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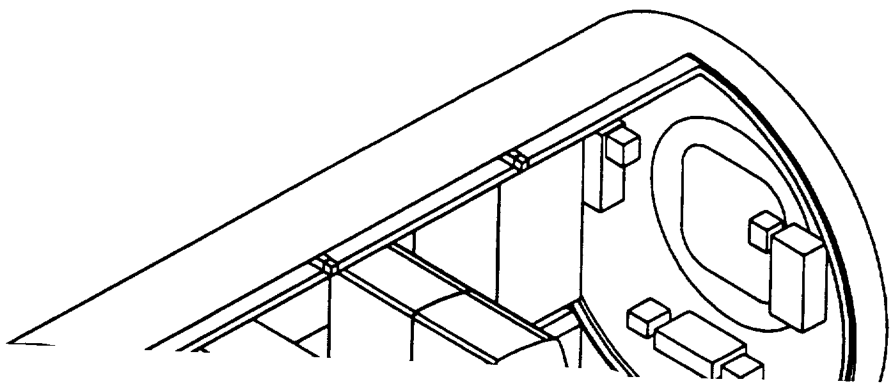
Space Transfer Concepts and Analyses for Exploration Missions

Contract NAS8-37857

Final Report
Technical Directive 11
May 1992



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Advanced Civil Space Systems
Huntsville, Alabama

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Space Transfer Concepts and Analyses for Exploration Missions

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Technical Directive 11

Final Report

May 1992

Boeing Defense & Space Group
Advanced Civil Space Systems
Huntsville, Alabama

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D615-10054

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FOREWORD

The study entitled "Space Transfer Concepts and Analyses for Exploration Missions" (STCAEM) was performed by Boeing Missiles and Space, Huntsville, for the George C. Marshall Space Flight Center (MSFC). The current activities were carried out under Technical Directive 11 during the period February 1992 through April 1992. The Boeing program manager was Gordon Woodcock, and the MSFC Contracting Officer's Technical Representative was Alan Adams. The task activities were supported by M. Appleby, P. Buddington, J. Burress, S. Doll, R. Fowler, K. Imtiaz, S. LeDoux, J. McGhee, T. Ruff, and R. Tanner.

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ABBREVIATIONS AND ACRONYMS

A/B	Aerobrake
ACM	Atmosphere Composition Monitor
ACS	Atmosphere Control and Supply
A/L	Air Lock
Al	Aluminum
AR	Air Revitalization
BFO	Blood-Forming Organs
BMS	Bed Molecular Sieve
BREM	Boeing Radiation Exposure Model
BYRNTRN	Baryon Transport code
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAM	Computer Anatomical Man
c.g.	Center of Gravity
CHeCS	Crew Health Care System
CO_2	Carbon Dioxide
COP	Coefficient of Performance
ECLSS	Environmental Control and Life Support System
ECWS	Environmental Control Workstation
EPS	Electrical Power System
EVA	Extravehicular Activity
FEM	Finite Element Model
FDS	Fire Detection and Suppression
FLO	First Lunar Outpost
g	Acceleration in Earth Gravities (acceleration 9.80665 m/s^2)
h	hyperbaric
ICRP	International Commission on Radiation Protection
ITCS	Internal TCS
JSC	Johnson Space Center
K	Temperature in Kelvin Units
kg	kilograms
km	kilometers
km/sec	kilometers/second
kW_e	Kilowatts electric
kW_t	Kilowatts thermal
LAS1, LAS2	SSF laboratory science racks 1 and 2
lbf	Pounds force
L/D	Lift-To-Drag Ratio
LEO	Low Earth Orbit
LET	Linear Energy Transfer

ABBREVIATIONS AND ACRONYMS (Continued)

LiOH	Lithium Hydroxide
LRU	Lunar Replaceable Unit
LSS	Life Support System
m	meters
MEV	Mars Excursion Vehicle
MLI	Multi Layer Insulation
MSFC	Marshall Space Flight Center
MTC	Man-tended Capability
mt	Metric Ton (1000kg)
NLS	National Launch System
nh	nonhyperbaric
O_2	Oxygen
Pb V/W	Tank material performance factor (tank burst press/density)
PDOSE	Proton Dose Code
PEP	Personnel Emergency Provisions
PHC	Personal Hygiene Compartment
psia	pounds per square inch absolute
RFC	Reactor Fuel Cell
SEI	Space Exploration Initiative
SSF	Space Station Freedom
STCAEM	Space Transfer Concepts and Analyses for Exploration Missions
STS	Space Transportation System (Shuttle)
t	metric tons (1000 kg), thickness
TCS	Thermal Control System
THC	Temperature and Humidity Control
Ti	Titanium
TPS	Thermal Protection System
VECTRACE	Vector Trace
WRM	Water Recovery and Management
$\Delta 1$	Delta One (1)
$\Delta 2$	Delta Two (2)
$\Delta 3$	Delta Three (3)
ρ	density
E	Modulus of Elasticity (Pa)

ABBREVIATIONS AND ACRONYMS (Concluded)

G	Modulus of Rigidity (Pa)
μ	Poisson's Ratio
σ_{ty}	Allowable Tensile Yield Stress (Pa)
σ_{cy}	Allowable Compressive Yield Stress (Pa)
σ_{sy}	Allowable Shear Yield Stress (Pa)

ABSTRACT

The current technical effort is part of the third phase of a broad-scoped and systematic study of space transfer concepts for human lunar and Mars missions. The study addressed the technical issues relating to the First Lunar Outpost (FLO) habitation vehicle with emphasis in the structure, power, life support system and radiation environment.

1.0 INTRODUCTION

The "Space Transfer Concepts and Analyses for Exploration Missions" (STCAEM) study was initiated under NASA contract NAS8-37857 for the Marshall Space Flight Center in August 1989 to address in-space transportation systems for human exploration missions to the Moon and Mars. The first phase of study (reported in ref. 1) was 18 months, covering the entire scope of feasible in-space transportation options for these missions, with concept definitions and analyses directed to narrowing down the field of concepts to a few preferred ones. The second phase covered the period from January to December 1991, and is reported in reference 2. Its main effort was to develop additional concept trades and definition for nuclear thermal propulsion missions to Mars, as this space propulsion system was recommended by Phase 1 as a preferred system and was selected by the Synthesis Group (in its report, "America at the Threshold") as the preferred means of Mars transfer propulsion. The second phase also addressed flight mechanics and concept issues and options for Mars landing site access, launch windows from Earth orbit, orbital assembly, radiation protection for astronauts during Earth-Mars and Mars-Earth transfers, and launch vehicle lift capabilities and shroud sizes.

Study of launch vehicle payload capability and shroud size was continued in January and February of 1992 under a technical directive and reported in reference 3. This study period also included analysis of the lunar dress rehearsal mission for Mars as recommended by the Synthesis Group, development of a biconic high L/D Mars lander option, and radiation analyses for an Apollo-shaped lunar crew return vehicle. These analyses are included in the referenced report.

These studies concentrated largely on Mars mission transportation since parallel contracted studies for MSFC were addressing lunar transportation in the context of in-space transportation vehicles to meet lunar and geosynchronous orbit transportation requirements. Phase 1 of the present study performed a vehicle family analysis for lunar transportation and mission modes, in which a direct-mode lunar mission was recommended as promising for an initial return to the Moon. It was recognized that a desirable scheme for an initial return would involve a two-flight mission with the first flight emplacing a somewhat austere habitat (called a Campsite) adequate for a crew of four for a few days up to about 45 days on the Moon, and the second flight transporting the crew in a direct mode (among other things, the direct mode leaves the entire return vehicle on the Moon for use anytime during the crew's stay on the Moon). Boeing conducted a study on IR&D to assess the commonality between a Space Station Freedom habitat module and a module of the same size outfitted as a lunar habitat. Subsequently, a brief study was performed under a TD on this contract to estimate the mass of such a habitat; this was reported to MSFC in briefings. A summary is given in reference 2.

Early in 1992, the NASA Office of Exploration adopted this mission approach as a working baseline for a return to the Moon, with the title *First Lunar Outpost.* The present report, prepared under TD-11 of this contract, provides results of a much more detailed study of a *First Lunar Outpost* habitat, concentrating on the habitat module and how it can be optimally derived from the Space Station Freedom habitat module, with adaptations as needed to function on the lunar surface. Trades and concepts for airlocks, electrical power and thermal control were also conducted are are reported herein.

In addition, this report includes a summary of some concluding work on medium and high lift-to-drag ratio (L/D) Mars lander concepts.

The *First Lunar Outpost* work is continuing under TD-13 (TD-12 analyzed laser-beam-powered electric propulsion and is reported separately). This continuing work will be reported later in 1992.

2.0 LUNAR OUTPOST HABITATION

2.1 INTRODUCTION

The current study has focused on defining and exploring the issues concerning *First Lunar Outpost* (FLO) concepts. Specifically, our involvement has been to apply data and experience gained from previous and on-going activities, such as the Lunar Campsite study (ref. 4) and Space Station Freedom (SSF) (refs. 5 to 8), to the development of Outpost Habitation and Airlock configurations and masses. The Campsite approach is intended to provide the first significant manned lunar access and capability beyond Apollo-style sorties and to serve either in a remote stand-alone mode or as a precursor to a more permanent base. FLO is also based on this philosophy but has afforded a more detailed examination of the concept and each of its systems. The methodology and current results of this initial activity will be discussed.

2.2 GROUND RULES FOR *FIRST LUNAR OUTPOST*

In the work presented herein, the following ground rules have been followed: (1) one-and-a-half lunar day mission duration with 72-hours contingency (for a total of 45-Earth days), (2) "existing" systems used to maximum extent, (3) total mass of 25 mt very desirable, (4) crew of four, (5) 200-mt launch vehicle with 10m x 30m payload shroud, (6) crew arrives in separate but common lander (with ascent stage), and (7) growth should not be precluded. Furthermore, the effort has concentrated on the habitation and airlock elements and systems which comprise the Outpost and did not include mission analyses, lander configuration studies, etc., for the FLO. In accordance with these constraints, FLO concepts were defined as shown in figure 2-1. The methodology adopted makes extensive use of SSF data as well as lessons learned from the Lunar Campsite study to develop a reference Outpost concept. The purpose of this reference concept is not only to provide traceability and justification for mass and power estimates but also to serve as the basis for subsequent options.

2.3 PRELIMINARY CONCEPTS FOR *FIRST LUNAR OUTPOST*

During the performance of this study, it became clear that the airlock is a major driver in the Outpost concept; moreover, airlock design appears to depend upon four basic requirements: (1) hyperbaric capabilities and associated needs, (2) size of Lunar Replaceable Unit (LRU) to be passed through the airlock, (3) number of crewmembers to be cycled through at one time, and (4) hatch and interior dimensions necessary to allow crewmembers to pass through the airlock. Hyperbaric treatment is preferred for decompression sickness and other disorders which may occur during EVA or other space activities. Although its need and appropriateness for the Outpost remains uncertain,

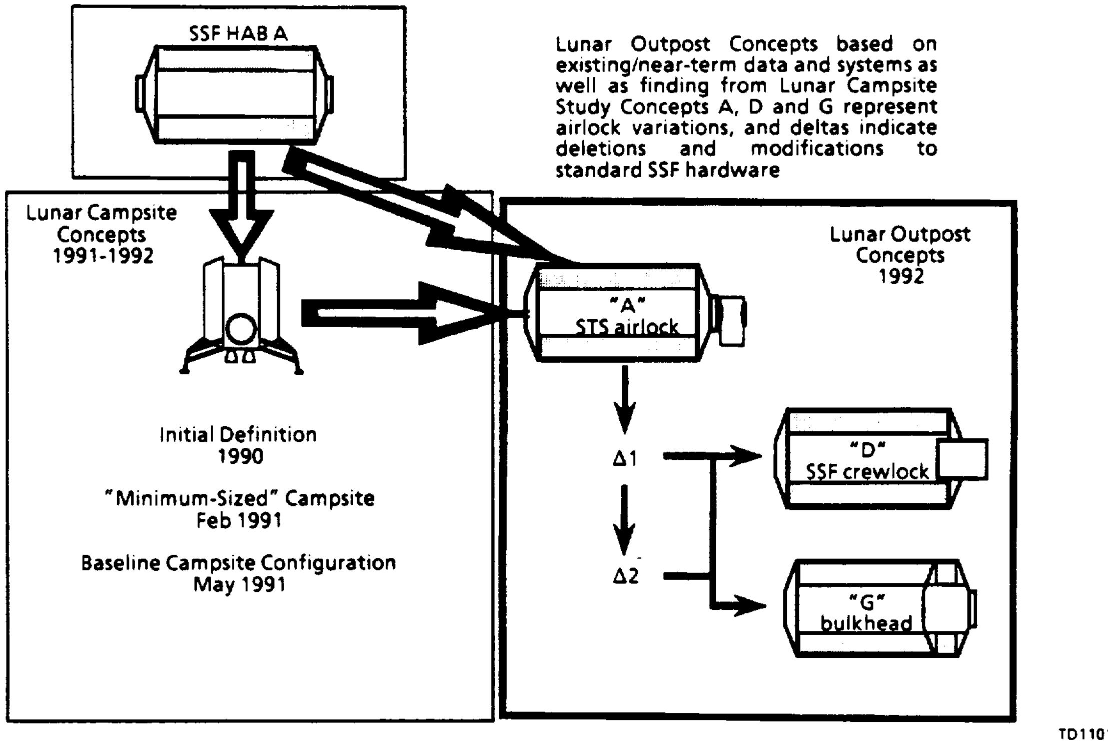


Figure 2-1. Outpost Habitat Methodology

hyperbaric operations have potential of greatly increasing size, mass, and complexity of both the airlock and the habitat (ref. 9). These impacts include: (1) airlock structure will depend upon internal pressure (recommended hyperbaric pressure is 2.8 atmospheres absolute or 2.8 times 14.7 psia irrespective of EVA suit or lunar module pressure (ref. 9) and volume (SSF requirements state that the patient must be horizontal and attended by a crew medical officer who has access to all sides of the patient); (2) internal airlock systems must support extended shirt-sleeve operations (hyperbaric treatment may last as long as 72 hours); (3) additional make-up gases, monitoring and control equipment, etc., must be included to support hyperbarics; and (4) medical equipment must be included within the airlock to monitor, diagnose, and respond to the patient's condition. The other three basic airlock requirements mainly impact internal volume needs, which consequently lead to sizing make-up gas quantities, depress pump size and power, operational procedures.

In response to these concerns, numerous alternatives to the FLO habitat/airlock combination were examined. Several configuration options which utilize a Shuttle airlock (Schemes A, B and C), a SSF Crewlock (Schemes D and E), or an internal bulkhead which separates a portion of the habitat module to be used as an airlock (Schemes F and G) are shown in figure 2-2. Accompanying each of these airlock element options are the

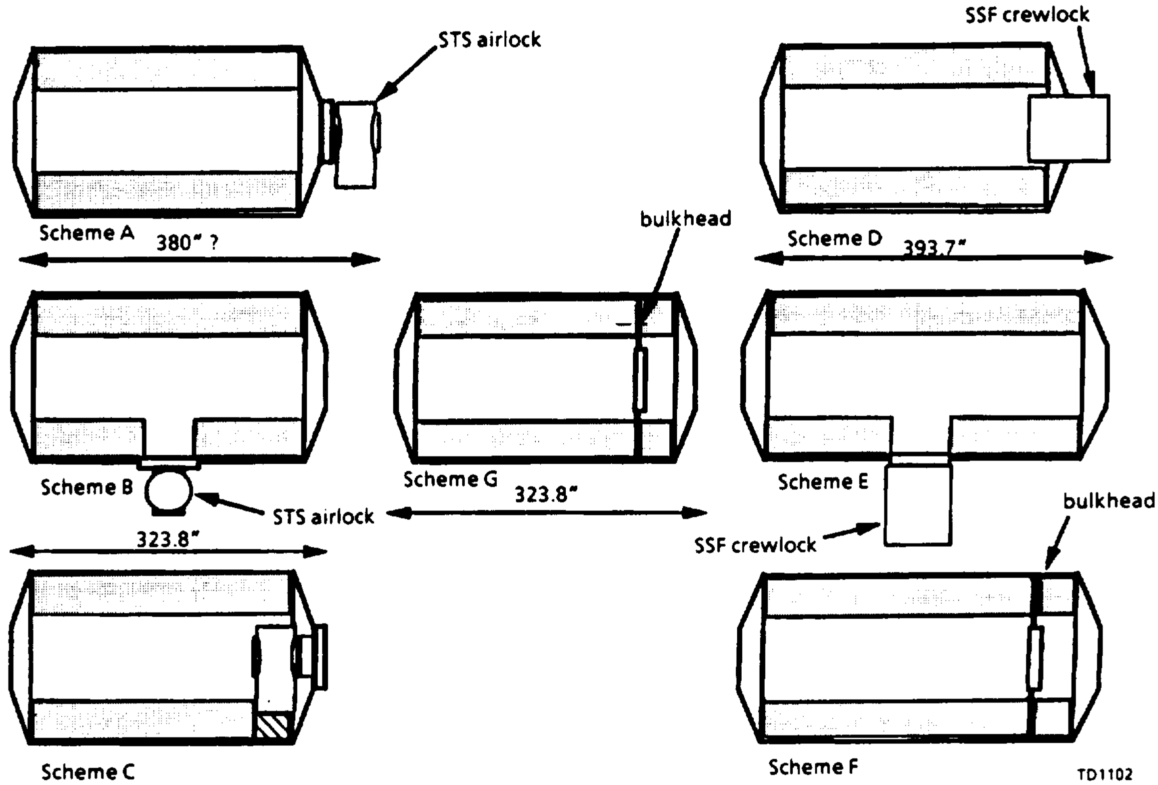
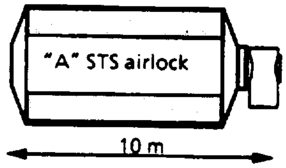


Figure 2-2. Lunar Hab Airlock Configuration Options

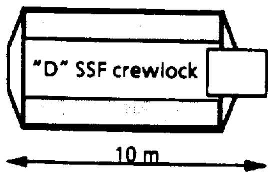
Extravehicular Activity (EVA) systems which facilitate both EVA and airlock operations. EVAs include suit processing and maintenance, depressurization pumps, controls and stowage which have been burdened upon the hab module for the concepts explored in this study. SSF system mass and power data have been used to estimate EVAs for all habitat/airlock configurations.

A qualitative study was performed to identify advantages and disadvantages associated with each of the above airlock options. These assessments identified the STS airlock, mounted externally to the endcone of the habitat module via a simple adaptor, as potentially the least impact solution and was thus chosen for further evaluation along with alternatives using either the SSF Crewlock or the integral bulkhead airlock. For this study, only options which seem to require minimal changes to the SSF module have been included; thus, Configurations A, D and G were chosen as the representative set of habitat/airlock combinations. Each airlock concept's effect on the habitat internal systems, internal volume, structure, power/thermal systems as well as crew egress/ingress capabilities were analyzed. Also, both hyperbaric and nonhyperbaric capabilities were assumed and examined for Configurations D and G. The qualitative comparison for these three configurations is given in figure 2-3.



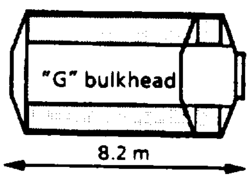
Nonhyperbaric only

- Not capable of meeting hyperbaric requirements
- Provides minimum volume airlock, reducing depress power requirements
- Adequate size for two suited astronauts, vertical orientation
- Designed for microgravity ops, making egress/ingress difficult in lunar gravity
- Minimizes impact on endcone utilities
- Airlock/EVA suit support equipment located in habitat



Hyperbaric and nonhyperbaric

- Designed for hyperbaric use
- Airlock/EVA support equipment located in habitat
- Designed for use in microgravity
- Geometry and orientation not optimal for lunar gravity
- Intruding airlock volume may reduce or eliminate access to four internal racks
- Requires endcone modification, impacts utilities



Hyperbaric and nonhyperbaric

- Allows airlock/EVA equipment to be colocated in airlock; may improve dust management
- Eliminates addition of separate structural element
- Internal bulkhead attached at existing girth ring provides structural mass competitive with STS airlock (nonhyperbaric versions only)
- Added complexity due to standoff utility penetration of bulkhead and structure and equipment cycling
- May eliminate four internal rack locations

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Figure 2-3. Lunar Outpost Configuration Airlock Alternatives and Assessment

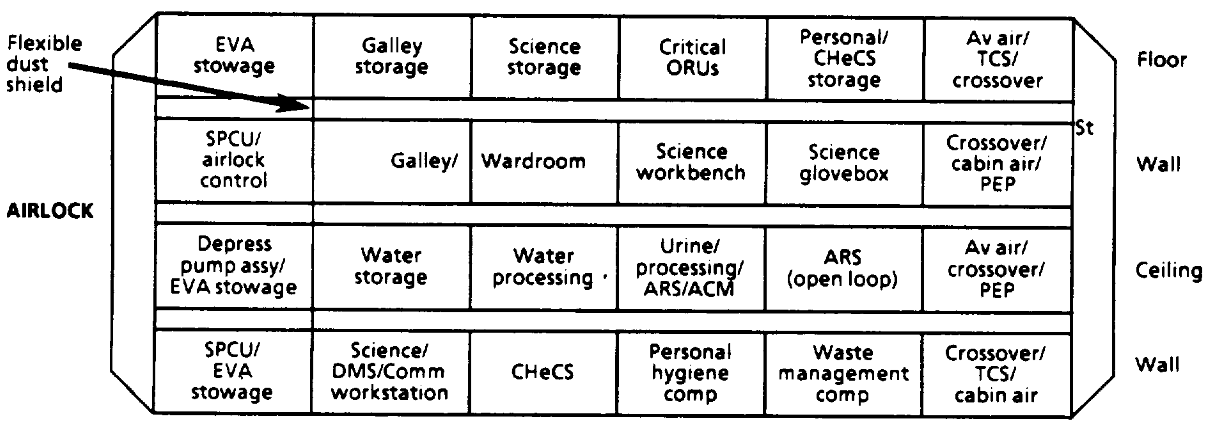
Based upon Configuration A, the reference Outpost was developed using the module, architecture, and internal systems from SSF Hab-A, an airlock from the Space Shuttle Orbiter, and external utilities based on near-term technologies. Appendix A provides detailed descriptions and mass breakdowns for this reference Configuration A; a higher level mass summary is given in figure 2-4. The module layout corresponding to this reference, as shown in figure 2-5, does differ from SSF Hab-A in that the Outpost habitat must support: (1) airlock operations and EVA systems, (2) internal science capabilities, and (3) crew health functions. These additional capabilities were accommodated by the deletion from the standard SSF Hab-A of several racks of crew systems equipment, including a dedicated shower, trash compactor, refrigerators/freezers, dedicated wardroom, and reduction of some stowage volume. Although each of the study concepts propose significant changes at the rack (and, as discussed later, at the subsystem) level, heritage is maintained to SSF in the following ways: (1) the Outpost module structure is assumed identical to SSF Hab-A (see a more detailed discussion of structures in section 4.0); (2) relative arrangement of internal systems are preserved, especially with regard to ECLSS (see section 3.0); (3) overall architecture as well as capabilities (redundancies, technologies, etc.) of the Outpost habitat are assumed to be identical to SSF Hab-A; and (4) most of the mass and power estimates are derived or taken directly from SSF data (thus, SSF internal systems have

	Airlock Options (mass in kg)				
	A	(D)nh	(D)h	(G)nh	(G)h
Hab structure	7,879	7,879	7,788**	7,879	7,788**
Hab and contents	17,114	17,114	16,879	17,114	16,879
Hab, contents, and airlock/EVA support	18,651	19,886	20,229	18,632	22,187
Hab, contents, and airlock/EVA support, external systems, and consumables	26,900	28,470	28,982	27,337	30,966
Contingency	2,310	2,403	2,451	2,437	24,58
Total Hab System Mass	29,210	30,873	31,433	29,774	33,424

h = Hyperbaric
nh = Non-hyperbaric

** Hab structure for hyperbaric option is reduced by 91 kg due to deletion of PHC reck (rack is added back for housing hyperbaric support systems burdened on Hab). Hyperbaric support systems burdened on airlock included SSF Crewlock rack mass. (location of this rack in internal bulkhead airlock is TBD)

Figure 2-4. Mass Summary for Reference Configuration A



Does not include:
Crew quarters
Dedicated wardroom (3)
Refrigerators/freezers (1.5)
Trash compactors (0.5)
Dedicated shower (1)
Dedicated radiation protection

Reduces:
SSF galley complement (1)
SSF stowage (?) (1)

Exchanges 8 racks in SSF Hab A

Adds:
SPCUs (2)
D/R pumps (1)
EVA stowage (1)
CHeCS (1)
Science Glovebox (1)
Science Workbench (1)
Science Storage (1)

Expands:
DMS/Comm into Workstation

Figure 2-5. Lunar Outpost Habitation Module Boeing Configuration-A Reference Layout been assumed). Although this heritage allows concepts to be defined which are traceable and as complete as possible, it must be recognized that future efforts will necessarily go to greater detail as a fully integrated and coherent concept is developed. For example, SSF Hab-A values for utilities in the standoffs and endcones have been assumed but will require changes as Outpost packaging needs are clarified; likewise, a unique and comprehensive redundancy scheme has yet to be applied to the FLO. However, it would be prudent to perform substantial requirement, mission analyses, design trades and alternative feasibility studies to define the context of the Outpost before one particular configuration concept is exhaustively detailed.

Alternative Configurations D and G substitute their respective airlock candidates but maintain the same basic habitat and external utilities as described for the reference. Significant differences between these alternatives and the reference configuration exist but have not yet been thoroughly studied. Included in these differences are: (1) most significantly, both Configurations D and G potentially impact four internal rack locations and volumes. The SSF Crewlock of D must be embedded approximately 48 inches in the habitat module to fit within the 10-meter launch payload shroud envelope; thus, the bay of four racks (as well as standoff and endcone equipment) located at that end of the module may be blocked from access and made unuseable. Similarly, the placement of a bulkhead within the module might be accommodated also by displacing a bay of four racks; however, the required shape of the integral bulkhead has not been finalized. For this study, the bulkhead mass and size was assumed to be the same as a SSF endcone; but, if the "airlock" portion of the habitat module would be used as a "safe haven" (in case the remainder of the module had become depressurized for any reason) or if hyperbaric capabilities were necessary, then the bulkhead would need to contain pressure differentials from either side and the design could be quite different from that assumed. In fact, a flat bulkhead might be used which would reduce the impact to internal volume (but would be more massive); (2) the internal bulkhead of Configuration G will also impact standoff utility runs as well as subject equipment and hardware on the "airlock" side to pressure cycling not normally encountered on Space Station Freedom. The impacts of these concerns have not yet been quantified; and (3) hyperbaric operations (for which SSF Crewlock is designed and to which Configuration G could be modified) will require at least one dedicated hyperbaric support rack within the habitat module (which must displace some existing rack); likewise, additional utilities and medical support will be required within the airlock itself. This study has estimated the system changes required by hyperbarics for both Configurations D and G; however, structural modifications have been approximated for G but, due to insufficient data, not to D.

Appendix B provides additional details on each of the airlock options, including an item by item breakdown for the Configuration D airlock based upon SSF Crewlock data (refs. 10 and 11).

2.3.1 Delta One (Δ1) Changes

Changes to the reference (identified as "Deltas" in this study) were defined and applied to all three options, with the goal of improving the FLO concept through the addition, deletion, or modification of reference systems or equipment in accordance with the Outpost environment and mission. This current study has concentrated mainly upon the latter two of the three means of improvement in attempts to meet the original 25-mt mass "desirement"; however, these changes have continued allegiance to the reference approach and have not yet proposed major deviations from SSF or near-term technologies.

Delta One (Δ1) involves the removal or reduction of unnecessary and self-contained items from reference (or SSF Hab-A) systems (any currently identified additions have already been included in the Reference Configuration A). A list of these Δ1 modifications along with mass details for each of the three configurations are given in appendix C. Mass summaries for Δ1 options are given in figure 2-6. Delta One suggests changes in six habitat/airlock areas: (1) Structures/Mechanisms. Proposed here is the removal of one of the module hatches since the airlock hatch should suffice at that end

Δ1 Airlock Options (mass in kg)

	A	(D)nh	(D)h	(G)nh	(G)h
Hab Structure	7321	7321	7230**	7321	7230**
Hab and contents	16,118	16,118	16,027	16,118	16,027
Hab, contents, and airlock/EVA support	17,415	18,650	19,137	17,396	21,095
Hab, contents, airlock/EVA support, external systems, and consumables	24,535	26,095	26,700	24,694	28,496
Contingency	1994	2085	2118	2043	2072
Total Hab System Mass	26,529	28,180	28,818	26,737	30,568

h = Hyperbaric
nh = Nonhyperbaric

Reference Configuration A = 29,210 kg

** Hab structure for hyperbaric option is reduced by 91 kg due to deletion of PHC rack (rack is added back for housing hyperbaric support systems burdened on Hab). Hyperbaric support systems burdened on airlock include SSF crewlock rack mass. (Location of this rack in internal bulkhead airlock is TBD.)

Figure 2-6. Mass Summary for Δ1 Options

(a discrepancy exists for Configuration G which will require an additional third hatch; also, because the habitat is located on the lunar surface (and on top of the lander in LEO), the lower half of the micro-meteoroid debris shielding has been removed; (2) Life

Support. Obsolete or unneeded items include out-of-date information (contained in ref. 5) as well as SSF connections between modules; (3) Crew Systems. Due to the mission's relative shortness compared to the SSF tour of duty and the premium being put on habitat overall mass reduction, only the minimum required crew accommodations would be included; thus, the convection oven and Personal Hygiene Compartment (changing room and vanity) were deleted; (4) Power. See details in section 5.0; (5) Heat Rejection. See details in section 5.0; and (6) Airlock Systems. The SSF EVA toolbox is sized for requirements beyond that currently identified for the Lunar Outpost and was reduced to 15% of the tool mass.

2.3.2 Delta Two (Δ2) Changes

Delta Two modifications are made to SSF hardware because of known lunar outpost requirements or due to the lunar environment. Appendix D contains the Δ2 mass details which are summarized in figure 2-7. This second set of changes correspond to four habitat/airlock areas: (1) Structures. In accordance with the details given in section 3.0, rack structural mass was reduced by approximately 30% through the elimination of STS-specific launch "pseudo-forcing" functions; (2) Life Support. The lunar gravity environment may allow removal of system complexities added to SSF due to the weightlessness of Low Earth Orbit (LEO); replacement systems have not yet been estimated; (3) Power. Section 5.0 offers further possible power system reductions, including re-electrolyzing fuel cell reactants over the number of lunar visits between manned visits (which adds complexity but does not seem to significantly reduce mass); and (4) Airlock Systems. Further reductions are proposed in EVA tool mass.

2.3.3 Delta Three (Δ3) Changes

Delta Three changes have not yet been detailed but will involve candidate major departures from SSF hardware, systems, operations, and/or current outpost scenarios. Some of these proposed modifications may include optimizing the module structural design, examining 14-day and 30-day manned missions, studying alternatives to housing systems within racks (the purpose and utility of racks in the *First Lunar Outpost* should be examined), assessing new or exotic power generation options, modifying or developing new airlock designs, and incorporating solutions to address operational concerns such as loading/unloading, dust removal, system deployment and safing. In addition to Δ3 options, future studies will continue to submit enhanced and updated Δ1 and Δ2 changes as the concept definition continues.

Δ2 Airlock Options (mass in kg)

	A	(D)nh	(D)h	(G)nh	(G)nh
Hab Structure	6622	6622	6531**	6622	6531**
Hab and contents	15,072	15,072	14,981	15,072	14,981
Hab, contents, and airlock/EVA support	16,113	17,348	17,835	16,094	19,793
Hab, contents, airlock/EVA support, external systems, and consumables	23,029 (22,885)*	24,591	25,192	23,181	26,996
Contingency	1936 (1896)*	2028	2060	1984	2017
Total Hab System Mass	24,965 (24,781)*	26,618	27,252	25,165	29,013

* Numbers in parenthesis for Configuration AΔ2 represent option of re-electrolyzing fuel cell reactants over 5 lunar days (between manned visits), which result in less than 200-kg savings

** Hab structure for hyperbaric option is reduced by 91 kg due to deletion of PHC rack (rack is added back for housing hyperbaric support systems burdened on Hab). Hyperbaric support systems burdened on airlock include SSF crewlock rack mass. (Location of this rack in internal bulkhead airlock is TBD.)

h = Hyperbaric
nh = Nonhyperbaric

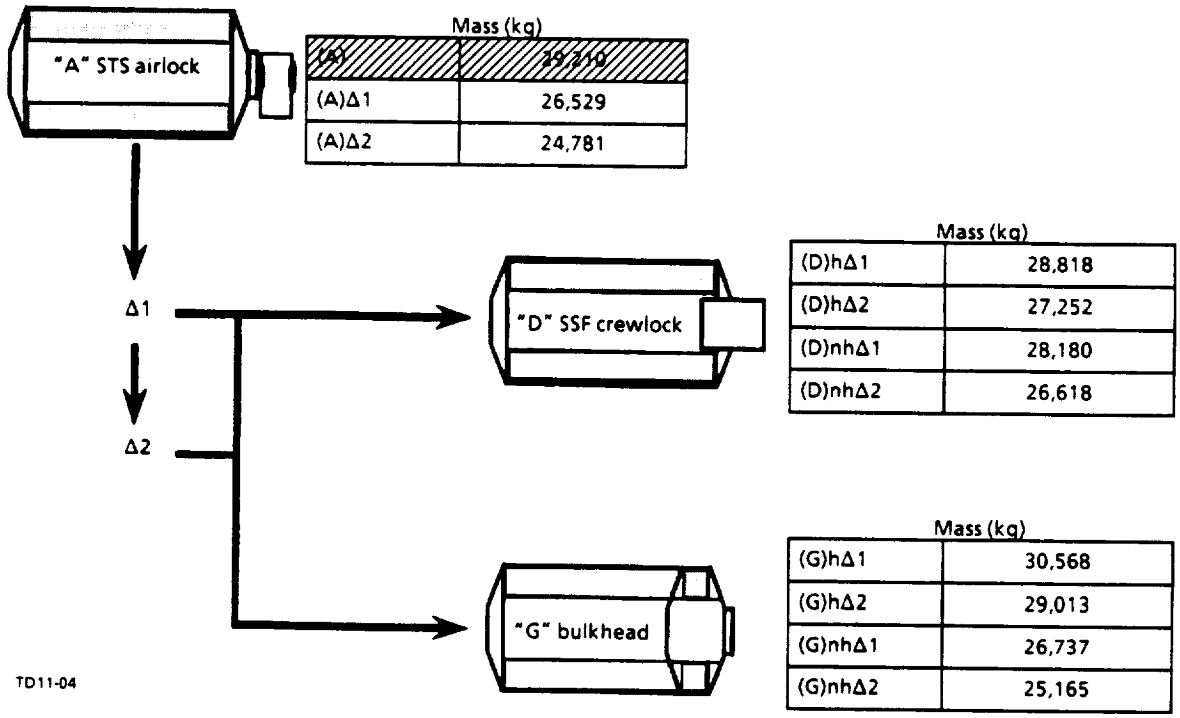
Reference Configuration A = 29,210 kg

Figure 2-7. Mass Summary for Δ2 Options

One other investigation was conducted to determine what mass savings, if any, could be gained from substituting the standard SSF endcone structure, which is designed to withstand STS docking loads, with a specialized end "dome", that would also act as an airlock adaptor. This work was done under the assumption that the airlock is being supported by the lander structure, and is not cantilevered off the Hab. Results of this cursory study indicate a potential savings of a few hundred kilograms but have not been incorporated into any of the options offered by this study.

2.4 SUMMARY

A mass summary for each of the configurations and options examined during the course of this study is given in figure 2-8. A brief "history" of these results is illustrated in figure 2-9, which follows the trends of Configurations A and D as they progressed through the study, beginning with the May 1991 Lunar Campsite concept foundation and building toward the present Δ2 mass estimates. From these charts, it is evident that current preliminary estimates for the Lunar Outpost may range from 25 mt to 31 mt, with only two configurations (AΔ2 and GnhΔ2) currently coming close to the original 25-mt goal. Of course, several unknowns persist with all of these options and include those given on figure 2-10. Included in this list of unaccounted items is the Gas Conditioning Assembly (GCA) used on SSF. Our concept for FLO is to use dedicated metabolic oxygen



Mass (kg)

(A)	29,210
(A)Δ1	26,529
(A)Δ2	24,781

Mass (kg)

(D)hΔ1	28,818
(D)hΔ2	27,252
(D)nhΔ1	28,180
(D)nhΔ2	26,618

Mass (kg)

(G)hΔ1	30,568
(G)hΔ2	29,013
(G)nhΔ1	26,737
(G)nhΔ2	25,165

Figure 2-8. Lunar Outpost Habitat Mass Summary

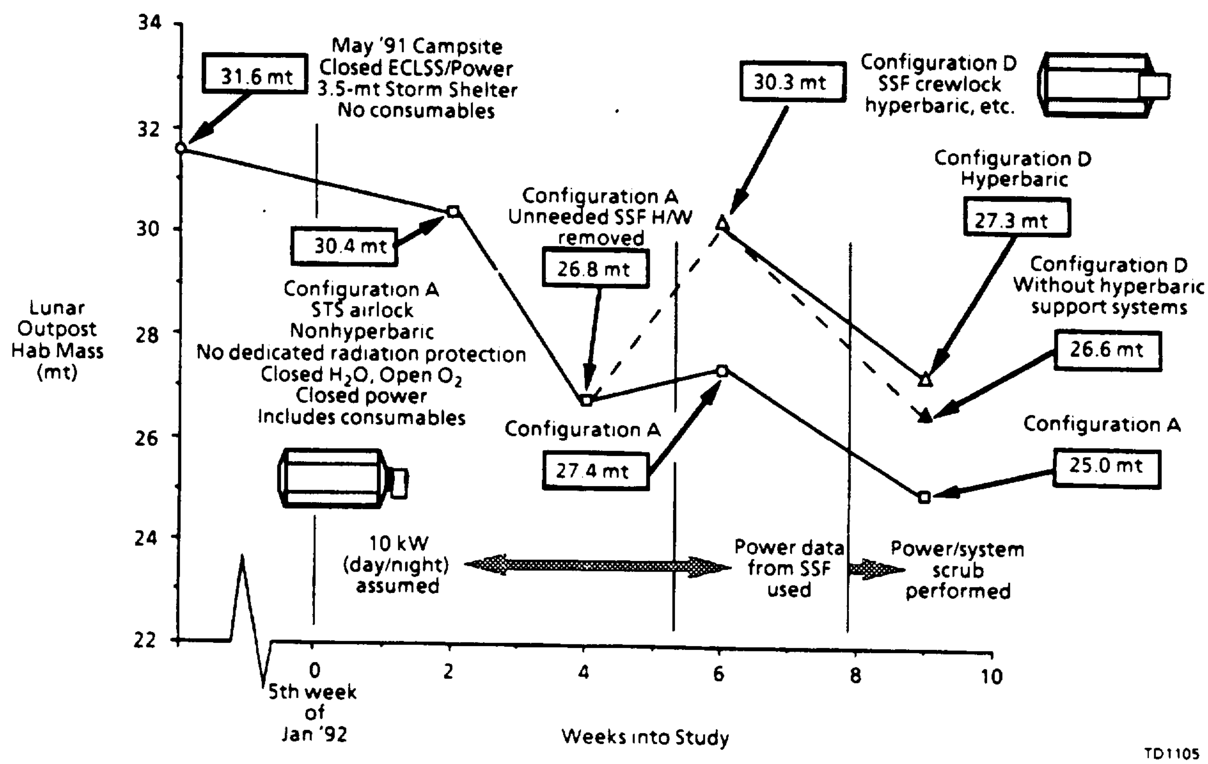


Figure 2-9. Boeing STCAEM Lunar Outpost Habitat Status

and separate high pressure make-up/contingency gases which would not require an elaborate GCA to function. It is assumed that a lower mass Pressure Regulating and Thermal Conditioning (PRTC) unit would be sufficient; however, an estimated PRTC mass has not yet been included.

Future activity in support of this task may involve additional Δ1, Δ2, and Δ3 changes as well as developing answers to identified questions. Specific candidates for further study are proposed on figure 2-11. The Lunar Outpost is a promising concept for manned return to the Moon; its continued definition in the context of overall lunar mission analysis and requirements development should offer viable concepts and approaches to be studied and traded as SEI matures.

Unaccounted Items
- Gas conditioning assembly (potential 1-2 mt addition)
- ASE and required additional launch load structure (original SSF Hab A launch support is included)
- External equipment support and deployment structure
- External science needs
- Rover and rover support requirements

Issues/Questionable Items
- Radiation/dust/gravity/thermal impacts and needs
- Impact of internal bulkhead airlock on racks, standoffs, and endcone/standoff equipment
- Requirements, impacts, capabilities and limits for EMUs (size, regenerable or not, etc.), airlock volume, hatch size and suit location
- Redundancy/contingency requirements/operations
- Lander/habitat interface
- Lander configuration
- Outpost startup, shutdown and dormancy requirements/operations
- Resupply/maintenance/refurbishment operations
- Surface, lander and module access requirements
- Crew lander cargo capabilities

Low Confidence Items
- Adequacy of SSF Hab A-based utilities and distribution
- DMS/C&T requirements
- Spares

Figure 2-10. Lunar Outpost Potential Additional Impacts

- Definition and resolution of operations and mass issues for landers, crew vehicle, habitat and airlock
- Power System:
  - Assessment of reduced residual requirements
  - Utilization of less conservative tank material working stresses
  - Assessment of array degradation effects
  - Analysis of open vs. closed systems
- Structure
  - Further research into launch vehicle environment impacts
  - External support structures
- ECLSS
  - Analysis of open vs. closed systems
  - Assessment of water balance
- Modified and new airlock capabilities and design
- Development of Δ3 options
- Internal volume assessment
- Internal layout and packaging assessment
- Interaction of outpost with crew lander
  - Delivery of consumables
  - Crew transfer
  - Abort and rescue operations
- Overall mission analysis
  - What do we want to do there?
  - How do we do it?

Figure 2-11. Candidates for Further Study

3.0 HUMAN SUPPORT

3.1 ECLSS

U.S. space flight experience has been for short-duration missions (days), with Apollo and the Shuttle, and medium-duration missions (months) with Skylab. Space Station Freedom will provide experience in long-duration (months to years) presence in space. Life support systems for short missions are traditionally open loop. That is, life support resources such as water and oxygen are brought from Earth, and waste products are discarded. As mission duration increases so does the quantity of resources that must be carried. Longer duration missions employ closed-loop technologies which recover resources from waste materials, thus reducing the mass of supplies which must be brought from Earth. The lunar outpost mission (45 days) fills in the area between short- and medium-duration missions. Additional analysis is required to determine the optimal life support system for this application; and, whether it is appropriate to use open- or closed-loop systems. The two major life support subsystems that are candidates for closed-loop or regenerative technologies are Water Recovery and Management (WRM) and air revitalization (AR).

Functions provided by the water recovery subsystem include potable and hygiene water supply, water distribution and disposal of urine. Potable water is ingested by the crew and converted into waste products such as urine, perspiration and respiration vapor. Hygiene water is converted to "dirty" hygiene water after being used by the crewmembers for showers, handwash, laundry, etc. Potable and hygiene water can be provided by stored water (open loop) or by converting waste water products back into useful resources (closed loop). Dirty hygiene water and condensate can be processed to directly provide usable water. Urine can be collected and stored or dumped or it can be processed to recover the water. There is still some debate over whether water recovered from urine should be used by the crew. Examples of other, non-crew related uses for water recovered from urine include electrolysis for production of oxygen or cooling water for EVA sublimators.

Primary air revitalization functions include oxygen supply, and removal of carbon dioxide, trace gases and particulates from the atmosphere. Crewmembers consume oxygen and produce carbon dioxide as a waste product. Oxygen can be provided from storage, high pressure or cryogenic (open loop), or can be generated from other sources. There are several processes that use CO_2 as the feed source and convert it to O_2 (closed loop). Conversion can be accomplished in a reactor which either converts CO_2 directly to O_2, or produces water as an intermediate step which is then electrolyzed to produce oxygen. Either way, CO_2 conversion is closed-loop technology because it converts waste material into a useful product. If excess water from urine processing or fuel cells, for example, is available, it can be electrolyzed directly to produce oxygen. This is not a closed-loop system because the CO_2 waste, produced as crewmembers consume O_2, would not be recovered. Carbon dioxide can be removed from the air by physical and/or chemical means. The two technologies which have been used in the past to remove CO_2 are lithium hydroxide (LiOH) absorption and molecular sieve extraction. The former is a chemical process which permanently binds the CO_2, and the spent LiOH is discarded. In the latter, the CO_2 is preferentially absorbed onto a zeolite material which can be desorbed using vacuum or heat. If one of the regenerative technologies to recover O_2 from CO_2 is used, a compatible CO_2 removal system must also be employed.

An analysis was performed to determine which combination of life support technologies should be used for the lunar outpost. Power, mass and volume were calculated for four life support system options using different combinations of technologies. Systems were sized for a crew of four using SSF technologies for closed-loop systems. Mass penalties (kg/kW_e, kg/kW_t, kg/m^3) were assigned for power, heat rejection and volume for each option based on the lunar outpost concept outlined earlier. System mass and mass penalties were summed to give system "equivalent" mass. A graphical representation which shows the increase in equivalent mass of the four life support system options as mission duration increases is shown in figure 3-1.

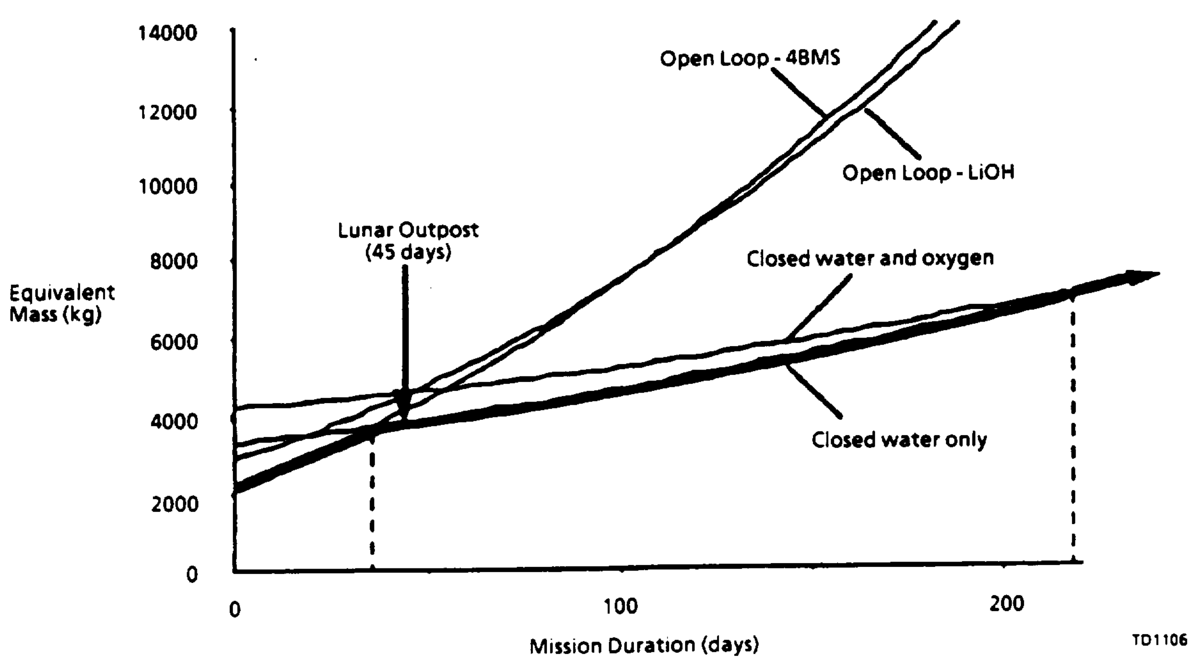


Figure 3-1. Life Support System Open to Closed Loop Crossover

The four LSS options which were evaluated included the two open-loop systems, a partially-closed system and a fully-closed system listed below:

a. Open loop - LiOH: open-loop water and oxygen, LiOH carbon dioxide removal.
b. Open loop - 4BMS: open-loop water and O_2, four bed molecular sieve (4BMS) CO_2 removal.
c. Closed - water only: closed-loop water, open-loop oxygen, 4BMS carbon dioxide removal.
d. Closed - water and oxygen: closed-loop water, open-loop oxygen, 4BMS carbon dioxide removal.

System crossovers occur at 40 days (transition from open-loop water and oxygen to closed water, open oxygen) and at 220 days (transition from closed water, open oxygen to closed water and oxygen). The heavy lines follow the system with the lowest mass. For a 45-day mission, the preferred LSS option is closed-loop water, open-loop oxygen. The proposed life support configuration (closed-loop water, open-loop oxygen) is similar to that proposed for SSF during the Man Tended Capability (MTC) phase.

The SSF habitat ECLSS was used as a starting point to estimate LSS mass, power and volume. "Rack-based" mass estimates were reconciled with ECLSS level numbers and then used to double check overall system numbers. Changes were made to the MTC Habitat to adapt it to the lunar outpost application. The subsystem affected, a description of the change, the reason for the change and an estimate of the increase or decrease in mass (given in kilograms) are summarized in figure 3-2. Modifications made to establish a reference for the first lunar outpost are annotated as "Delta-0" and include items such as the deletion of the refrigerator/freezer and the addition of a CHeCS (Crew Health Care System) rack. "Delta-1" changes eliminated or added stand-alone components as deemed necessary for outpost application. Examples of ECLSS components that would not be needed for the outpost include intermodule ventilation, because there is only one module and the 8-inch duct delta for extended module. Additional components were needed to accommodate changes in number of powered racks. Finally, "Delta-2" changes were elimination of components within an assembly which may not be required, primarily because of the partial gravity environment.

Subsystem	Changes to SSF Habitat ECLSS	Category	Mass
THC	Add PHC rack support	Delta-0	+2.9
	Delete IMV components	Delta-1	-144.6
	Delete refrigerator/freezer	Delta-0	-206.6
	Delete rack support (R/F, Shower, Wardroom, PHC)	Delta-0	-24.0
	Delete PHC rack support	Delta-1	-2.9
	Add rack support for 6 additional powered racks	Delta-0	73.7
	Remove water separator	Delta-2	-17.7
	Delete 8" duct delta for extended module	Delta-1	-12.89
	Delete standoff fans	Delta-2	-45.8
			-377.9
ACS	Delete 4 N_2 Rack User I/F (WRM, THC racks)	Delta-1	-63.0
	Add 3 N_2 Rack User I/F (CHeCS, 2 Sci racks)	Delta-0	+47.3
	Delete O_2/N_2 Bulkhead Pen and Tubing	Delta-1	-51.3
			-67.0
AR	Include MCA and CRM as critical ORUs	Delta-1	0.0
			0.0
FDS	Add PHC rack support	Delta-0	+4.3
	Delete rack support (R/F, Shower, Wardroom, PHC)	Delta-0	-15.9
	Add rack support for 6 additional powered racks	Delta-0	+48.9
	Delete 8" duct delta for extended module	Delta-1	-1.7
			+35.6
WRM	Remove half water storage and associated hardware	Delta-2	-524.9
	Delete obsolete hardware components (RO-old data)	Delta-1	-92.0
	Delete water vent	Delta-1	-98.4
	Delete tank pressurization hardware	Delta-2	-135.0
	Reduce tank mass (remove bellows)	Delta-2	-21.6
	Delete STS interface hardware	Delta-1	-13.7
	Delete 8" duct delta for extended module	Delta-1	-2.6
	Remove urine fan/separator	Delta-2	-19.6
			-907.8
	Adjustments to Lunar Outpost ECLSS		***-1317.0***

Figure 3-2. Changes to SSF Habitat ECLSS for Lunar Outpost

An indepth analysis performed by SSF Work Package 1 to address orientation-critical testing for SSF ECLSS, showed that the orientation of certain components, relative to the gravity vector, is critical for operation in a gravity field. The ECLSS components effected are valves (CO_2 removal, FDS central tank), urine processor distillation drum and fluids pump, water separators (condensing heat exchanger, commode/urinal, potable water processor), water processor filtration beds and bellows tanks. If minimal changes to SSF hardware is a requirement and "Delta-2" changes are not possible, there are a number of ECLSS components that may be sensitive to lunar gravity effects. Therefore, location of this hardware in a lunar outpost must be carefully considered before a final configuration can be established. Several other changes, such as simplification of the avionics and cabin air systems, were proposed for the outpost ECLSS but were not included in the baseline because of potentially significant design impact. These and other changes may be incorporated at a later date after further investigation.

3.2 FOOD SUPPLY

Information on the ambient temperature storage of food is summarized to provide a rationale for baselining no refrigerated food (ref. 12). The requirements for military operations are remarkably similar to those for space exploration: "need to appeal to changing individual preferences under extreme physical and emotional stress; food may be the only break from unpleasantness, discomfort, or monotony; food must travel long distances and maintain properties which make them suitable and desirable for consumption; economical of labor in unloading, handling, and preparation; conservation of weight and space in transport and storage precludes reliance upon freezers." The military has been doing research for decades to develop technologies to prepare and package food that does not require refrigeration. Some of the technologies being looked at include freeze drying or binding water, dehydration, thermoprocessing, ionizing radiation, modified atmosphere packaging and various combinations of the above. Soldiers routinely eat army rations for long periods of time with no detrimental effects. The proposed 45-day mission to the moon falls well within the extensive successful military experience (minimum requirements for ambient storage of food; 3 years at 80°F or 6 months at 100°F).

3.3 CREW HEALTH SYSTEM

Crew health care system requirements for exploration missions fall into two major categories; (1) operational health care and (2) monitoring and countermeasure development equipment. The operational health care system includes the following: (1) medical equipment includes dental, fluid management, diagnostic equipment, monitoring equipment, etc.; (2) environmental monitor equipment includes monitoring respirable atmosphere, surfaces, water, radiation, microbial, light, acoustic, etc.; (3) health equipment includes stress test equipment, nutrition monitor/analysis, laboratory, etc.; (4) minimum countermeasures equipment includes exercise equipment, hazardous spill and cleanup supplies, etc.; and (5) supplies and stowage. Additional monitoring and countermeasure development equipment are required for ensuring crew health and for biomedical investigations. Initial mass estimates for each set of equipment were 648 and 517 kilograms, respectively. After further evaluation, it was determined that some of the equipment could be deferred until later missions. Potential reductions were up to 140 and 191 kilograms, respectively. This brought the combined mass of the two sets of crew health care equipment to 834 kilograms. Skylab experience exceeded the 45-day expected lunar mission duration and encountered more serious reduced-gravity effects than expected on the lunar surface. If this experience is applicable, then the countermeasure development equipment could be further reduced by another 166 kilograms, bringing the minimum health care system mass down to 668 kilograms. There is some concern that eliminating this equipment would introduce unacceptable risk to the lunar outpost mission because our experience on the lunar surface was for mission durations significantly less than 45 days.

3.4 HYPERBARIC TREATMENT

There are two reasons for having hyperbaric treatment capability on a lunar mission; one is routine, the other is contingency (ref. 13). The first is related to routine EVA operations. The pressure differential between the cabin and the EVA suit can potentially cause problems. If the ratio of the cabin nitrogen partial pressure and the suit pressure is small enough (i.e., cabin at 8 psia, suit at ~4-5 psia), the risk of decompression sickness can be eliminated. The second cause of decompression sickness is accidental crewmember exposure to vacuum. The decision about whether or not to have hyperbaric capability will determine what the program will permit as acceptable risk to the crew.

Hyperbaric requirements can have a significant impact on airlock structural design. Two issues identified were position of a crewmember during treatment and treatment pressure requirements. A fully reclining position for a crew member being treated could be the major driver for sizing the airlock. However, a horizontal position for the patient might not be necessary in lunar gravity and that the most important requirement for patient orientation is attendant access to the patient, especially the head. The 2.8-atmosphere requirement for hyperbaric treatment places specific structural demands on the airlock. A reduction in this requirement (based on a cabin pressure less than one atmosphere) would result in weight savings for the lunar outpost airlock. Current hyperbaric treatment requirements are based on the extensive experience that is available using this pressure. Medical experts felt that a different treatment pressure might be adequate for lunar missions where the pressurized volume is below 14.7 psia, but that extensive testing would be necessary to establish protocols for a new treatment regime. This type of testing is currently underway, but it will take a considerable amount of time to develop a revised treatment regime. In the meantime, the requirement for hyperbaric treatment will continue to be 2.8 atmospheres for the foreseeable future.

4.0 PRELIMINARY STRUCTURAL EVALUATION

A preliminary structural evaluation of the SSF Hab module was conducted in order to determine the feasibility of using it as a Lunar Hab module.

4.1 LOADS AND REACTIONS

The SSF Hab launch and abort-landing loads/reactions were evaluated. Lunar Hab's launch configuration is 90 degrees to the SSF Hab's launch configuration (similar to the SSF Hab landing configuration). Basic geometry and the reaction locations are shown in figures 4-1 and 4-2, respectively. Since Lunar Hab is expected to be heavier than the SSF Hab, the loads and reactions will also be higher. In order to evaluate the magnitude of the loads, the following assumptions were made:

a. SSF Hab will be used without major structural modifications.
b. Baseline mass of 17.5 mt will be used.
c. Lunar Hab will be launched aboard an NLS-type launch vehicle.
d. Lunar Hab will be supported at the same reaction points as the SSF Hab.
e. Space Shuttle forcing functions will be used for dynamic loads calculations.

Calculations were based upon the Lunar Hab launch "g" loading provided (fig. 4-3, ref. 14). Static loads and reactions were calculated for the Lunar Hab for three mass configurations of 17.5-, 20.0- and 23.0-metric tons. Dynamic loads and reactions were generated for 17.5- and 23-metric ton mass configurations using the "g" loading and Space Shuttle forcing functions. SSF Hab support points were used for calculating the reaction loads. Dynamic reactions for 20-metric ton Hab were interpolated from the 17.5-mt and 23-mt reactions. Once the static and dynamic loads and reactions were available, dynamic amplification factors were obtained for each of the three mass configurations by taking a ratio of dynamic-to-static reaction loads. Dynamic amplification factors provide a means of determining reaction load changes with changing mass. Reaction loads and the dynamic amplification factors are provided in figure 4-4.

The dynamic reaction loading on the Lunar Hab is nonlinear with mass increase, as shown in figure 4-4. Increasing the mass from 17.5 mt to 20 mt (which is a 14% increase) results in an increase in the reaction loads by almost 70%, and increasing the mass from 17.5 mt to 23 mt (a 30% increase) results in an increase in the reaction loads by almost 120%. It is concluded that the SSF Hab can be used without major modifications as long as the mass is kept at or below 18 mt. The severe loading increase observed when

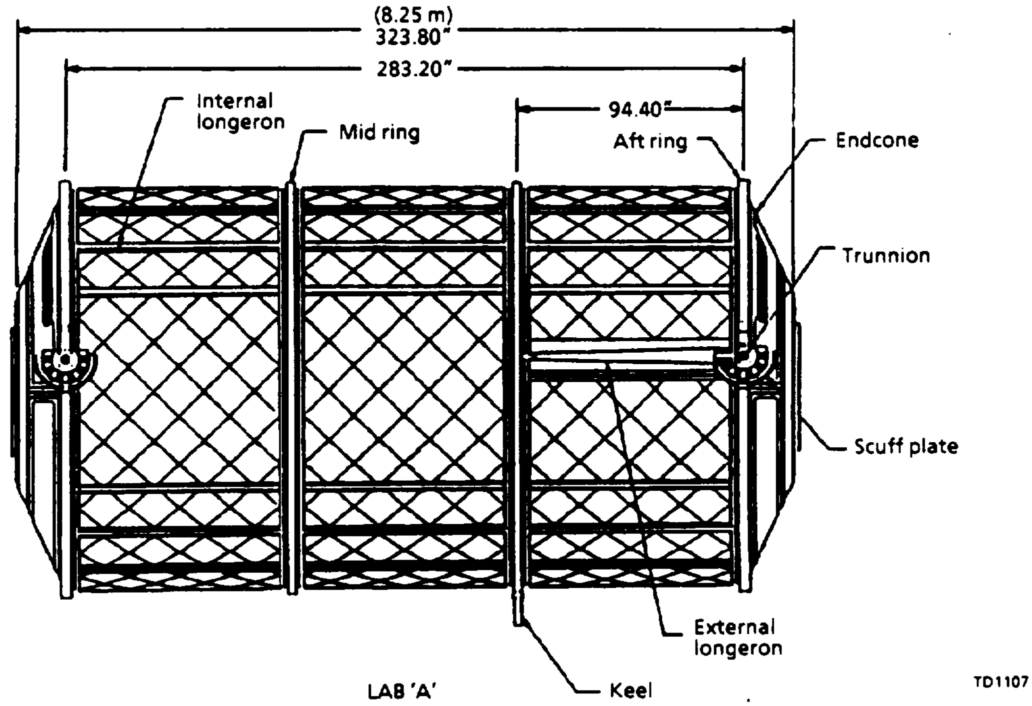


Figure 4-1. SSF Hab Module - General Information

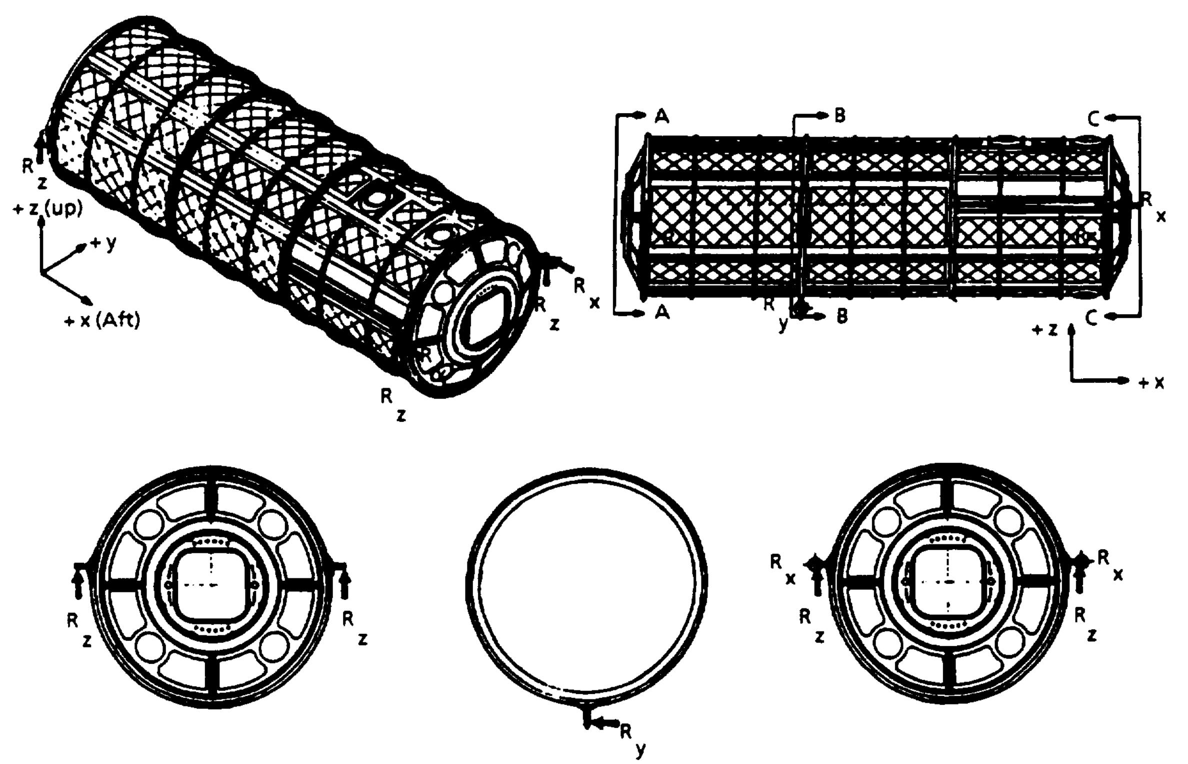


Figure 4-2. SSF Hab Module - Attachment Point Reactions

Lunar Habitation Study - Structures

Assessment of the effect of different launch loads on the SSF module

SSF Modules	Lunar Habitat
Vertical orientation	Horizontal orientation
Launched on Shuttle	Launches on HLLV-derived vehicle
Launch loads Axial: .2 g's Lateral: 2.5 g's	Launch loads Axial: 4.0 g's Lateral: 2.7 g's
Modules mounted on trunnions	
Modules required to survive an abort landing	
Landing loads Axial: 1.7 g's Lateral: 3.6 g's	

- Determine minimum modifications required to SSF modules to support the Lunar Habitat mission
- Determine modifications required to provide an optimized module for the Lunar Habitat mission

Figure 4-3. Lunar Hab Module - Launch Loading (MSFC)

Lunar Hab Launch Reaction Loads
Static - Dynamic Loads Comparison
17.5 mT/20 mT/23 mT

		Axis	Load factor (g)	Total static load (lbf)	No. of reaction points	Maximum static reaction (lbf)	Maximum dynamic reaction (lbf)	Dynamic amplification factor	
SSF Configuration 38600 (lbs)	Launch (17.5 mT)	X	3.4	131240	2	65620	71000	1.08	
		Y	1.0	38600	1	38600	42000	1.09	
		Z	3.2	123520	4	30880	46000	1.49	
	Abort landing	X	1.4	54040	2	27020	30000	1.11	
		Y	1.0	38600	1	38600	42000	1.09	
		Z	3.7	142820	4	35705	43000	12.0	
Lunar Hab Configuration 51000	Launch (23 mT)	X	2.7	137700	2	68850	89100	1.29	
		Y	1.0	51000	1	51000	51000	1.00	
		Z	4.0	204000	4	51000	96100	1.88	
Lunar Hab Configuration 44000	Launch (20 mT)	X	2.7	118800	2	59400	70570	1.19	*
		Y	1.0	44000	1	44000	45938	1.04	*
		Z	4.0	176000	4	44000	74227	1.69	*

* Dynamic amplification factor for 20 mT is obtained by linear interpolation of 17.5-mT and 23-mT amplification factors

Figure 4-4. Maximum Reactions and Dynamic Amplification Factors increasing the Lunar Hab mass will require major structural changes to the SSF Hab. A more detailed and realistic analysis must be performed as the launch vehicle and Lunar Hab launch configuration are better defined. Realistic forcing functions for the Lunar Hab launch vehicle are required in order to calculate accurate dynamic amplification factors.

4.2 WEIGHT REDUCTION EFFORTS

An investigation was undertaken to reduce the structural mass of the SSF Hab. A detailed breakdown of the SSF Hab structural mass and payload was performed, and those areas were identified that showed a potential of weight reduction. A new bulkhead without a hatch was proposed for one of the two ends which could save as much as 250 kg. Changing the pressure vessel material from 2219 Al to aluminum-lithium will also result in a potential weight saving.

Storage racks seemed to be an ideal candidate for a potential weight savings as they were an add-on structure and could be modified without redesign of SSF Hab primary structure. The present total weight of the racks is 2335 kg (74% as heavy as the basic SSF Hab structure). It was found that the driving factors for the rack design are the frequency requirements of 25 Hz and high-design loads resulting from two very conservative "Pseudo Forcing Functions". The rack design loads are shown in figure 4-5. These pseudo forcing functions account for 40% to 60% increase in rack loads. It was proposed that the pseudo forcing functions which are very specific to Space Shuttle and Booster dynamics, not be considered when calculating dynamic loads for the Lunar Hab racks. Penalizing Lunar Hab racks by imposing Space Shuttle forcing functions is not appropriate in the conceptual design phase. Forcing functions other than pseudos shall be considered as usual. This results in a potential weight savings of about 20% to 30% (approximately 700 kg). The final design and sizing of the rack will be accomplished as the Lunar Hab launch vehicle is better defined.

	Design limit load factors					
	N_X	N_Y	N_Z	R_X	R_Y	R_Z
Hab	3.4	1.1	3.7	—	—	—
Racks	±9.0	±7.6	±8.0	±53.4	±42.0	±31.5

• Design ultimate load factors are 1.4* limit load factors

Figure 4-5. SSF Hab Module - Rack Design Load Factors

4.3 HYPERBARIC VS. NONHYPERBARIC - STRUCTURAL EVALUATION

A preliminary structural evaluation was carried out to compare the selected configurations of the Lunar Hab airlock with and without hyperbaric operations. These configurations are shown in figure 4-6. Primary structural masses for configurations A, G and F were evaluated for nonhyperbaric operations. Structural weight penalties for operating configurations G(h) and F(h) in hyperbaric mode were calculated. Configurations G(h) and F(h) both required major modifications to the bulkhead and skin. Mass estimates for all configurations are provided in figure 4-7. Configuration A (nonhyperbaric), with a SSF airlock, was the baseline configuration. Configuration G (nonhyperbaric, with internal bulkhead) had the same structural mass as that of the baseline configuration. Configuration F (Extended Hab, nonhyperbaric) and configuration D (hyperbaric with SSF Crewlock) were both about 12% higher than the baseline. Both configuration G(h) and F(h) seemed to be about 80% heavier than the baseline. Thus, configuration D seems to be the optimum choice for hyperbaric capabilities. The impact of SSF Crewlock installation is yet to be investigated both from structures and from rack space point of view.

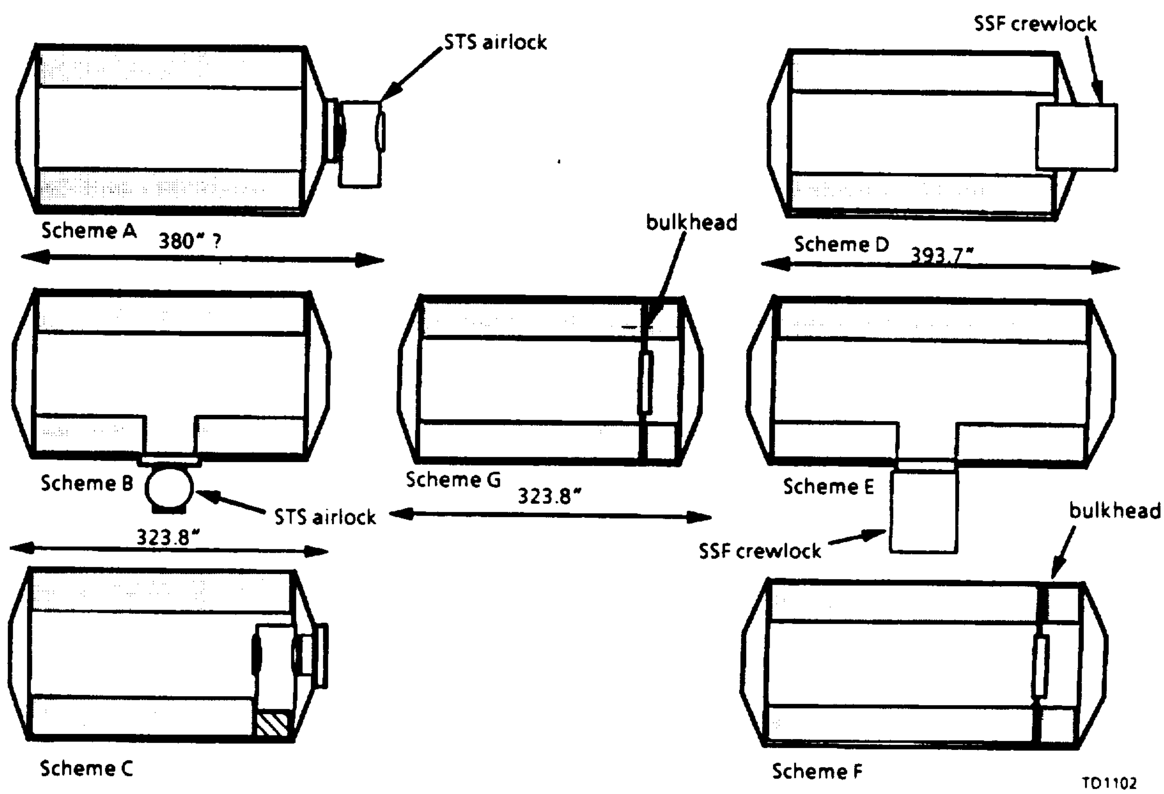


Figure 4-6. Lunar Hab Module - Airlock Configurations

Primary Structure Weight Comparison
Outpost Airlock Options

	Nonhyperbaric Mass (kg)			Hyperbaric Mass (kg)		
	Ref (A)	(G)nh	(F)nh	(D)nh or (D)h	(G)h	(F)h
Basic module structural weight	3175	3175	3175	3175	3175	3175
STS airlock weight	454					
SSF crewlock structural weight				726		
Airlock-to-module adapter	113			227		
New bulkhead structural weight		415	576		1728	1728
New cylinder skin			284			851
New bulkhead/skin installation		129	68		91	91
Existing bulkhead structural mod					1111	1111
Existing skin mod					850	
Trunnion modification			45	45	68	68
Total	3742	3719**	4148	4173	7023*	7024*
Percent Change from Ref. (A)	0%	-1%	11%	12%	88%	88%

** Using existing mid ring . * May be optimized for possible mass reduction

Figure 4-7. Hyperbaric vs. Nonhyperbaric Structural Mass Comparison

5.0 POWER SYSTEM SIZING/ANALYSIS SUMMARY

5.1 INTRODUCTION

An analysis of power and thermal control system options for the First Lunar Outpost (FLO) habitat concept has been performed. Although a majority of the work concentrated on the determination of the Electrical Power System (EPS) requirements and sizing, a significant effort was devoted to sizing the external heat rejection system. A more thorough assessment of the heat rejection system will follow as the outpost configuration becomes better defined. The activities undertaken were divided into three main areas: they include the power system requirements determination, power system sizing and heat rejection system sizing. Campsite power requirements were derived for three different power system options, as well as three airlock options. The power requirements for each option were utilized to size a solar/Reactor Fuel Cell (RFC) power system. A significant portion of this analysis was devoted to refining the power system components sizing procedure, and investigating options to reduce the EPS mass. The heat rejection system was sized based on the electrical power level and module/crew induced loads.

5.2 POWER REQUIREMENTS

After an initial 10-kW power system was sized to serve as a reference, a power budget was derived for a new reference system. The campsite power budgets were broken down to the element level, utilizing a SSF power summary (ref. 6) where possible. The reference top-level power budget is shown in figure 5-1. The detailed breakout is included in appendix E, along with supporting assumptions. The reference power budget included all systems outlined in the SSF Habitat module summary of the report, along with additional power requirements associated with the laboratory science racks LAS1 and LAS2 (the ECWS and science/workbench racks). The science/glovebox power was derived from an older SSF power summary, since it is no longer included in the baseline SSF design. The Gas Conditioning Assembly (GCA) is included in the power statement, although it is not included in the mass statement. SSF power growth numbers were also included in the total. The reference power budget served as a baseline for all additional trades aimed at reducing power system mass.

The first power system requirements trade involved revising the reference power summary to reflect the following operational and hardware changes. The revised top-level power budget summary ($\Delta 1$) is shown in figure 5-2, and the detailed breakdown is included in appendix F. The major differences from the reference included the following:

Item	All Loads in Watts	
	Connected Load	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	2499	2085
Galley/Wardroom	4334	504
Science	2952	895
Crossover - cabin air	1404	512
Water stor./Proc.	1125	292
Air Revit. System	1299	1194
Crew Health	911	91
Fire Det./Suppression	838	40
Waste Management	455	46
RPC Modules	312	312
M/S Hygiene	1642	242
Hab Growth	393.5	393.5
Gas Cond. Assembly	240	240
Heat Pump - Day - Night	3749 300	3749 300
Totals: - Day - Night	23582 W 20133 W	11480 W 8031 W

Figure 5-1. Lunar Campsite Overall Power Budget Summary - Reference

Item	All Loads in Watts	
	Connected Load	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	1849	1535
Galley/Wardroom	1934	456
Science	1769	702
Water stor./Proc.	1125	292
Air Revit. System	1298.6	796
Crew Health	911	91
Fire Det./Suppression	838	40
RPC Modules	312	312
Waste Management	455	46
M/S Hygiene	821	133
Hab Growth	345	345
Gas Cond. Assembly	240	240
Heat Pump - Day - Night	2840 300	2840 300
Totals: - Day - Night	16166 W 13626 W	8712 W 6172 W

Figure 5-2. Lunar Campsite Overall Power Budget Summary - $\Delta 1$

a. Power requirements listed by subsystem; some components were removed/modified as follows:
   1. Airlock: removed growth power; 5/10% duty cycles (depending on component); removed ECLS and THC.
   2. TCS: removed IMV fan and resized ITCS pump and Avionics air for lower loads.
   3. Crew systems: replaced oven with 600-watt microwave unit.
   4. Crew health: duty cycle = 10%.
   5. ACM: duty cycle = 25/100% (day/night).
   6. PEP equipment: remove all PEP loads.
   7. Glovebox: power level set at 250 W and a 10% duty cycle.
   8. Workstation: removed blowers, H_2O pumps, and second set of lights; task light fixture duty cycle set at 10%.
b. SSF power growth numbers scaled and added to total.

This revision resulted in a reduction of ~2 to 2.5 kW in the average power requirements. The Δ1 case was further revised to reflect the removal of standoff fans and water/air separators (not required in gravity field). The final revision, Δ2, is summarized in figure 5-3; as with the reference and Δ1 case, the detailed breakdown is included in appendix G. The Δ2* case is simply the Δ2 case with multiple lunar day fuel cell recharge. The reduction in average power for the Δ2 configuration was roughly 300 - 500 W. Major differences from the Δ2 case included the following:
a. Some components removed/modified as follows:
   1. TCS - removed standoff fans.
   2. Crew systems - removed all H_2O/air separators.
b. SSF power growth numbers scaled and added to total.

Power system peak capabilities were determined as 1.5 x average power, which was determined as a reasonable assumption based on previous spacecraft systems. This assumption, although somewhat arbitrary, is reasonable for the prescribed application until more design and operational detail is available for the outpost internal and external systems. The array system was sized to provide peak power and nominal electrolyzer charging power simultaneously. Additional power, when needed, can be derived from the fuel cell reactant electrolyzer budget during the day and additional fuel cell capacity at night. Arrays are sized for 5 year End-of-Life (EOL) performance, as derived for each cell type. It should be noted that the overall system mass is not as sensitive to peak power as it is to average <u>night-time</u> power. The power required for the external heat pump system was scaled from total internal and airlock power, based on derived COP for given operating conditions (primarily condenser and evaporator temperatures and working fluid chosen).

Item	All Loads in Watts	
	Connected Load	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	1552	1271
Galley/Wardroom	1629	443 6
Science	1769	702
Water stor./Proc	1125	292
Air Revit. System	1298 6	796
Crew Health	911	91
Fire Det./Suppression	838	40
RPC Modules	312	312
Waste Management	205	27
M/S Hygiene	516	108
Hab Growth	328	328
Gas Cond. Assembly	240	240
Heat Pump - Day	2684	2684
Heat Pump - Night	300	300
Totals: - Day	14836 W	8219 W
Totals: - Night	12452 W	5835 W

Figure 5-3. Lunar Campsite Overall Power Budget Summary - Δ2

The heat pump is not required at night, however, due to the much lower effective sink temperature that the radiator "sees" during the lunar night (~120 K vs. ~300 to 320 K during the lunar day). Its heat transport capabilities are replaced during the night with a single phase pumped system which requires only ~300 W. The radiator is sized to reject both internal and external loads, with the exception of electrolyzer inefficiencies. The electrolyzers were assumed to reject their own waste heat.

The next step of the power budgeting process was to derive average- and peak-power requirements for the STS type airlock, and both the hyperbaric and nonhyperbaric SSF derived crewlock and internal bulkhead airlocks. The summaries, shown in figure 5-4, include internal equipment as well as additional heat-pump power requirements for the additional thermal loads they impose on the system. Airlock required pump power was determined assuming a 5-minute pumpdown for the STS and SSF derived airlocks, and a 10-minute pumpdown for the bulkhead airlock. The pumpdown time for the bulkhead option was extended, since the added volume allowed for more crew operations to be performed during the process, and pumpdown power requirements were

Item	All Loads in Watts		
	Connected Load	Duty Cycle (%)	Av. Load
A&G NONHYPERBARIC			
Control/sel.	9.6	0.21	0.02
A/L ACS	11.6	100	11.6
Flame detector	14	100	14
Smoke sensors	14	100	14
A/L audio	84.6	10	8.5
A/L video	43.5	10	4.4
SPCU	1240	27	335
CMDM	106	50	53
RPCMs	45	100	45
Depress D&C Panels (2)	20	100	20
Pumps (config. A/G)	1684/3150	10	236/441
Heat Pump Delta: Total:	327/418 W (Avg) 3272/4738 W	491/627 W (Peak)	1069/1365 W
D NONHYPERBARIC			
Cabin air fan	292	100	292
Cab air - electrical I/F	25	100	25
Cab air - temp. ctrl.	34	1.7	0.57
Cab air - H_20 sep.	43	100	43
Control/sel.	9.6	0.21	0.02
A/L ACS	11.6	100	11.6
Flame detector	14	100	14
Smoke sensors	14	100	14
A/L audio	84.6	10	8.5
A/L video	43.5	57	24.6
SPCU	1240	27	335
CMDM	106	50	53
RPCMs	45	100	45
0_2-N_2 control/vent	11.1	100	11.1
Depress D&C Panels (2)	20	100	20
Pumps (config. D/G)	1684/3150	14	236/441
Heat Pump Delta: Total:	500/590 W (Avg) 3677/5143 W	750 W (Peak)	1633/1928 W
D&G HYPERBARIC			
Cabin air fan	292	100	292
Cab air - electrical I/F	25	100	25
Cab air - temp. ctrl.	34	1.7	0.57
Cab air - H_20 sep.	43	100	43
Control/sel.	9.6	0.21	0.02
A/L ACS	11.6	100	11.6
Flame detector	14	100	14
Smoke sensors	14	100	14
A/L audio	84.6	10	8.5
A/L video	43.5	57	24.6
SPCU	1240	27	335
CMDM	106	50	53
RPCMs	45	100	45
0_2-N_2 control/vent	11.1	100	11.1
Depress D&C Panels (2)	20	100	20
Pumps (config. D/G)	1684/3150	14	236/441
Hyperbaric audio I/F unit	28.6	2	0.452
Hyperbaric gas and press ctrl. assembly	100	10	10
Hyperbaric environ. ctrl. assembly	1175	10	118
Hyperbaric lighting assembly	100	10	10
Heat Pump Delta: Total:	561/478.6* W (Avg) 5081/6547 W	841/718 W (Peak)	1833/1956 W

* Derived from minimum A/L + hyperbaric equipment.

Figure 5-4. Lunar Campsite Airlock/EVA Systems Power Budget Summary - A&G Nonhyperbaric significantly lower. Assumptions made for the calculations include initial/final pressures of 10.2/1.02 psi, and pump and electric motor efficiencies of 70% and 85%, respectively. The majority of the pumpdown power required is derived from electrolyzer power bleed, which should be kept below 50% total for short periods. A 10% duty cycle was assumed, since power system oversize for off-peak times can be utilized to replenish the electrolyzer, although a high number of A/L cycles may require an array oversize. Hyperbaric pressures were assumed to be obtained from stored gas (SSF method), and a portion of the gas vented after use (mission likely aborted). The nominal use airlock pumpdown gas was assumed routed into the Hab module. Five airlock options were derived from the three power summaries:

a. Minimum A/L with two required pump powers for STS derived (option A - lower power), and bulkhead (option G - higher power) options; bulkhead option ECLS equipment power requirements are included in Hab mass/power.
b. SSF derived A/L with adjusted pumping power primarily for configuration D (SSF crewlock).
c. SSF derived A/L with hyperbaric capabilities for configurations D and G.

5.3 POWER SYSTEM SIZING

The first set of power system masses, derived from previous lunar campsite material, were for a system sized to provide a continuous 10 kW over consecutive lunar day/night cycles (fuel cells recharged over one lunar day). This resulted in rather large tank masses, since the required storage temperature is high for the lunar day (~300 K), which results in low H_2 and O_2 densities at even the higher tank pressures. Solar array sizes were also large, in order to provide the high power levels needed by the water electrolyzer and outpost during the lunar day. The initial power-system mass was over 6000 kg, which made it a leading candidate for possible mass savings. An initial pass was made to validate the parametric sizing code (SURPWER). Several refinements were made to the analysis, which resulted in reduced system mass. The fuel cell duty cycle was adjusted from 375 to 354 hours to more closely model the average lunar night, which decreased the amount of reactants and storage capacity required. Power level remained at 10 kW. The effective yield strength of the filament-wound composite tanks was increased to a less conservative value of 125 ksi (although this is still a relatively low value for advanced composite tanks). These adjustments resulted in a system mass of ~5100 kg; a reduction of approximately 1200 kg compared to the original system mass. A summary of the top-level power system sizing assumptions is shown in figure 5.5, for a representative 10 kW case, and more generally in figure 5.9 for all other cases.

In order to further reduce the mass of the power system, an analysis was conducted to make use of the lunar night for refrigeration of the electrolyzer during the lunar day. Once again, the power system was sized to provide 10 kW of electrical power for a lunar day/night/day cycle (manned), but was modified to provide a nominal power of ~2 kW for 5 lunar day/night cycles. The fuel cell reactants depleted during the first lunar night would be re-electrolyzed over 5 lunar days. This time period coincides with 180day mission centers. High-pressure tanks are utilized to hold enough reactants to provide 2 kW during the lunar night, and 20% of the next manned mission reactant supply. During the lunar night, the "hot" reactants are cooled and transferred to larger, insulated lower-pressure tanks. These tanks are sized to contain the highest pressures attained as a result of the parasitic heat leak during the day. This option resulted in a ~600 kg decrease in system mass. By refrigerating the larger tanks during the day, the system mass was decreased another 230 kg, at the expense of increased complexity. Heating rates (and refrigeration power required) were determined assuming a 300-K surface temperature, and a 1-inch thickness of multi-layered insulation. The mass summaries are shown in figure 5-5, along with supporting assumptions, for the revised 10-kW systems (option 3 = 1 day recharge; option 4 = 5-day recharge; option 4a = 5-day, refrigerated). The analysis procedure is outlined below.

a. System Description
   1. Option 3: Recharge fuel cells each lunar day. Pwr level =10/10 kW (day/nt.)
   2. Option 4: Recharge fuel cells over 5 days. Pwr level =10/2 kW (day/nt.)
   3. Option TBD: 14-day mission; array only; no fuel cells. Pwr level = 10 kW (day)
b. Lunar night utilized to "refrigerate" reactants electrolyzed over each lunar day (~20% of total reactants).
c. Two tankset designs utilized: smaller set utilized to hold daily electrolyzer output; larger tanks well insulated (1inch MLI) to maintain low temperatures obtained during lunar night.
d. Heat leak estimated to obtain tankage conditions (temperature and pressure) at end of lunar day; tanks sized for these pressure levels.
e. Electrolyzer, solar arrays, etc., downsized because of reduced capacity requirements over system completely charged in one lunar day.

A more detailed look at the trade of electrolyzing the reactants over 5 lunar days resulted in only a moderate mass savings (300 - 500 kg) for the revised power level systems (ref. Δ1 and Δ2), at the expense of system complexity (additional tanks, etc.). Greater savings may be possible for higher-power systems, and/or systems requiring less

Item	Option 3 (kg)	Option 4 (kg)	Option 4a (kg)	Option TBD (kg)
Fuel Cells	100	100	100	0
Electrolyzer	182	95	95	0
Radiator	53	53	53	0
Hydrogen Reactant	143	172	143	0
Hydrogen Residual	41	41	41	0
Oxygen Reactant	1145	1374	1145	0
Oxygen Residual	327	327	327	0
Hydrogen Tank(s)	2075	1773	1565	0
Oxygen Tank(s)	932	617	574	0
Water Tank	64	64	64	0
Solar Array	196	128	141	108
Support Equipment	152	152	168	152
(Cables, converters, etc.)			20 (refrig. equip.)	
Total:	5310	4896	4436	260

ASSUMPTIONS AND OPTIONS

Item	Assumption	Rationale
Power level	10 kW	System Requirements
Discharge cycle time	354 hrs	Lunar Night
Total number of cycles	5	System Requirements
Solar cell selection	CLEFT/GaAs/CIS	Several leading candidates
Reactant storage press.	3000/400/225 psi	Minimize high press vol.
Reactant storage temperature	300°K/140-230°K	Utilize lunar night for refrig.
Tank type	filament wound composite	Lower tank mass
Tank yield strength	~125 ksi	Derived from vendor data
Tank safety factor	1.5	Typical press, vessel s.f.
Array supplied power	26/13.2 kW	Day power, fuel cell recharge, and margin (opt. 3/opt. 4)

Figure 5-5. Power System Mass Summary

"housekeeping" power for unmanned lunar night operations (2 kW was assumed for the current trade analysis - much lower level of design required to determine actual requirements). It should be noted that the single day system can also be recharged over several lunar days, resulting in a much greater flexibility in night-time peak power availability.

In order to better understand the outpost options and to aid in the application of proper power system requirements to each, a matrix was built showing the module/airlock options investigated. This matrix, along with the overall power system masses, is shown in figure 5-6. An example summary mass statement (option A, minimum airlock) which breaks down the power-system mass to the subsystem level, is shown in figure 5-7. Array power, area and fuel cell power requirements were also summarized for each option, and the results for the example summary are given in figure 5-8. These are the design drivers used to size the various power systems summarized in the matrix (fig. 5-6). Complete sets of these data are included appendix H.

Item	Min A/L			Nonhyperbaric			Hyperbaric		
	ref	Δ1	Δ2	ref	Δ1	Δ2	ref	Δ1	Δ2
(A) STS A/L	X	X	X						
(D) Crew Lock				X	X	X	X	X	X
(G) Int. Bulkhead		X*	X*	X			X	X*	X*

Power System Overall Mass Matrix (all masses in kg)

Item	Min A/L			Nonhyperbaric			Hyperbaric		
	ref	Δ1	Δ2	ref	Δ1	Δ2	ref	Δ1	Δ2
(A) STS A/L	5183	4136	3947 3803**						
(D) Crew Lock				5493	4445	4255	5655	4554	4365
(G) Int. Bulkhead		4298	4109	5603			5670	4407	4218

*Denotes A/L minus ECLS equipment already accounted for in Hab.
**Multi-day recharge case.

Figure 5-6. Power/External Heat Rejection System Sizing Matrix

Item	Reference (kg)	Δ1 (kg)	Δ2 (kg)	Δ2* (kg)
Fuel Cells	137	109	104	104
Electrolyzer	165	131	126	126
Radiator	49	39	37	37
Hydrogen Reactant	130	103	99	99
Hydrogen Residual	37	30	28	37
Oxygen Reactant	1042	829	791	791
Oxygen Residual	298	237	226	291
Hydrogen Tank(s)	1883	1503	1434	1373
Oxygen Tank(s)	856	686	655	499
Water Tank	59	47	44	44
Solar Array	240	198	191	191
Support Equipment	287	224	212	212
(Cables, converters, etc.)	---	---	---	---
Total:	5183	4136	3947	3803

Figure 5-7. Power System Mass Summary Configuration A - Min. A/L

Item	Array Power (kW)	Array Area (m^2)	Avg. Day. Pwr. (kW)	Avg. Nt. Pwr. (kW)	Heat Pump Pwr. (kW)	Electrolyzer Power (kW)
Reference case	33.25	144	12.6	9.1	4.08	14.4
Δ1 case	26.2	113	9.8	7.24	3.17	11.5
Δ2 case	24.9	107 7	9.3	6.9	3.01	10.9
Δ2* case same as Δ2 case (sized for 1 day contingency)						

*Note: Peak day/night power = average power x 1.5
Required power = Peak power + electrolysis + system inefficiency (day)
= 1.5 x average night power (night)

Figure 5-8. Power System Top Level Area, Mass and Power Breakdown Configuration A - Min. A/L

The top-level design assumptions relating to the power system are summarized below:

a. Lunar night utilized to "refrigerate" reactants electrolyzed over each lunar day (~20% of total reactants + night-time level) for Δ2* case.

b. All cases (except Δ2*) electrolyze all reactants over 1 lunar day.

c. Filament wound composite tanks utilized for high-pressure gas storage to reduce tankage mass; storage press. = 3000 psi, Temp. = 300 K.

d. Array oversize allowed for lunar surface degradation effects;
Example: reference A Δ1 case: array power = 26.16 kW, peak rqt. = 14.7 kW+10 kW (electrolyzer) oversize ~6.5 kW (1.5 kW + 50% electrolyzer power).

e. Off peak power surplus can be utilized for electrolyzer makeup.

A more detailed set of top-level design assumptions is shown in figure 5-9. The solar cell selection (CLEFT/GaAs/CIS) was chosen as the reference for representative purposes only. Galium Arsenide on germanium cells will probably be chosen as the reference due to their higher technology maturity level, simplicity, flexibility (i.e., pointing accuracy), and lower sensitivity to temperature induced degradation as compared to silicon arrays. Since specific degradation data was not known by the time the analyses were completed, more accurate array oversize assumptions could not be made. The 125-ksi tank yield strength was derived using performance factors, and used to size the fuel cell reactant tanks (the single heaviest element of the power system). Due to the complexities involved in accurately analyzing the stresses in a composite tank, masses are based on these relative performance factors of various tankage materials (P_bV/W - burst pressure/material density - inches), which are included in the various vendor data. Representative pressure vessel performance factors are shown in figure 5-10.

Item	Assumption	Rationale
Power level	Varies w/opt and A/L combination	System Requirements
Discharge cycle time	354 hrs	Lunar Night
Total number of cycles	5 +	System more sens. to miss. length
Solar cell selection	CLEFT/GaAs/CIS	Several leading candidates
Reactant storage press.	3000 psi	Minimize high press vol.
Reactant storage temperature	300°K	Typical outer surface equil. temp.
Tank type	Filament wound composite	Lower tank mass
Tank yield strength	~125 ksi	Derived from vendor data
Tank safety factor	1.5	Typical press vessel s f
Array supplied power	~25 to 33 kW	Day power fuel cell recharge, and margin (varies w/opt on)

Figure 5-9. Power System Assumptions and Options

Material	PbV/W (in.x 10^6) Spherical	Cylindrical
2219-T87 Al	324 - 360	243 - 270
6AL-4V Ti	533 - 594	400 - 445
Kevlar-49 Titanium	800 - 900	NA
Graphite Titanium	800 - 1000	NA
Kevlar-49 Aluminum	550 - 700	550 - 700
Graphite/Aluminum*	800 - 1000	800 - 1000

* Aerospace/commercial

Figure 5-10. Typical Performance Factors

A brief example is shown below to illustrate this point:

PbV/W = 360000 in (Aluminum); PbV/W = 900000 in (typical of composite)

The mass of the tank is proportional to working stress, σ, which is, in turn, proportional to performance factors:

$$\frac{m_{Al\,tank}}{m_{comp\,tank}} \propto \frac{\sigma_{Al}}{\sigma_{comp}} \propto \frac{P_bV/W_A \,\big]_{Al}}{P_bV/W_A \,\big]_{comp}} \propto \frac{360000}{900000}$$

Either of two tank sizing options give same results:

a. Size as for aluminum, with scaled σ and above ratio (ex: 50 ksi/0.4 = 125 ksi)

b. Scale tank mass by above ratio [m_{tank} (comp) = m_{tank} (Al) x 0.4]

A final activity undertaken in the power-system sizing task was to adjust and verify the SURPWER sizing-code process for calculating tank residuals. The routine, which had originally been written to calculate residuals for lower-pressure storage systems, was modified to produce more accurate residual allowances for the high-pressure storage system. The residual pressure in the hydrogen and oxygen storage tanks was assumed to be ~80 psi (60-psi fuel cell operating pressure, +20-psi line pressure drop). This resulted in a significant reduction of reactants and required storage-system mass. A summary of the revised power-system masses is shown in figure 5-11. As can be seen in the figure, the system mass decreased approximately 16%, or about 600 to 700 kg. All future power-system sizing activities will utilize the new residual computation procedure.

Item	Min A/L			Nonhyperbaric			Hyperbaric		
	ref	Δ1	Δ2	ref	Δ1	Δ2	ref	Δ1	Δ2
(A) STS A/L	4365	3480	3323 3341*						
(D) Crewlock				4625	3736	3578	4717	3827	3669
(G) Int. Bulkhead		3615	3457	4761			4773	3705	3548

*Multi-day recharge case.

Figure 5-11. Power System Overall Mass Matrix Revised Residual Estimates (all masses in kg)

5.4 HEAT REJECTION SYSTEM SIZING

Rejection of waste heat at the lunar surface is a significant problem due to the high-surface temperatures experienced during the lunar day (~380 K at lunar "noon"). Methods to increase radiator efficiency can be effected by either reducing sink temperatures from decreased exposure to the surface or sun (shielded, pointed away, etc.), by increasing the radiator operating temperature, or by constructing the radiator of materials with selective optical/thermal properties (low-solar absorptivity, high emissivity). Any combination of these methods can be even more effective in increasing radiating efficiency. Increasing the rejection temperature of the radiator is an especially effective method, as can be seen by a simple radiative heat-exchange equation;

$$q = \varepsilon\alpha \left(T_{surf}^{\ 4} - T_{sink}^{\ 4}\right)$$

Where q is the heat rejection per unit area, and ε and α are the surface emissivity and absorptivity, respectively. As can be seen from the equation, any increase in surface temperature, or to a lesser degree decrease in sink temperature, greatly effects the heat-rejection capability. Additionally, an increase in the emissivity of a radiating surface will have roughly a linear effect on heat-rejection capability. For this study, a heat-pumped, augmented system was chosen, based on its flexibility to performance degradation, reduced radiator area requirements and mass. The assumptions for the heat rejection system were:

a. SSF-derived internal heat acquisition/transport system design.
b. Vertical unshielded radiator utilized; heat-pump augmented rejection.
c. Electrolyzer rejects its own heat passively.
d. Heat-pump motor/pump assembly rejects waste heat at condenser temperature (conservative assumption - probably 20 - 50°C higher).
e. Compressor isentropic efficiency = 0.6 (from terrestrial systems data).
f. Heat-pump system mass ~31.83 x Q (from terrestrial systems data).
g. Heat-pump power provided by main arrays.
h. αrad = 0.25 (absorptivity)　　fin efficiency = 0.85
   εrad = 0.8 (emissivity)　　radiator rejection temperature = 360 K
   radiator specific mass ~5.2 kg/m
i. Radiator sized for 1.5 x $Q_{nominal}$ at lunar day "worst case".
j. $Q_{nominal}$ = 132 W/person x 4 crew.

Radiator surface properties were taken from SSF End Of Life (EOL) data. More favorable EOL surface property data (higher ε, lower α) would enhance the applicability of a non-heat pumped system. Significant radiator/shielding trades (both heat pumped and non-heat pumped) cannot be carried out until configuration work commences. The top-level assumptions relating to external heat-rejection system sizing are as follows:

a. SSF-derived internal heat acquisition/transport design.
b. Electrolyzer rejects its own heat passively.
c. Heat-pump motor/pump assembly rejects waste heat at condenser temperature (conservative - probably 20 - 50 K higher).
d. Compressor isentropic efficiency = 0.6.

e. Heat-pump system mass $\sim 31.83 \times Q_{rej}^{0.476}$.

f. Heat-pump power provided by main arrays.

g. $\alpha rad = 0.25$ fin efficiency = 0.85

$\varepsilon rad = 0.8$ radiator rej. temp. = 360 K

specific mass ~5.2 kg/m^2

h. Radiator sized for 1.5 x $Q_{nominal}$ at lunar day "worst case".

i. $Q_{metabolic}$ = 132 W/person x 4 crew.

A summary of the external heat-rejection system masses is shown in figure 5-12, which follows the same option layout as the power/thermal system sizing matrix (fig. 5-6). A mass, rejection load and radiator area summary for the external heat-rejection system for configuration A, minimum airlock, is shown in figure 5-13. A complete set of this data is included in appendix I.

Item	Min A/L			*Non Hyperbaric			Hyperbaric		
	ref	Δ1	Δ2	ref	Δ1	Δ2	ref	Δ1	Δ2
(A) STS A/L	466	383	368						
(D) Crewlock					400	386		407	391
(G) Int. Bulkhead		399	377					393	384

*Multi-day recharge case.

Figure 5-12. Heat-Rejection System External Mass Summary Matrix (all masses in kg)

Item	Rej. Load (kW)	Rad Area (m^2)	Rad Mass (kg)	Support Mass (kg)	Heat Pump Mass (kg)	Heat Exch. Mass (kg)	Total Ext. Mass (kg)
Reference case	13.2	43.2	225	45	134	62.4	466
Δ1 case	10.45	34.1	177	35.4	120	50.4	383
Δ2 case	9.94	32.5	169	34	117	48	368
Δ2* case same as Δ2 case (sized for peak loads)							

Figure 5-13. Heat-Rejection System Top-Level Mass Breakdown Configuration A - Min. A/L

6.0 FIRST LUNAR OUTPOST (FLO) RADIATION ASSESSMENT

6.1 TASK UPDATE

The initial assessment of crew dose resulting from exposure to three large solar proton events has been completed. A follow-on analysis of two NASA developed storm-shelter concepts has also been completed. Results of these analyses are presented in this report. The Boeing Radiation Exposure Model (BREM) assessment system has been used to perform this work.

6.2 BACKGROUND INFORMATION

Evaluating the radiation environment inside the habitat involves determining the incident radiation flux at the surface of the module and transporting the radiation through its structure to derive the attenuated radiation environment. To determine the exposure and resulting risk to crew, the internal spacecraft radiation environment must be further transported through the crewman's body to determine the radiation field at critical organs. Because BREM's shield distribution is based on CAD systems, highly detailed models can be coupled to less detailed but accurate models of the habitat structure to yield a precise shield distribution.

Accurate radiation assessments require precise models made through direct measurements of the natural space radiation environment, the shielding provided by the complex habitat structure and the anatomy of the astronaut. The attenuation of the incident radiation field by the shielding, the biophysical models to convert the radiation field properties at the critical organs to risk of deleterious medical consequences and the models to transform the internal habitat spectra to exposure rates is also required.

NASA-approved radiation transport codes and a CAD-based shield distribution modeling system form the primary modules of BREM. Because of BREM's speed and accuracy, detailed radiation analysis can be moved forward and keep pace with design programs where design changes will have minimal impact on vehicle complexity, mass and ultimately program cost.

6.3 METHOD

An improved radiation exposure assessment methodology for the First Lunar Outpost has been developed. This methodology features improved natural radiation environment modeling and more accurate determination of the habitat's shielding distribution. For risk determination, already available critical human organ shield models developed from detailed mathematical anthropomorphic models were used in calculating the critical organ dose. A functional flow of BREM is provided in figure 6-1.

Radiation assessment of the First Lunar Outpost was completed using the Boeing Radiation Exposure Model.

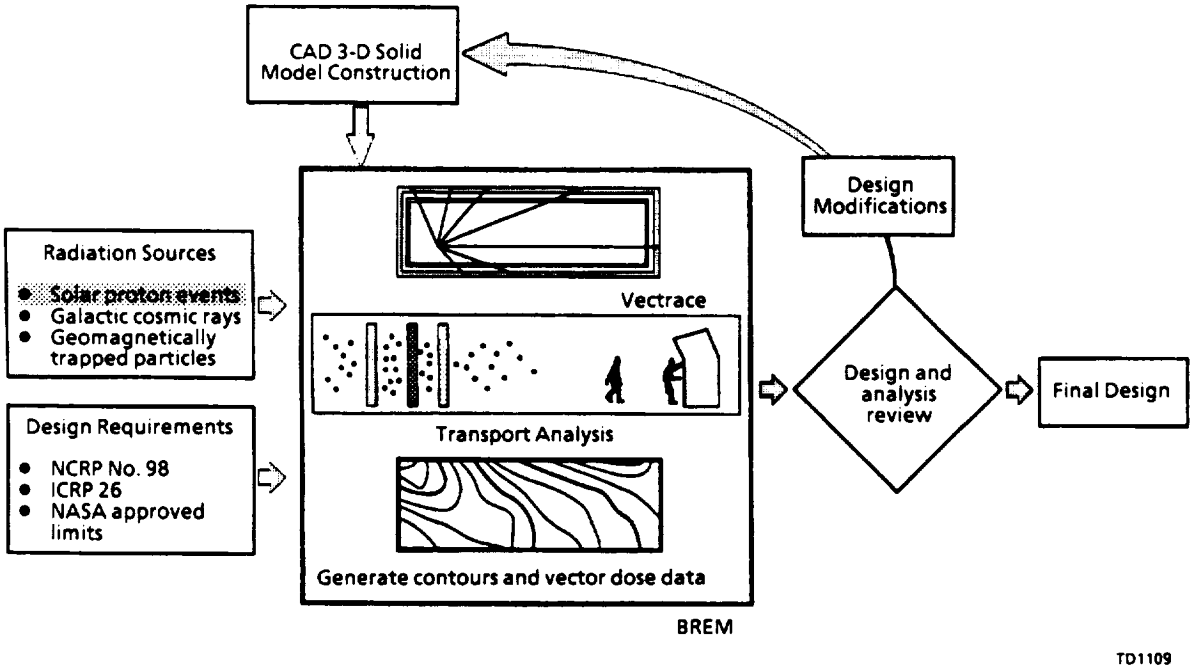


Figure 6-1. Analysis Method - Boeing Radiation Exposure Model

6.3.1 Shield Distribution Modeling System (VECTRACE)

Once the incident spectra have been determined, they must be transmitted through the habitat structure to determine the degraded spectrum at the point or points of interest. The degradation of the spectra will be a function of the incident spectral characteristics and the thickness and composition of the material traversed.

BREM uses a custom ray-tracing subroutine called VECTRACE which was used to determine the shield distribution about the desired analysis points within the habitat. The detailed analysis of FLO required establishment of a single assessment grid plane along the mid-line of the habitat. Assessment of the storm-shelter configurations on the other hand used either a 9-point grid or a line of 3 points, depending on the internal volume of the shelter. VECTRACE divides the 2π (specifically for surface operations; otherwise normally 4π) solid angle surrounding a detector point into a number of equal solid angles, the number of which is specified by the user. Vectors are co-aligned with the centers of the solid angles that traverse the spacecraft shielding to determine the shield thickness and composition. For this assessment, 256 rays were chosen for developing FLO's shield distribution. VECTRACE creates an ASCII data file containing: the vector azimuth and inclination, path length (cm) of the vector as it traverses a solid element, the density (g/cm^3) of that element and the areal density (g/cm^2) associated with an element intersected. This output provides the needed parameters for the radiation transport codes that determine the attenuation and propagation of charged particles as they pass through shield materials.

6.3.2 Transport Analysis

Solar proton calculations were performed using a modified version of the Proton Dose Code (PDOSE), reference 15. PDOSE has adopted a continuous slowing down approximation to calculate the attenuation and propagation of particles in various shield materials. Secondary particles generated by nuclear interactions are not included in PDOSE. Results from PDOSE have been extensively compared against Shuttle measurements by NASA (Johnson Space Center) and have been found to be fairly accurate (ref. 16). Three large reference flares were selected for this analysis, all of which have unique spectral characteristics figure 6-2. The flares selected were the February 1956, August 1972 and October 1989 events. Materials defined by assigning densities in the solid model are converted to an equivalent aluminum form for use in PDOSE by one of two methods: (1) by determining the ratio of stopping powers between aluminum and the defined material and (2) by basing the conversion on the mass properties of the modeled element and Aluminum. In the case of racks, where no clear definition of the components of each rack exists, the mass and volume of the outfitted

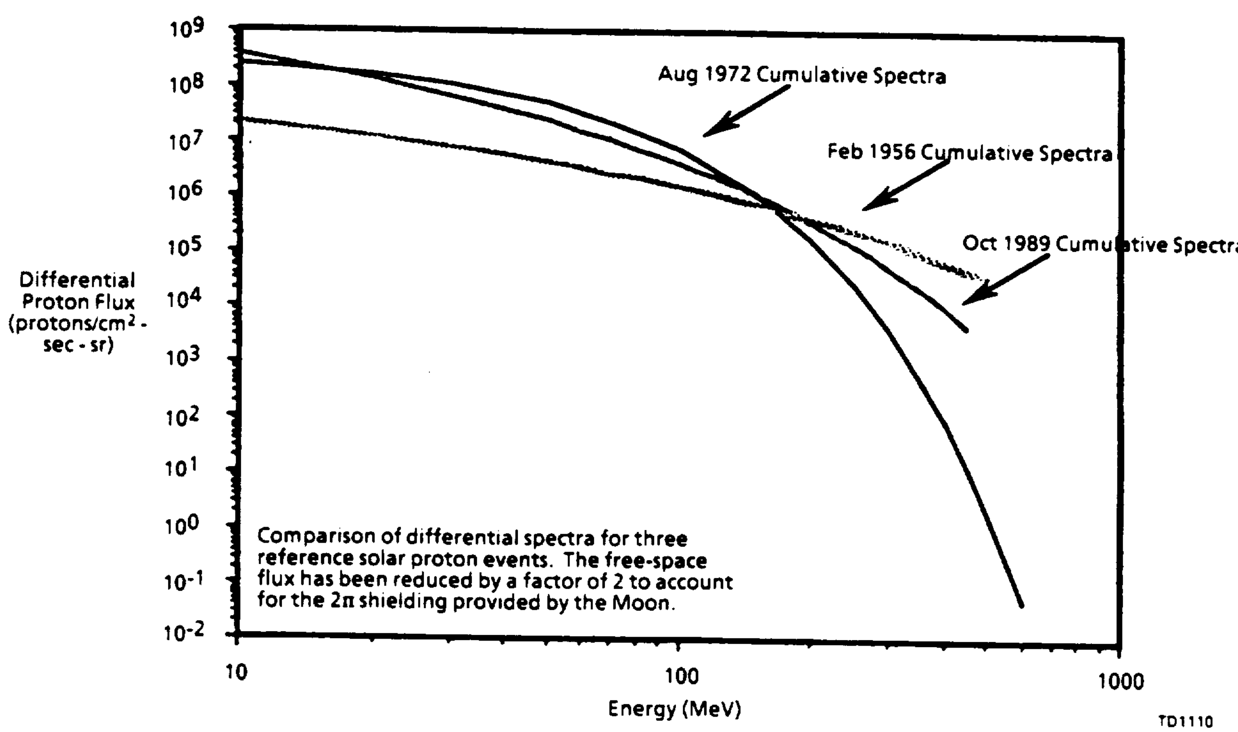


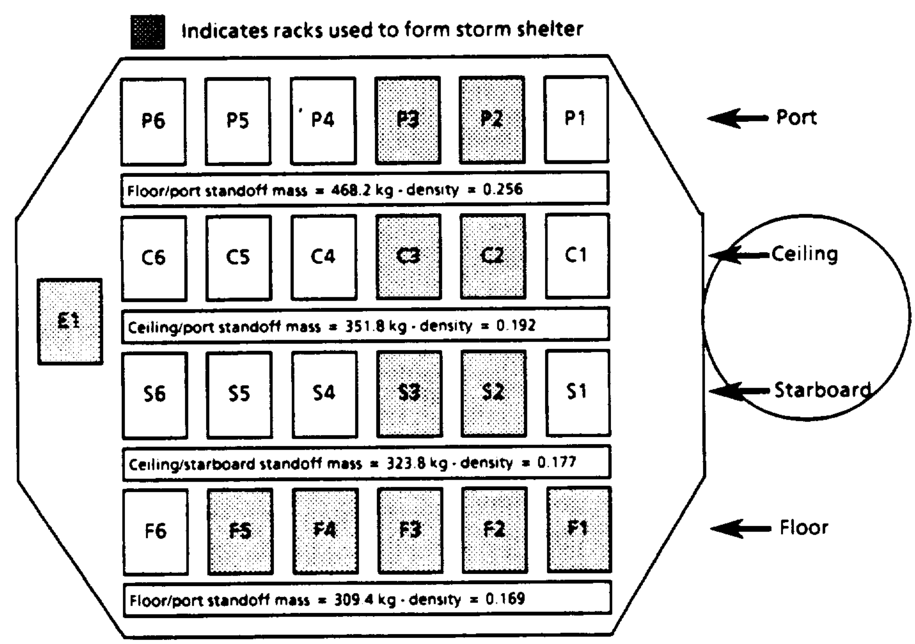
Figure 6-2. Differential Lunar Spectra Comparison Feb '56, Aug '72, Oct '89 SPEs

rack were used to obtain a uniformly distributed density of each rack. A breakdown of individual rack masses and densities are provided in figures 6-3 and 6-4. The conversion was then made by simply determining the ratio of the rack density to that of Aluminum (2.7 g/cm^3) and then multiplying this ratio by the vector path length to give the new areal density. Various habitat racks contain storage for food, water and EMU backpacks. A detailed breakdown for these racks are provided in figures 6-5 and 6-6, which correspond to masses shown in figures 6-3 and 6-4 respectively. Conversions using the ratio of stopping powers involves the preselection of materials (i.e., that used for the debris bumper or pressure vessel) and subsequent determination of stopping powers using NASA's transport code BRYNTRN (Baryon Transport Code - NASA/Langley Research Center) for a 50MeV/nucleon proton. A list of Space Station materials used for the FLO analysis are also shown in figure 6-7.

The previously documented improvements in dose assessment methodology have been combined with well-established procedures for determining the dose and dose equivalent at critical body organs. The organ dose calculations, necessary for risk assessment, are performed using a very detailed and realistic mathematical anthropomorphic phantom. The phantom model, called the Computer Anatomical Man

Rack volume - 1.872 m^3

Rack Location	Mass (kg)	Density (g/CM^3)
C1	292.1	0.156
C2	671.4**	a
C3	689.7°	b
C4	579.3	0.310
C5	436.0	0233
C6	332.1	0.177
S1	623.9*	c
S2	368.1	0.196
S3	596.5∞	d
S4	648.1	0.346
S5	410.0	0.219
S6	313.2	0.167
F1	463.3*	e
F2	295.0	0.158
F3	501.4	0.268
F4	618.2	0.330
F5	503.7	0.269
F6	350.3	0.187
P1	297.9*	f
P2	313.3	0.167
P3	418.0	0.223
P4	235.0	0.125
P5	329.3	0.176
P6	419.6	0.224
E1	417.7	0.223

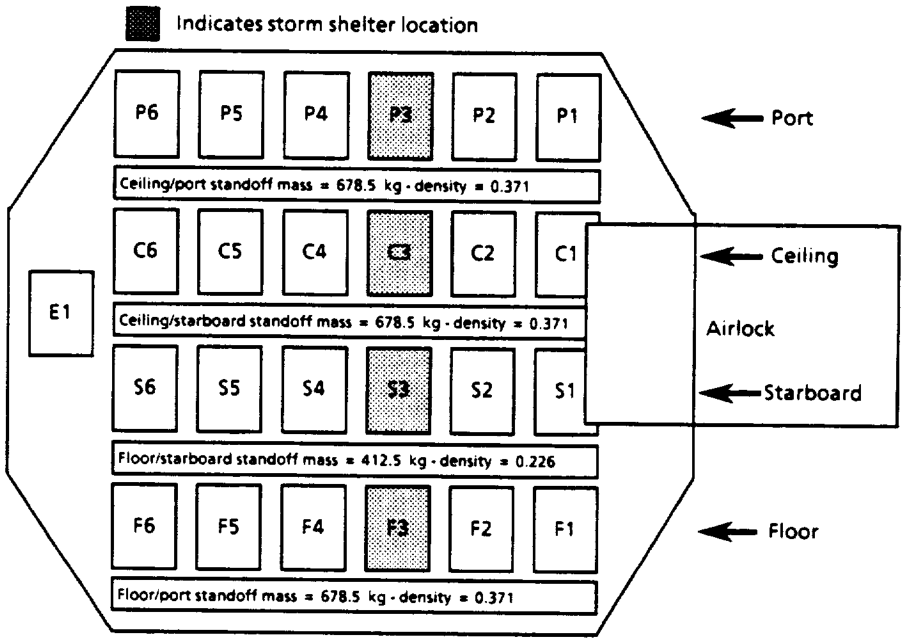


* Includes mass for STS EMUs
** Includes 238.3 kg of water
° Includes 79.4 kg of water
∞ Includes 360 kg of food
a-f: Refer to following chart for detailed density description

Figure 6-3. Rack Densities Specified in Solid Model SSF Habitat Module Retrofit

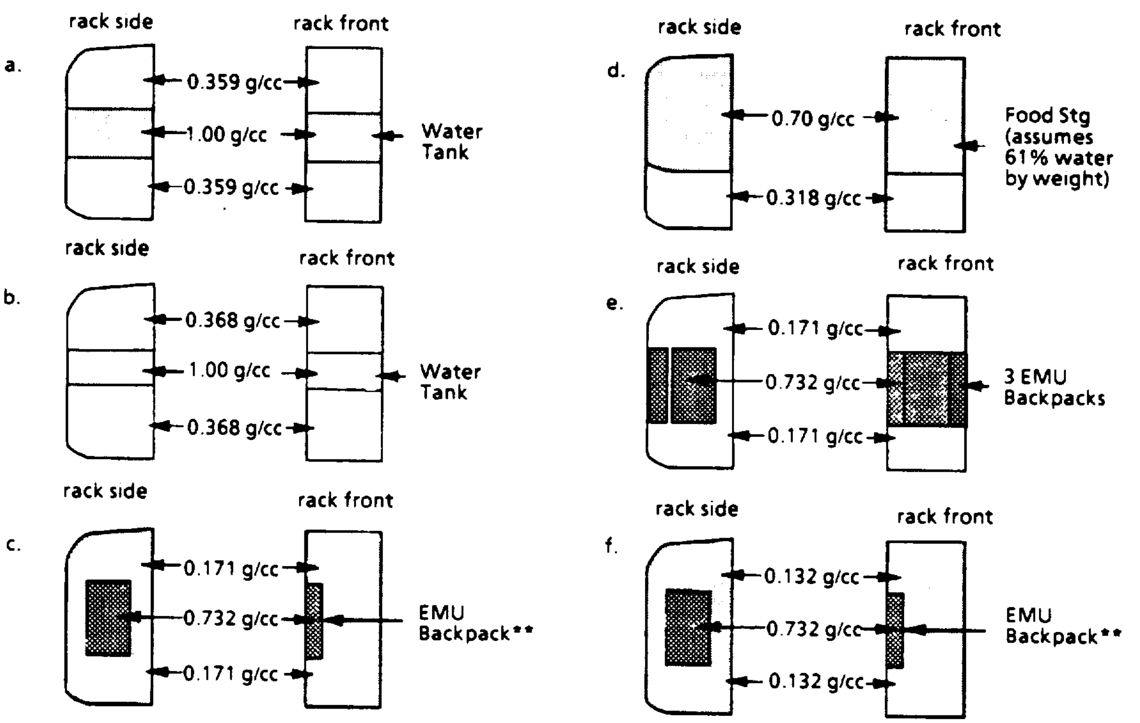
Rack volume - 1.872 m^3

Rack Location	Mass (kg)	Density (g/CM^3)
C1	547.5	0.292
C2	347.1	0.185
C3	400.0*	a
C4	418.0	0.223
C5	418.0	0.223
C6	280.9	0.150
S1	659.2	0.352
S2	297.1	0.159
S3	658.4*	b
S4	861.1	0.460
S5	622.4	0.333
S6	341.0	0.182
F1	473.3	0.253
F2	396.8	0.212
F3	216.0	0.115
F4	372.0	0.199
F5	517.6	0.277
F6	442.1	0.236
P1	606.5	0.324
P2	476.0	0.254
P3	883.3**	c
P4	531.0	0.284
P5	339.6	0.181
P6	242.8	0.130
E1	460.0	0.246



* Includes 232 kg of food
** Includes 113.4 kg water

Figure 6-4. NASA Shelter Concept - Rack Densities SSF Habitat Module Retrofit



** Backpack dimensions - 81.24 x 58.42 x 17.78 cm; mass = 61.78 kg

TD1111

Figure 6-5. Detailed Description of Densities Assigned to Non-uniform Racks

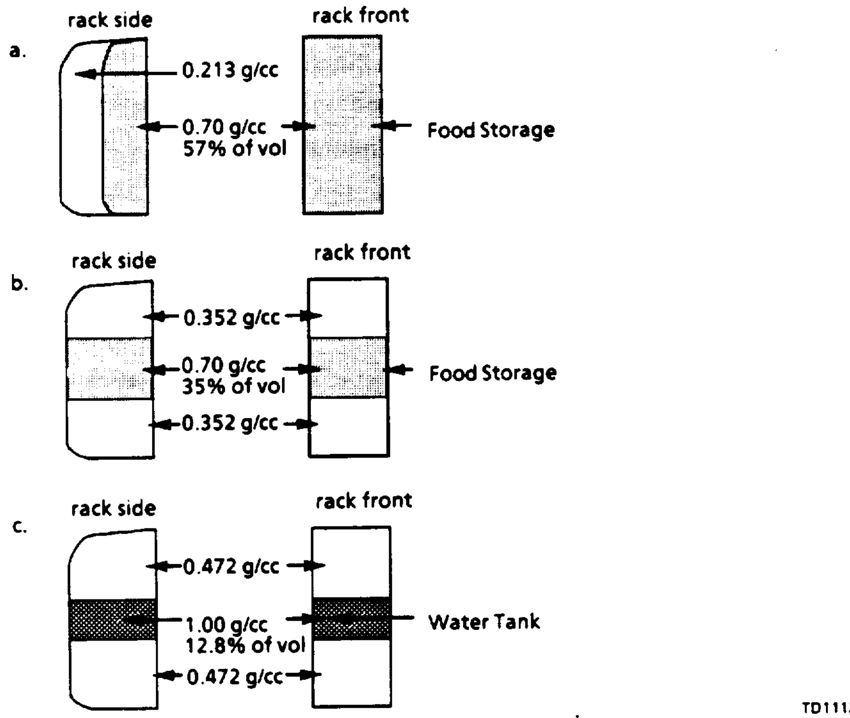


Figure 6-6. Detailed Description of Densities NASA Shelter Concept

Structure	Density (g/cm^3)	Material	Thickness
Pressure vessel	2.86	2219 A1	0.318
Debris shield	2.71	6061 A1	0.127
MLI blanket	0.192*	*	0.352
Modeled racks	**	**	**

* Space station MLI is configured in 21 layers. Sheldahl catalog data was used to calculate the nominal area of the layers at .068 g/cm^2. The MLI is composed of glass cloth, Teflon, Dacron, Mylar, Kapton, and Nomex, with microthin layers of vapor deposited aluminum. The compressed thickness of the MLI is estimated at .35 cm, leading to an average density of .192 g/cm^3. Composition for use in the model are as follows: C - 47.2%, O - 35.3%, Si - 11.8%, H - 3.7%, Al - 1.0%, and N - 1.0%.

** Rack and standoff densities have been assigned in accordance with individual rack and utility raceway mass and volumes described on the following chart.

Figure 6-7. Solid Model Construction - Material List

(CAM), represents the anatomical structure of a 50 percentile Air Force male. CAM provides a more realistic shield distribution for the blood-forming organs, ocular lens, and skin than simple water sphere geometries commonly used in space radiation assessments. In this assessment, the BFO and skin distributions actually represent the average distribution of 33 points distributed throughout the BFO and skin organs, respectively. The lens-shield distribution is found for a point at the center of the lens of the right eye. In determining the dose to the critical organ, the spectrum is first generated inside the spacecraft following particle transport through the inherent shielding. This procedure is then repeated for all 256 rays to yield the cumulative transmitted spectrum at the dose point. This transmitted flux is then assumed to be omnidirectional and is transmitted through the organ distribution to determine the dose received. Because the analysis is performed for a habitat operating within a gravity environment (CAM is currently configured for the weightless environment, where the body has unlimited degrees of freedom), it is necessary to assume that the astronaut moves through a number of positions (including lying down) for the 3 days of confinement. By first determining the transmitted spectrum inside the vehicle and then using it to determine the dose behind the organ shield distribution, any orientational effects of the astronaut relative to the spacecraft shield distribution are removed. This two-step process for determining the organ dose and the dose equivalent is a more realistic computational method than previous procedures which effectively aligned the astronaut with a specific orientation relative to the spacecraft shield distribution. The quality factor (Q) as a function of particle LET from ICRP 26 is used to determine the resulting dose equivalent.

Finally, BREM's graphical display attributes allow analysts to view on-screen the spacecraft model, analysis points, topological or iso-dose contours of exposure levels, and identify shield deficiencies through relative-dose vectors. By proper selection of graphical attributes, it is easy to spot areas which may exhibit high-exposure rates (undesirable for crew quarters) and radiation "hot-spots", which may require avoidance or additional shielding. Through the interactive shield alteration provided by CAD, attempts to improve dose-rate topology or the elimination of "hot-spots" and shield deficiencies can be rapidly evaluated on-screen.

6.4 DESIGN REQUIREMENTS

The current recommended astronaut limits are used for comparative purposes in the analysis. These limits have been established for low-Earth orbit operations (figure 6-8). For discussion purposes only, they are typically applied to exploration missions. For this analysis, 25 cSv (25 rem) and 150 cSV (150 rem) were selected. These limits correspond to the monthly limits for the blood-forming organs and skin respectively.

6.5 THE SOLID MODEL

The solid model used to perform the shield-distribution analysis was constructed using the current design data for Space Station Freedom. The solid model used in the initial radiation assessment is shown in figure 6-9. The large cylinder represents the airlock. With few exceptions, the models are identical. Differences include a redefinition of the uniformly distributed rack and standoff densities so that they reflect

All values presented in cSv

Time Period	BFO*	Lens of Eye	Skin
30 day	25	100	150
Annual	50	200	300
Career	See table below	400	600

* Blood-forming organs. This term has been used to denote the dose at a depth of 5 cm.

Career whole body dose equivalent limits based on a lifetime excess risk of cancer mortality of 3%

Age (years)	Female	Male
25	100	150
35	175	250
45	200	320
55	300	400

- Data from Guidance on Radiation Received in Space Activities, NCRP Report No. 98

Figure 6-8. Current Limit

the FLO mass statement. Additionally, a model of the Shuttle airlock was located externally at the front of the module. A delta model was constructed that incorporates modifications made to establish a storm shelter. Analysis of the two additional storm-shelter concepts required modifications to the original habitat. In addition to redefining the rack densities, the initial airlock was replaced with an imbedded airlock. The storm-shelters in all three cases were formed by repositioning racks to provide a safe haven region. The foundation of the shelter is established around the food and water storage racks.

6.6 ANALYSIS AND RESULTS

6.6.1 Initial FLO Radiation Assessment (Habitat and Storm-Shelter Evaluations)

The analysis was conducted in two phases: (1) assessment of the exposure received within the habitat module and (2) determination of exposure inside the storm shelter. For the habitat (without shield augmentation), the analysis was completed using a 21-point (3 x 7) grid plane centered between floor- and ceiling-rack faces (fig. 6-10). Analysis of the storm-shelter required use of a 9-point grid as shown in figure 6-11. Astronaut exposure has been determined for critical organs as described above. Values are given in dose equivalent rates per event (cSv/event). The maximum ionizing radiation dose determined for the blood-forming organs for the habitat was 16.5 cSv and for the storm shelter, 8.9 cSv (fig. 6-12). These doses were the result of exposure from the Aug. '72 and Feb. '56 solar proton events, respectively. The hard nature of the Feb.

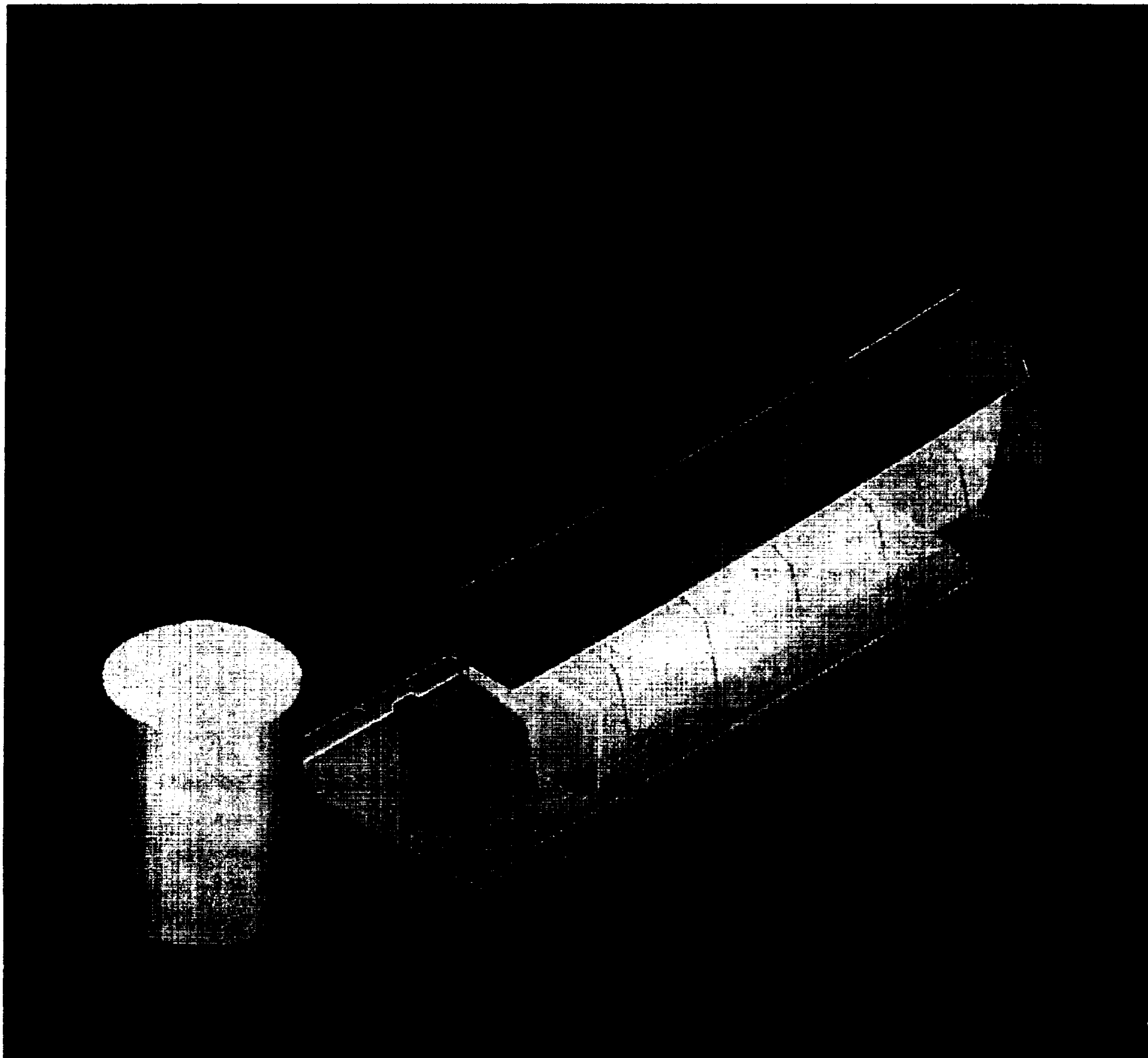
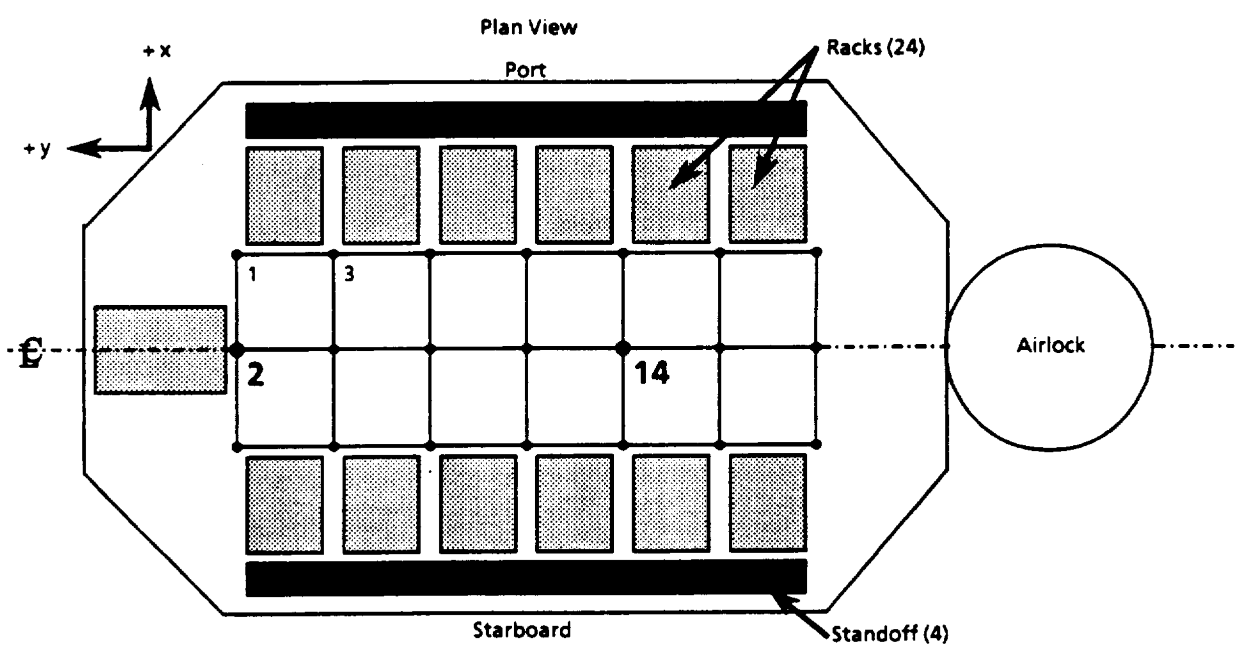


Figure 6-9. Lunar Habitat Solid Mass

'56 spectrum allows its particles to penetrate through a greater amount of shielding. The maximum exposure to the skin was calculated to be 124 cSv in the habitat and 34 cSv in the storm shelter (figs. 6-13 and 6-14, respectively). The calculated dose in both cases was the result of exposure from the Aug. '72 event.

6.6.2 NASA Storm-Shelter Concept Radiation Analyses

An analysis was performed for two NASA storm-shelter concepts. The concepts, described as 'M' and 'N', were analyzed using a single line of 3 points due to the reduced internal shelter volume. The points again were located midway between the ceiling and floor racks. Concept 'M' used a protection method that was similar to that employed in the initial phase of the study in which storage racks located in the floor and the single end-cone rack were moved to establish the shelter (fig. 6-15). Concept 'N', on the other hand, staggered port and starboard racks to augment the shielding (fig. 6-16). For shelter 'M', the maximum dose equivalent estimated for the blood-forming organs was 6.4 cSv (6.4 rem) and for the staggered concept ('N') was 7.0 cSv. These maximums were both the result of exposure to the February '56 solar proton event. Exposure to the skin from the August 1972 SPE resulted in the maximum doses for both shelter concepts.



- Detector locations 2 and 14 represent positions of maximum and minimum dose rates respectively
- Shield distribution established for 21 points with 256 rays over 2π steradians.

Figure 6-10. Lunar Habitat Radiation Assessment Configuration

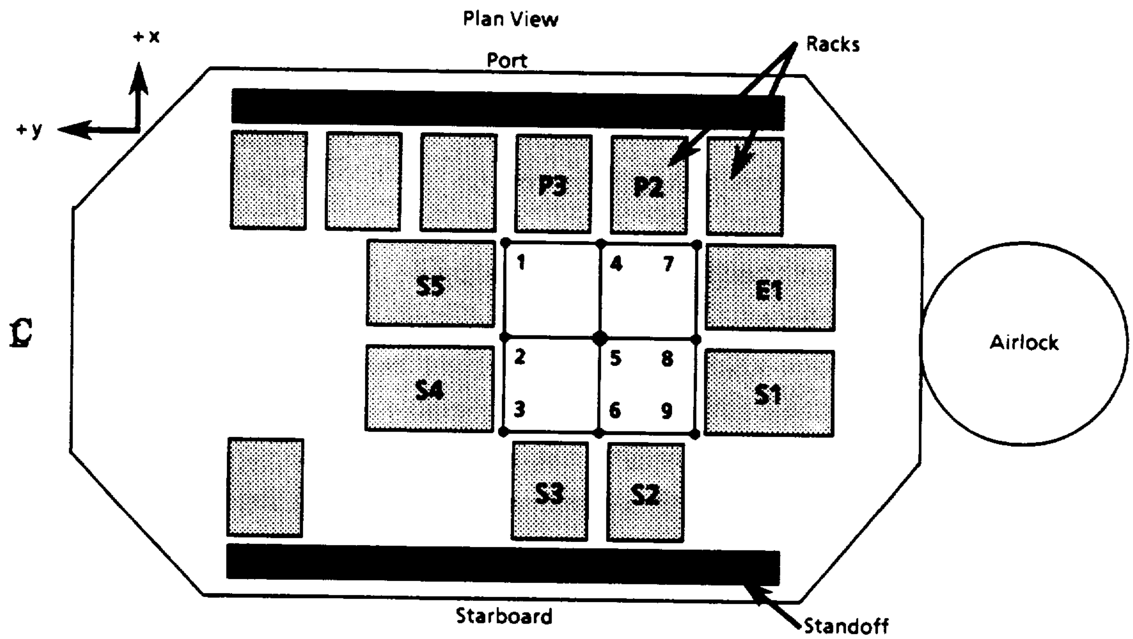


Figure 6-11. Radiation Storm-Shelter Configuration

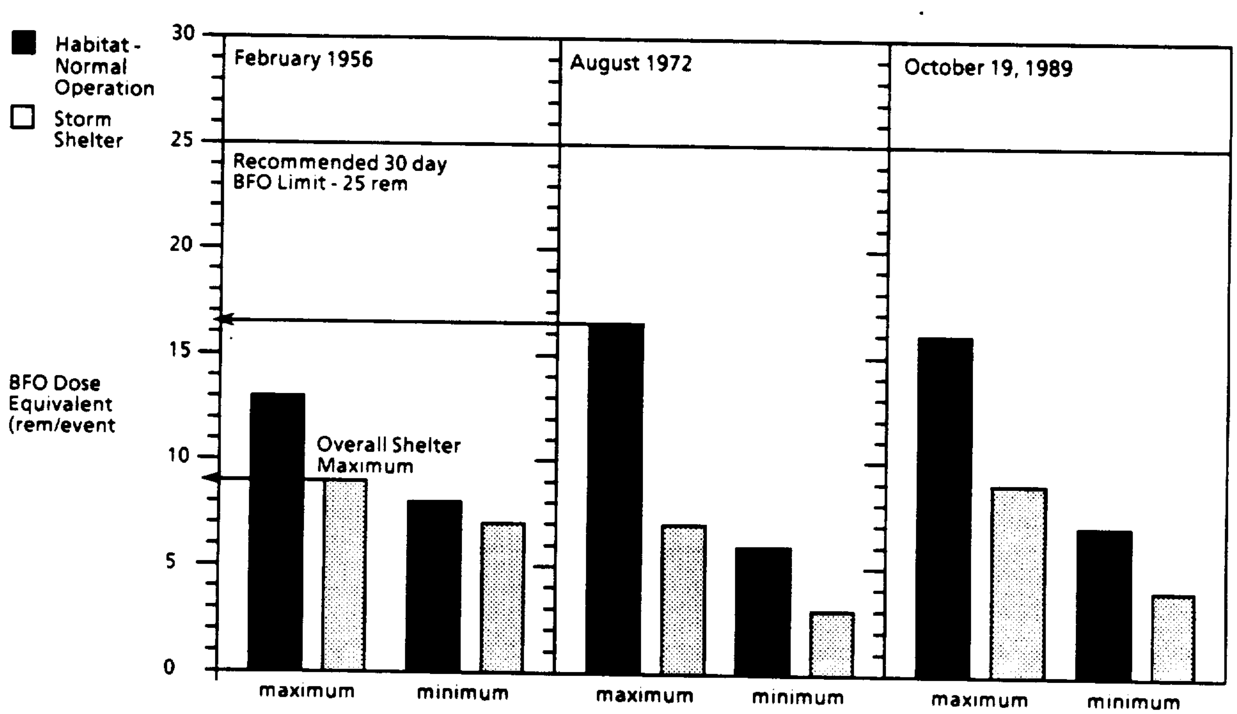


Figure 6-12. Maximum and Minimum Calculated Blood-Forming Organ Dose Rate Points

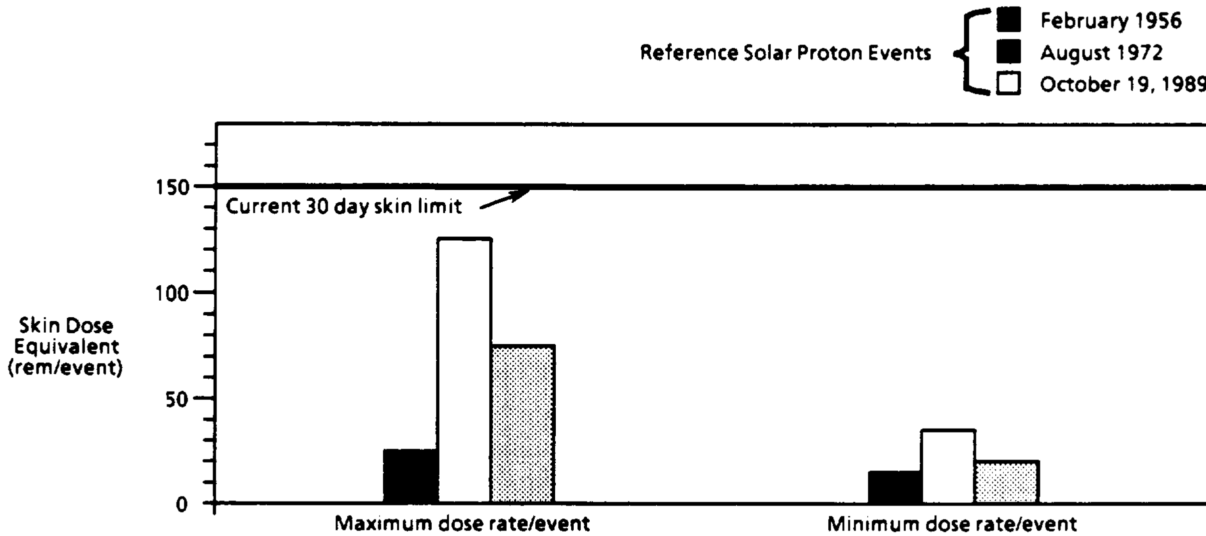


Figure 6-13. Maximum and Minimum Calculated Dose Rate Points to the Skin for the Habitat

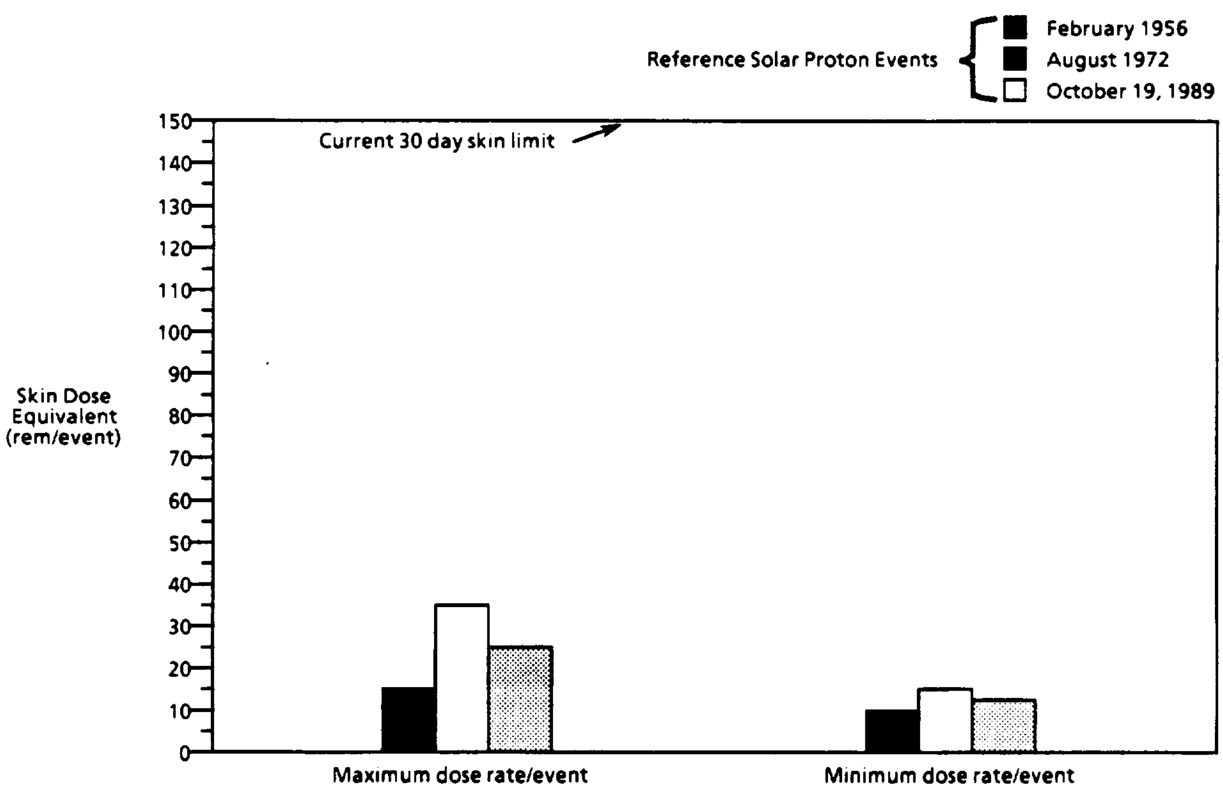


Figure 6-14. Maximum and Minimum Calculated Dose Rate Points to the Skin Within the Storm Shelter

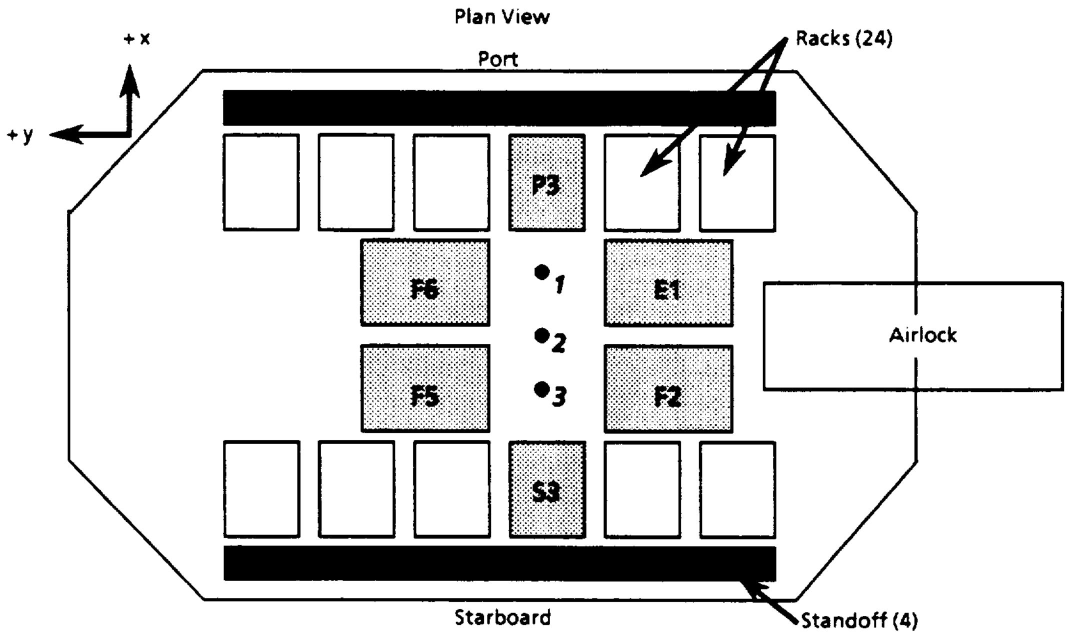


Figure 6-15. Lunar Habitat Radiation Assessment Configuration - Concept M

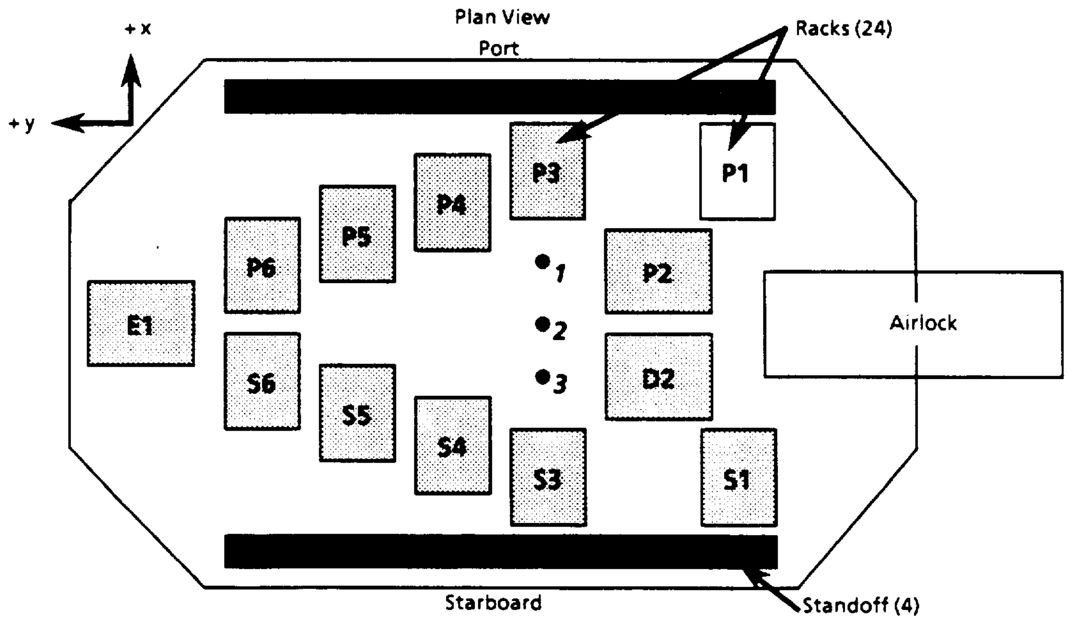


Figure 6-16. Lunar Habitat Radiation Assessment Configuration - Concept N

The calculated maximum doses were 13.8 cSv and 20.6 cSv for concepts 'M' and 'N' respectively. The ranges of doses for each of the concepts and reference solar proton events are presented in figure 6-17.

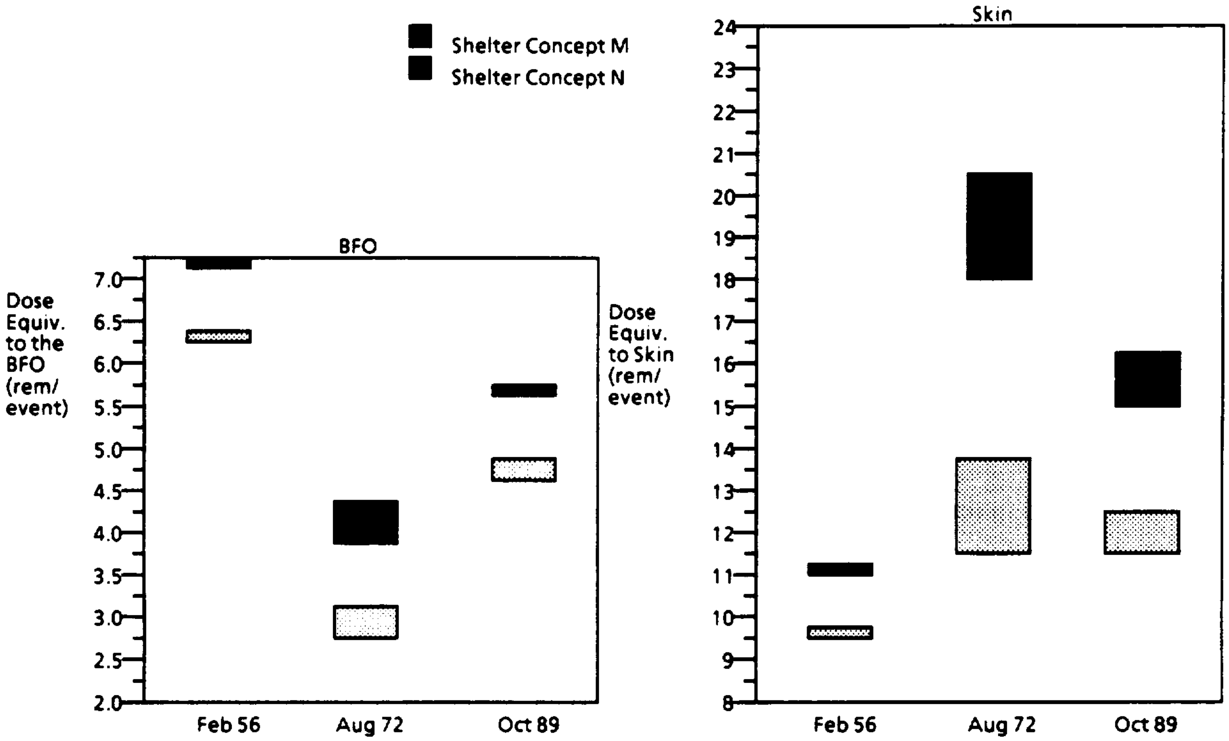


Figure 6-17. Blood-Forming Organ and Skin Dose Equivalent Comparison for Shelter Concepts M and N

6.7 DISCUSSION OF RESULTS

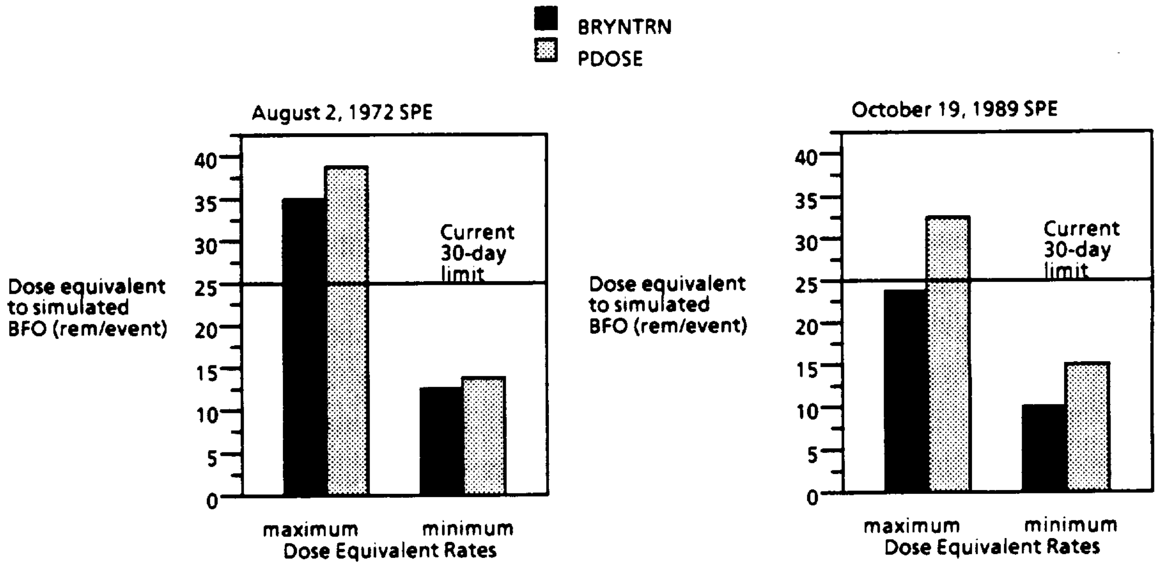
Radiation has been brought to the preliminary design phase where it has the greatest benefit and can permit significant reduction in mass, complexity and cost to a vehicle. The protection methods that have been devised use inherent mass (equipment and structure) of the vehicle first. If needed, these methods can be augmented by utilizing a dedicated mass of some kind. Food, water and other "light" (low-atomic weight) materials are very good attenuators of protons. Shield augmentation may include the use of local materials such as the lunar regolith. Recognizing the fact that operational procedures need to be investigated if using regolith, this method does have some identifiable advantages. At the very least, the protection method employed within the habitat should use as much on-board equipment and mass as possible.

Astronauts realize a great advantage in being on the surface of the moon. Even though the radiation environment is the same as that found in interplanetary space and proceeds unhindered to the lunar surface, the omni-directional flux of both galactic cosmic rays and solar protons event can be reduced by a factor of 2 due to the shielding capabilities provided by the mass of the 'planet'.

Although the results are less than the current recommended limits for BFO and skin, they should not be misinterpreted. There still remains a large number of uncertainties regarding the determination of crew exposure. The fundamental causes of these uncertainties include, but are not limited to, transport theory, nuclear cross-section determination and environment modeling. As a result of these uncertainties, exposures can potentially be in error by as much as a factor of 2. Additionally, the total potential exposure has not been determined. Additions to the exposure will come from trapped particles during lunar and Earth transfers, the occasional 'ordinary' solar proton events, galactic cosmic rays and man-made sources such as small reactors. Protection to the astronauts will vary during the course of a mission from the relative safety of the habitat to the protection provided only by a space suit during EVA. Still another question must be raised when we are reviewing astronaut exposure. To what level do we provide protection from solar proton events? Do we look at the theoretical worst case flare which integrates spectral characteristics from the February 1956 and August 1972 solar proton events; and how many such events should we allow the astronauts to withstand before bringing them home? The uncertainties discussed could potentially cause higher cancer rates, an increased burden to spacecraft mass, complexity, and cost, and finally could reduce mission durations to a minimum.

Recall also that the current limits are established for operations taking place in LEO. Here, the radiation environment is better understood; the environment is far more benign than the interplanetary (lunar) environment. Radiation protection and limits issues are currently being addressed by NASA, the National Commission on Radiation Protection and the International Commission on Radiation Protection in support of SEI missions. What will come of this is uncertain at this point.

Comparisons were made in this analysis between results returned using PDOSE which does not account for secondary particles and BRYNTRN which does. The results using both transport methods are in fairly good agreement and shown on figure 6-18. The reason for this can be tied to the way in which the propagation and attenuation of the particles is performed. PDOSE, as previously mentioned, has adopted a continuous slowing down process and BRYNTRN provides a solution to the 1-D Boltzmann transport equation.



* Developed by J. Wilson *et.al.*, - High Energy Physics Branch - NASA/LaRC
** Developed by A. C. Hardy - Space Radiation Analysis Branch - NASA/JSC

Figure 6-18. Comparison of Dose Equivalent Calculations using BRYNTRN and PDOSE* for a 5-cm Phantom*

7.0 MARS EXCURSION VEHICLE ANALYSIS

7.1 MEV BICONIC LANDER

The MTS analysis work consisted of development of configurations for Mars landing vehicles, utilizing a biconic shape body. Issues addressed were the size and placement of the surface habitat cargo and the location of engines and propellant tanks. A biconic shape was selected to provide an L/D of about 1.5, and a packaging study was done to determine the minimum size biconic body required. The resulting shape has a base diameter of 8 meters, and an overall length of 24.5 meters (fig. 7-1). For the cargo vehicle, the surface habitat it carries is a 2-level pressure vessel located at the c.g. of the vehicle, providing the crew with a total living area of 120-square meters. Area requirements were derived from NASA standards, architectural standards and terrestrial analogies (fig. 7-2). The habitat structure is integral with the lander airframe and does not need to be "unloaded". The crew lander carries an ascent vehicle, which consists of storable propellant and tankage, four 18-klb engines, and a crew cab for six (fig 7-3).

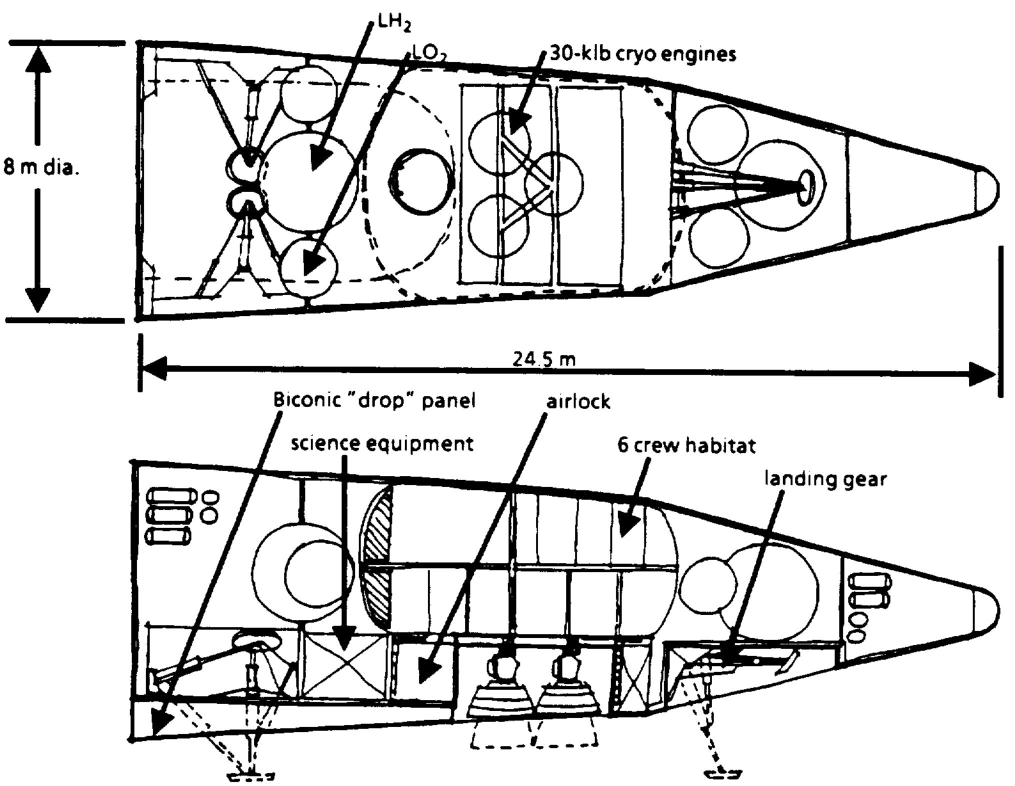
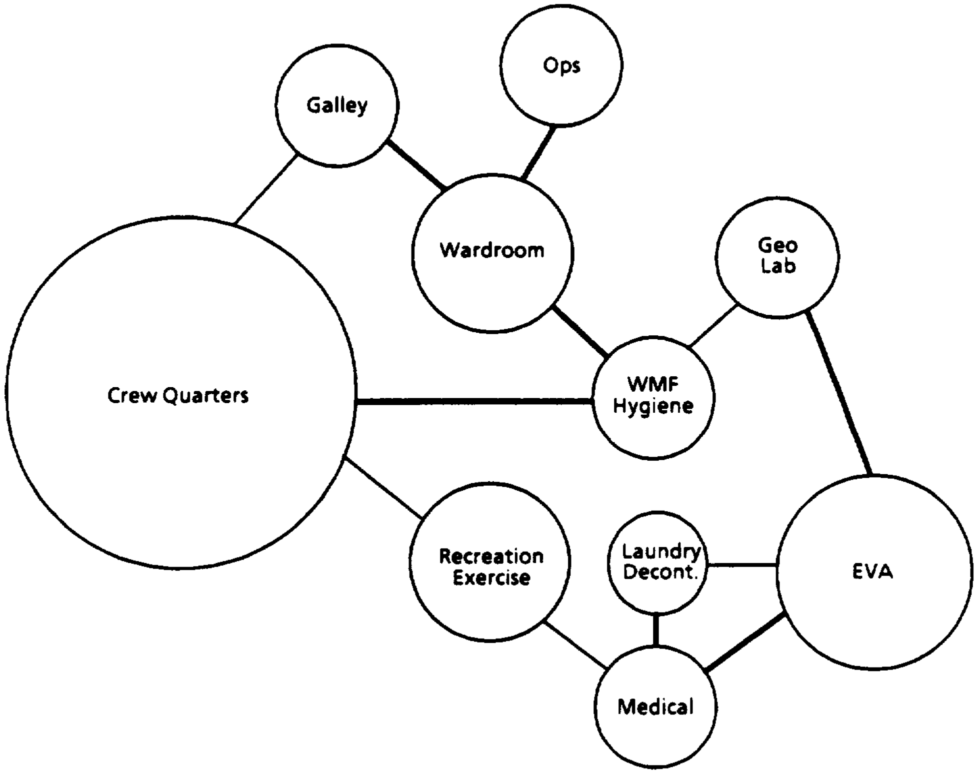


Figure 7-1. Biconic MEV Lander 6 Crew Habitat



Proximity Diagram

Area Allocations

Crew Quarters: (12)	36.0 m^2
Wardroom	20.0 m^2
Galley	4.0 m^2
WMF/hygiene: (2)	4.0 m^2
Laundry	1.0 m^2
Recreation/exercise	10.0 m^2
Medical	3.0 m^2
EVA	10.0 m^2
Operations: (2 workstations)	4.0 m^2
Life sciences lab:	6.0 m^2
Geochemistry and Petrology lab	6.0 m^2
Circulation (15%)	16.0 m^2
Total Area	**120.0 m^2**

Figure 7-2. Biconic MEV/Habitat Internal Arrangement

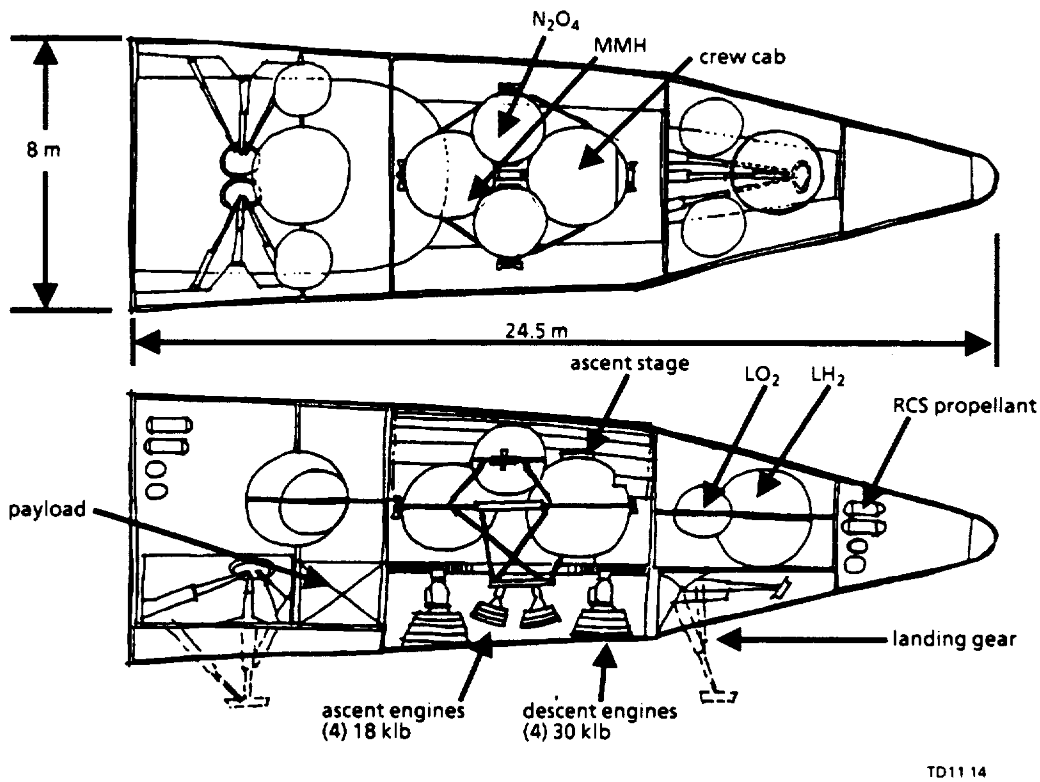


Figure 7-3. Biconic MEV Crew Vehicle

either abort launch during descent or launch from the surface. Previous biconic designs located balanced sets of engines on either side of the c.g. of the vehicle, landing the vehicle on its "side", or located engines in the base area, landing the vehicle on its "tail". The current concept utilizes a cluster of four engines located below the c.g. and the payload. In the event that an engine fails during descent, the opposite engine would shut down in order to balance thrust, and the remaining two engines would throttle up to continue the landing maneuver. The crew and cargo MEVs are essentially the same vehicle; however, the descent engines are placed farther apart in the crew version to allow room for the ascent engines.

7.2 LOW L/D AEROBRAKE (MEV) - STRUCTURAL ANALYSIS

7.2.1 Thermal Load Analysis

Low L/D aerobrake structure was previously investigated for aerodynamic loads during Mars aerocapture maneuver (refs. 2 and 3). In the current study, a structural evaluation of this aerobrake is carried out which involves thermal loading caused by the aerocapture heating. The Mars Excursion Vehicle (MEV) is a low L/D (~0.5) blunt hyperboloid aerobrake which is 30 meters in length (fig. 7-4) and has a total payload-plus-aerobrake mass of 84-metric tons. The payload truss structure is attached to the aerobrake at four points.

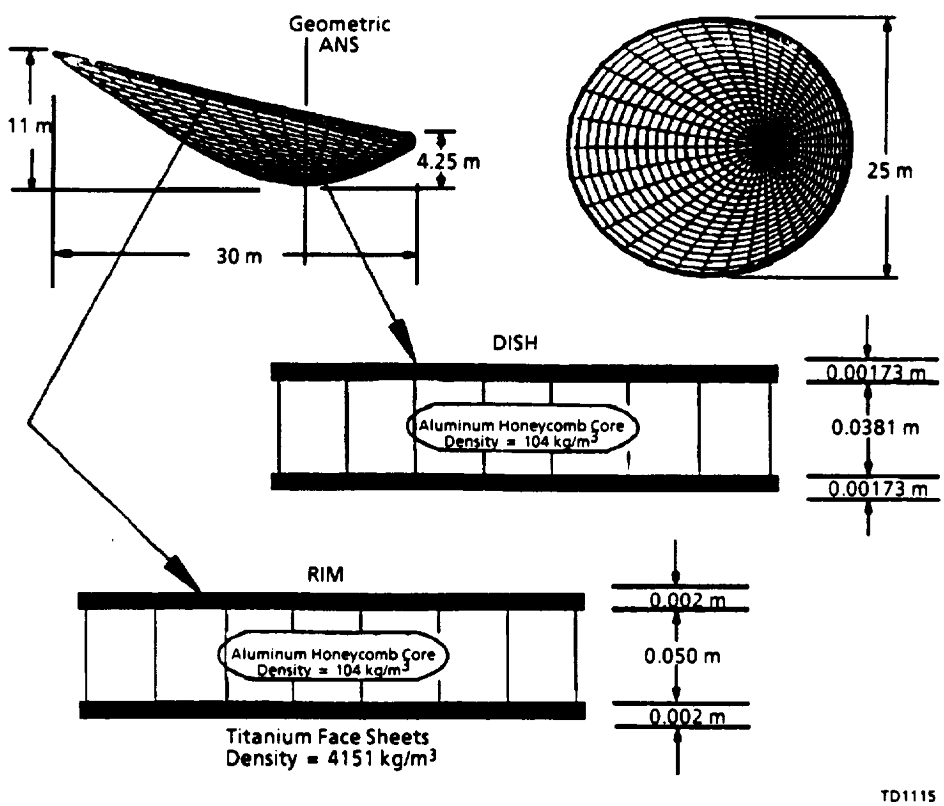


Figure 7-4. Low L/D Aerobrake - Preliminary Configuration

Aerobrake structure under investigation is a sandwich shell with 3.81-cm deep aluminum (5056 Al) core and 0.173-cm thick titanium (Ti-6Al-4V) face sheets. Ti-6Al-4V alloy was chosen for the face sheets for its high specific strength and the fact that it can withstand prolonged exposure to temperatures of up to 750°F without loss of ductility. It has a curved rim which is stiffened by increasing the core depth to 5.0 cm and face sheet thickness to 0.2 cm in order to reduce excessive deformations observed during preliminary analysis with aerodynamic loads. The total mass of the aerobrake structure was calculated to be approximately 17-metric tons.

7.2.2 Finite Element Model

A Finite Element Model for the sandwich shell structure was generated using PATRAN as a preprocessor. Honeycomb sandwich was simulated as a titanium plate by giving proper bending stiffness and coupling. A variable-thickness TPS was considered which would provide a constant back surface temperature of 750°F. Constant temperature distribution on the titanium face sheet would eliminate the possibility of hot spots on the structure providing an even thermal expansion and would result in an optimal TPS mass.

The model (NASTRAN data deck) consisted of 1093 grids, 6448 degrees of freedom, 1032 CQUADR and 40 CTRIA3 elements. Each payload attachment location was modeled as a surface having 17-grid points, each constrained for translation in the x, y and z directions. The model is shown in figure 7-5. Material properties for titanium (Ti-6Al-4V) used in the model are as follows:

Modulus of Elasticity	(E)	=	1.103E11	Pa
Modulus of Rigidity	(G)	=	0.427E11	Pa
Poisson's Ratio	(μ)	=	0.310	
Density	(ρ)	=	4.429E03	kg/m^3
Ult. Tensile Stress	(F_{tu})	=	11.030E8	Pa
Comp. Yield Stress	(F_{cy})	=	10.617E8	Pa
Ult. Shear Stress	(F_{su})	=	11.030E8	Pa

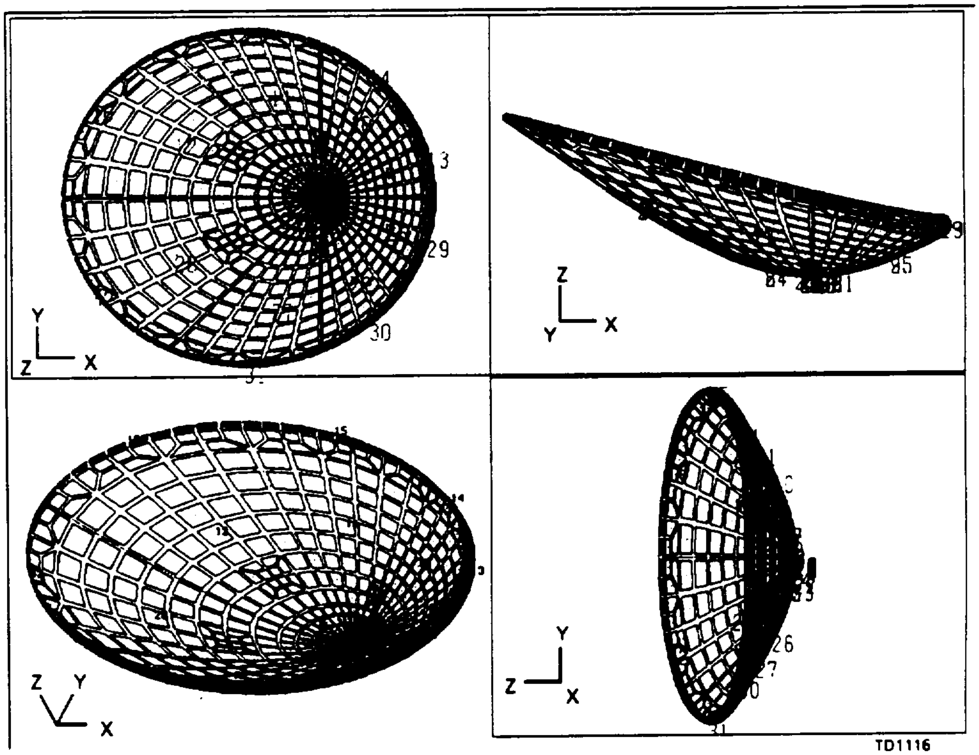


Figure 7-5. Low L/D Aerobrake - Finite Element Model

7.2.3 Loading

There is a time lag between peak "g" loading and peak heating. Peak heating occurs at the stagnation point on the TPS outer surface some Δt seconds following the peak "g" loading. Due to the thermal conductivity of the TPS, it takes another 50 to 100 seconds for the titanium face sheet to reach the design temperature of 750°F. By this time, the "g" loading reduces to less than one "g" (fig. 7-6). It was therefore decided to treat thermal loading with 1.0-g aero loading as one case and the peak "g" loading without thermal loading (reported in ref. 3) as another. For the thermal loads analysis, a constant temperature change from 0°F to 750°F was applied across the entire outer surface of the aerobrake.

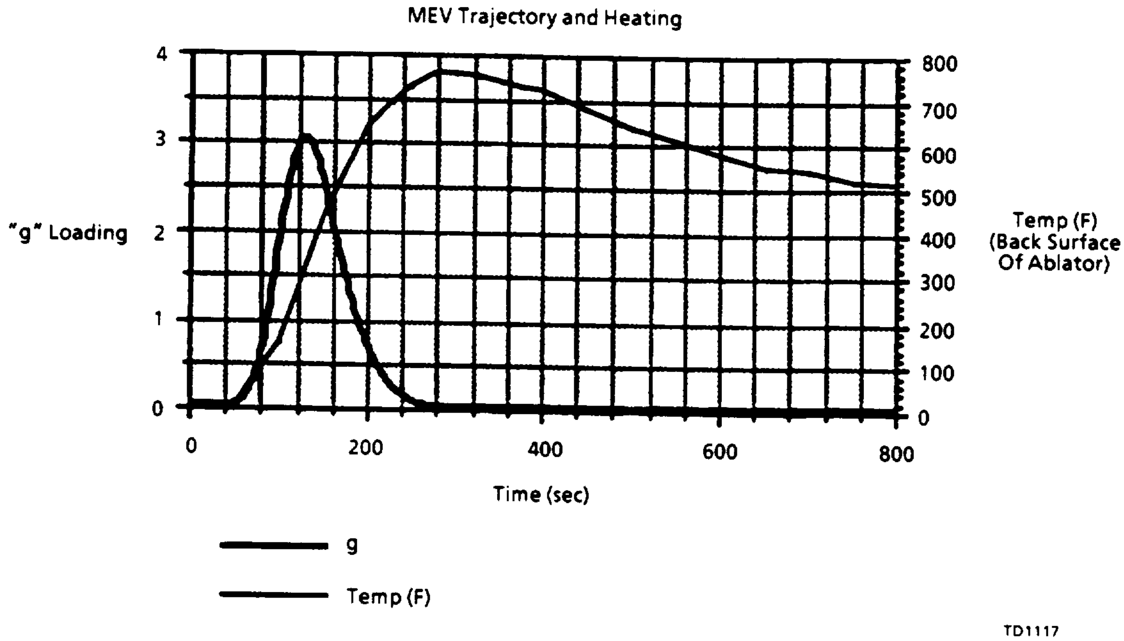


Figure 7-6. Peak "g" Loading vs. Peak Heating

7.2.4 Analysis

NASTRAN Solution 101 was used to carry out the analysis with PATRAN utilized to perform the post processing function. A uniform temperature change of 750°F along with one "g" loading resulted in a maximum deflection of about 10.5 cm. The max deflection occurred between the two aft MEV attach points as shown in figure 7-7. The max deflection was considered to be very small due the fact that it was less than 0.4% of the largest dimension of the aerobrake. An exaggerated deformation plot, figure 7-8, is provided for visualization purpose. Highest stresses occurred at the 4 MEV attach points. The yield strength margin of safety was calculated to be about 40%. A fringe plot of the Von Mises stress distribution is shown in figure 7-9. A summary of the results is provided as follows:

	Aero Loading (6 g)	Thermal Loading
Maximum Displacement	26 cm	11 cm
Max Disp. to Max Dimension Ratio	0.87%	0.35%
Max Principal Stress	2.31e08 Pa	6.80e08 Pa
Stress Margin of Safety	389%	62%

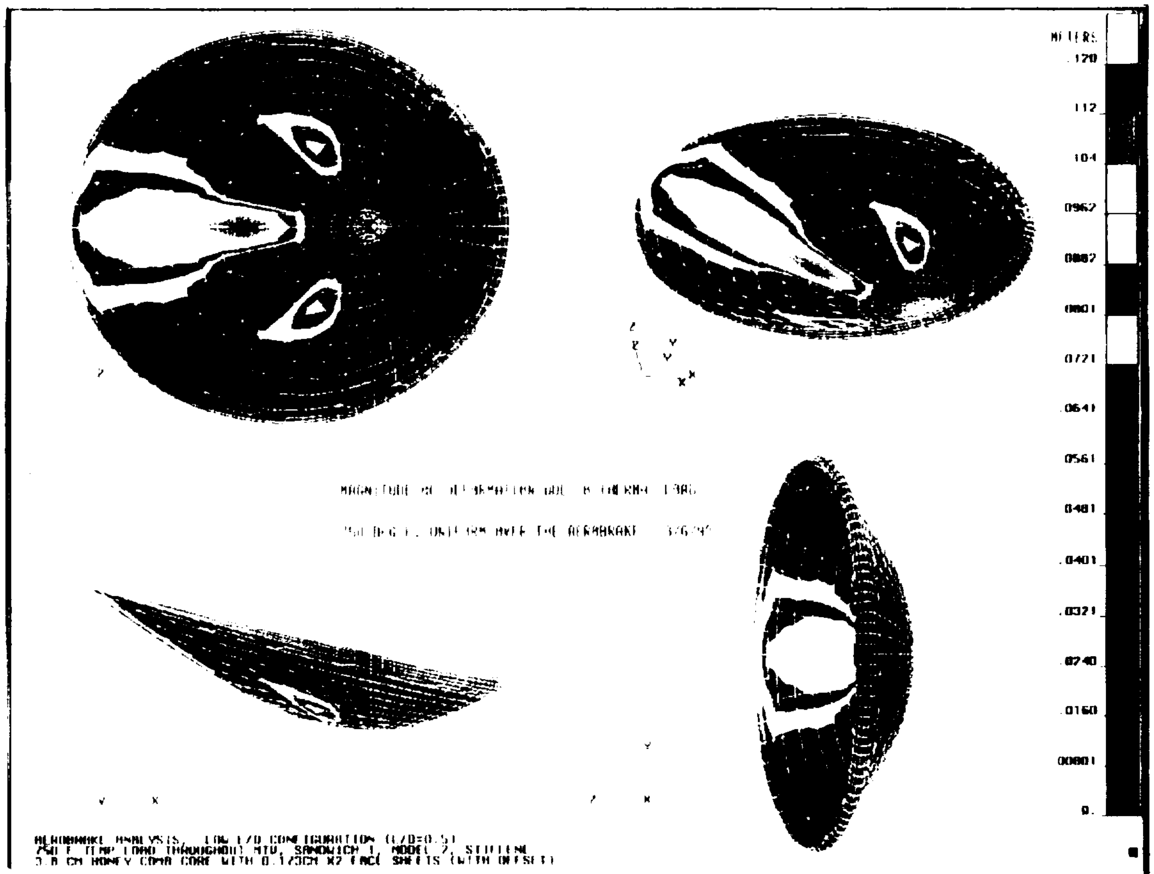


Figure 7-7. Maximum Deformations Due to Thermal Loads

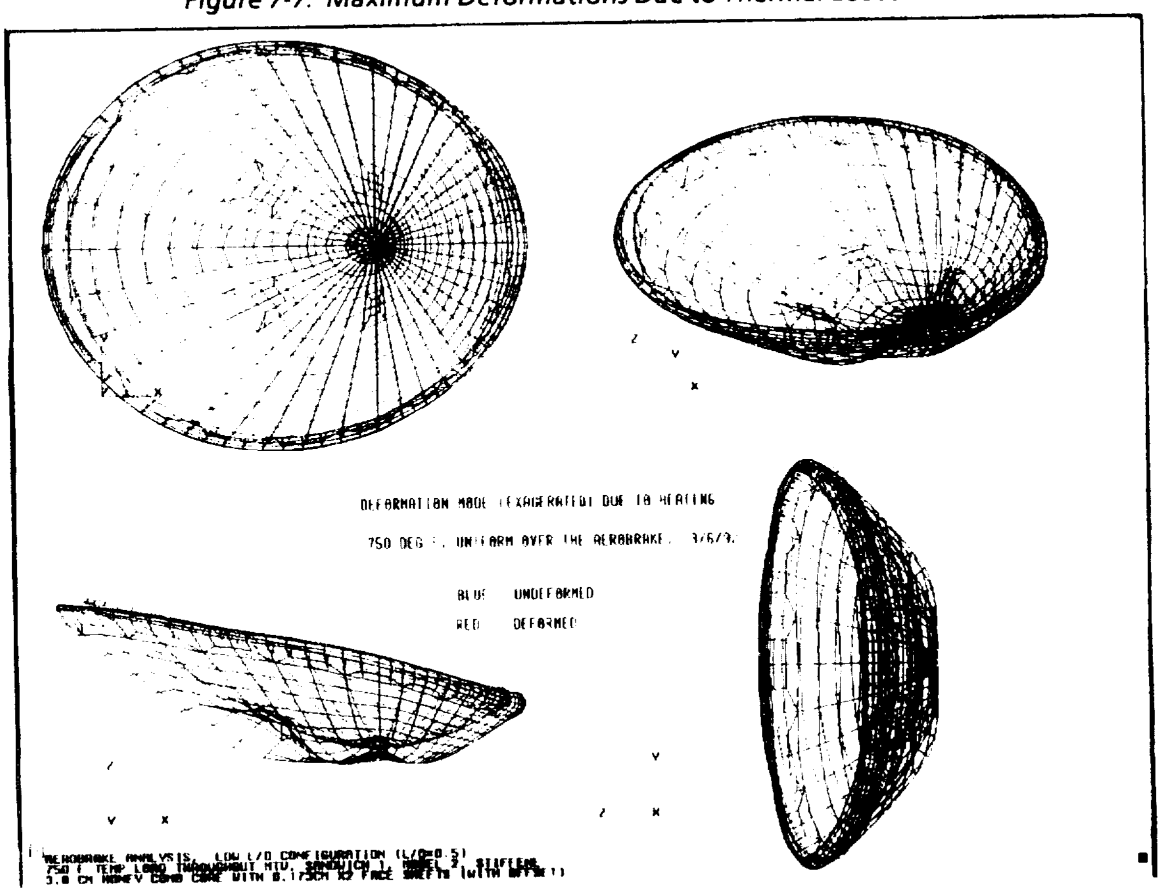


Figure 7-8. Exaggerated Deformation Plot

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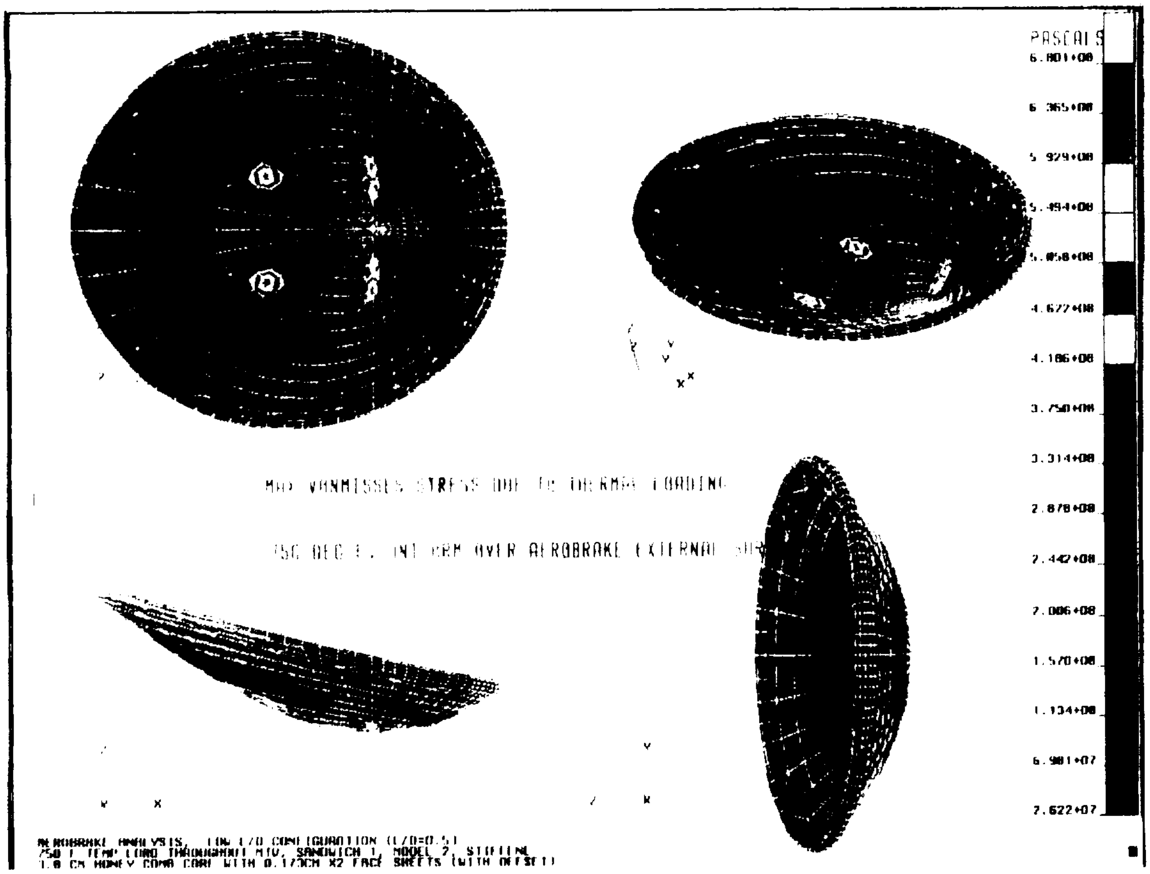

Figure 7-9. Maximum Stresses Due to Thermal Loads

7.2.5 Conclusions

Low L/D thermal analysis shows that while the deflections are lower when compared with peak "g" loading case, the stresses produced by the peak heating are higher. Slightly higher stresses in the peak heating case may be attributed to the fact that the MEV payload was not modeled along with the aerobrake model. In reality, the truss structure that will be used to attach the MEV payload to aerobrake will not be as rigid as the current model constraints and will flex under thermal expansion of aerobrake reducing local deflections and stresses. There is a potential for further design refinements and mass optimization with advanced materials.

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8.0 CONCLUDING REMARKS

In the earlier two phases of the "Space Transfer Concepts and Analyses for Exploration Missions" study, a broad range of topics in the human exploration to the Moon and Mars were discussed. The current report focussed its activities on the issue relating to the habitat/airlock for the "*First Lunar Outpost.*" Alternatives were examined based upon the SSF Hab module with the shuttle airlock, SSF Crewlock or internal bulkhead to provide nonhyperbaric and hyperbaric capabilities. Starting with the SSF Hab module as reference, changes were considered in line of the requirements and operations for a "First Lunar Outpost" habitat. These changes had an impact on the environmental control system, power, structure and radiation protection which all effected the total hab mass. The preliminary outcome of the study indicated that the system mass may range from 31 mt (the initial estimate) to 27 mt for a hyperbaric configuration or 25 mt for a nonhyperbaric configuration. Additional work is necessary to improve the confidence level of these assessments.

A small effort was spent in the evaluation of the structural loading of the low L/D (~0.5) hyperboloid aerobrake under thermal loads. Calculations for the honeycomb structure indicated that the thermal loading imposed a higher stress level on the structure than the 6-g aero loading that was previously calculated. Changes in the physical design of the system would modify and reduce these stress levels.

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8. Personal Communication, Boeing SSF engineers (structures, ECLSS, power, thermal), February - March, 1992.

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13. Personal Communication, M. Barrett and B. McKinley, April 1992.

14. Personal Communication, R. Hage, NASA Marshall Space Flight Center, March, 1992.

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16. Personal Communication, A. C. Hardy, NASA Johnson Space Center, September, 1991.

Appendix A

Configuration A Mass Breakdown

- Boeing Outpost Hab Module is based very closely on SSF HAB A:
  - module size and design identical
  - equipment and packaging associated with endcones and standoffs identical to SSF HAB A
  - Outpost Hab also possesses closed water and open air ECLSS
  - Outpost Hab maintains the same ECLSS tier and crossovers as SSF HAB A
  - all internal system masses based on SSF data

- Boeing Outpost Hab Module does differ from SSF HAB A:
  - Outpost must support airlock and EVA systems, crew health functions, and internal science within the module
  - to provide these capabilities, Outpost removes dedicated shower, trash compactor, dedicated wardroom, and refrigerators/ freezers and reduces some storage from SSF HAB A
  - need to confirm SSF HAB A utilities are sufficient for changes
  - redundancy scheme assumed to be handled by careful ORU selection (SSF HAB A depends upon other SSF elements for some backup and/or capabilities)

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- **Structures:**
  - Mass represents SSF HAB A values for cylinder, bulkheads, and secondary structure
  - Two escape paths are provided by a hatch at each end of module
  - SSF HAB A micrometeoroid/debris protection is included
  - Rack masses represent structure/attachments assoc. w/ the 24 racks in reference layout
- **Electrical Power System:**
  - Two power feeds are provided to each operating rack
  - Redundant DDCUs and SPDAs (1 failure reduces capability); may not be sized for Outpost power levels
  - Internal EPS summed from SSF HAB A endcones/standoffs and reference racks
  - External power systems based on GaAs solar cells for lunar daytime power; regenerable fuel cells with high pressure storage reactants for lunar night time power
  - External systems sized for needs of reference layout based on SSF data
  - Lunar environment impact analysis not complete (MLI needs, dust degradation, etc.)
- **Data Management System:**
  - DMS cabling and endcone-mounted equipment taken directly from SSF HAB A
  - Internal DMS summed from SSF HAB A endcones/standoffs and reference racks
  - One DMS/Comm workstation included (shared with science); may not be sufficient
- **Internal Audio/Visual System:**
  - One fault tolerant function (requires further investigation to confirm)
  - Wireless system provides additional audio capability
  - IA/V summed from SSF HAB A endcones/standoffs and reference racks

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Habitat : Reference Configuration A

Systems Description and Capabilities of Boeing Reference

- **Caution and Warning System:**
  - One fault tolerant function (requires further investigation to confirm)

- **Thermal Control System:**
  - Internal TCS contains both low and a moderate temperature loops which may be physically connected to provide backup function at reduced capability
  - Internal TCS summed from SSF HAB A endcones/standoffs and reference racks
  - External TCS sized for reference load (uses heat pumps during lunar day)
  - Lunar environment impact analysis not complete (MLI needs, dust degradation, etc.)

- **Environmental Control and Life Support Systems:**
  - ECLSS based on SSF requirements, which includes 14.7 psi atmosphere
  - Reference layout places ECLSS tier in ceiling to assist radiation protection, reduce dust contamination, and prevent crew walking loads
  - Several systems (including ducting) may be oversized for Outpost (which has reduced water and air circulation needs compared to SSF)
  - 45 day supply of ECLSS consumables and expendables included under "Consumables"

  Temperature and Humidity Control
  - Two systems for Avionics Air (rack air temperature monitoring and control, airborne heat rejection) are located in SSF HAB A; each system capable of supplying entire module needs
  - Two systems for Cabin Air (cabin atmospheric temperature and humidity monitoring and control, latent and sensible heat rejection) are located in SSF HAB A; each system capable of supplying entire module needs

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- **Environmental Control and Life Support Systems (cont):**

  Temperature and Humidity Control (cont)
  - Both Avionics and Cabin Air systems interdependent with other ECLSS and TCS functions; all powered racks dependent upon Avionics Air
  - THC summed from SSF HAB A endcones/standoffs and reference racks

  Atmosphere Control and Supply
  - Redundant valves and distribution
  - Makeup gases provide for leakage and airlock losses as well as 2 module represses
  - ACS summed from SSF HAB A endcones/standoffs and reference racks

  Atmosphere Revitalization
  - Single string CO_2 removal, TCCS, and ACMA (w/ critical ORU for CRM & MCA)
  - CO_2 vented
  - AR systems interdependent with other ECLSS and DMS functions
  - AR summed from SSF HAB A endcones/standoffs and reference racks

  Fire Detection and Suppression
  - FDS sized to support fire suppression in whole module (multiple fires)
  - Portable extinguishers are available as backup
  - Module venting may be necessary during and/or after emergency
  - FDS is dependent upon THC and DMS for some detection capability
  - FDS summed from SSF HAB A endcones/standoffs and reference racks

Habitat : Reference Configuration A
Systems Description and Capabilities of Boeing Reference (cont)

- **Environmental Control and Life Support Systems (cont):**

  Water Recovery and Management

  - Water recovery and processor and storage system sized for 4 crew and SSF PMC water requirements (which may be in excess of Outpost needs)
  - Plumbing failure handled by valves and jumpers
  - Back-up water may be available from landers, EVA supply, power system, etc.
  - WRM interdependent with other ECLSS functions
  - WRM summed from SSF HAB A endcones/standoffs and reference racks

  Waste Management

  - Solid wastes collected and stored
  - Urine is pretreated at urinal, delivered to and processed at urine processor, product stored in tanks
  - WM interdependent with other ECLSS functions
  - WM summed from SSF HAB A endcones/standoffs and reference racks

- **Crew Systems:**
  - Endcone/standoff and rack support includes closeout and 0g restraint/mobility structure
  - Galley provides drink dispenser with chiller, microwave/convection oven, and stowage
  - Hammocks deployed in aisle; minimal wardroom provided
  - Separate changing area/vanity and commode/urinal racks provided; multiple handwashes
  - No refrigerator/freezer provided; no dedicated shower included (Shuttle type possible ?)
  - Stowage capacity similar to HAB A (slightly reduced)
  - CHeCS equipment and supplies based on input from JSC medical
  - 45 day supply of food/system consumables/expendables included under "Consumables"

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- **Internal Science:**
  - Three generic science racks included (glovebox, maintenance workbench, stowage)
  - No rover support included
  - No external science support/mass included
  - Workstation shared between science and DMS/Comm (capability needs to be examined)

- **EVA and Airlock Systems:**
  - Boeing Reference Outpost assumes Shuttle airlock derivative and capabilities
  - Hab burden contains SPCU, airlock pump and controls, and EVA stowage based on SSF Equipment Lock
  - EVA sublimator water required for 22 EVAs included under "Consumables" (comprehensive water balance not yet complete)
  - EVA tools included in Reference based on SSF data ("toolbox" may be oversized)
  - No hyperbaric capabilities or support
  - No EMU suits in Reference (spares and expendables are included in "Consumables")
  - No dedicated dust removal mass in Reference
  - No dedicated 1/6 g accommodation mass included in Reference
  - "Surface Access" mass includes placeholder for ladders/stairs, platforms, etc.

- **Communications and Tracking:**
  - External systems only (IA/V contains internal portion)
  - Based on previous study and historical data
  - Assumed to provide Outpost-to-Earth, surface-to-orbit, and surface-to-surface communication capabilities (may be combined with lander needs)

Habitat : Reference Configuration A

Systems Description and Capabilities of Boeing Reference (cont)

- **Radiation Protection:**
  - Additional protection required by Outpost is TBD
  - Analysis underway to give preliminary characterization of Reference environment
- **Growth/Contingency:**
  - Masses quoted from SSF reports include SSF imposed growth allowances (no additional growth added to these numbers)
  - Boeing options do add 28% growth to calculated and unconfirmed masses ("External Systems" and "Consumables"); 28% factor is consistent with SSF maturity scale
  - "Airlock and Adapter" uncertainties have not been included under "Growth/ Contingency"

Habitat : Reference Configuration A

Systems Description and Capabilities of Boeing Reference (cont)

Lunar Outpost Hab Module "Standard" Configurations A, D, and G Mass Breakdowns

Outpost Hab Options (mass in kg)		Boeing Ref A	Boeing Dh	Boeing Dnh	Boeing Gh	Boeing Gnh
System	Subsystem	3/23/92	3/23/92	3/23/92	3/23/92	3/23/92
Module Structure		7879	7788	7879	7788	7879
	Primary	3175	3175	3175	3175	3175
	Secondary	2149	2149	2149	2149	2149
	Racks	2555	[-91 = 2464]	2555	[-91 = 2464]	2555
External Structure						
Life Support		3248	[-3.3 = 3244.7]	3248	[-3.3 = 3244.7]	3248
Medical Support		668	668	668	668	668
Crew Systems		1840	1725	1840	1725	1840
	Endcone/Standoff Support	127	127	127	127	127
	Rack Support	639	[-5.8 = 633.2]	639	[-5.8 = 633.2]	639
	Workstation Support	25	25	25	25	25
	Galley/WR Functions	220	220	220	220	220
	PHC/WMC Functions	200	[-109.6 = 90.4]	200	[-109.6 = 90.4]	200
	Critical ORUs	429	429	429	429	429
	Surface Access	200	200	200	200	200
Storm Shelter						
CDMS		761.4	761.4	761.4	761.4	761.4
	DMS	563.8	563.8	563.8	563.8	563.8
	IAV	97.6	97.6	97.6	97.6	97.6
	C&T	100	100	100	100	100
Power Source		4429	4752	4646	4746	4707
	Internal	754	[-22.6 = 731.4]	754	[-22.6 = 731.4]	754
	External (w/o reactants)	3675	4021	3892	4015	3953
Heat Rejection		1746	1774	1770	1785	1781
	Internal	1280	[-3.4 = 1276.6]	1280	[-3.4 = 1276.6]	1280
	External	466	497	490	508	501
Airlock System		1537	3350	2772	5308	1518
	SPCU	303	881	303	789	303
	Depress pump	117	117	117	117	117
	Airlock/adaptor/tools	1117	2352	2352	4402	1098
Systems Subtotal		22108	24063	23584	26026	22402
Contingency		2310	2451	2403	2458	2437
Total Systems		24418	26514	25987	28484	24839
Consumables		2300.5	2300.5	2300.5	2300.5	2300.5
Fuel Cell Reactants		1508	1634	1601	1655	1650
EVA Suits						
Internal Science		984	984	984	984	984
Total Landed		29210	31433	30873	33424	29774

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Structures						
PS1	Primary		Fwd bulkhead	577.00	9%	SSF HAB A Mass Properties Report (12/15/91)
PS2			Aft bulkhead	581.50	9%	"
PS3			Cylinder skin, rings, launch support	2016.20	5-13%	"
	Sub			**3174.70**		
SecS1	Secondary		Windows & MMDS	873.20	11-16%	"
SecS2			Endcone mounting, Standoff assy, etc.	793.03	12-20%	" SSF HAB A DI includes 491 lbs of rack -related structure which is removed from here and distributed within the rack-based systems
SecS3			Hatch/track - axial	233.10	13%	"
SecS4			Window shutter	6.35	18%	"
SecS5			Berthing mech/support	243.60	5-18%	May not be needed for lunar outpost
	Sub			**2149.28**		
Sub				**5323.98**		
Dist Sys - Endcone/ Standoff- Mounted Equipment and Utilities						
EP1	Endcone - fwd/ext	EPDS		**0.00**		SSF HAB A Mass Properties Report (12/15/91)
EP2	Endcone - fwd/int	EPDS	remote switch	0.71		"
			Cable Assy	12.47		"
			Sensor/Effector cable	2.26		"
			SPDA struct. and integ.	32.15		"
			Feedthru(DDCU)	2.19		"
			RPDA utility rails	4.25		"
			RPC's	47.85		"
			DC-DC converter	50.00		"
	Sub			**151.88**	5%	

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
EP3	Endcone - aft/ext	EPDS		**0.00**		"
EP4	Endcone - aft/int	EPDS	Remote switch	0.71		"
			Cable Assy.	12.47		"
			Sensor/effector cable	2.26		"
			SPDA	32.15		"
			Feedthru, DDCU	2.19		"
			RPDA Utility rails	4.25		"
			RPC Modules	47.85		"
			Converter, DDCU	50.00		"
		Sub		**151.88**	5%	
EP5	S/off - ceiling/ starboard	EPDS	Lighting	21.44		"
			Cable Assy.	13.97		"
			Utility outlet	4.29		"
		Sub		**39.70**	5%	
EP6	S/off - floor/	EPDS	Cable Assy.	**15.58**	5%	"
EP7	S/off - floor/port	EPDS	Cable Assy.	48.20		"
			Sensor/effector cable	9.07		"
			utility outlet	4.29		"
		Sub		**61.56**	5%	
EP8	S/off - ceiling/port	EPDS	Lighting	21.44		"
			Cable Assy.	26.49		"
			Sensor/effector cable	2.26		"
		Sub		**50.19**	5%	
EP9	Cylinder			**0.00**		"
	EPDS Sub			**470.79**		
EC1	Endcone - fwd/ext	ECLSS-ACS	Vent and Relief assy.	8.57		SSF HAB A Mass Properties Report (12/15/91)
12.23			Plumbing	0.72		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		Sub		**9.29**	5-28%	
		ECLSS-ARS	Non-prop. vent	**2.94**	5-28%	*
EC2	Endcone - fwd/int	ECLSS-THC	Bacteria filter	13.66		*
103.69			Isolation valve	4.67		*
			Duct, cab air	4.94		*
			welds	0.12		*
			cable, sensor effector	2.26		*
		Sub		**25.65**	5-28%	
		ECLSS-ACS	Pres. equal. valves	9.09		*
			Vent & relief assy	8.76		*
			O2/N2 control and dist.	24.66		*
			Plumbing	12.05		*
			cable, sensor effector	5.66		*
		Sub		**60.22**	5-28%	
		ECLSS-FDS	Flame detector	1.52		*
			Portable Fire Extinguisher	5.23		*
			Fluid CO2	2.72		*
			Sensor/effector cable	0.90		*
		Sub		**10.37**	5-28%	
		ECLSS-ARS	Sensor/effector cable	2.26		*
			CO2 vent system	2.93		*
		Sub		**5.19**	5-28%	
		ECLSS-WRM	Sensor/effector cable	**2.26**	5-28%	*
EC3	Endcone - aft/ext	ECLSS-WRM	Bulkhead penetration	1.42		*
44.59			Vents	33.65		*
			Isolation Valve	9.52		*
		Sub		**44.59**	5-28%	
EC4	Endcone - aft/int	ECLSS-THC	Fan, IMV	5.14		*
96.54			Isolation Valve	4.67		*
			Ducting	25.22		*
			Welds	0.12		*

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Sensor/effector cable	2.26		•
		Sub		**37.41**	5-28%	
		ECLSS-ACS	Pressure Equalization	1.23		•
			O2/N2 control and dist.	29.52		•
			Sensor/effector cable	5.67		•
			plumbing	1.71		•
		Sub		**38.13**	5-28%	
		ECLSS-ARS	Sensor/effector cable	2.27		•
			plumbing	0.64		•
			Feed-thru	1.45		•
		Sub		**4.36**	5-28%	
		ECLSS-FDS	Flame detector	1.52		•
			Portable fire ext.	5.24		•
			Sensor/effector cable	0.90		•
			CO2-fluid	2.72		•
		Sub		**10.38**	5-28%	
		ECLSS-WRM	Sensor/effector cable	2.26		•
			plumbing	4.00		•
		Sub		**6.26**	5-28%	
EC5	S/off - ceiling/ starboard	ECLSS-THC	Fan	5.19		•
159.35			Ducting	145.14		•
			Insulation	5.52		•
		Sub		**155.85**	5-28%	
		ECLSS-FDS	Sensors	1.63		•
			CO2 release valve	1.19		•
			Sensor/effector cable	0.68		•
		Sub		**3.50**	5-28%	
EC6	S/off - floor/	ECLSS-THC	Fan	5.19		•
91.3			Valves	8.47		•
			Ducting	28.80		•
			Sensor/effector cable	5.60		•
		Sub		**48.06**	5-28%	

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		ECLSS-ARS	Plumbing	0.54	5-28%	*
		ECLSS-FDS	Sensors	1.63		*
			Valves	1.19		*
			Plumbing	9.14		*
			Ductwork	0.77		*
			Sensor/effector cable	0.45		*
		Sub		13.18	5-28%	
		ECLSS-WRM	Sensor/effector cable	11.33		*
			Plumbing	4.59		*
			Fluid-water	13.60		*
		Sub		29.52	5-28%	
EC7	S/off - floor/port	ECLSS-THC	Fan	5.19		*
118.95			Ductwork	29.94		*
			Sensor/effector cable	6.79		*
		Sub		41.92	5-28%	
		ECLSS-ACS	Sensor/effector cable	2.26		*
			plumbing	3.17		*
		Sub		5.43	5-28%	
		ECLSS-ARS	Sensor/effector cable	13.60		*
			plumbing	0.59		*
		Sub		14.19	5-28%	
		ECLSS-FDS	Sensors	1.63		*
			plumbing	5.38		*
			Sensor/effector cable	0.45		*
		Sub		7.46	5-28%	
		ECLSS-WRM	Sensor/effector cable	29.46		*
			plumbing	6.89		*
			Fluid	13.60		*
		Sub		49.95	5-28%	
EC8	S/off - ceiling/port	ECLSS-THC	Fan	5.19		*
72.14			Ductwork/Insulation	22.43		*
			Sensor/effector cable	6.11		*
		Sub		33.73	5-28%	

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		ECLSS-ARS	plumbing	**0.67**	5-28%	"
		ECLSS-FDS	Sensors	1.63		"
			plumbing	15.10		"
			Sensor/effector cable	0.45		"
		Sub		**17.18**	5-28%	
		ECLSS-WRM	Sensor/effector cable	13.60		"
			plumbing	6.96		"
		Sub		**20.56**	5-28%	
EC9	Cylinder	ECLSS-ACS	Module atmosphere	**147.40**	5-28%	"
	ECLSS Sub			**846.19**	5-28%	
DM1	Endcone - fwd/ext	DMS	none	0		SSF HAB A Mass Properties Report (12/15/91)
DM2	Endcone - fwd/int	DMS	Cabling	16.38		"
			Feedthrus	1.81		"
			Transducer	0.54		"
			Acoustic sensor	2.06		"
			Ring Concentrator	22.67		"
			Display panel	2.26		"
			MDM-large	20.86		"
			EMADS	9.07		"
			Signal processor	16.66		"
	Sub			**92.31**	5-28%	
DM3	Endcone - aft/ext	DMS		**0.00**		"
DM4	Endcone - aft/int	DMS	Cabling	16.38		"
			Feedthrus	1.81		"
			Transducer	0.54		"
			Acoustic sensor	2.06		"
			Ring Concentrator	22.67		"
			Display panel	2.26		"
			MDM-large	20.86		"
			EMADS	9.07		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		Sub		75.65	5-28%	
DM5	S/off - ceiling/ starboard			0.00		•
DM6	S/off - floor/	DMS	Cable	19.33		•
			Fiber distribution/data	6.27		•
			Time dist. bus	4.99		•
		Sub		30.59	5-28%	
DM7	S/off - floor/port	DMS	Cabling and Dist. bus	61.20	5-28%	•
DM8	S/off - ceiling/port	DMS	Cabling and Dist. bus	30.60	5-28%	•
DM9	Cylinder		Thermographic scanner	19.05	5-28%	•
	DMS Sub			309.40		
IA1	Endcone - fwd/ext	IAV		0.00		SSF HAB A Mass Properties Report (12/15/91)
IA2	Endcone - fwd/int	IAV	Crew wireless battery chrg.	7.31		•
			Fiber optic cable	0.09		•
		Sub		7.40	5-28%	
IA3	Endcone - aft/ext	IAV		0.00		•
IA4	Endcone - aft/int	IAV	Microphone	1.43		•
			Camera body	10.64		•
			Zoom lens	3.69		•
			Fiber optic cable	0.09		•
		Sub		15.85	5-28%	
IA5	S/off - ceiling/ starboard	IAV		0.00		•
IA6	S/off - floor/	IAV	Antenna	9.07		•
			Fiber optics	5.94		•

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		Sub		15.01	5-28%	
IA7	S/off - floor/port	IAV	Fiber optics	13.20	5-28%	"
IA8	S/off - ceiling/port	IAV	Fiber optics	5.37	5-28%	"
IA9	Cylinder	IAV		0.00		"
	IAV Sub			56.83		
MS1	Endcone - fwd/ext	Man-Systems	Handrail	6.55		SSF HAB A Mass Properties Report (12/15/91)
			Slidewire	2.26		"
			Berth vestibule	1.90		"
		Sub		10.71	5-20%	
MS2	Endcone - fwd/int	Man-Systems	Handrail Assy.	1.02		"
			Closeouts	23.15		"
		Sub		24.17	5-20%	
MS3	Endcone - aft/ext	Man-Systems	Handrail	6.55		"
			Slidewire	2.26		"
			Berth vestibule	1.90		"
		Sub		10.71	5-20%	
MS4	Endcone - aft/int	Man-Systems	Handrail Assy.	1.02		"
			Closeouts	23.15		"
		Sub		24.17	5-20%	
MS5	S/off - ceiling/ starboard	Man-Systems	Closeouts	2.30	5-20%	"
MS6	S/off - floor/	Man-Systems	Closeouts	2.30		"
			Sensor/effector cable	4.53		"
		Sub		6.83	5-20%	
MS7	S/off - floor/port	Man-Systems	Closeouts	2.30		"
			Sensor/effector cable	22.67		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		Sub		**24.97**	5-20%	
MS8	S/off - ceiling/port	Man-Systems	Closeouts	2.30		"
			Sensor/effector cable	4.53		"
		Sub		**6.83**	5-20%	
MS9	Cylinder	Man-Systems	Handrail	6.19		"
			slidewire	1.98		"
			PFR sockets	1.49		"
			Aisle partition assy.	7.14		"
		Sub		**16.80**	5-20%	
	Man-Sys Sub			**127.49**		
TC1	Endcone - fwd/ext	TCS	Insulation Blanket	33.42	5%	SSF HAB A Mass Properties Report (12/15/91)
TC2	Endcone - fwd/int	TCS	Insulation	2.04		"
			Paint	4.50		"
			Tubing, cables,	17.78		"
			Fluid - water	10.89		"
			Cold plates	22.14		"
			Rack flow control assy	6.81		"
		Sub		**64.16**	5%	
TC3	Endcone - aft/ext	TCS	Plumbing	29.73		"
			Heater	4.76		"
			Heat Exchanger	16.37		"
			Transducer	0.95		"
			Temp sensor	0.27		"
			Insulation Blanket	33.42		"
		Sub		**85.50**	5%	
TC4	Endcone - aft/int	TCS	Plumbing	50.24		"
			Valve	1.31		"
			Cold plate	24.42		"
			Bulkhead penetration	3.23		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Sensor effector cable	4.53		*
			Heater	1.05		*
			Fluid (water)	10.88		*
			Paint	2.04		*
			Insulation	4.49		*
		Sub		102.19	5%	
TC5	S/off - ceiling/ starboard	TCS	Plumbing	6.66		*
			Insulation	6.42		*
		Sub		13.08	5%	
TC6	S/off - floor/	TCS	Plumbing	10.29		*
			Sensor/effector cable	9.07		*
			Insulation	5.90		*
			Fluid (water)	13.60		*
		Sub		38.86	5%	
TC7	S/off - floor/port	TCS	Plumbing	39.50		*
			Insulation	6.42		*
			Sensor/effector cable	15.87		*
			Fluid(water)	13.60		*
		Sub		75.39	5%	
TC8	S/off - ceiling/port	TCS	Plumbing	16.93		*
			Insulation	6.42		*
			Sensor/effector cable	15.87		*
			Fluid(water)	36.28		*
		Sub		75.50	5%	
TC9	Cylinder	TCS	Insulation blanket	216.98		*
			Paint	13.74		*
		Sub		230.72	5%	
	TCS Sub			718.82		
Endcone and Standoff Sub				2529.52		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
Rack-Based Functions						
EVS1	EVA Stowage	Pack	Rack alone	72.60	17%	SSF HAB A Mass Properties Report (12/15/91) (Contents of this rack are included as part of EVA suits and consumables)
EVS2			Rack attachments	23.20	11%	"
	Sub			**95.80**		
GS1	Galley Stowage	Pack	Rack structure	72.62	16-17%	SSF HAB A (based on Galley/Wardroom Storage Rack) Mass Properties Report (12/15/91) (Contents of this rack are included as part of food and galley consumables)
			Rack attachments	26.85		"
		M/S	Foot restraints	0.58		"
		92.09	Handrail	1.40		"
			Closeouts	3.12		"
			Drawers	86.99		"
	Sub			**191.56**		
SciS1	Science Stowage	Pack	Rack Structure	72.62	16-17%	SSF HAB A (based on SSF LAC3 Rack without rack generic systems) Mass Properties Report (12/15/91) (Equipment complement may not be
			Rack attachments	26.85		"
		M/S	Closeouts	3.12		"
		90.11	Drawers	86.99		"
SciS2		Exprmnt	Autoclave	34.90		"
SciS3		311.8	Battery charger	10.00		"
SciS4			Cleaning equip	18.10		"
SciS5			Oscilloscope	24.00		"
SciS6			Dosimeter	29.90		"
SciS7			Etching equip	6.00		"
SciS8			Fluid handling tools	65.00		"
SciS9			Gen purpose hand tools	59.00		"
SciS10			Mass measurement	39.90		"
SciS11			Specimen labeling	5.00		"
SciS12			Surgery dissection tools	20.00		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Sub			501.38		
CORU1	Critical ORUs	Pack	Rack Structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) (Necessary and desired spares for Outpost not yet defined - this acts as a placeholder only ??)
			Rack attachments	26.85		"
		M/S	Closeouts	3.12		"
		518.71	Drawers	86.99		"
CORU2			ORUs (?)	428.60	5%	"
	Sub			618.18		
Pers1	Personal/ CHeCS Storage	Pack	Rack Structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) (Personal contents of this rack are included in consumables; CHeCS is included as total for CHeCS
			Rack attachments	26.85		"
		M/S	Closeouts	3.12		"
		90.11	Drawers	86.99		"
	Sub			189.58		
AvOne1	Av Air/TCS/ Crossover	Pack	Rack structure	102.10	5-23%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachments	29.68		"
		EPDS	Cable assy.	3.97	5-23%	"
		12.81	RPC	7.03		"
			RPDA	1.81		"
AvOne2		TCS	Plumbing	16.26	5-23%	"
		125.99	Pump assy.	74.16		"
			Controls	18.01		"
			Cold plate	3.15		"
			Regenerative HX (8000W)	10.72		"
			Fluid (water)	2.72		"
			Insulation	0.97		"
AvOne3		ECLSS-THC	Valves	4.22	5-23%	"
		63.56	Sensors	0.10		"
			Av Air cooling assy.	45.73		"
			Ductwork	9.66		"
			Insulation	3.85		"

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Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
AvOne4		ECLSS-ACS	N2 rack-user I/F assy.	2.38	5%	"
		7.13	Feedthru assy.	1.42		"
			N2 S/O to rack jumper	3.33		"
		ECLSS-FDS	Sensor	0.81	5-23%	"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63		"
		Man-systems	closeouts	5.06		"
	Sub	5.06		350.21		
SPCOne1	SPCU/Airlock Control	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Guess of what rack support would be needed ? - based on HAF4 without removable center panel)
			Rack attachments	35.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
SPCOne2		EVA	SPCU - suit drying assy #1	7.67	25%	SSF WP02 Mass Properties Report (Jan or Jun 91) (one of the two SPCUs and controls are captured
		39.78	SPCU - rack ventilation assy #1	4.85	25%	"
			SPCU - don/doff assy #1	17.01	25%	"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			SPCU - cable set	1.72	25%	"
SPCOne3			Depress/repress console	8.53	25%	"
	Sub			217.76		
GWOne1	Galley/ Wardroom #1	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Based on Galley/Oven/DD rack plus Handwash)
			Rack attachments	17.89		"
		EPDS	Cable assy	3.97		"
		14.78	Converter	1.97		"
			RPC	7.03		"
			RPDA	1.81		"
		TCS	Plumbing	5.17		"
		18.73	Flow control assy.	6.81		"
			Cold plate	3.15		
			Insulation	0.88		"
			Fluid(water)	2.72		"
		ECLSS-THC	Valves	4.23		"
		4.76	Sensor	0.09		"
			Ductwork	0.44		"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63		"
		ECLSS-WRM	Valve	0.47		"
		2.81	Plumbing	2.34		"
GWOne2		Man-systems	Oven	63.80	15%	"
GWOne3		232.59	Water dispenser	74.80	15%	"
GWOne4			Handwash	36.20	5%	"
GWOne5			I/F structure	21.70	15%	"
GWOne6			Stowage	28.10	15%	"
			Restraints/handrails	2.93		"
			closeouts	5.06		"
	Sub			368.06		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
GWTwo1	Galley/ Wardroom #2	Pack	Rack structure	72.62	16-17%	SSF HAB A Mass Properties Report (12/15/91) (Based on Galley Storage + Wardroom table- food for crew in consumables)
			Rack attachments	26.85		"
		Man-systems	Wardroom table and I/Fs	45.20		"
		137.04	Drawers	87.00		"
			Handrail	1.72		"
GWTwo2			closeouts	3.12	5-15%	"
	Sub			236.51		
SW1	Science Workbench	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Based on SSF LAB A Maintenance Workstation)
			Rack attachments	22.43		"
		EPDS	Cable Assy.	3.96		"
		24.51	converter	1.96		"
			RPC	14.06		"
			RPDA	4.53		"
		DMS	MDM	20.86		"
		IAV	Fiber optics	0.16		"
		TCS	Flow control assy.	6.81		"
		25.37	cold plate	3.37		"
			Heat exchanger	10.71		"
			plumbing	0.88		"
			Fluid(water)	2.72		"
			Insulation	0.88		"
		ECLSS-THC	Valve	3.37		"
		3.81	ductwork	0.44		"
		ECLSS-ACS	N2 jumper assy.	0.97		"
				7.14		
		ECLSS-FDS	Sensor	0.81		"
		3.31	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		Man-systems	Restraints, handrails	6.41		"
		18.95	closeouts	5.06		"
			Drawers	7.48		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
SW2		Experiment	Fluid system serv & leak test equip.	101.7	18%	"
SW3		454.97	Maintenance Workstation	279.10	5%	"
SW4			Local controller	20.90	5%	"
SW5			Test eq, meters, etc.	51.00		"
			Wipes, etc.	2.27		
	Sub			655.10		
SG1	Science Glovebox	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (rack and generic systems based on SSF LAB A Maintenance Workstation)
			Rack attachments	22.43		"
		EPDS	Cable Assy.	3.96		"
		24.51	converter	1.96		"
			RPC	14.06		"
			RPDA	4.53		"
		DMS	MDM	20.86		"
		IAV	Fiber optics	0.16		"
		TCS	Flow control assy.	6.81		"
		25.37	cold plate	3.37		"
			Heat exchanger	10.71		"
			plumbing	0.88		"
			Fluid(water)	2.72		"
			Insulation	0.88		"
		ECLSS-THC	Valve	3.37		"
		3.81	ductwork	0.44		"
		ECLSS-ACS	N2 jumper assy.	0.97		"
				7.14		
		ECLSS-FDS	Sensor	0.81		"
		3.31	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		Man-systems	Restraints, handrails	6.41		"
		18.95	closeouts	5.06		"
			Drawers	7.48		"
		Experiment	Glovebox	217.01		Based on "older" number for SSF LAB Materials Science Glovebox

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
	Sub			417.14		
CAOne1	Crossover/ Cabin Air/ PEP	Pack	Rack structure	102.10	5-28%	SSF HAB A Mass Properties Report (12/15/91) (PEP is an unknown - mass not identified in this report ?)
			Rack attachments	29.68		
		EPDS	Cable Assy.	3.96		
		12.79	RPC	7.03		
			RPDA	1.80		
		TCS	Flow control assy.	6.81		
		19.78	cold plate	3.15		
			plumbing	6.14		
			Fluid(water)	2.72		
			Insulation	0.96		
		ECLSS-FDS	Sensor	0.81		
		3.88	CO2 valve	1.19		
			Fire indicator panel	0.68		
			Quick disconnect	0.57		
			CO2 diffuser line	0.63		
		Man-systems	closeouts	5.06		
		5.76	Handrail assy.	0.70		
CAOne2		ECLSS-THC	Cabin Air assy.	106.00	5%	"
CAOne3		139.2	Valves, ducts, etc.	33.20	5%	"
	Sub			313.19		
DRP1	Depress Pump Assembly	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Guess of what rack support would be needed ? - based on HAF4 ,without removable center panel)
			Rack attachments	35.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
DRP2		EVA	Pump assy	78.10	8%	SSF WP02 Mass Properties Report (Jan or Jun 91) (Full rack may not be needed for this equipment ?)
DRP3		116.7	Valves	38.60	25%	"
	Sub			294.68		
WS1	Water Storage	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Outpost may require less water ?)
			Rack attachments	35.57		"
		EPDS	Cable Assy.	3.96		"
		12.79	RPC	7.03		"
			RPDA	1.80		"
		TCS	Flow control assy.	6.81		"
		16.51	cold plate	3.15		"
			plumbing	4.31		"
			Fluid(water)	1.36		"
			Insulation	0.88		"
		ECLSS-THC	Valves	4.23		"
		6.11	Sensors	0.09		"
			Ductwork	1.79		"
		ECLSS-ACS	N2 rack-user I/F assy.	2.38		"
		7.13	Feedthru assy.	1.42		"
			N2 S/O to rack jumper	3.33		"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63		"
WS2		ECLSS-WRM	Water assy	165.00	~10%	"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
WS3		511.53	Water (incl tanks ??)	331.20	~10%	"
WS4			Valves, etc.	15.33	~10%	"
		Man-systems	Closeouts	5.06		"
	Sub			671.20		
WP1	Water Processing	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Outpost may require less water ?)
			Rack attachments	35.57		"
		EPDS	Cable Assy.	3.96		"
		12.79	RPC	7.03		"
			RPDA	1.80		"
		TCS	Flow control assy.	6.81		"
		20.55	cold plate	3.15		"
			plumbing	5.17		"
			Fluid(water)	4.54		"
			Insulation	0.88		"
		ECLSS-THC	Valves	4.24		"
		5.84	Sensors	0.09		"
			Ductwork	1.51		"
		ECLSS-ACS	N2 rack-user I/F assy.	2.38		"
		14.27	Feedthru assy.	1.42		"
			N2 S/O to rack jumper	3.33		"
			O2 Rack user I/F assy.	7.14		"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57		"
			CO2 diffuser line	0.63	~13%	"
WP2		ECLSS-WRM	ECLSS water processor	351.07		"
WP3		518.45	Water (incl tanks ??)	110.12	~13%	"
WP4			Process control water quality monitoring	30.83	~13%	"
WP5			Valves, etc.	26.43	~13%	"
		Man-systems	Closeouts	5.06		"
		5.45	Handrails	0.39		"
	Sub			689.42		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
UP1	Urine Processing/ ARS/ACM	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Outpost may require smaller processor ?)
			Rack attachments	44.54		"
		EPDS	Cable Assy.	3.96		"
		14.75	converter	1.96		"
			RPC	7.03		"
			RPDA	1.80		"
		DMS	MDM	20.86		"
		TCS	Flow control assy.	6.81		"
		19.78	cold plate	3.15		"
			plumbing	6.14		"
			Fluid(water)	2.72		"
			Insulation	0.96		"
		ECLSS-THC	Valves	4.22		"
		6.43	Sensors	0.09		"
			Ductwork	2.12		"
		ECLSS-FDS	Sensor	0.81		"
		3.88	CO2 valve	1.19		"
			Fire indicator panel	0.68		"
			Quick disconnect	0.57	5%	"
			CO2 diffuser line	0.63	5-23%	"
UP4		ECLSS-ARS	ACM assy	100.64	5%	"
UP5		167.32	MCA/COA assy	66.63	5%	"
UP6			Sample line	0.05	5%	"
		ECLSS-WRM	Urine processor assy.	146.67		"
		158.3	Valves	1.43		"
			Plumbing	3.95		"
			Fluid-water	6.25		"
		Man-systems	closeouts	5.06		"
	Sub			513.54		
ARS1	ARS (open loop)	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Outpost may require 2nd CO2 Removal assy ? ORU mass assumed to contain this)
			Rack attachments	38.65		"
		EPDS	Cable Assy.	3.96		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		24.51	converter	1.96		•
			RPC	14.06		•
			RPDA	4.53		•
		DMS	MDM	20.86		•
		TCS	Flow control assy.	6.81		•
		30.93	cold plate	11.72		•
			plumbing	5.17		•
			Fluid(water)	6.35		•
			Insulation	0.88		•
		ECLSS-THC	Valves	4.22		•
		6.44	Sensors	0.10		•
			Ductwork	2.12		•
		ECLSS-ACS	Plumbing	0.71		•
ARS2		ECLSS-ARS	TCCS assy	75.78	5%	•
ARS3		231.83	CO2 Removal assy	148.80	5%	•
ARS4			Valves, etc.	7.25	5%	•
		ECLSS-FDS	Sensor	0.81		•
		3.88	CO2 valve	1.19		•
			Fire indicator panel	0.68		•
			Quick disconnect	0.57		•
			CO2 diffuser line	0.63		•
		Man-systems	closeouts	5.06		•
		5.45	Handrails	0.39		•
	Sub			**435.88**		
AvTwo1	Av Air/ Crossover/ PEP	Pack	Rack structure	102.10	5-28%	SSF HAB A Mass Properties Report (12/15/91) (PEP is an unknown - mass not identified in this report ?)
AvTwo2			Rack attachments	29.68	5-105%	•
		EPDS	Cable Assy.	3.96		•
		12.79	RPC	7.03		•
			RPDA	1.80		•
		TCS	Flow control assy.	6.81		•
		28.78	cold plate	3.15		•
			Regenerative heat	10.72		•
			plumbing	4.42		•
			Fluid(water)	2.72		•

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Insulation	0.96		"
		ECLSS-THC	Av Air assy	45.73		"
		112.29	Valves, sensors, ducts	66.56		"
		ECLSS-FDS	Sensors, valves,	4.91		"
		41.36	Central CO2 supply tank	21.43		"
			Fire indicator panel	0.68		"
			CO2 diffuser line	0.73		"
			Fluid - CO2	13.61		"
		Man-Systems	Closeouts	5.07		"
	Sub			332.07		
SPCTwo1	SPCU	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Guess of what rack support would be needed ? - based on HAF4 without removable center panel)
			Rack attachments	35.58		"
		EPDS	Cable assy.	3.97	5-23%	"
		14.78	RPC	7.03		"
			RPDA	1.81		"
			120VDC to 28VDC	1.97		"
		DMS	Large MDM	20.86		"
		TCS	Disconnects, tubing	5.17		"
		18.73	Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Insulation	0.88		"
			Fluid - water	2.72		"
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		"
		ECLSS-FDS	Disconnects, valve, sensor	2.58		"
		3.89	Fire indicator panel	0.68		"
			CO2 diffuser line	0.63		"
		M/S-Struc	Rack closeout	1.95		"
		5.07	Utility panel closeout	3.12		"
		EVA	SPCU - power supply and battery charger	18.10	25%	SSF WP02 Mass Properties Report (Jan or Jun 91) (second of the two SPCUs and controls are captured here)
		263.56	SPCU - battery storage locker	10.21		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			SPCU - oxygen reg & distr	25.54		•
			SPCU - H2O reg & distr	74.84		•
			SPCU - rack ventilation assy #2	4.85		•
			SPCU - umbilical I/F panel	36.88		•
			SPCU - hose set	8.53		•
			SPCU - cable set	11.93		•
			SPCU - suit dryer assy #2	7.67		•
			SPCU - don/doff assy #2	17.01		•
			SPCU - maintenance kit	19.87		•
			NSTS EMU launch fixtures	8.53		•
			Umbilical set	19.60		•
	Sub			**441.54**		
WS1	Science/DMS / Comm Workstation	Pack	Rack structure	72.62	5-28%	SSF HAB A (based on SSF LAB A ECWS Rack) Mass Properties Report (12/15/91) (Uncertain if this is adequate ?)
			Rack attachments	23.34		•
WS2		EPDS	RPC	7.03		•
		8.84	RPDA	1.81		•
WS3		DMS	Keyboard	2.27		•
		87.55	Hand controller	2.27		•
			Fixed MPAC processor	22.68		•
			Flat panel display	27.22		•
			Control panel	33.11		•
WS4		IAV	ATU	9.50		•
		40.41	ABC	6.34		•
			Audio cable assy	0.48		•
			Video recorder	13.75		•
			Video I/F unit	10.24		•
			Fiber optic cable	0.10		•
		TCS	Rack flow control assy	6.81		•
		32.49	Cold plates	17.12		•
			Tubing	0.88		•
			Fluid - water	6.80		•
			Insulation	0.88		•
		ECLSS-THC	Valves, sensors, diffusers	4.78		•

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
		ECLSS-FDS	sensor, disconnect, line	2.02		•
		3.89	Fire indicator panel	0.68		•
			CO2 release valve	1.19		•
		Man-Systems	Task light	3.10		•
		39.49	IMS bar code reader	11.91		•
			A/V tapes, etc	9.75		•
			Restraints/handrails	6.42		•
			Closeouts	5.07		•
			Single drawer	3.24		•
	Sub			313.41		
CHC1	CHeCS	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Guess of what rack support would be needed ? based similarly to SPCU)
			Rack attachments	35.58		•
		EPDS	Cable assy.	3.97	5-23%	•
		14.78	RPC	7.03		•
			RPDA	1.81		•
			120VDC to 28VDC	1.97		•
		DMS	Large MDM	20.86		•
		TCS	Disconnects, tubing	5.17		•
		18.73	Rack flow control assy	6.81		•
			Cold plate	3.15		•
			Insulation	0.88		•
			Fluid - water	2.72		•
		ECLSS-ACS		7.14		
		ECLSS-THC	Valves, sensors, diffuser, welds, intrarack duct	6.45		•
		ECLSS-FDS	Disconnects, valve, sensor	2.58		•
		3.89	Fire indicator panel	0.68		•
			CO2 diffuser line	0.63		•
		M/S-Struc	Rack closeout	1.95		•
		5.07	Utility panel closeout	3.12		•
CHC2		Medical Support	MTC ALS pack	13.20	5-12%	SSF WP02 Mass Properties Report (Jan or Jun 91) (One rack may not suffice ? This may not be the best medical complement for the Outpost ?)
CHC3		668	Med restraint sys	9.60	5-12%	•

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
CHC4			Ventilator	11.60	5-12%	"
CHC5			Defibrillator	11.40	5-12%	"
CHC6			Hydrocarbon analy	4.10	5-12%	"
CHC7			Organic analy	25.30	5-12%	"
CHC8			Organic sampler	2.80	5-12%	"
CHC9			Ion sel electrodes	5.00	5-12%	"
CHC10			Optical water q. analy	47.90	5-12%	"
CHC11			Water sampler	4.50	5-12%	"
CHC12			Fungal sport monitor	3.70	5-12%	"
CHC13			Surf sampler kit	0.50	5-12%	"
CHC14			H2O microb kit	1.10	5-12%	"
CHC15			Tissue couter	10.80	5-12%	"
CHC16			Intra chgd part direct	54.40	5-12%	"
CHC17			Rad detection monitor	0.90	5-12%	"
CHC18			Physicians equip	11.30	5-12%	"
CHC19			Exam light	5.00	5-12%	"
CHC20			Blood collection kit	6.80	5-12%	"
CHC21			Phys monitoring sys	12.70	5-12%	"
			Other (to meet JSC #)	425.40		Additional mass to meet Boeing understanding of input from JSC
	Sub			853.12		
PHC1	Personal Hygiene Compartmen	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91) (Based on SSF LAB A WMC without commode/urinal - wipes, etc. under PHC consumables)
			Rack attachments	17.89		"
		EPDS	Cable assy	3.97		"
		22.56	RPC	14.06		"
			RPDA	4.53		"
		TCS	Cold plate	3.37		"
		ECLSS-THC	Valve, diffuser, welds	1.31		"
		ECLSS-FDS	Sensor, tubing	1.95		"
PHC2		Man-Systems	Waste Mgmt Compartment	61.92		"
		115.32	Handwash	47.63		"
			Handrails	0.70		"
			Closeouts	5.07		"
	Sub			235.02		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
WMC1	Waste Management Compartmen	Pack	Rack structure	72.62	5-28%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachments	17.89		"
		EPDS	Cable assy	3.97		"
		12.81	RPC	7.03		"
			RPDA	1.81		"
		TCS	Cold plate	3.15		"
		ECLSS-THC	Valves, sensor, diffuser	4.78		"
		ECLSS-FDS	Sensor	0.82		"
		ECLSS-WM	Commode/urinal assy	121.36	19%	"
WMC2		Man-Systems	Waste Mgmt Compartment	52.39		"
WMC3		95.83	Handwash	36.24	5%	"
			Local controller	1.43		"
			Handrail	0.70		"
			Closeouts	5.07		"
	Sub			329.26		
CATwo1	Crossover/ TCS/Cabin Air	Pack	Rack structure	102.10	5-28%	SSF HAB A Mass Properties Report (12/15/91)
			Rack attachment	29.68		"
		EPDS	Cable assy	3.97		"
		12.81	RPC	7.03		"
			RPDA	1.81		"
CATwo2		TCS	Fluid disconnects	15.26		"
		115.28	ITCS pump assy	74.16		"
			System flow control assy	11.19		"
			Rack flow control assy	6.81		"
			Cold plate	3.15		"
			Tubing	1.00		"
			Fluid - water	2.72		"
			Insulation	0.97		"
CATwo3		ECLSS-THC	Cabin Air assy	105.99		"
CATwo4		140.45	Valves, sensor	4.33		"
			Diffuser	0.36		"

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
			Ducts and welds	29.77		"
		ECLSS-ACS	N2 rack-user I/F assy	2.38		"
		7.14	N2 rack feedthru	1.43		"
			N2 jumper	3.33		"
		ECLSS-FDS	Sensor	0.82		"
		3.89	CO2 release valve, disconnect, line	2.39		"
			Fire indicator panel	0.68		"
		Man-Systems	Handrail	0.70		"
		5.77	Closeouts	5.07		"
	Sub			417.10		
Ops1	Ops storage (located in endcone of Outpost)					SSF HAB A Mass Properties Report (12/15/91) (All mass in consumables below)
Rack-based Sub				9680.71		
Sub				17534.21		
Radiation Protection	?		?	?	?	ANALYSIS NEEDED (In Progress)
Airlock						
AL1	STS airlock - Configuratio			450.00		STS data for airlock structure and systems (additional reinforcements may be needed ?)
AL2	Hab-to Airlock Adapter			113.40		Estimated
	Tools and Toolbox			553.20		From SSF WP02 Mass Properties Report (toolbox itself masses 344.7 kg and is definitely oversized)
Sub				1116.60		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
External Support Systems						
ExtSA	Surface access			200.00		Guess for stairs, platforms, etc. (dust control and removal systems and approaches TBD)
ExtC&T	C&T			100.00		Guess for antennaes, etc. (based on earlier studies)
ExtTCS	Thermal Control System			466.00		Sized for using a heat pump during the lunar day
ExtEPS1	Power		Reactants	1507.68		High pressure (3000 psi) stored O2/H2 reactants for regenerable fuel cell operation
			Tanks	2739.21		
ExtEPS2			Arrays, fuel cells, etc.	935.95		All power and thermal masses based on needs of reference layout (thermal includes metabolic load from crew as well)
	Sub			**5182.84**		
Sub				**5948.84**		
Consumables						
ConsH2O	Crew water					Closed system needs included in above ECLSS
ConsFood	Food			360.00		4 people for 45 days (2 kg/p-d)
ConsGW	Galley/ Wardroom (non-food)		Wipes, bags, etc.	103.40		
ConsECLS1	ECLSS expendables		AR	20.90		
ConsECLS2			WRM	151.00		
ConsECLS3			WM	15.40		
ConsECLS4			THC	47.60		
	Sub			234.90		

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Category	Name	System	Subsystem	Mass (kg)	SSF Growth	Comment/Sources
ConsGas	Make-up gas		Repress, Airlock loss, module leakage	516.20		2 represses, 10% airlock loss, standard leakage (including hi-pressure tankage)
ConsO2	Metabolic oxygen			188.00		This assumes cryo storage (high pressure storage would mass at 331 kg). These numbers include
ConsEVAH2O	EVA sublimator water			160.00		16 lbs/EVA for 2 people for 7 hours (22 EVAs per mission)
ConsEMU	Suit spares, etc.			241.10		Assumed part of crew lander ? based on JSC's 3/6/92 value
ConsCHC	CHeCS			23.30		From WP02 Mass Report ?
ConsPH	Personal Hygiene			45.80		From HAB A Mass Report ?
ConsOps	Ops storage		Camera, cleaning, etc.	182.80		From HAB A Mass Report ?
ConsOther	Other crew accom-modations					See 2/5/92 report from JSC
ConsCloth	Clothing			245.00		3 lbs per person-day
Sub				2300.50		Unknowns remain for complete consumables number
Growth				2309.82		
TOTAL				29209.97		

Appendix B

Airlock Mass Breakdown

Airlock Mass Summary

Option / Mass estimate	Airlock Structure	Airlock Utilities	Non-hyperbaric EVA systems in Hab	Hyperbaric support in airlock	Hyperbaric support in Hab	Support/ attach/ Hab mods	Airlock sys. total, w/o tools
Reference Configuration "A" STS Airlock	450		420	—	—	113.4	983.4
Configuration "D" SSF Crewlock *Hyperbaric*	1188.8	428.9	420	192.8	293.2 incl. rack	272.2	2795.9
Non-Hyperbaric	1188.8	337.3	420	—	—	272.2	2218.3
Configuration "G" Internal bulkhead, standard hab module length *Hyperbaric*	1728.2	existing hab utilities assumed sufficient	420	192.8	293.2 incl. rack	2120.5	4754.7
Non-Hyperbaric	415.5	"	420		—	128.8	964.3
Configuration "F" Int. bulkhead, extended hab module length *Hyperbaric*	1728.2	TBD	420	192.8	293.2 incl. rack	2121.5	4755.7+
Non-Hyperbaric	576.1	TBD	420			396.9	1393.0+

Primary Structure Weight Comparison

Outpost Airlock Options

	Non-hyperbaric Mass (kg)			Hyperbaric Mass (kg)		
	Ref (A)	(G)nh	(F)nh	(D)nh or (D)h	(G)h	(F)h
Basic Module Structural Weight	3175	3175	3175	3175	3175	3175
STS Airlock Weight	454					
SSF Crewlock Structural Weight				726		
Airlock-to-Module Adapter	113			227		
New Bulkhead Structural Weight		415	576		1728	1728
New Cylinder Skin			284			851
New Bulkhead/Skin Installation		129	68		91	91
Existing Bulkhead Structural Mod					1111	1111
Existing Skin Mod					850	
Trunnion Modification			45	45	68	68
	3742	3719**	4148	4173	7023 *	7024 *
	0%	-1%	11%	12%	88%	88%

**Using existing mid ring

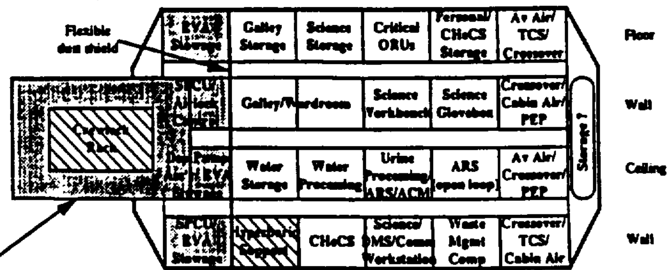
* May be optimized for possible mass reduction

STCAI:AMumbdAct/18Mar92

Crewlock and EVA Systems

Explanations and Back-up

Possible Habitat Layout using Configuration "D" (SSF Crewlock)
(only change from Reference Layout is to replace PHC with Hyperbaric Support rack and switch location with Workstation)



SSF Crewlock

- Nominal Airlock *(includes structure and some utilities)*
- Hyperbaric Support in Airlock *(adds rack and additional utilities)*

Outpost Habitat (derived from SSF Hab A)

- Nominal EVA Systems burdened onto Habitat *(following charts only contain mass for primary EVA systems located in hab; rack mass captured under structures and generic rack systems which support these EVA systems are included under the appropriate system masses)*
- Hyperbaric Support Rack burdened onto Habitat *(this mass contains the rack and its generic systems as well as the primary hyperbaric support system)*

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Crewlock Mass Breakdown

Includes Assumptions Based on WP02 and JSC Data (cont)

Crewlock Utilities:	Hyperbaric Mass (kg)	Assumed Non-hyperbaric Mass (kg)
hardware, fasteners, etc. (1/2 of total)	34.5	34.5
FDS (1/2 of total)	9.7	0
audio (1/2 of total)	7.5	0
video	12.6	12.6
ducting, valves, etc. (1/4 of total)	111.7	37.2
trapped air	9.8	9.8
equalization valves (1/2 of total)	19.3	19.3
depress/repress lines/coupling	34.4	34.4
TCS water (1/10 of total)	10.2	10.2
ECLSS ACS (1/10 of total)	2.5	2.5
ECLSS WRM	0.8	0.8
ITCS (1/10 of total)	1.2	1.2
external umbilicals	30.6	30.6
insulation	6.8	6.8
MLI (1/4 of total)	12.6	12.6
CETA lighting assembly	10.7	10.7
grapple fixture	21.8	21.8
SPCU - CL umbilical interface panel	22.7	22.7
5" insulated CL supply duct	2.6	2.6
depress/repress support structure	30.1	30.1
depress/repress console	7.4	7.4
crewlock umbilical set	29.4	29.4
Utilities Subtotal	*428.9*	*337.3*

may be located in Crewlock rack: depress/repress support structure, depress/repress console, crewlock umbilical set

STCAEM/Aunhab/Aer/27Mar92

Crewlock Mass Breakdown

Includes Assumptions Based on WP02 and JSC Data (cont)

Crewlock Hyperbaric Support:	**Hyperbaric Mass (kg)**	**Assumed Non-hyperbaric Mass (kg)**
Crewlock Rack		
rack structure	58.3	0
rack support structure	4.5	0
hyperbaric ltg support structure	8.8	0
HECA	78.4	0
Other		
hyperbaric lighting assembly	42.8	0
Hyperbaric Support Subtotal	***192.8***	***0***
Items not included in WP02 Mass Properties Report		
HGPCA CL O&C panel	?	*0*
CHeCS breathing mask interface	?	*0*
CHeCS equip utility interface panels	?	*0*
CHeCS restraint system mounting assy	?	*0*
CREWLOCK TOTALS	***2371.5*** *(includes 561 kg of tools, R&MA)*	***2087.1*** *(includes 561 kg of tools, R&MA)*

STCAEM/Aurhab/Aer/27Mar92

Hab Burden for Crewlock Mass Breakdown

Includes Assumptions Based on WP02 and JSC Data

** Rack structure book kept under hab racks; generic rack systems which operate both rack and EVA systems book kept under appropriate hab systems*

	Hyperbaric Mass (kg)	**Assumed Non-hyperbaric Mass (kg)**
1st SPCU Rack *:		
SPCU - suit drying assy #1	7.7	7.7
SPCU - rack ventilation assy #1	4.8	4.8
SPCU - don/doff assy #1	17.0	17.0
SPCU - cable set	1.7	1.7
depress/repress console	8.5	8.5
1st SPCU Subtotal	***39.7***	***39.7*** *(no change)*
2nd SPCU Rack *:		
SPCU - power supply and battery charger	18.1	18.1
SPCU - battery storage locker	10.2	10.2
SPCU - oxygen reg and distr	25.5	25.5
SPCU - H2O reg and distr	74.8	74.8
SPCU - rack ventilation assy #2	4.9	4.9
SPCU - umbilical I/F panel	36.9	36.9
SPCU - hose set	8.5	8.5
SPCU - cable set	11.9	11.9
SPCU - suit dryer assy #2	7.7	7.7
SPCU - don/doff assy #2	17.0	17.0
SPCU - maintenance kit	19.9	19.9
NSTS EMU launch fixtures	8.5	8.5
umbilical set	19.6	19.6
2nd SPCU Subtotal	***263.5***	***263.5*** *(no change)*

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Hab Burden for Crewlock Mass Breakdown

Includes Assumptions Based on WP02 and JSC Data (cont)

* Rack structure book kept under hab racks; generic rack systems which operate both rack and EVA systems book kept under appropriate hab systems	Hyperbaric Mass (kg)	Assumed Non-hyperbaric Mass (kg)
Depress Pump Assembly Rack *:		
airlock depress pump assy	78.1	78.1
valves	38.6	38.6
Depress Pump Subtotal	***116.7***	***116.7*** *(no change)*
Hyperbaric Support in Hab:		
hyperbaric gas and pressure control assy	66.1	0
pass-thru chamber	38.2	0
C&W panel	9.1	0
C&W panel mounting hardware	1.7	0
hab rack and generic systems	178.0	0
Hyperbaric Support in Hab Subtotal	***293.2***	***0***
Items Not Included in WP02 Mass Properties Report:		
CHeCS hyperbaric breathing mask assy	*?*	*0*
ATU	*?*	*?*
light controls	*?*	*0*
CHeCS HAL rack interface	*?*	*0*
HAB BURDEN FOR CREWLOCK TOTALS	***713.1***	***419.9***

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Appendix C

Habitat Modifications Δ1

Habitat Modifications : Δ1

Δ1 Strategy : *Removal or reduction of unnecessary and self contained items from Reference (or SSF Hab "A") systems or addition of required components.*

Structure:

- 1 hatch and its attachments removed from module at airlock end (airlock hatch assumed sufficient)
- 2nd module hatch retained for back-up egress/ingress
- berthing mechanisms removed
- one-half of MMDS removed from habitat module (assumed to be lower half portion)

Life Support:

- intermodule ventilation and extended module ducting and fans deleted
- water vents and STS fuel cell water interface hardware deleted
- water and urine processor reverse osmosis assemblies removed (obsolete hardware)
- ECLSS components associated with PHC eliminated
- N2 rack user I/F and O2/N2 bulkhead penetration and tubing deleted

Crew Systems:

- Man-systems components associated with PHC eliminated (empty PHC rack kept in structures for non-hyperbaric option
- convection oven deleted from galley (microwave oven remains)
- EVA and IVA microgravity restraint and mobility aids removed

Power:

- EPS components associated with PHC eliminated
- power req'ts reduced by deletion of other Δ1 equip and judicious reduction of some duty cycles

Heat Rejection:

- TCS components associated with PHC eliminated

Airlock Systems:

- EVA toolbox mass reduced to 15% of tool mass

STCAEM/19Mar92/crf16

Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

Outpost Hab Options (mass in kg)		Boeing Ref A	Boeing A Δ1	Boeing A Δ2	MSFC #1	MSFC #2
System	**Subsystem**	**04/30/92**	**04/30/92**	**04/30/92**	**(Blkhd A/L)**	**(SSF Crwlk)**
Module Structure		7879	7321	6622	7876	7284
	Primary	3175				
	Secondary	2149	-558	-558		
	Racks	2555		-699		
External Structure					658	658
Life Support		3248	[-221 = 3027]	[-221-347 = 2680]	2777	2777
Medical Support		668	668	668	445	445
Crew Systems		1840	1649	1649	1285	1285
	Endcone/Standoff Support	127	-33	-33		
	Rack Support	639	-34	-34		
	Workstation Support	25				
	Galley/WR Functions	220	-14	-14		
	PHC/WMC Functions	200	-110	-110		
	Critical ORUs	429				
	Surface Access	200				
Storm Shelter					1000	1000
CDMS		761.4	761.4	761.4	707	707
	DMS	563.8				
	IAV	97.6				
	C&T	100				
Power Source		4429	3667	3534 (3316)	3408	3408
	Internal	754	-23	-23		
	External (w/o reactants)	3675	-739	-872 (-1090)		
Heat Rejection System		1746	1660	1645	1898	1998
	Internal	1280	-3	-3		
	External	466	-83	-98		
Airlock System		1537	1297	1041	3295	4267
	SPCU	303				
	Depress pump	117				
	Airlock/adaptor/tools	1117	-240	-496		
Systems Subtotal		22108	20050	18600 (18382)	23349	23829
Contingency		2310	1994	1936 (1896)	2335	2383
Total Systems		24418	22044	20536 (20278)	25684	26212
Consumables		2300.5	2300.5	2300.5	1264	2040
Fuel Cell Reactants		1508	[-308 = 1200]	[-364 = 1144 (-290 = 1218)]	1811	1811
EVA Suits						1260
Internal Science Equip		984	984	984	500	50
Total Landed		29210	26529	24965 (24781)	29259	31373

Lunar Outpost Hab Module Configuration D $\Delta 1$ Mass Breakdown

Outpost Hab Options (mass in kg)		Boeing Config D $\Delta 1$ (Hyperbaric)	Boeing Config D $\Delta 1$ (Non-hyperbaric)
System	**Subsystem**	**04/30/92**	**04/30/92**
Module Structure		*7230*	*7321*
	Primary		
	Secondary	*-558*	*-558*
	Racks	*-91*	*[-91+91]*
External Structure			
Life Support		*[-221 = 3027]*	*[-221 = 3027]*
Medical Support		*668*	*668*
Crew Systems		*1649*	*1649*
	Endcone/Standoff Supp	*-33*	*-33*
	Rack Support	*-34*	*-34*
	Workstation Support		
	Galley/WR Functions	*-14*	*-14*
	PHC/WMC Functions	*-110*	*-110*
	Critical ORUs		
	Surface Access		
Storm Shelter			
CDMS		*761.4*	*761.4*
	DMS		
	IAV		
	C&T		
Power Source		*3959*	*3882*
	Internal	*-23*	*-23*
	External (w/o react)	*-447*	*-524*
Heat Rejection System		*1684*	*1677*
	Internal	*-3*	*-3*
	External	*-59*	*-66*
Airlock System		*3110*	*2532*
	SPCU & HB Support	*578*	*[578-578]*
	Depress pump		
	Airlock/adaptor/tools	*[-240+1235]*	*[-240+1235]*
Systems Subtotal		**22088**	**21517**
Contingency		*2118*	*2085*
Total Systems		**24206**	**23602**
Consumables		*2300.5*	*2300.5*
Fuel Cell Reactants		*[-181 = 1327]*	*[-215 = 1293]*
EVA Suits			
Internal Science Equip		*984*	*984*
Total Landed		**28818**	**28180**

Lunar Outpost Hab Module Configuration G Δ1 Mass Breakdown

Outpost Hab Options (mass in kg)		Boeing Config G Δ1 (Hyperbaric)	Boeing Config G Δ1 (Non-hyperbaric)
System	**Subsystem**	**04/30/92**	**04/30/92**
Module Structure		*7230*	*7321*
	Primary		
	Secondary	*-558*	*-558*
	Racks	*-91*	*[-91+91]*
External Structure			
Life Support		*[-221 = 3027]*	*[-221 = 3027]*
Medical Support		***668***	***668***
Crew Systems		***1649***	***1649***
	Endcone/Standoff Supp	*-33*	*-33*
	Rack Support	*-34*	*-34*
	Workstation Support		
	Galley/WR Functions	*-14*	*-14*
	PHC/WMC Functions	*-110*	*-110*
	Critical ORUs		
	Surface Access		
Storm Shelter			
CDMS		***761.4***	***761.4***
	DMS		
	IAV		
	C&T		
Power Source		***3856***	***3780***
	Internal	*-23*	*-23*
	External (w/o react)	*-550*	*-626*
Heat Rejection System		***1670***	***1676***
	Internal	*-3*	*-3*
	External	*-73*	*-67*
Airlock System		***5068***	***1278***
	SPCU & HB Support	*486*	*[486-486]*
	Depress pump		
	Airlock/adaptor/tools	*[-240+3285]*	*[-240-19.1]*
Systems Subtotal		23929	20160
Contingency		***2072***	***2043***
Total Systems		26001	22203
Consumables		***2300.5***	***2300.5***
Fuel Cell Reactants		*[-226 = 1282]*	*[-259 = 1249]*
EVA Suits			
Internal Science Equip		***984***	***984***
Total Landed		30568	26737

Appendix D

Habitat Modifications Δ2

Habitat Modifications : $\Delta 2$

$\Delta 2$ Strategy: *modifications made to SSF hardware because of known lunar outpost requirements or due to the lunar environment*

$\Delta 2$ contains all modifications made in $\Delta 1$, plus the following:

Structural:
- rack structure weight reduced by 30% from SSF (which is sized by STS- specific launch "pseudo-forcing" functions)

Life Support:
- water separators removed (lunar gravity systems assumed but no mass included)
- two water storage tanks and associated hardware removed (Outpost needs one-half that of SSF)
- water tank pressurization hardware and bellows deleted
- standoff fans removed (natural convection assumed sufficient)

Power:
- power requirements reduced by deletion of other $\Delta 2$ equipment
- power values in parentheses refer to re-electrolyzing fuel cell reactants over number of lunar days between manned visits

Airlock Systems:
- EVA tool stowage (and associated stowage) reduced further

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Lunar Outpost Hab Module Configuration D Δ2 Mass Breakdown

Outpost Hab Options (mass in kg)		Boeing Config D Δ2 (Hyperbaric)	Boeing Config D Δ2 (Non-hyperbaric)
System	**Subsystem**	**04/30/92**	**04/30/92**
Module Structure		6531	6622
	Primary		
	Secondary	-558	-558
	Racks	[-699-91]	[-699-91+91]
External Structure			
Life Support		[-221-347 = 2680]	[-221-347 = 2680]
Medical Support		668	668
Crew Systems		1649	1649
	Endcone/Standoff Supp	-33	-33
	Rack Support	-34	-34
	Workstation Support		
	Galley/WR Functions	-14	-14
	PHC/WMC Functions	-110	-110
	Critical ORUs		
	Surface Access		
Storm Shelter			
CDMS		761.4	761.4
	DMS		
	IAV		
	C&T		
Power Source		3825	3749
	Internal	-23	-23
	External (w/o react)	-581	-657
Heat Rejection System		1668	1663
	Internal	-3	-3
	External	-75	-80
Airlock System		2854	2276
	SPCU & HB Support	578	[578-578]
	Depress pump		
	Airlock/adaptor/tools	[-496+1235]	[-496+1235]
Systems Subtotal		20636	20068
Contingency		2060	2028
Total Systems		22696	22096
Consumables		2300.5	2300.5
Fuel Cell Reactants		[-237 = 1271]	[-270 = 1238]
EVA Suits			
Internal Science Equip		984	984
Total Landed		27252	26618

Lunar Outpost Hab Module Configuration G Δ2 Mass Breakdown

Outpost Hab Options (mass in kg)		Boeing Config G Δ2 (Hyperbaric)	Boeing Config G Δ2 (Non-hyperbaric)
System	**Subsystem**	04/30/92	04/30/92
Module Structure		6531	6622
	Primary		
	Secondary	-558	-558
	Racks	[-699-91]	[-699-91+91]
External Structure			
Life Support		[-221-347 = 2680]	[-221-347 = 2680]
Medical Support		668	668
Crew Systems		1649	1649
	Endcone/Standoff Supp	-33	-33
	Rack Support	-34	-34
	Workstation Support		
	Galley/WR Functions	-14	-14
	PHC/WMC Functions	-110	-110
	Critical ORUs		
	Surface Access		
Storm Shelter			
CDMS		761.4	761.4
	DMS		
	IAV		
	C&T		
Power Source		3723	3647
	Internal	-23	-23
	External (w/o react)	-683	-759
Heat Rejection System		1661	1654
	Internal	-3	-3
	External	-82	-89
Airlock System		4812	1022
	SPCU & HB Support	486	[486-486]
	Depress pump		
	Airlock/adaptor/tools	[-496+3285]	[-496-19.1]
Systems Subtotal		22485	18703
Contingency		2017	1984
Total Systems		24502	20687
Consumables		2300.5	2300.5
Fuel Cell Reactants		[-282 = 1226]	[-315 = 1193]
EVA Suits			
Internal Science Equip		984	984
Total Landed		29013	25165

Appendix E

Outpost Internal Systems Power Budget Summary - Reference

Lunar Campsite Internal Systems Power Budget Summary - Reference

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Electrical Power Distribution System (EPDS)			
Lights	360	50	180
Cable power losses	228	100	228
Data Management System (DMS)			
Ring concentrators	48	100	48
C&W control panel	7.5	100	7.5
EMADS	10	100	10
Multiplexer-demultiplexer (MDM)	313	100	313
Signal Processor Interface			
Data acquisition signal proc.	40	100	40
Internal Audio & Video			
Crew wireless unit batt.	22.5	10	2.25
Camera body	34.3	10	3.5
Zoom lens	9.2	2	0.18
Audio bus couplers (3)	39.9	40	16
Video switching unit	104.5	10	10.5
Audio terminal units (2)	56	30	17
Portable video monitor	155	5	7.75
Totals:	1428 W		884 W

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Thermal Control System (TCS)			
Rack flow control assy.	91	25	23
Crossover assy.	56	~0	~0
ITCS pump assy.	575	100	575
System flow ctrl. assy.	14	50	7
Temp. & Humidity Ctrl. (ECLSS-THC)			
Isolation valves	100	~0	~0
IMV fan	55	100	55
Isolation valves - IMV	100	~0	~0
Rack air ctrl. valves	28	0.025	0.01
Avionics air fan	650	100	650
Av. air - I/F box	10	100	10
Cabin air - electrical I/F	25	100	25
Cabin air fan	450	100	450
Cabin air - Temp. ctrl.	34	1.6	0.57
Cabin air - H2O separator	43	100	43
Fan, ceiling ventilation	22	~0	~0
Standoff fan	220	100	220
Atmosphere control (ECLSS-ACS)			
Isolation valve	2.4	100	2.4
Line press. sensor	1.8	100	1.8
Totals:	2477 W		2063 W

power disk/jrm/18Mar92

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Atmosphere control (ECLSS-ACS)			
Line temperature sensor	0.02	100	0.02
O2/N2 discharge diffuser	6.8	100	6.8
PCA firmware controller	14	100	14
Vent & relief subassembly	1	100	1
Galley / Wardroom			
Handwash			
Diverter motor	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
H2O / air separator	305	4.2	12.7
H2O dispenser			
Chiller	280	0.7	196
Electronic control	16	100	16
Flow control assy.	144	16.7	24
Heater assy.	210	0.7	147
Insertion/dispensing	57	16.7	9.5
Elec. converter (120 -28 VDC)	2.9	100	2.9
Oven	3000	2	60
Totals:	**4356 W**		**526 W**

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Science/workbench			
Bar code reader	20	75	16
Light fixture	50	100	50
Converter	9.6	32	3.1
Local controller	68	~0	~0
Blowers (2)	475	17	81
Control electronics	31.3	33	10.3
Control panels (2)	25	33	8.25
Delta press sensors (5)	50	33	16.5
Press. transducers / sensors	31.5	33	10.3
Temp. sensors	0.4	40	0.16
Vacuum cleaner	237.5	5	11.9
Valves (5)	228	1	2.3
H2O pumps (2)	367.6	10.5	38.6
Lights	112.5	24	27
Science/Glovebox	250	10	25
Crossover - Cabin Air PEP(2)	1404	37	512
Water Storage	70	20	14
Totals:	**3430 W**		**826 W**

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Water Processing			
Water processor	600	33	200
Process ctrl. H2O quality	100	~0	~0
Urine processing			
Distillation assy.	175	16.5	29
Embedded ctrl.	30	100	30
Fluid ctrl. assy.	5	100	5
Fluid pump ORU	70	17	12
Pressure ctrl.	5	17	0.83
Purge pump	70	1.4	1
Air Revitalization System (ECLSS - ARS)			
CO2 vent valve	40	0.001	0.0004
Atmos. comp. monitor	531	100	531
CO2 removal assy.	523.4	100	523.4
Converter	7.2	100	7.2
THC supply valve	20	100	20
Heater	150	57	85.5
TCCS - elec. I/F assy.	10	100	10
Totals:	2337 W		1455 W

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Air Revitilization System -Cont.- (ECLSS - ARS)			
TCCS - flow ctrl. assy.	15.4	100	15.4
Flow meter & cable	1.6	100	1.6
Science / DMS / Comm. / Workstation	996	59	595
Crew Health (CHeCS)	911	10	91
Fire Detection / Suppression			
Flame detector	14	100	14
CO2 release valve	800	0.25	2
Sensors, smoke - duct & area	23.8	100	23.8
Waste Management			
Commode/urinal assy.			
C/U - commode fan	50	2.5	1.25
Compactor	130	0.55	0.72
Fan/separator	250	7.5	19
User panel	25	100	25
Totals:	3217 W		789 W

Lunar Campsite Internal Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
<u>M/S Hygiene</u>			
Waste mgt. & pers hygiene compartments (2)			
Cabin air fans	60	70	42
Cabin air heaters	200	8	16
Cabin air temp. sensors	20	100	20
Lighting systems	60	20	12
Local controllers	54	100	54
Handwashes (2)			
Diverter motors	3.6	4.2	0.15
Local controls	3.2	100	3.2
Signal cond.	12	100	12
Temp. meas.	1	100	1
H2O supply	618	9	56
H2O / air separators	610	4.2	25.4
<u>Hab Growth</u>	393.5	100	393.5
Totals:	2035 W		635 W

Lunar Campsite External Systems Power Budget Summary - Reference (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
<u>Gas Conditioning Assembly (GCA)</u>			
GCA - N2			
N2 cond. assy.	113.6	100	113.6
N2 growth	9.1	100	9.1
GCA - O2			
O2 cond. assy.	108.8	100	108.6
O2 growth	8.7	100	8.7
<u>RPC Modules</u>	312	100	312
<u>Rad. Ht Pump (for avg. load+ 10%)</u>	3749/300	100	3749 /300
Totals: - Day/Night	4301/852 W		4301/852 W

Lunar Campsite Overall Power Budget Summary - Reference

- All Loads in Watts -

	Continuous	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	2499	2085
Galley / Wardroom	4334	504
Science	2952	895
Crossover - cabin air	1404	512
Water stor. / Proc.	1125	292
Air Revit. System	1299	1194
Crew Health	911	91
Fire Det. / Suppression	838	40
Waste Management	455	46
RPC Modules	312	312
M/S Hygiene	1642	242
Hab Growth	393.5	393.5
Gas Cond. Assy.	240	240
Heat Pump - Day	3749	3749
- Night	300	300
Grand Totals: - Day	23582 W	11480 W
- Night	20133 W	8031 W

Appendix F

Outpost Internal Systems Power Budget Summary - Δ1

Lunar Campsite Internal Systems Power Budget Summary - Δ1

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Electrical Power Distribution System (EPDS)			
Lights	360	50	180
Cable power losses	228	100	228
Data Management System (DMS)			
Ring concentrators	48	100	48
C&W control panel	7.5	100	7.5
EMADS	10	100	10
Multiplexer-demultiplexer (MDM)	313	100	313
Signal Processor Interface			
Data acquisition signal proc.	40	100	40
Internal Audio & Video			
Crew wireless unit batt.	22.5	10	2.25
Camera body	34.3	10	3.5
Zoom lens	9.2	2	0.18
Audio bus coupler	39.9	40	16
Video switching unit	104.5	10	10.5
Audio terminal units	56	30	17
Portable video monitor	155	5	7.75
Totals:	1428 W		884 W

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Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Thermal Control System (TCS)			
Rack flow control assy.	91	25	23
Crossover assy.	56	~0	~0
ITCS pump assy.	300	100	300
System flow ctrl. assy.	14	50	7
Temp. & Humidity Ctrl. (ECLSS-THC)			
Isolation valves	100	~0	~0
Rack air ctrl. valves	28	0.025	0.01
Avionics air fan	520	100	520
Av. air - I/F box	10	100	10
Cabin air - electrical I/F	25	100	25
Cabin air fan	360	100	360
Cabin air/H2O separator	43	100	43
Cabin air temp. ctrl.	34	1.6	0.57
Fan, ceiling ventilation	22	~0	~0
Standoff fan	220	100	220
Atmosphere control (ECLSS-ACS)			
Isolation valve	2.4	100	2.4
Line press. sensor	1.8	100	1.8
Line temperature sensor	0.02	100	0.02
O2/N2 discharge diffuser	6.8	100	6.8
Totals:	1834W		1520 W

Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
ECLSS - ACS (Cont.)			
PCA firmware controller	14	100	14
Vent & relief subassembly	1	100	1
Galley / Wardroom			
Handwash			
Diverter motor	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
H2O / air separator	305	4.2	12.7
H2O dispenser			
Chiller	280	0.7	196
Electronic control	16	100	16
Flow control assy.	144	16.7	24
Heater assy.	210	0.7	147
Insertion/dispensing	57	16.7	9.5
Elec. converter (120 -28 VDC)	2.9	100	2.9
Microwave oven	600	2	12
Science/workbench			
Bar code reader	20	75	16
Light fixture	50	10	5
Converter	9.6	32	3.1

Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Science/workbench (Cont.)			
Local controller	68	~0	~0
Control electronics	31.3	33	10.3
Control panels (2)	25	33	8.25
Delta press sensors (5)	50	33	16.5
Press. transducers / sensors	31.5	33	10.3
Temp. sensors	0.4	40	0.16
Vacuum cleaner	237.5	5	11.9
Science/Glovebox	250	10	25
Water Storage	70	20	14
Water Processing			
Water processor	600	33	200
Process ctrl. H2O quality	100	~0	~0
Urine processing			
Distillation assy.	175	16.5	29
Embedded ctrl.	30	100	30
Fluid ctrl. assy.	5	100	5
Fluid pump ORU	70	17	12
Pressure ctrl.	5	17	0.83
Purge pump	70	1.4	1
Totals:	3542 W		851 W

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Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Air Revitalization System (ECLSS - ARS)			
CO2 vent valve	40	0.001	0.0004
Atmos. comp. monitor	531	(nt/day) 25/100	133/531
CO2 removal assy.	523.4	100	523.4
Converter	7.2	100	7.2
THC supply valve	20	100	20
Heater	150	57	85.5
TCCS - elec. I/F assy.	10	100	10
TCCS - flow ctrl. assy.	15.4	100	15.4
Flow meter & cable	1.6	100	1.6
Science / DMS / Comm. / Workstation	996	59	595
Crew Health (CHeCS)	911	10	91
Fire Detection / Suppression			
Flame detector	14	100	14
CO2 release valve	800	0.25	2
Sensors, smoke - duct & area	23.8	100	23.8
Totals:	4043 W		1522 / 1920 W

Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Waste Management			
Commode/urinal assy.			
C/U - commode fan	50	2.5	1.25
Compactor	130	0.55	0.72
Fan/separator	250	7.5	19
User panel	25	100	25
M/S Hygiene			
Waste management compartment			
Cabin air fan	30	70	21
Cabin air heater	100	8	8
Cabin air temp. sensor	10	100	10
Lighting system	30	20	6
Local controller	27	100	27
Handwash			
Diverter motors	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
H2O / air separator	305	4.2	25.4
Totals:	1276 W		179.4 W

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Lunar Campsite Overall Power Budget Summary - Δ1

- All Loads in Watts -

	Continuous	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	1849	1535
Galley / Wardroom	1934	456
Science	1769	702
Water stor. / Proc.	1125	292
Air Revit. System	1298.6	796
Crew Health	911	91
Fire Det. / Suppression	838	40
RPC Modules	312	312
Waste Management	455	46
M/S Hygiene	821	133
Hab Growth	345	345
Gas Cond. Assy.	240	240
Heat Pump - Day	2840	2840
- Night	300	300
Grand Totals: - Day	16166 W	8712 W
- Night	13626 W	6172 W

Lunar Campsite Internal/External Systems Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Hab Growth (scaled from SSF: ~5.4% Pavg)	345	100	345
Gas Conditioning Assembly (GCA)			
GCA - N2			
N2 cond. assy.	113.6	100	113.6
N2 growth	9.1	100	9.1
GCA - O2			
O2 cond. assy.	108.8	100	108.6
O2 growth	8.7	100	8.7
RPC Modules	312	100	312
Rad. Ht Pump (for avg.+10%)	2840 / 300	100	2840 / 300
Totals:	3409 / 869 W		3409 / 869 W

Appendix G

Outpost Internal Systems Power Budget Summary - $\Delta 2$

Lunar Campsite Internal Systems Power Budget Summary - Δ2

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Electrical Power Distribution System (EPDS)			
Lights	360	50	180
Cable power losses	228	100	228
Data Management System (DMS)			
Ring concentrators	48	100	48
C&W control panel	7.5	100	7.5
EMADS	10	100	10
Multiplexer-demultiplexer (MDM)	313	100	313
Signal Processor Interface			
Data acquisition signal proc.	40	100	40
Internal Audio & Video			
Crew wireless unit batt.	22.5	10	2.25
Camera body	34.3	10	3.5
Zoom lens	9.2	2	0.18
Audio bus coupler	39.9	40	16
Video switching unit	104.5	10	10.5
Audio terminal units	56	30	17
Portable video monitor	155	5	7.75
Totals:	1428 W		884 W

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Thermal Control System (TCS)			
Rack flow control assy.	91	25	23
Crossover assy.	56	~0	~0
ITCS pump assy.	300	100	300
System flow ctrl. assy.	14	50	7
Temp. & Humidity Ctrl. (ECLSS-THC)			
Isolation valves	100	~0	~0
Rack air ctrl. valves	28	0.025	0.01
Avionics air fan	520	100	520
Av. air - I/F box	10	100	10
Cabin air - electrical I/F	25	100	25
Cabin air fan	360	100	360
Fan, ceiling ventilation	22	~0	~0
Atmosphere control (ECLSS-ACS)			
Isolation valve	2.4	100	2.4
Line press. sensor	1.8	100	1.8
Line temperature sensor	0.02	100	0.02
O2/N2 discharge diffuser	6.8	100	6.8
PCA firmware controller	14	100	14
Vent & relief subassembly	1	100	1
Totals:	1552 W		1271 W

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Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Galley / Wardroom			
Handwash			
Diverter motor	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
H2O dispenser			
Chiller	280	0.7	196
Electronic control	16	100	16
Flow control assy.	144	16.7	24
Heater assy.	210	0.7	147
Insertion/dispensing	57	16.7	9.5
Elec. converter (120 -28 VDC)	2.9	100	2.9
Microwave oven	600	2	12
Science/workbench			
Bar code reader	20	75	16
Light fixture	50	10	5
Converter	9.6	32	3.1
Local controller	68	~0	~0
Control electronics	31.3	33	10.3
Control panels (2)	25	33	8.25
Delta press sensors (5)	50	33	16.5

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Science/workbench (Cont.)			
Press. transducers / sensors	31.5	33	10.3
Temp. sensors	0.4	40	0.16
Vacuum cleaner	237.5	5	11.9
Science/Glovebox	250	10	25
Water Storage	70	20	14
Water Processing			
Water processor	600	33	200
Process ctrl. H2O quality	100	~0	~0
Urine processing			
Distillation assy.	175	16.5	29
Embedded ctrl.	30	100	30
Fluid ctrl. assy.	5	100	5
Fluid pump ORU	70	17	12
Pressure ctrl.	5	17	0.83
Purge pump	70	1.4	1
Totals:	**3527 W**		**836 W**

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Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Air Revitalization System (ECLSS - ARS)			
CO2 vent valve	40	0.001	0.0004
Atmos. comp. monitor	531	(nt/day) 25/100	133/531
CO2 removal assy.	523.4	100	523.4
Converter	7.2	100	7.2
THC supply valve	20	100	20
Heater	150	57	85.5
TCCS - elec. I/F assy.	10	100	10
TCCS - flow ctrl. assy.	15.4	100	15.4
Flow meter & cable	1.6	100	1.6
Science / DMS / Comm. / Workstation	996	59	595
Crew Health (CHeCS)	911	10	91
Fire Detection / Suppression			
Flame detector	14	100	14
CO2 release valve	800	0.25	2
Sensors, smoke - duct & area	23.8	100	23.8
Totals:	4043 W		1522 / 1920 W

Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Waste Management			
Commode/urinal assy.			
C/U - commode fan	50	2.5	1.25
Compactor	130	0.55	0.72
User panel	25	100	25
M/S Hygiene			
Waste management compartment			
Cabin air fan	30	70	21
Cabin air heater	100	8	8
Cabin air temp. sensor	10	100	10
Lighting system	30	20	6
Local controller	27	100	27
Handwash			
Diverter motors	1.8	4.2	0.075
Local control	1.6	100	1.6
Signal cond.	6	100	6
Temp. meas.	0.5	100	0.5
H2O supply	309	9	28
Totals:	721 W		135 W

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Lunar Campsite Internal/External Systems Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

	Continuous	Duty Cycle(%)	Av. Load
Hab Growth (scaled from SSF; ~5.4% Pavg)	328	100	328
Gas Conditioning Assembly (GCA)			
GCA - N2			
N2 cond. assy.	113.6	100	113.6
N2 growth	9.1	100	9.1
GCA - O2			
O2 cond. assy.	108.8	100	108.6
O2 growth	8.7	100	8.7
RPC Modules	312	100	312
Rad. Ht Pump (for avg.+10%)	2684 / 300	100	2684 / 300
Totals:	3236 / 852 W		3236 / 852 W

Lunar Campsite Overall Power Budget Summary - Δ2

- All Loads in Watts -

	Continuous	Av. Load
EPDS/DMS/SPI/IAV	1428	884
TCS/THC/ACS	1552	1271
Galley / Wardroom	1629	443.6
Science	1769	702
Water stor. / Proc.	1125	292
Air Revit. System	1298.6	796
Crew Health	911	91
Fire Det. / Suppression	838	40
RPC Modules	312	312
Waste Management	205	27
M/S Hygiene	516	108
Hab Growth	328	328
Gas Cond. Assy.	240	240
Heat Pump - Day	2684	2684
- Night	300	300
Grand Totals: - Day	14836 W	8219 W
- Night	12452 W	5835 W

power disk/jrm/18Mar92

Appendix H

Power System Summary

Power System Top Level Area, Mass, & Power Breakdown

- Configuration A - Min A/L -

	Array Pwr. (kW)	Array Area (m2)	Avg. Day. Pwr. (kW)	Avg. Nt. Pwr. (kW)	Heat pump Pwr (kW)	Nom. Electrol. Pwr. (kW)
reference case	33.25	144	12.6	9.1	4.08	10
Δ1 case	26.2	113	9.8	7.24	3.17	10
Δ2 case Δ2* case same as Δ2 case (sized for 1 day contingency)	24.9	107.7	9.3	6.9	3.01	10

* Note: Peak day/night power = average power x 1.5
Required power = Peak power + electrolysis + sys. inefficiency (day)
= 1.5 x avg. night power (night)

Power System Top Level Area, Mass, & Power Breakdown (Cont.)

- Configuration D -

	Array Pwr. (kW)	Array Area (m2)	Avg. Day. Pwr. (kW)	Avg. Nt. Pwr. (kW)	Heat pump Pwr (kW)	Electrol. Pwr. (kW)
<u>Non hyp. A/L</u> Δ1 case	27.9	121	10.4	7.8	3.34	10
Δ2 case	26.6	115	9.9	7.5	3.2	10
<u>Hyperbaric A/L</u> Δ1 case	28.5	123.5	10.6	8.0	3.4	10
Δ2 case	27.2	118	10.1	7.7	3.24	10

* Note: Peak day/night power = average power x 1.5
Required power = Peak power + electrolysis + sys. inefficiency (day)
= 1.5 x avg. night power (night)

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Power System Top Level Area, Mass, & Power Breakdown (Cont.)

- Configuration G -

	Array Pwr. (kW)	Array Area (m2)	Avg. Day. Pwr. (kW)	Avg. Nt. Pwr. (kW)	Heat pump Pwr (kW)	Electrol. Pwr. (kW)
Non hyp. A/L $\Delta 1$ case	27.1	117	10.1	7.6	3.3	10
$\Delta 2$ case	25.8	112	9.6	7.2	3.1	10
Hyperbaric A/L $\Delta 1$ case	27.7	120	10.3	7.7	3.32	10
$\Delta 2$ case	26.4	114	9.8	7.4	3.2	10

* Note: Peak day/night power = average power x 1.5
Required power = Peak power + electrolysis + sys. inefficiency (day)
= 1.5 x avg. night power (night)

power disk/jrm/19Mar92

Power System Mass Summary Configuration A - Min. A/L

	reference	$\Delta 1$	$\Delta 2$	$\Delta 2$*
Fuel Cells	137 kg	109 kg	104 kg	104 kg
Electrolyzer	165 kg	131 kg	126 kg	126 kg
Radiator	49 kg	39 kg	37 kg	37 kg
Hydrogen Reactant	130 kg	103 kg	99 kg	99 kg
Hydrogen Residual	37 kg	30 kg	28 kg	37 kg
Oxygen Reactant	1042 kg	829 kg	791 kg	791 kg
Oxygen Residual	298 kg	237 kg	226 kg	291 kg
Hydrogen Tank(s)	1883 kg	1503 kg	1434 kg	1373 kg
Oxygen Tank(s)	856 kg	686 kg	655 kg	499 kg
Water Tank	59 kg	47 kg	44 kg	44 kg
Solar Array	240 kg	198 kg	191 kg	191 kg
Support Equipment (cables, converters, etc.)	287 kg	224 kg	212 kg	212 kg
Total:	5183 kg	4136 kg	3947 kg	3803 kg

power2 disk/jrm/19Mar92

Power System Mass Summary
Configuration D - Non-hyp. A/L

	Δ1	Δ2
Fuel Cells	117 kg	112 kg
Electrolyzer	142 kg	136 kg
Radiator	42 kg	40 kg
Hydrogen Reactant	112 kg	107 kg
Hydrogen Residual	32 kg	31 kg
Oxygen Reactant	894 kg	855 kg
Oxygen Residual	255 kg	244 kg
Hydrogen Tank(s)	1618 kg	1549 kg
Oxygen Tank(s)	738 kg	707 kg
Water Tank	50 kg	48 kg
Solar Array	208 kg	201 kg
Support Equipment (cables, converters, etc.)	236 kg	225 kg
Total:	4445 kg	4255 kg

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Power System Mass Summary
Configuration G - Non-hyp. A/L

	Δ1	Δ2
Fuel Cells	113 kg	108 kg
Electrolyzer	137 kg	131 kg
Radiator	40 kg	38 kg
Hydrogen Reactant	108 kg	103 kg
Hydrogen Residual	31 kg	30 kg
Oxygen Reactant	863 kg	825 kg
Oxygen Residual	246 kg	235 kg
Hydrogen Tank(s)	1564 kg	1495 kg
Oxygen Tank(s)	713 kg	682 kg
Water Tank	49 kg	46 kg
Solar Array	203 kg	196 kg
Support Equipment (cables, converters, etc.)	231 kg	219 kg
Total:	4298 kg	4109 kg

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Power System Mass Summary
Configuration D - Hyperbaric A/L

	Δ1	Δ2
Fuel Cells	120 kg	115 kg
Electrolyzer	145 kg	139 kg
Radiator	43 kg	41 kg
Hydrogen Reactant	115 kg	110 kg
Hydrogen Residual	33 kg	32 kg
Oxygen Reactant	917 kg	878 kg
Oxygen Residual	262 kg	251 kg
Hydrogen Tank(s)	1659 kg	1590 kg
Oxygen Tank(s)	756 kg	725 kg
Water Tank	52 kg	49 kg
Solar Array	211 kg	204 kg
Support Equipment (cables, converters, etc.)	241 kg	230 kg
Total:	4554 kg	4365 kg

Power System Mass Summary
Configuration G - Hyperbaric A/L

	Δ1	Δ2
Fuel Cells	116 kg	111 kg
Electrolyzer	141 kg	135 kg
Radiator	41 kg	39 kg
Hydrogen Reactant	111 kg	106 kg
Hydrogen Residual	32 kg	30 kg
Oxygen Reactant	886 kg	848 kg
Oxygen Residual	253 kg	242 kg
Hydrogen Tank(s)	1604 kg	1536 kg
Oxygen Tank(s)	732 kg	701 kg
Water Tank	50 kg	48 kg
Solar Array	206 kg	199 kg
Support Equipment (cables, converters, etc.)	235 kg	224 kg
Total:	4407 kg	4218 kg

Appendix I

Heat Rejection Summary

Heat Rejection System Top Level Mass Breakdown

- Configuration A - Min A/L -

	Rej. load (kW)	Rad area (m2)	Rad mass (kg)	Support mass (kg)	Heat pump mass (kg)	Heat exch. mass (kg)	Total Ext. mass (kg)
reference case	13.2	43.2	225	45	134	62.4	466
Δ1 case	10.45	34.1	177	35.4	120	50.4	383
Δ2 case	9.94	32.5	169	34	117	48	368
Δ2* Case same as Δ2 case (sized for peak loads)							

Heat Rejection System Top Level Mass Breakdown (Cont.)

- Configuration D -

	Rej. load (kW)	Rad area (m2)	Rad mass (kg)	Support mass (kg)	Heat pump mass (kg)	Heat exch. mass (kg)	Total Ext. mass (kg)
<u>Non hyp. A/L</u> Δ1 case	11.04	36	187	37.4	123	53	400
Δ2 case	10.53	34.4	179	36	120	51	386
<u>Hyperbaric A/L</u> Δ1 case	11.26	36.7	191	38	124	54	407
Δ2 case	10.73	35	182	36	121	52	391

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Heat Rejection System Top Level Mass Breakdown (Cont.)

- Configuration G -

	Rej. load (kW)	Rad area (m2)	Rad mass (kg)	Support mass (kg)	Heat pump mass (kg)	Heat exch. mass (kg)	Total Ext. mass (kg)
Non hyp. A/L							
Δ1 case	10.98	36	186	37	122.5	53	399
Δ2 case	10.25	33.5	174	34	119	50	377
Hyperbaric A/L							
Δ1 case	10.77	35	183	36	121	52	393
Δ2 case	10.46	34	178	36	120	50	384

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