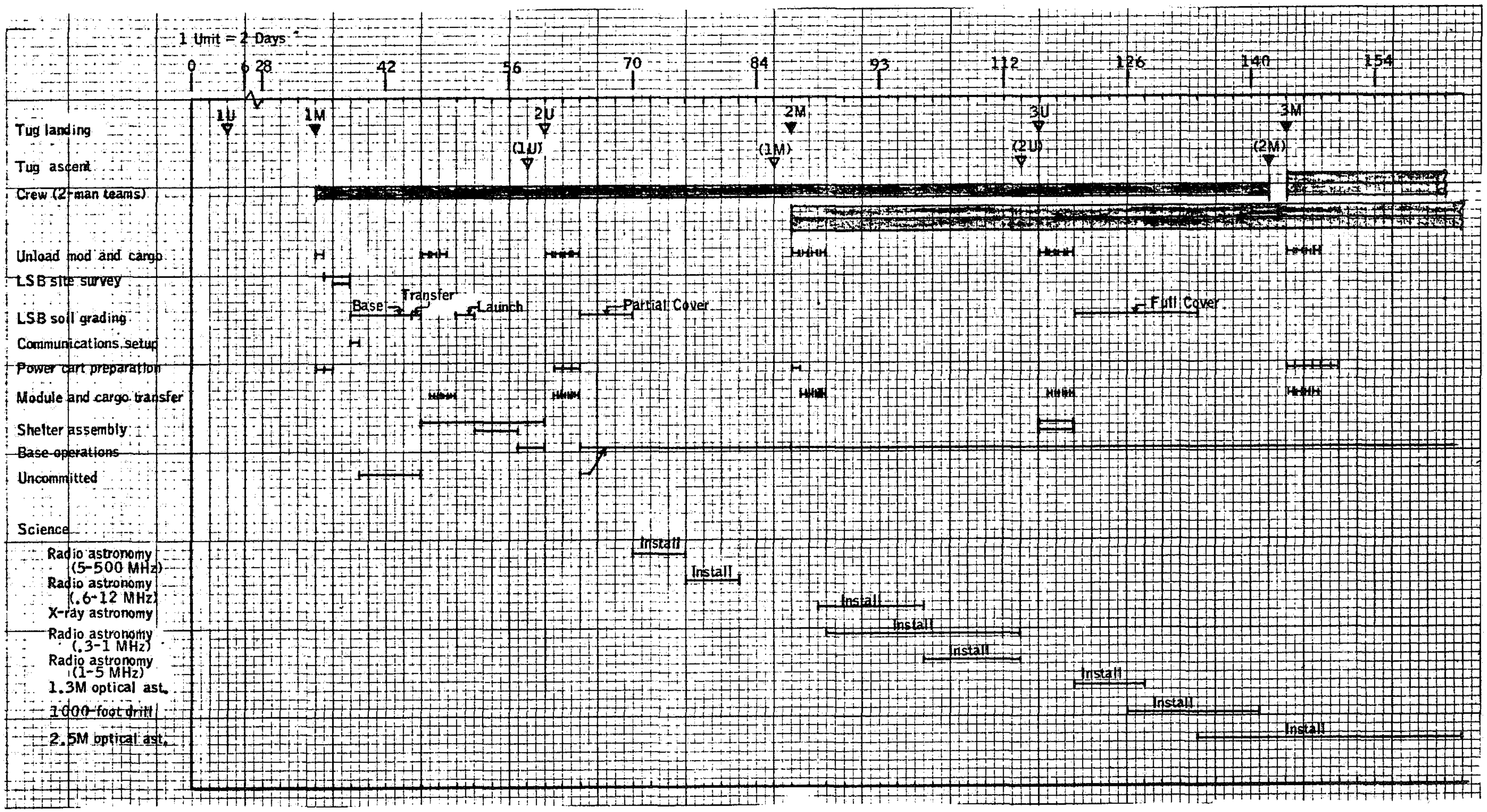


Figure 4.3-1. Base Buildup Timeline

Table 4.4-1. Resupply Requirements
12-Man Base - Normal Operations

	lbm/ 180 Days	lbm/Man 180 Days
A&CS		
Consumables	-	1753
Expendables		
Spares	500	
Medical	-	25
EVA Spares		
Suits, APLSS, etc.		148
Science Support		
Sortie	477	-
Drilling	-	-
Astronomy	980	-
Communication and Data		
Systems	840	-
VHF relay links	1000	-
EPS (Po 210 assumed)		
Isotopes and holders	800/cart	-
Systems	195/cart	-
Mobility Systems		
Spares	1000/prime movers	
Cargo Modules	1800/landing	
Crew	375/man-landing	

Summary:

Resupply = 3797 lbm/180 days + 995 lbm/180 days-power cart + 1000 lbm/180 days-prime mover + 1800 lbm/landing + 375 lbm/man-landing + 1925 lbm/man-180 days

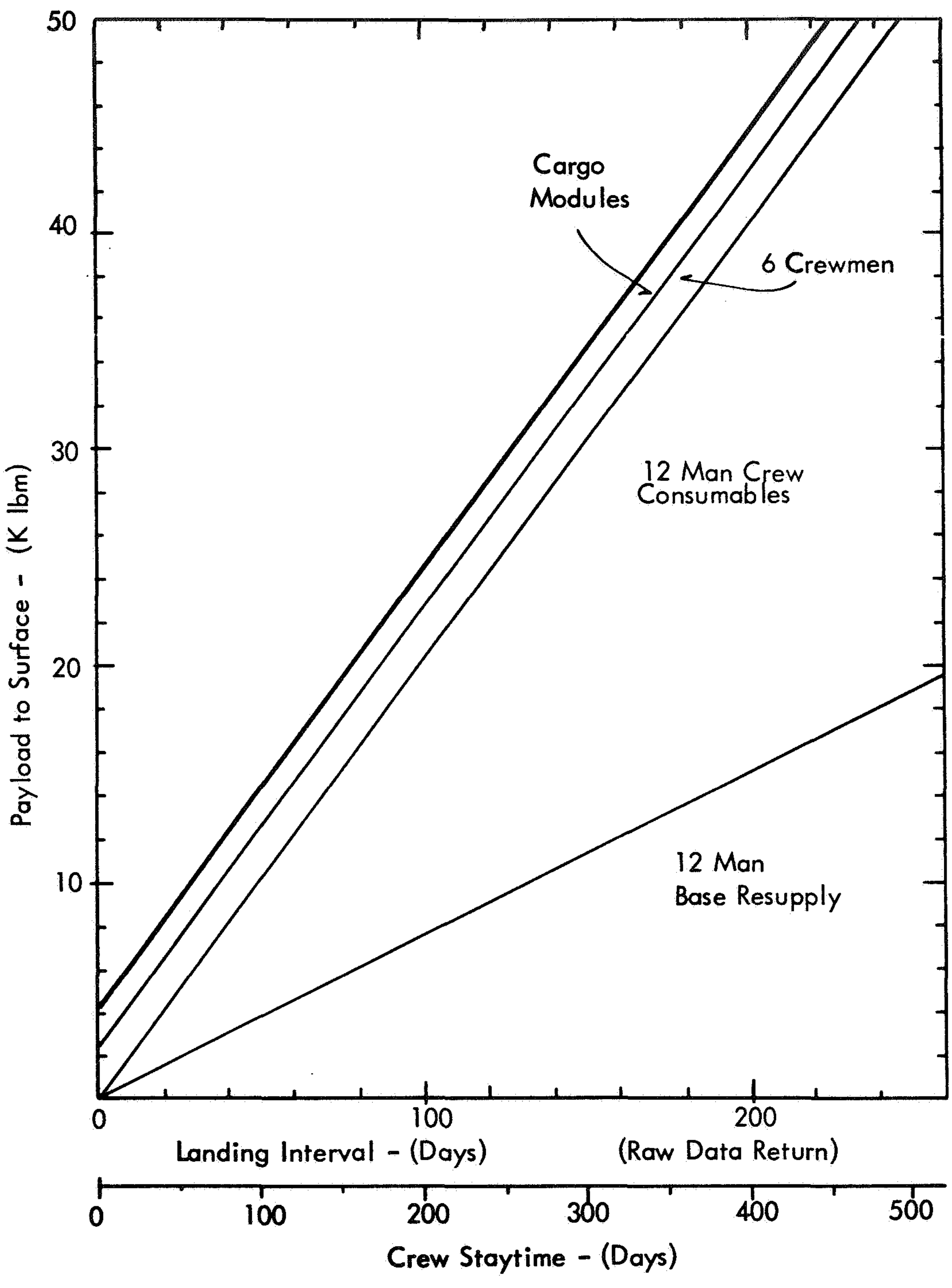


Figure 4.4-1. Resupply Requirements Versus Logistics Interval

5.0 SAFETY AND MISSION ASSURANCE

Providing a safe environment for the base personnel and assuring the success of the LSB mission are key issues for both the design and operational concept. A significant proportion of the study effort was expended in the analysis of potential emergency situations and the development of contingency requirements. The results were considered in both the design and the proposed operations.

The following definitions are used in the discussion:

Personnel safety is the ability to assure no loss of life or deleterious effect on any LSB personnel throughout their tenure at the LSB. It includes both preventive and curative measures.

Mission assurance is the ability to accomplish a given objective within the minimum time period. For the LSB situation, an objective (opportunity) missed on one day, one sortie, first attempt, etc., can be reattempted at a later time. Time to perform a given objective therefore becomes a major factor in mission assurance. It therefore becomes more of a value parameter; the faster an objective is accomplished the less the objective and therefore the mission may cost.

5.1 EMERGENCY SITUATION POTENTIAL

Since personnel safety involves the life and health of the crew, emergency situations are those events which influence the personnel critical functions. Figure 5.1-1 identifies the LSB systems along with the potential causations. It is indicated that three factors can create an emergency:

1. A system failure to perform its intended function within its constraints.

2. An environmental anomaly which exceeds a system's design margins (such as a very large meteor).

3. A human error which causes a system (or systems) to not operate when required, or to operate incorrectly.

Figure 5.1-1 and the definitions both lead to the conclusion that for an LSB emergencies exist only when one of the atmospheric management or crew services (A&CS) functions are influenced. The other systems enter into consideration only as they influence the A&CS functions. For example, loss of electrical power may result in loss of any or all of them. Emergencies such as fire and explosion will be treated separately; however, even these are really emergencies only because they abrogate some A&CS functions.

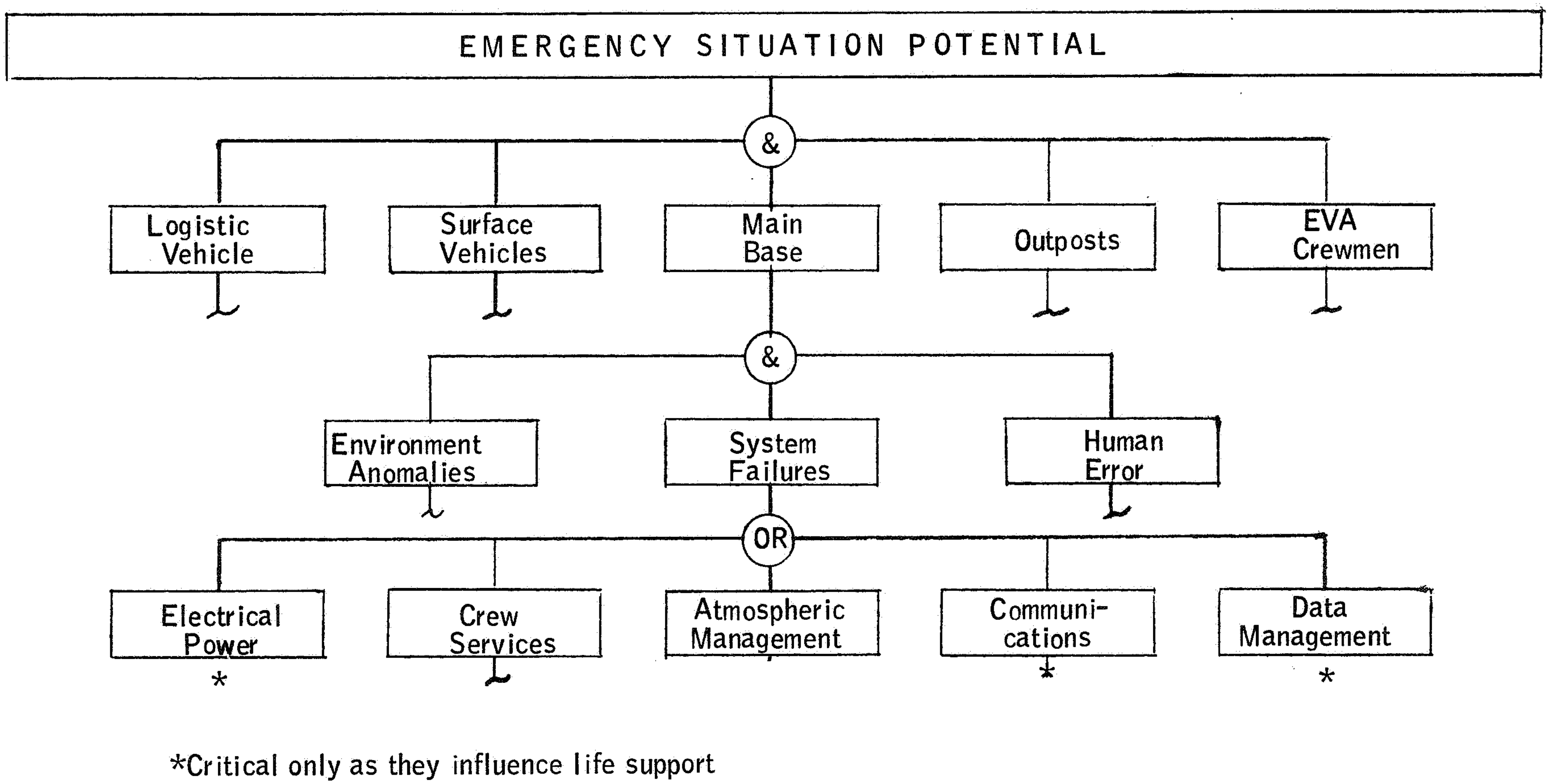


Figure 5.1-1. Potential Sources of Emergency Situations

5.2 EMERGENCY SITUATIONS DEFINITION

Each potential emergency situation has been identified and analyzed for its influence on systems and crew. The results are summarized in Table 5.2-1. These data define the potential causes of the emergency and the situation that exists as the result of the event. To these must be added the fire and explosion hazards which can be caused by any one of several systems and any one of the potential sources.

A study of the character of these emergency situations indicates that they are time dependent. From the time sensitivity data in Table 5.2-1 it may be noted that only the pressure management function (aside from fire and explosion) can create an emergency with a short response time. This event is very improbable with the proposed LSB deployment concept. Figure 5.2-1 illustrates the time history for the rapid decompression event. This figure is based on the assumption that a single LSB module was involved, with a meteoroid puncture producing an irregular hole and subsequent loss of atmosphere. A similar examination of the time history of probable events leads to the conclusion that there is a reasonable amount of time to deal with emergencies and, except in the event of catastrophic explosion, there is adequate time to implement a solution.

Emergency situations can arise at other than the main shelter location as a function of the program activity. These have been assessed in the same manner as for the shelter; the results are summarized and compared with the shelter situation potential by Table 5.2-2.

5.3 LSB CONTINGENCY PLAN

Contingency planning is the preparation for an emergency such that there is a safe reaction possible should the event occur. Figure 5.3-1 identifies the contingency plans considered applicable to this study. They form the basis for the safety recommendations.

If all possible hazards and the parametrics associated with their occurrence are identifiable the most straightforward approach would appear to be to eliminate the hazards in the design stage. However, although the potential hazards may be known, in practice all potential causes can be identified only at the functional level and even large design margins do not completely eliminate the hazards. The resultant approach involves accepting some likelihood of the potential hazard occurring and providing a means of neutralizing the effect should the emergency arise. Such a concept embodies a reliability/maintainability approach which takes optimum advantage of both. The NR-developed "Availability Concept" which optimizes the design around this approach is illustrated by Figure 5.3-2. This concept is based on the assumption that either the primary or redundant systems can be out of service (for maintenance) for some portion of the total mission cycle and uses this time to restore normal operations to the affected component (i.e., availability for use) through planned maintenance.

Table 5.3-1 presents a summary of potential design and operational options recommended to preclude the specifically identified emergency as

Table 5.2-1. Potential Emergencies, Source and Definition Summary

Critical Function	Time Sensitivity	Emergency Level	Potential Source: System Failure	Potential Source: Environ. Anomaly	Potential Source: Human Error
Makeup Gas O_2 N_2	Hours None	3 psia 10 psia	• Regulators • Source	Meteoroid	Accidental interference
Contaminant Control (Chem., Bio, and Partic.)	Weeks	Variable	• Catalytic burner • Filters • Dust cont.	Unknown toxics	Failure to follow procedure
Thermal Control	Hours	115 F 45 F	• Radiator stoppage • Coolant system	Meteoroid through radiator	Improper maintenance
CO_2 Management Removal	Hours	15 mm Hg	• Circul. system • Bed stoppage	None	Improper maintenance
Disposition	Weeks	O_2 depletion	• Sabatier • Electrolysis	None	Improper maintenance
Pressure Management	Minutes	3.0 psia	Leaky hatches	Meteoroids	--
Crew Services Management (All functions)	Days	Variable	• Water storage • Water recovery • Food storage	None	• Accidents • Improper mainten. • Improper operation
Isotope Overheat	Hours	1200 F	• Coolant syst.	Meteoroid	Accidents

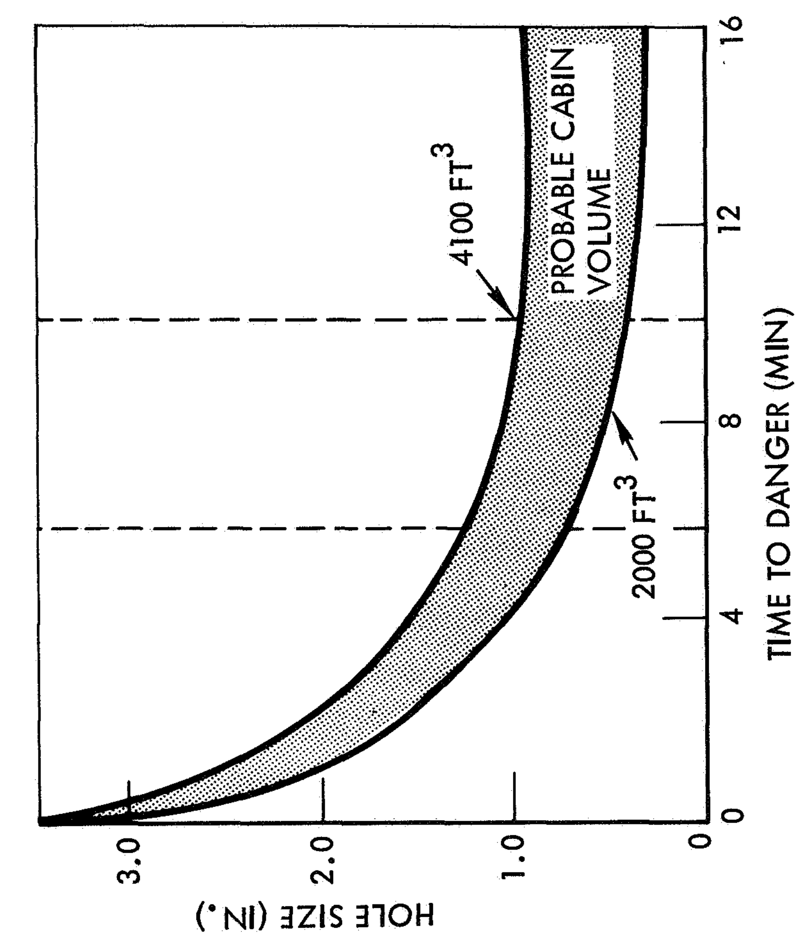


Figure 5.2-1. Time History, Rapid Decompression Event

Table 5.2-2. Emergency Situations

Equipment Assembly	General Sources of Emergency	Classes of Emergency							
		Explosion	Pressure Excursion	Electrical Failure	Collision or Overturn	Contamination	Radio-activity	Temperature Excursion	Fire
LSB Shelter	Equipment malfunction	I, R, S	R, S	R, S		I, R, S	S	S	I, R
	Environmental anomaly		S	R		S	S	S	
	Personnel error	S	S	R, S	I, S	I, R, S	S	S	I, R
	Operational deficiency	R, S	S	R, S		R, S			R
Sortie Train	Equipment malfunction	I, S	S	S	I	I, S	S	S	I, R
	Environmental anomaly		R	R	I		S	S	
	Personnel error		S		I	S	S	S	R
	Operational deficiency								
Flyer (in flight)	Equipment malfunction	I	I	I	I	I			I
	Environmental anomaly		I	I	I				
	Personnel error		I	I	I				
	Operational deficiency								
Tug Lander (in standby)	Equipment malfunction	I, S	S	S	I	S		S	S
	Environmental anomaly		S	S				S	
	Personnel error								
	Operational deficiency								
	I = Immediate Effect R = Rapid Effect S = Slow Effect								

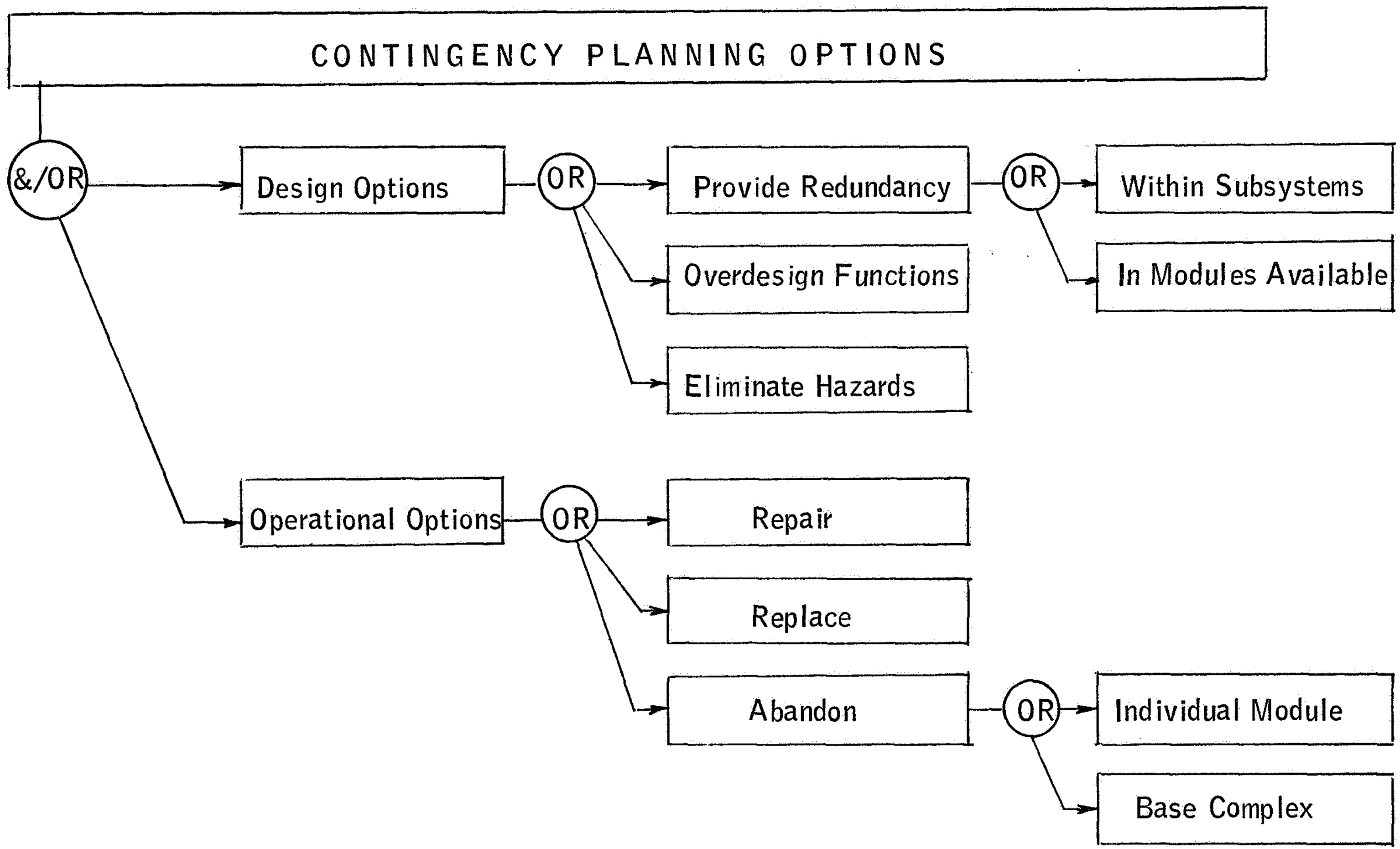


Figure 5.3-1. Contingency Planning Options Considered

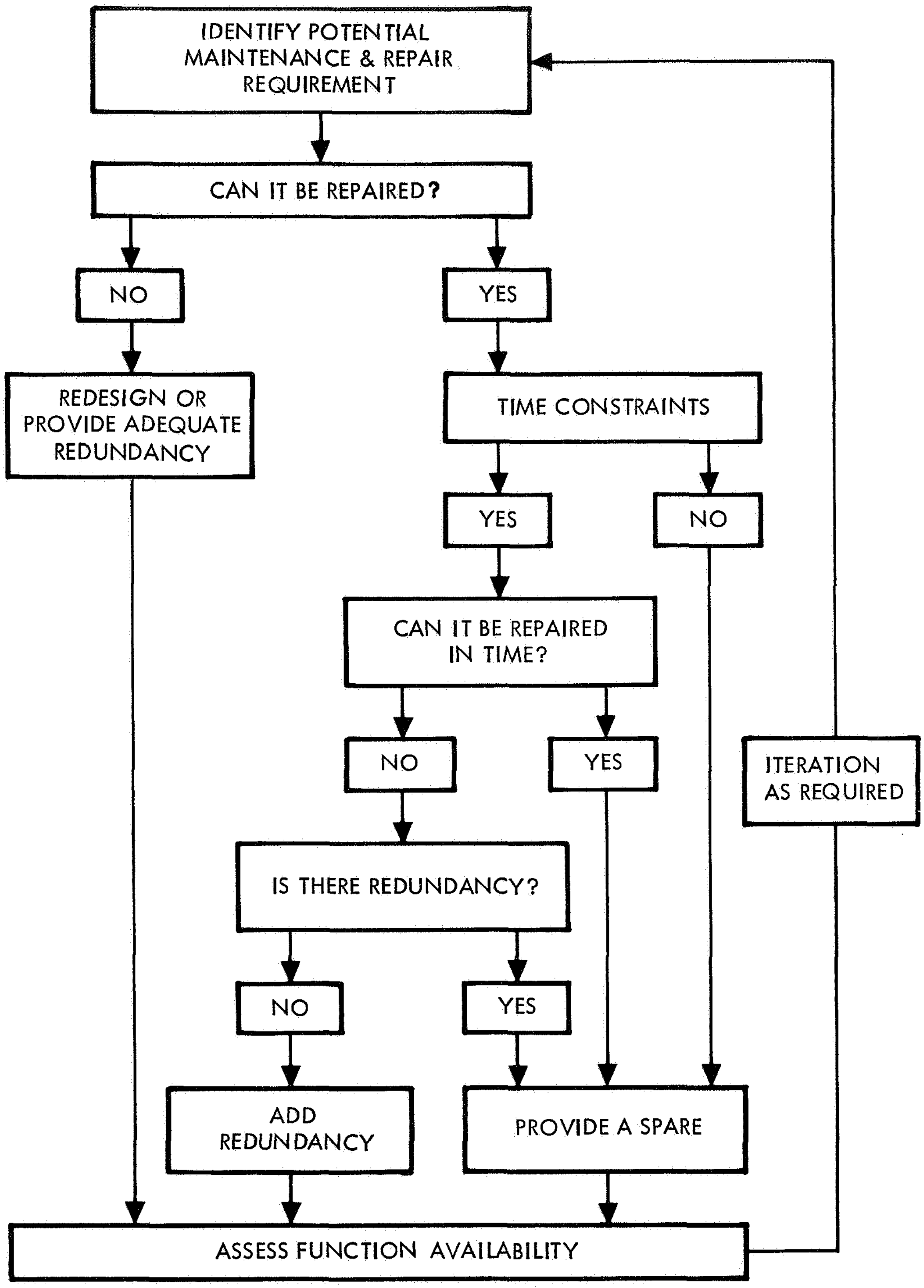


Figure 5.3-2. Analytical Process, Availability Concept for Mission Assurance

Table 5.3-1. Safety Design and Operational Options (Loss of Atmospheric Management)

FUNCTION AFFECTED	DESIGN OPTIONS	OPERATIONAL OPTIONS
MAKEUP GAS	REDUNDANT REGULATION & SOURCES EMERGENCY O_2 SUPPLY FROM OUTLETS	SUPPLY FROM ADJACENT MODULES MANUAL CONTROL
CONTAMINANT CONTROL	SEPARATE FUEL & EXPER. VENTS REDUNDANT CLEANING PATHS REDUNDANT SYSTEMS	CONFINE FUELS & BIOL. AGENTS TO HOODS EXHAUST AFFECTED VOLUMES USE OTHER ENTRANCE/MODULE
THERMAL CONTROL	REDUNDANT COOLING LOOPS & RADIATORS	SUPPLY FROM ADJ. MODULE MANUAL CONTROL SHUT DOWN NON-ESSENTIAL FUNCTIONS
CO_2 MGMT. - REMOVAL	REDUNDANT CIRCULATION EQUIP. INCREASED DESIGN MARGIN	SYSTEM MAINTENANCE
- DISPOS.	REDUNDANT SABATIER EQUIP. DESIGN FOR NO RETURN-TO-ATMOS. PATH	EXPEND CO_2 TO VACUUM PROVIDE EMERGENCY O_2 SUPPLY
PRESSURE MANAGEMENT	REDUNDANT VENT/RELIEF VALVES EMERGENCY O_2 SUPPLY DOUBLE HATCHES	MANUAL CLOSING CAPABILITY UNDER INTERNAL PRESSURE SUPPLY FROM ADJACENT MODULE

they apply to the atmospheric management function. A detailed review of all subsystem functions was conducted and the specific contingency recommendations are summarized in Table 5.3-2. In addition to the specific design features recommended in Table 5.3-2, the following more general guidelines can be identified:

1. Design all equipment for full mission life. Anticipated wearout should be minimized because of the expense of resupply. Should development of an extended life part become too expensive, then special maintenance procedures may be necessary, e.g., monitor output for performance trend, and repair or replace just before reaching the specification limits.

2. Develop the highest reliability consistent with cost and schedule. When wearout is not a significant problem, the part failure occurrences can be characterized as random in time, i.e., a constant failure rate. Continued development to reduce that failure rate can become expensive for the expected reliabilities. However, replacement of a failed part can also be expensive in cost of delivery and cost of crew time. For the LSB, relatively high reliability is desirable, i.e., reliabilities comparable with earth-bound central station generating plants.

3. Eliminate single failure emergencies which result in immediate catastrophy. The crew should have an alternate path to safety. Again, blanket provisions may not be consistent with cost and operating efficiency constraints; e.g., protection against all meteoroids would be excessively heavy in surface vehicles, landers, and flyers and would compromise operations. Identification and justification of any single point failure leading to crew and mission loss is required.

4. Compensate for low reliability of parts by selective redundancy. Criticality of subsystem characteristics and resupply cycle time influence the extent of redundancy.

5. Provide shelter mechanical shielding sufficient that accidental collision by lunar exploration vehicles would have no mission effect. Based on earth surface experience with mobile machines, the long mission duration presents a high probability of collision of surface vehicles and flyers with each other and the shelter. LSB shelters should be covered entirely by lurain of sufficient thickness to prevent any damage from inadvertent collision by any vehicle, or explosion hazard.

6. Design for hazard containment. Obviously, a localized hazard primarily affects the local area and leaves other areas intact. Undamaged areas would then be the sources of repair services. Specific design features include automatic closing of shelter interconnections upon pressure decay or fire in any one, providing a shelter wall design which does not propogate a crack or hole, and insulating storage shelters to prevent escape of contents following individual failure. In this way, initial failures can be kept to repairable size.

Table 5.3-2. LSB Specific Design Features for Safety and Reliability

- Shelter Structure
  - -Provide margin.
  - -Design such that failure of a single piece does not propagate to adjacent pieces and is repairable within safe time limits.
  - -Remove combustible materials.
  - -Prevent energy sources for fire.
  - -Keep active chemicals in separate environments.
- Metabolic and Reactant Storage
  - -Provide an outer layer(s) of crushable material such that the chances of rupture are much reduced in the event of drop or collision with personnel or vehicles.
- Food Management
  - -Keep food samples on earth under lunar environments and test periodically for biological contamination.
  - -Provide redundant checks for residual biological contamination in all food related equipment, e.g., LSB crew and logistics supply crew.
- Displays and Controls
  - -Control LSB by on-board personnel. The overall communications, data handling, and control should be accomplished from one shelter module with redundant equipment in another. Further, individual shelter environmental control must be possible from each shelter and assistance in atmospheric supply to adjacent shelters should be possible.
- Water Management
  - -Provide redundant relief valves for each tank.
  - -Store in compatible environment.
  - -Provide redundant checks for recycled water purity.
  - -Keep weight inventory of all deadly chemicals.
- Atmospheric Composition and Control
  - -Provide automatic, redundant sampling of atmosphere for hazardous levels.
  - -Supply high pressure through isolable accumulators.
  - -Isolate experiment laboratory to prevent cross-contamination.
  - -Monitor the quantities of all noxious or hazardous chemicals and biological agents. The closed ecology demands careful use of materials. Special inventory of known hazardous materials will give advanced warning of concentration buildup in shelter atmosphere.
- Lander
  - -Protection of LSB complex against lander explosion, collision, or rocks thrown by rocket exhaust, e.g., shielding each shelter from all sides and top, and providing a smooth and blast shielded landing field at safe distance from shelters.
- Cargo Module
  - -Provide blast shield internal to cargo module to direct explosion force and shrapnel from impingement on shelters.
  - -Provide entries to shelters which are not seen by others; i.e., a cargo module explosion should not damage more than one shelter entry.
  - -Provide multiple exits from and entries to each shelter.
  - -Cover shelters with sufficient protective material so that the cargo module transfer vehicle or meteoroids cannot cause damage.
  - -Provide extension and retraction gear in each shelter exit for cargo handling.
  - -Provide redundant monitor of combustible materials in crew compartment.
- Flyer
  - -Provide reloading platform at launch site.
  - -Isolate reloading and launch area to prevent sympathetic damage to LSB from explosion or rocket exhaust.
  - -Utilize visual and automatic checkout of each flyer before launch.
  - -Include emergency provisions for the stranded contingency.
  - -Keep a spare flyer in readiness for remote rescue.
  - -Every landing near the LSB complex must be monitored by LSB personnel.
  - -Design LSB complex so that a flyer can land anywhere on top and not damage any shelter.
- Surface Vehicles
  - -Service and load the surface vehicles in the garage.
  - -Provide redundant measures of emitted radioactivity.
  - -Design LSB complex so that the vehicles can climb over without any damage
  - -Provide redundant means for detecting solid objects immediately ahead.
  - -Provide sensing and automatic stopping at cliff side.
  - -Design prime mover so that the forward cab can go over a cliff and still be recoverable.
  - -Keep a spare vehicle available at all times.

5.4 MAINTENANCE AND REPAIR CONSIDERATIONS

5.4.1 Maintenance Level

The recommended mission assurance concept imposes systems maintenance and repair as a requirement on the base. A preliminary maintenance plan considered applicable to this study was developed and is included in Appendix F. This plan forms the basis for maintenance requirements estimates. Of major import in establishing the maintenance requirements is the selection of the level at which the repair or replacement will be performed. The options are summarized by Table 5.4-1. Assembly level maintenance is recommended and forms the basis of the maintenance and sparing estimates.

Table 5.4-1. Maintenance Level Options

Options	Option Requirements	Capability
Manual Switching	Procedural training	Limited application
Minor Adjustments	Simple tools Procedural training Direct .ccess High manual dexterity	Insignificant
Assembly Replacement	Simple tools Procedural training Diagnostic equipment (self-check) Access Low manual desterity	Covers probable failures
Part Repair Replacement	Detailed diagnostic routines High manual dexterity Direct access Large spares inventory High skill levels Complex tools and jigs	Universal application

5.4.2 Shelter Module Maintenance

Maintenance time and spares requirements for the LSB shelter were derived by extrapolation of data generated in other studies of extended duration manned space systems (References 6 and 7). Summaries of the estimated requirements by subsystem are contained in Volume II, Part 2, in connection with the development of the required crew level. Table 5.4-2 presents the same data and Table 5.4-3 provides the more detailed backup for the scheduled maintenance. Unscheduled maintenance estimates were based on complexity factors.

Table 5.4-2. Maintenance Time Summary

Subsystem	(Man-Hours per Month (Averaged) Scheduled	Unscheduled
Crew	150.0	19.0
Structures	5.0	4.0
Facilities	24.0	9.0
A&CS	61.5	11.1
Mobility	160.0	--
Electrical	5.0	2.5
Information	42.0	4.2
Subtotal	447.5	49.8
Total	497.3	

5.4.3 Vehicle Maintenance Time

As indicated in Tables 5.4-2 and 5.4-3, the mobility systems are expected to make up a large part of the maintenance workload. Because of this heavy load and also because of the potential need for a garage to perform this maintenance, additional emphasis was placed on the analysis of the probably maintenance effort. Experience data obtained from heavy equipment contractors, USAF and Army and NR operations were used to estimate the man-hour requirements for unscheduled maintenance, i.e., failure rate and average repair time estimates for each major system as a function of the active operating time. Table 5.4-4 lists the numerics based on the average mission time of 76 days at three exploration sites. Unscheduled maintenance time of approximately 50 hours per sortie is estimated to be required to repair the equipment and give a high probability of sortie success.

Scheduled maintenance was estimated on the basis of relative complexity of equipments. The prime mover interior systems will require the most because of expendable fluid replacement, waste disposal, and detailed electronics checkout. The electrical power cart should require lubrication and electrical system checkout with careful monitoring of isotope and cooling

Table 5.4-3. LSB Maintenance Estimates

Subsystem and Functions	Maintenance Time (hr)	Men Required	Maintenance Frequency (days)	Average Time (m-hr/mo)
Crew Systems				
Suit maintenance				
PGA seals	9	2	30	18
PGA liners	6	2	30	12
Cleaning	12	1	7	48
PLSS maintenance				
PLSS seals	8	3	30	24
Cleaning	12	1	7	48
Structures				
Inspect and repair	2.5	2	30	5
Facilities				
Base	5	2	30	10
Experiment	9	1	30	9
Garage	5	1	30	5
A&CS				
System inspection	1	1	7	4.0
CO_2 management				
Sabatier	1.6	1	30	1.6
Steam desorb	1.0	1	90	0.3
Electrolysis	3.6	1	180	0.6
Atmosphere control				
Contaminant	1.6	1	30	1.6
Bacterial	1.0	1	30	1.0
Humidity and temperature	4.0	1	30	4.0
Fans	1.5	1	90	0.5
Pressure	1.2	1	180	0.2
Filters	4.0	1	7	4.0
Active thermal				
Water loop	1.2	1	180	0.2
Rad. loop	1.2	1	180	0.2
Water management				
Vapor comp.	6.0	2	30	12.0
Reverse osmosis	0.6	1	180	0.1
Syst. service	8.0	2	30	15
Distr. syst.	0.6	1	180	0.0
Waste management				
Collection	5.0	2	30	10.0
Trash unit	0.6	1	180	0.1
Hygiene				
Shower	0.6	1	30	0.6
Lavatory	2.0	1	30	2.0

Table 5.4-3. LSB Maintenance Estimates (Cont'd)

Subsystem and Functions	Maintenance Time (hr)	Men Required	Maintenance Frequency (days)	Average Time (m-hr/mo)
Food management Ref. and ovens	6.0	2	180	2.0
Mobility				
Prime movers	40	2	30	80
Flyers	20	2	30	40
Portable shelter	10	2	30	20
Power supplies	20	1	30	20
EPS				
Lights	5	2	90	3.3
Miscellaneous	5	1	90	1.7
IMS	6.5	2	7	42.0

Table 5.4-4. Sortie Vehicles Unscheduled Maintenance

		Active	Total
Mission: 28 days travel @ 8 hr/day	=	224 hr	672 hr
48 days on-site @ 1 hr/day	=	48 hr	1152 hr
		272 hr	1824 hr

Equipment	Replacement	t-Hr.	$\lambda \times 10^{-6}$	$\overline{M}$-Hr.	$t \lambda \overline{M}$-Hr.
Prime Mover					
Pressurized Cabin					
Structure	Earth	1824	1	-	-
EC/LSS	Spare Parts	272	10,000	2.2	5.98
Cooling System	Spare Parts	272	1,200	2.2	0.72
Comm. & Data Mngmt. System	Spare Parts	272	20,000	1.1	5.98
Controls	Spare Parts	272	1,000	1.1	.30
Instruments	Spare Parts	1824	1,000	1.1	2.01
Electrical Power Dist.	Spare Parts	272	10	1.1	0.00
Tractor					
Wheels	Spare Parts	272	10	2.2	0.01
Brakes	Spare Parts	272	100	2.2	0.06
Electric Drive	Spare Parts	272	1,000	2.2	0.60
Structure	Earth	272	1	-	-
Electrical Power Dist.	Spare Parts	272	10	1.1	0.00
					15.66
Electrical Power Trailer					
Radioisotope Assembly					
Radioisotope Material	Earth	1824	1	-	-
Shielding	Earth	1824	1	-	-
Pressure Shell	Earth	1824	10	-	-
Cooling System					
Fluid	Spare Supply	1824	100	2.2	0.40
Pumps	Spare Parts	1824	100	2.2	0.40
Piping	Earth	1824	10	-	-
Radiator	Earth	1824	100	-	-
Power Generation Assembly	Spare Parts	272	5,000	2.2	2.99
Power Conditioning					
Inverter (AC to DC)	Spare Parts	272	10,000	1.1	2.99
Battery Charger	Spare Parts	272	1,000	1.1	0.30
Batteries	Spare Parts	1824	100	1.1	0.20
Wagon (Wheels, Axles, Etc.)	Spare Parts	272	100	2.2	0.06
					7.16
Cargo Carrier	Spare Parts	272	200	2.2	0.12
					0.12
Drill					
Wagon (Wheels, Axles, Etc.)	Spare Parts	272	100	2.2	0.06
Electric Drive	Spare Parts	384	1,000	2.2	0.84
Drill Mechanism (Gears, Bearings)	Spare Parts	384	10,000	2.2	8.45
					9.35

status. The cargo carrier has least checkout of all because of the standard, mechanical parts. The drill may need extra attention because of the potential bearing wear in the drill drive mechanism. The 140 hours of scheduled maintenance represents less than one week prior and one week subsequent to the sortie by two mechanics. Table 5.4-5 summarizes all maintenance hours for sortie vehicles in terms of hours required per sortie.

Table 5.4-5. Sortie Vehicles Maintenance Summary - Hour/Sortie

	Unscheduled	Scheduled	Total
Prime Movers 15.66 x 2 =	31.32	80	111.32
Electrical Power Trailer	7.16	20	27.16
Cargo Carrier	0.12	4	4.12
Drill	9.35	16	25.35
Total	47.95	140	167.95
~ 105 Hours IVA ~ 63 Hours EVA			

The maintenance required for the base support prime mover was estimated on the basis of a much shorter daily utilization - two hours per day continuously. Unscheduled maintenance was determined from the active operating hours. Scheduled maintenance was considered to be required on a bi-monthly basis, i.e., all expendables replenished and a full checkout. In addition, battery charging required a special hookup to the LSB every day; so the scheduled maintenance percentage increased over the sortie vehicle. The 18 hours of total maintenance indicated in Table 5.4-6 can be accomplished by two mechanics in approximately one day/month, or more likely, two days in two months.

5.4.4 Space Suit Maintenance

Although the maintenance requirement data for the existing spacesuit (Reference 8) is not necessarily appropriate to a 1980 version, it does present some useful guidelines that may be extrapolated. The following guidelines were derived:

1. Two suits are needed per crewman, rotating them on a weekly basis with maintenance and repair accomplished during the off period.

2. A technician must be trained and responsible for suit maintenance to assure an acceptable operational reliability for long-term lunar work.

Table 5.4-6. Base Support Prime Mover Maintenance - Hour/Month

Monthly Utilization: 2 Hr./Day For 30 Days = 60 Hr. Active
22 Hr./Day For 30 Days = 660 Hr. Passive

Equipment	Replacement	t-Hr.	$\lambda \times 10^{-6}$	$\bar{M}$-Hr.	$t\lambda\bar{M}$-Hr.
Pressurized Cabin					
Structure	Earth	660	1	-	-
EC/LSS	Spare Parts	60	10,000	2.2	1.32
Cooling System	Spare Parts	60	1,200	2.2	0.16
Comm. & Data Mngmnt. Sys.	Spare Parts	60	20,000	1.1	1.32
Controls	Spare Parts	60	1,000	1.1	0.08
Instruments	Spare Parts	660	1,000	1.1	0.73
Electrical Power Dist.	Spare Parts	60	10	1.1	0.00
					3.61
Tractor					
Wheels	Spare Parts	60	10	2.2	0.00
Brakes	Spare Parts	60	100	2.2	0.01
Electric Drive	Spare Parts	60	1,000	2.2	0.07
Structure	Earth	60	1	-	-
Electrical Power Dist.	Spare Parts	60	10	1.1	0.00
Batteries	Spare Parts	660	100	1.1	0.07
					0.15

Unscheduled Maintenance Total Hr./Month = 3.76

% of Time In Pressurized Cabin = $\frac{3.61}{3.76} \times 100$ = 96 %

Scheduled Maintenance Time Estimate = 14 Hr./Month

Unscheduled Maintenance Time Estimate = 3.76 Hr./Month

Total = 17.76 Hr./Month

M_{IVA} = 16 Hr./Month

M_{EVA} = 1.8 Hr./Month

3. The following spares are estimated for a 6-month staytime:

   a. EV gloves - 1 pair/man-month

   b. Lunar boots - 1 spare pair/man

   c. EV visor - 1 spare/man

   d. Torso limb suit liner - 1/man-month

   e. Liquid cooled garment - 2/cycle

   f. EMU maintenance kit - 1/cycle

4. The EMU maintenance kit has a special tape for outer garment repair and an internal pressure bladded patch kit. There are a set of O-rings and installation tool, a lubricant, and a cleaning and anti-fogging agent for the visor.

5. The suit liner requires approximately one hour replacement, including removal of the old one from the torso limb suit.

5.4.5 Maintenance Kit Recommendations

A study of the recommended maintenance operations has permitted a preliminary identification of tools and repair kits required to support the LSB program. These are listed in Table 5.4-7, along with their estimated weight (Reference 7).

5.5 SPECIAL HAZARDS STUDIES

The LSB mission presents some unusual hazards that influence both the operational concepts and the base configurations. Three such factors that were evaluated in additional detail were the effects of engine plume on soil, the potential effects of a logistic vehicle explosion on the pad, and the sortie emergency.

5.5.1 Soil Ejecta Ranges from Engine Plume Impingement

Since the lunar gravity is about one-sixth that of earth and there is no atmospheric drag, the ballistic range of ejected soil particles, clumps, and rocks will be about 12 times as great as for similar earth conditions. In addition, the combination of the lower orbital velocity (about one mile per second) and the engine plume exhaust gas velocities of about three miles per second, creates the possibility of propelling the very fine particles very long ranges. This phenomenon could impair the effectivity of optical windows, antennas, and solar arrays.

Table 5.4-7. Maintenance Tool/Kit Requirements, LSB

No. Req.	Item	Weight (lb)
2	Standard tool kit (mechanics)	322
1	Standard electronics tool kit	14
2	Electron beam welder	26
1	Leak detection equipment	2
1	Temperature measurement kit	7
1	Water test kit	7
2	Battery test kit	20
2	Electrical repair kit	20
2	Lubrication kit	28
2	Fabric repair kit	8
1	Airflow meter	8
2	Vehicle jacks	294
1	Vacuum cleaner	60
1	Microfilm reader	5
1	Electronic diagnostic equipment	110
	Total Kit Weight	931

The general method developed in Reference 9 has been used for the analysis of this phenomenon as it affects the LSB complex. In the absence of detailed engine nozzle performance data an approximated vacuum exhaust plume served as the basis for estimating soil impingement pressures, particle acceleration, ballistic velocity and range for a variety of nozzle exit plane heights and particle sizes.

Plume Approximation and Impingement Pressures

Past experience with vacuum plumes for a variety of propellants and engine thrust ranges has shown that most of the exhaust flow (90-95 percent) occurs within an axisymmetric cone of 45-degree half angle. Using this approximation in the absence of detailed engine nozzle performance data, the average surface impingement pressure from any height, h, may be estimated as:

$$p_I = \frac{F_{vac} \; \overline{\cos\theta}}{\pi (h + R_e)^2} \qquad (1)$$

Thus, for impingement pressures on a flat surface, before erosion and bowl formation occur, with F_{vac} = 10,000 lb, $\overline{\cos\theta}$ = 0.83 for the average element within the conical expansion, R_e = 1.27 ft (from $I_{sp\ vac} \cong 430$ seconds, for LO_2/LH_2 in the weight ratio 5/1), the results are as follows:

h (ft)	p_I (psia)
0	11.6
5	0.5
10	0.144
20	0.041
50	0.007
100	0.0018

Particle Acceleration

Figure 5.5-1 shows apparent test agreement with theoretical "no-soil erosion" height limits based on Robert's Theory (Reference 10). For the 10,000-pound engine with R_e = 1.27 feet, the critical particle diameters corresponding to the range of nozzle exit heights considered are:

h (ft)	h/R_e	D (microns)	D (inches)
5	4	30,000	1.20
10	8	8,000	0.32
20	16	2,000	0.08
50	40	300	0.012
100	79	100	0.004

Robert's complex theory and methodology deals extensively with bowl depth and radius formation versus time but provides little help with respect to the ejecta distances required for assessing safe distances to personnel and structures. A simplified approach, pending further study of the Apollo 10 and 11 data, and of more recent NASA studies than Reference 10, is to assume that the particles are accelerated from the center to the periphery of the conical plume intersection with the surface, then ejected at ballistic velocity. The acceleration force is the impact pressure times the particle cross-section, with zero pressure assumed on the aft side, since the boundary layer velocity is still high (> 1000 ft/sec).

The acceleration in ft/sec^2 is then

$$a = \frac{F_p}{M_p} = \frac{p_I \pi D^2/4}{\rho_p \pi D^3/6} = \frac{1.5\, p_I}{\rho_p D} \qquad (2)$$

where p_I = impingement pressure in pounds/square foot, ρ_p = particle mass density in slugs/ft^3, and D = particle diameter in feet.

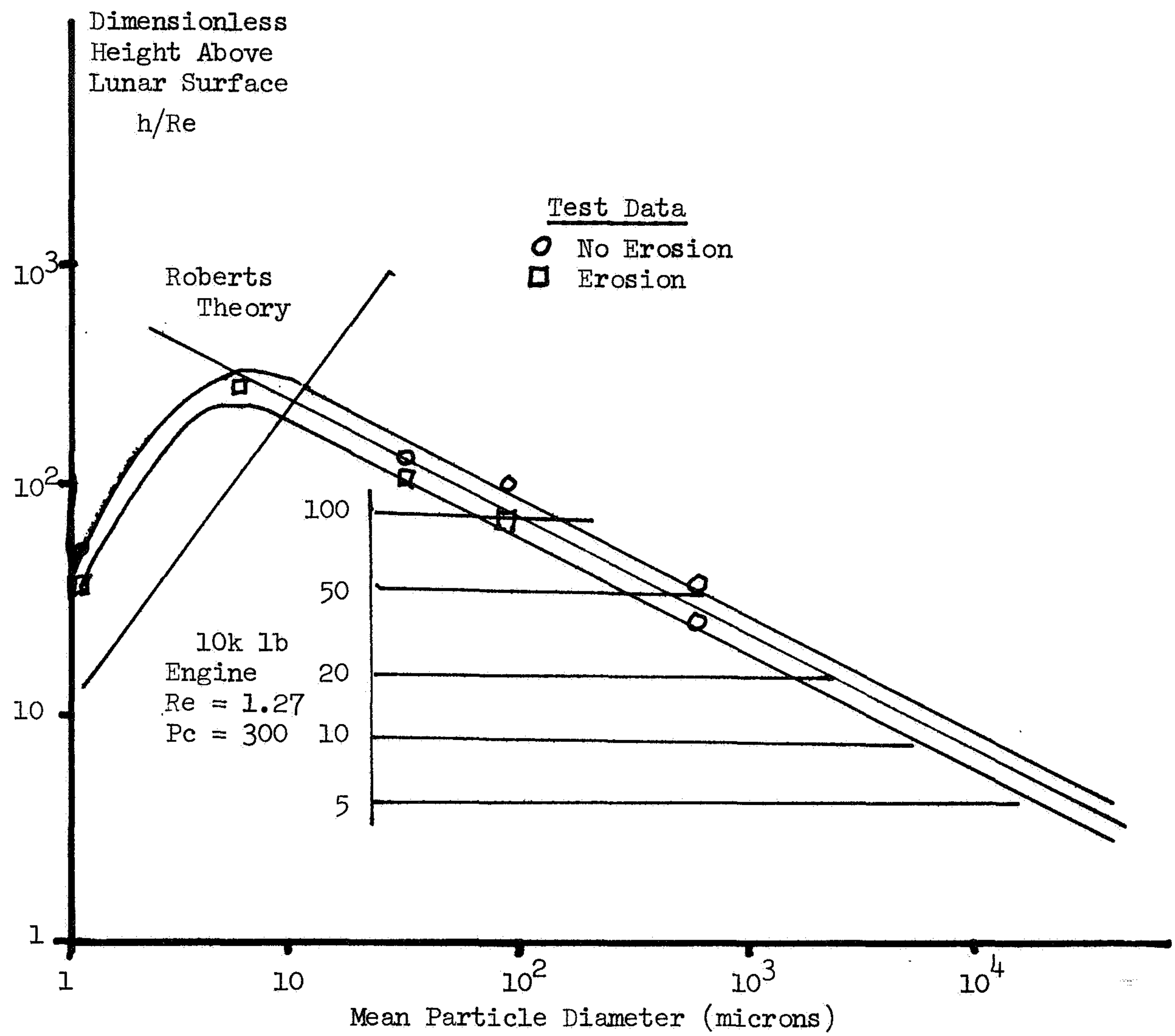


Figure 5.5-1. Soil Erosion Height Limits

For a lunar surface density of 1.8 to 2.0 g/cc (earth units) or about 1.9 x 62.4/32.2 = 3.7 slugs/ft^3 at an assumed porosity of 50 percent, the soild particle mass density would be double, or 7.4 slugs/ft^3. The particle diameter is usually specified in micros, requiring a conversion in Equation (2) of D/300,000, with p_I from Equation (1) substituted to yield

$$a = 1.6 \times 10^8/(h + R_e)^2 D \qquad (2a)$$

Ballistic Range

The only difference in ballistic range, X_b, from the earth vacuum formula involves reflection of the influence of lunar gravity, or

$$X_b = \frac{V_b^2}{g_M} \sin 2\alpha \qquad (3)$$

where V_b is the ballistic ejection velocity after acceleration as in Equation (2a), $g_M = 5.3$ ft/sec^2, and α = the elevation angle ($\sin 2\alpha = 1$, for 45 degrees maximum, and 0.94 for 35 degrees assumed as an average bowl exit angle from earth tests).

The velocity attained for constant acceleration in the distance $(R_e + h)$ is:

$$V_b \cong \sqrt{2a(R_e + h)} \qquad (4)$$

This relationship is shown plotted in Figure 5.5-2.

When Equations (1) to (4) are combined, it is seen that the range

$$X \propto F_{vac}/ \rho_p D (h + R_e) \qquad (5)$$

or directly as the engine thrust, inversely as the lunar soil particle diameter and mass density, and inversely as the nozzle height.

Support for this simplified theory and method is supplied by Reference 11 which states that the dust shower caused by the few seconds impingement of the Apollo 12 LM engine on the Surveyor III TV camera (≈ 1000-pound throttled level thrust) was equivalent to 950 days exposure of meteoric dust and reached a distance of 180 meters (590 feet). Thus, 10,000 pounds of thrust in Equation (5) would indicate over a mile range for a particle diameter of 1000 microns.

The conclusions to be drawn on the influence on the LSB are:

1. The estimated ejecta distances for reasonable engine cutoff heights of 10 to 20 feet are great enough over a wide range of particle sizes to indicate a definite need for barricades to protect personnel and/or sensitive structures such as solar arrays, optical devices, and antenna.

2. To permit closer approach to structures, a prepared hardened landing surface should be provided.

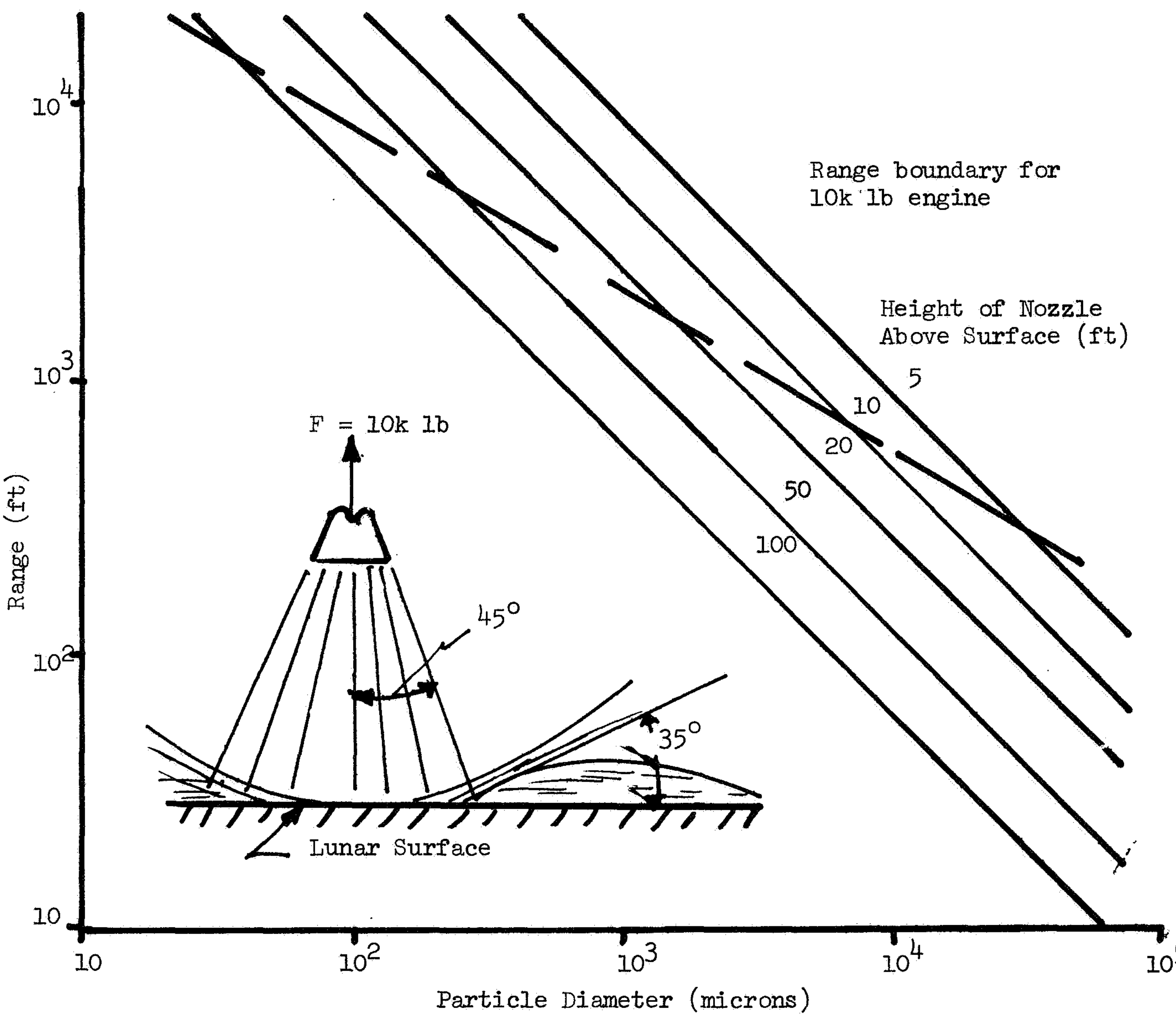


Figure 5.5-2. Dust Particle Velocities

3. Further study is recommended to obtain updated data, particularly from the Apollo 11 and 12 flights. One sequence of the motion pictures of the LEM leaving the lunar surface taken from the command module showed a solid horizontal stream of particles, entrained by the take-off engine plume. Blowups of these frames may provide some needed data on particle velocities.

5.5.2 Logistic Vehicle Explosion Hazard

The logistic vehicle may be resting on the LSB pad for the full resupply cycle. The potential danger to LSB components resulting from an explosion of the vehicle was analyzed utilizing data from work performed on the Saturn II program by NR/SD (Reference 12).

Based on experimental results, the partitioning of the explosive energy, from 18 to 28 percent of the potential energy to be transferred into kinetic energy of the fragments. Further, the kinetic energy of each fragment is found to be proportional to the ratio of the area of the fragment exposed to the pressure and the total internal area. In determining the potential fragments distribution, their trajectory must first be calculated. The initial velocities are plotted in Figure 5.5-3 as a function of the area ratios and the inverse of particle mass in pounds; i.e., $\frac{A_f}{A_s m}$

The number and partitioning of fragments was found by scaling from a 500-pound bomb to the baseline logistic vehicle (the space tug). A total of 24.3k fragments were estimated with the following characteristics:

Shape	Percent	Density (lb/ft^3)	Max. Velocity (ft/sec)
Cubes	10	0.05 to 0.2	780
Cylinders	23	0.01 to 0.5	1236
Plates	67	0.1 to 1.7	2220

The particle ranges were estimated based on these data and are illustrated for three assumed angles in Figure 5.5-4. Theoretically, plates could travel up to 170 miles. However, when a probability/particle distribution plot is made of these data, a different picture is presented. Figure 5.5-5 indicates that the particle density in numbers per square mile becomes insignificant after about one mile. This is, therefore, considered a safe separation distance.

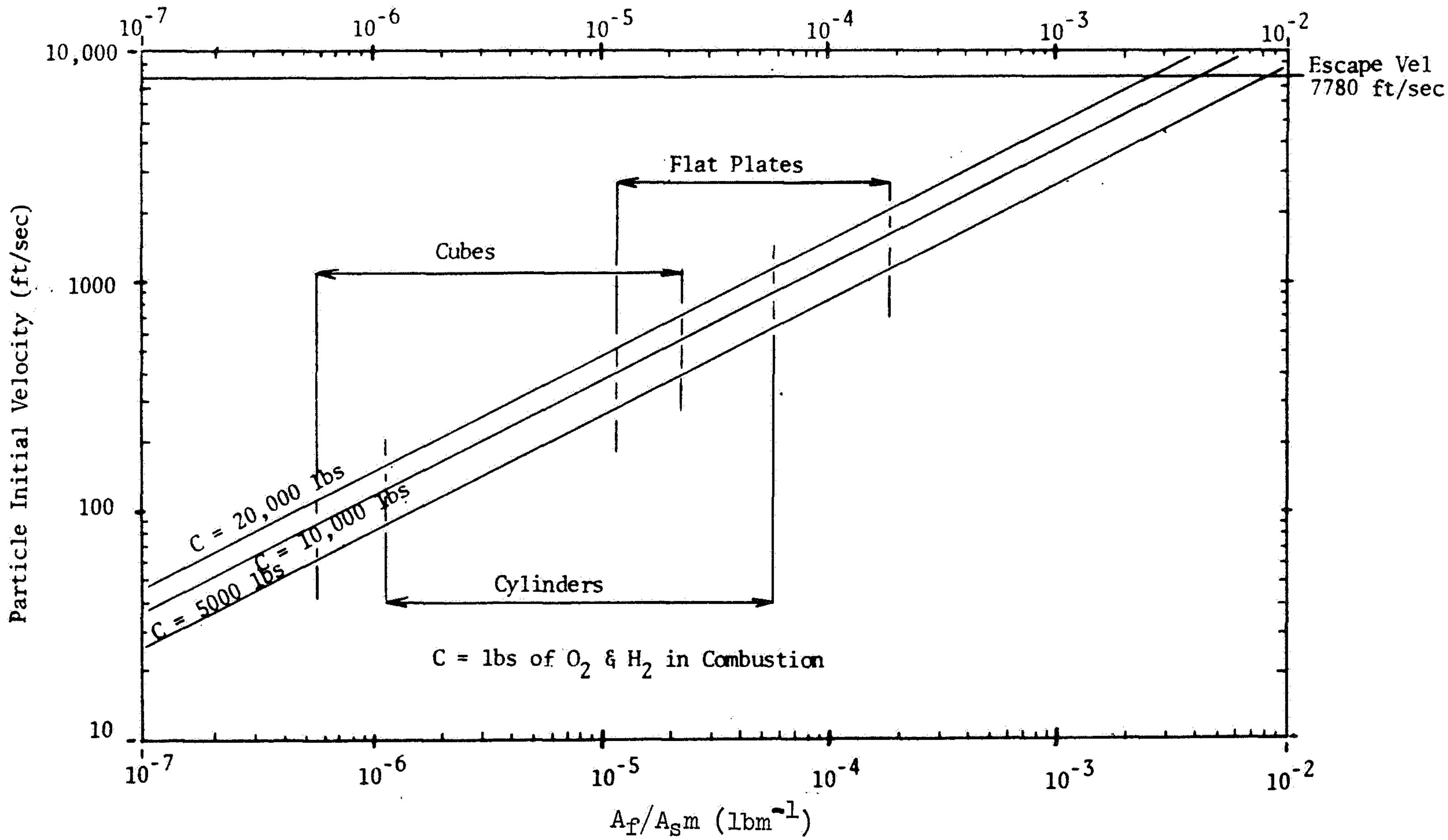


Figure 5.5-3. Particle Dispersion From Potential Explosion of Projected Logistic Vehicle

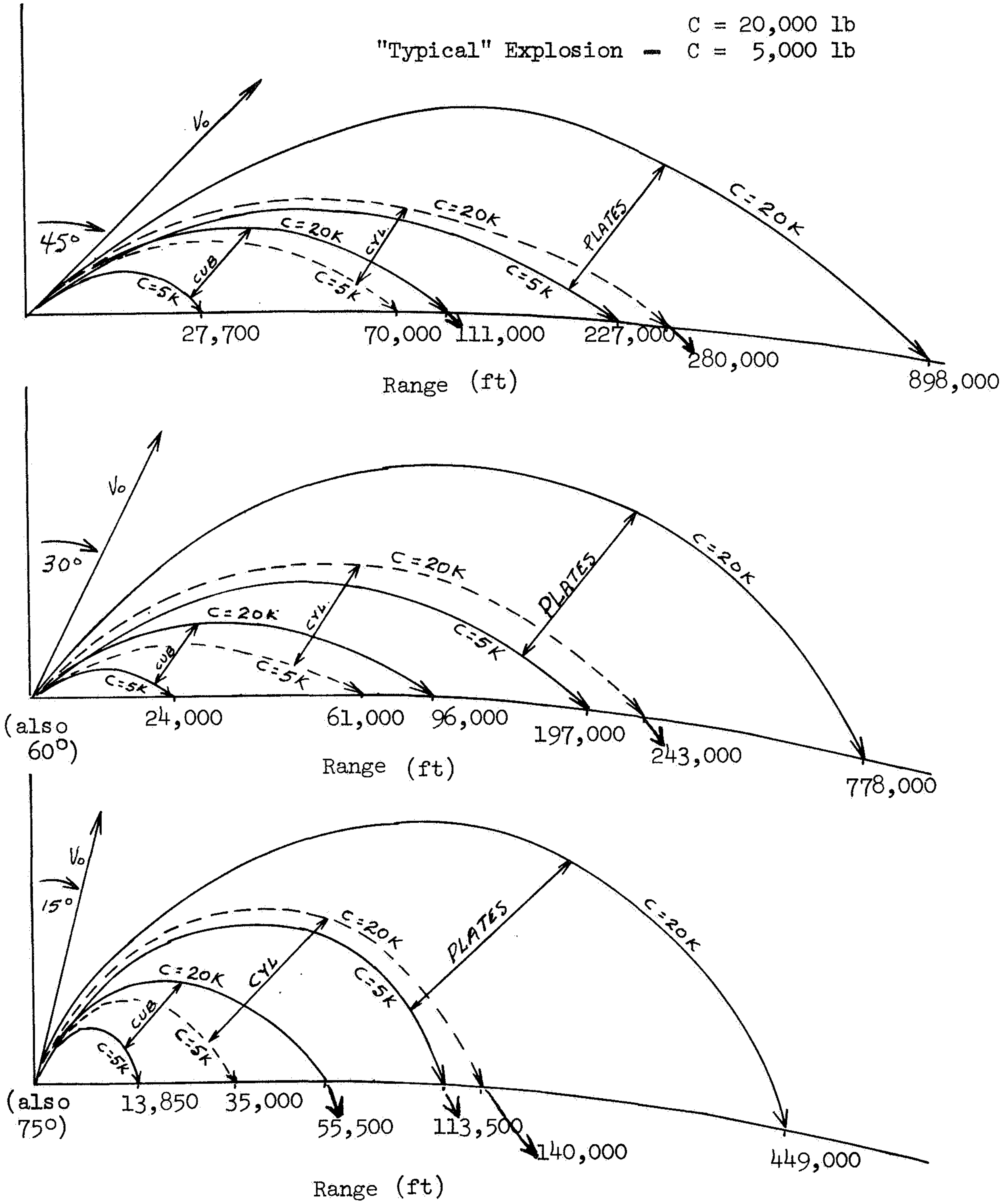


Figure 5.5-4. Trajectory Maximum Particle Range

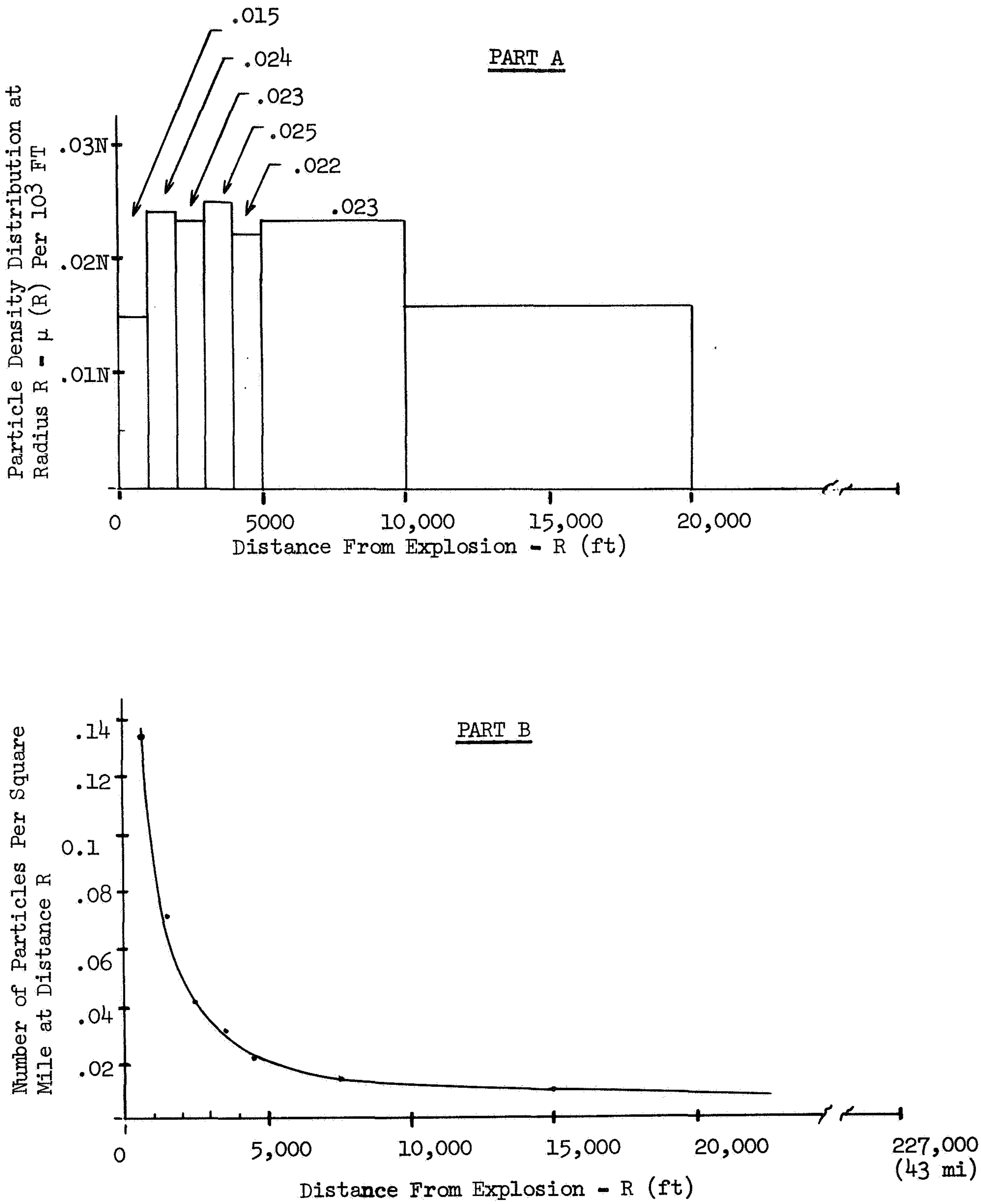


Figure 5.5-5. Fragment Distribution Resulting from Explosion of the Space Tug on the Lunar Surface (5000 lb of the 20,000 lb Fuel)

5.5.3 Disabled Sortie Hazard

Since the sortie train is expected to make long trips away from the LSB to distances of up to 300 miles, there is a remote possibility of a serious failure, see Table 5.2-2. This is perhaps the most critical source of danger to the sortie crew and should be treated accordingly. In the event any of these emergencies arise, multiple options should be available. From the example anomalies fault tree in Figure 5.5-6, it may be seen that most of the potential anomalies are similar to those of the base. The differences are associated with the geography of the problem; i.e., remote from the main shelter. The question, therefore, is how to return to the LSB without the loss of life. The potential options may be grouped to two classes, those associated with local actions and those depending on outside actions.

The local action options are similar to those identified in Figure 5.3-1. The recommended sortie concept provides the following design and operational options:

1. Two prime movers, either one of which will control the total system
2. Redundant shelters, two prime movers, and the mobile shelter (3 shelters)
3. Redundancy within all operational subsystems, two primary and a secondary power source
4. All systems designed for field repair

The outside action options include an overland rescue, a surface-to-surface spacecraft (tug), or a tug coming from somewhere in space.

1. The options involving use of a spacecraft require that a vehicle be available and ready. The flight will require more than 30,000 pounds of fuel and may require from one to five or more days to reach the disabled sortie train depending on location and operational status.
2. The overland rescue involving use of one (or two) prime movers, and a mobile power trailer can make the trip for little additional expenditure and will take less than seven days to reach the site in the worst case. In addition the prime mover(s) could recover any or all of the disabled equipment.

The overland concept appears preferable if outside action is required. Development of suitable contingency plans for emergency resolution by local action should reduce the potential need for rescue to a very low level.

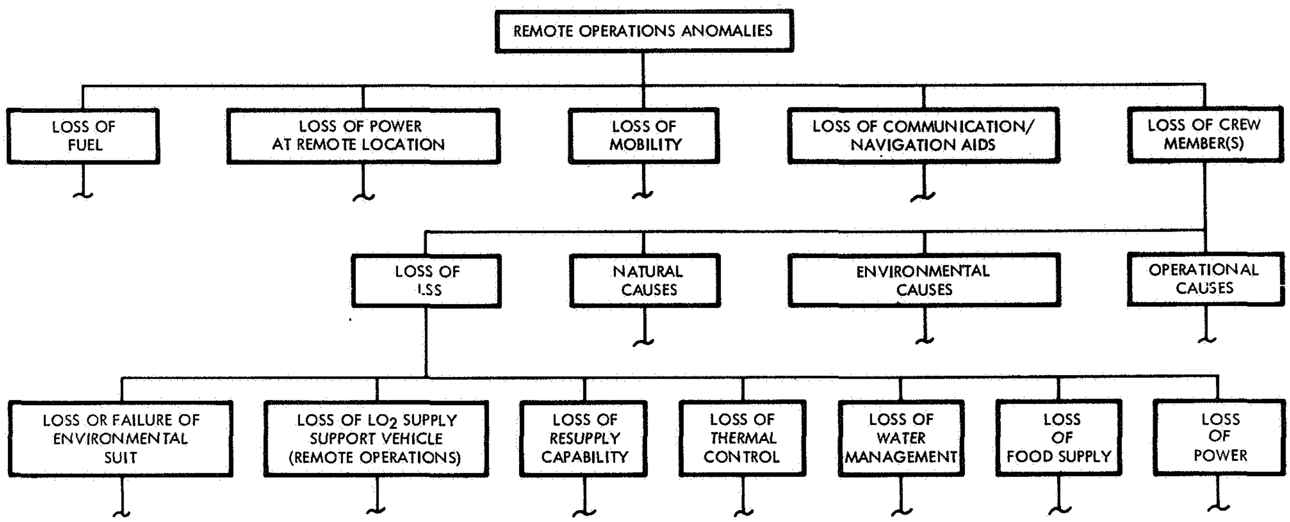


Figure 5.5-6. Example Remote Operations Anomalies Fault Tree

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