Space Transfer Concepts and Analyses for Exploration Missions
Contract NAS8-37857

Final Report
Technical Directive 11
May 1992

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

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Space Transfer Concepts and Analyses for Exploration Missions

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Title

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Date
92-5-29

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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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<td>A/B</td>
<td>Aerobrake</td>
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<tr>
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<td>Atmosphere Composition Monitor</td>
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<td>ACS</td>
<td>Atmosphere Control and Supply</td>
</tr>
<tr>
<td>A/L</td>
<td>Air Lock</td>
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<tr>
<td>A1</td>
<td>Aluminum</td>
</tr>
<tr>
<td>AR</td>
<td>Air Revitalization</td>
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<tr>
<td>BFO</td>
<td>Blood-Forming Organs</td>
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<td>BMS</td>
<td>Bed Molecular Sieve</td>
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<td>BREM</td>
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<td>BYRNTRN</td>
<td>Baryon Transport code</td>
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<tr>
<td>CAD/CAM</td>
<td>Computer-Aided Design/Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer Anatomical Man</td>
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<tr>
<td>c.g.</td>
<td>Center of Gravity</td>
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<tr>
<td>CHeCS</td>
<td>Crew Health Care System</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>COP</td>
<td>Coefficient of Performance</td>
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<tr>
<td>ECLSS</td>
<td>Environmental Control and Life Support System</td>
</tr>
<tr>
<td>ECWS</td>
<td>Environmental Control Workstation</td>
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<td>EPS</td>
<td>Electrical Power System</td>
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<td>Fire Detection and Suppression</td>
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<td>FLO</td>
<td>First Lunar Outpost</td>
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<td>g</td>
<td>Acceleration in Earth Gravities (acceleration 9.80665 m/s²)</td>
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<td>h</td>
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<td>ICRP</td>
<td>International Commission on Radiation Protection</td>
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<td>kWₑ</td>
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<td>kWₜ</td>
<td>Kilowatts thermal</td>
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<td>LAS1, LAS2</td>
<td>SSF laboratory science racks 1 and 2</td>
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<tr>
<td>Ibf</td>
<td>Pounds force</td>
</tr>
<tr>
<td>L/D</td>
<td>Lift-To-Drag Ratio</td>
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<td>LEO</td>
<td>Low Earth Orbit</td>
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<td>LiOH</td>
<td>Lithium Hydroxide</td>
</tr>
<tr>
<td>LRU</td>
<td>Lunar Replaceable Unit</td>
</tr>
<tr>
<td>LSS</td>
<td>Life Support System</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
</tr>
<tr>
<td>MEV</td>
<td>Mars Excursion Vehicle</td>
</tr>
<tr>
<td>MLI</td>
<td>Multi Layer Insulation</td>
</tr>
<tr>
<td>MSFC</td>
<td>Marshall Space Flight Center</td>
</tr>
<tr>
<td>MTC</td>
<td>Man-tended Capability</td>
</tr>
<tr>
<td>mt</td>
<td>Metric Ton (1000kg)</td>
</tr>
<tr>
<td>NLS</td>
<td>National Launch System</td>
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<tr>
<td>nh</td>
<td>nonhyperbaric</td>
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<tr>
<td>O₂</td>
<td>Oxygen</td>
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<tr>
<td>Pb V/W</td>
<td>Tank material performance factor (tank burst press/density)</td>
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<td>PDOSE</td>
<td>Proton Dose Code</td>
</tr>
<tr>
<td>PHC</td>
<td>Personal Hygiene Compartment</td>
</tr>
<tr>
<td>psia</td>
<td>pounds per square inch absolute</td>
</tr>
<tr>
<td>RFC</td>
<td>Reactor Fuel Cell</td>
</tr>
<tr>
<td>SEI</td>
<td>Space Exploration Initiative</td>
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<td>Space Transfer Concepts and Analyses for Exploration Missions</td>
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<tr>
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<tr>
<td>t</td>
<td>metric tons (1000 kg), thickness</td>
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<tr>
<td>TCS</td>
<td>Thermal Control System</td>
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<tr>
<td>THC</td>
<td>Temperature and Humidity Control</td>
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<tr>
<td>Ti</td>
<td>Titanium</td>
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<td>TPS</td>
<td>Thermal Protection System</td>
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<td>ρ</td>
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<td>E</td>
<td>Modulus of Elasticity (Pa)</td>
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ABBREVIATIONS AND ACRONYMS (Concluded)

G  Modulus of Rigidity (Pa)
μ  Poisson's Ratio
σ_{ty}  Allowable Tensile Yield Stress (Pa)
σ_{ey}  Allowable Compressive Yield Stress (Pa)
σ_{sv}  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 and 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,
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
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.
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)

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<th></th>
<th>A</th>
<th>(D)nh</th>
<th>(D)h</th>
<th>(G)nh</th>
<th>(G)h</th>
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<td>7,879</td>
<td>7,788**</td>
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<td>7,788**</td>
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<td>16,879</td>
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<td>33,424</td>
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</table>

** Hhab 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 Hhab). 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

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### Figure 2-5. Lunar Outpost Habitation Module Boeing Configuration-A Reference Layout

- **Flexible dust shield**
- **AIRLOCK**
  - SPCU/airlock control
  - Depress pump assy/EVA stowage
  - SPCU/EVA stowage

- **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 (2)

- **Adds:**
  - SPCUs (2)
  - D/R pumps (1)
  - EVA stowage (1)
  - CheCS (1)
  - Expands: DMS/Comm into Workstation

- **Exchanges 8 racks in SSF Hab A**
- **Waste management comp**
- **Crossover/TCS/cabin air**

- **Personal hygiene comp**
- **Cabin air/PEP**
- **Science Crossover/Glovebox (1)**
- **Science Workbench (1)**
- **Science Storage (1)**

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**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 unusable. 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 hyperbaries 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 (A1) 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 (A1) 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 A1 modifications along with mass details for each of the three configurations are given in appendix C. Mass summaries for A1 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

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<tr>
<th>A1 Airlock Options (mass in kg)</th>
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<tr>
<td>** 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.)</td>
</tr>
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</table>

Figure 2-6. Mass Summary for A1 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.
Hab, contents, and airlock/EVA support

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<th>(D)h</th>
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<td>27,252</td>
<td>25,165</td>
<td>29,013</td>
</tr>
</tbody>
</table>

* Numbers in parenthesis for Configuration A2 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.)

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 A2 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 (A2 and GnhA2) 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...
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, regenerative 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 crew members 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. Crew members 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\textsubscript{2} as the feed source and convert it to O\textsubscript{2} (closed loop). Conversion can be accomplished in a reactor which either converts CO\textsubscript{2} directly to O\textsubscript{2}, or produces water as an intermediate step which is then electrolyzed to produce...
oxygen. Either way, CO₂ 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 CO₂ waste, produced as crewmembers consume O₂, 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 CO₂ are lithium hydroxide (LiOH) absorption and molecular sieve extraction. The former is a chemical process which permanently binds the CO₂, and the spent LiOH is discarded. In the latter, the CO₂ is preferentially absorbed onto a zeolite material which can be desorbed using vacuum or heat. If one of the regenerative technologies to recover O₂ from CO₂ is used, a compatible CO₂ 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/kWe, kg/kW₁, kg/m³) 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](image)
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 O₂, four bed molecular sieve (4BMS) CO₂ 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.
<table>
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<th>Mass</th>
</tr>
</thead>
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<tr>
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</tr>
<tr>
<td></td>
<td>Delete IMV components</td>
<td>Delta-1</td>
<td>-144.6</td>
</tr>
<tr>
<td></td>
<td>Delete refrigerator/freezer</td>
<td>Delta-0</td>
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<tr>
<td></td>
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<td></td>
<td>Delete PHC rack support</td>
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<tr>
<td></td>
<td>Add rack support for 6 additional powered racks</td>
<td>Delta-0</td>
<td>73.7</td>
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<tr>
<td></td>
<td>Remove water separator</td>
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<tr>
<td></td>
<td>Delete 8” duct delta for extended module</td>
<td>Delta-1</td>
<td>-12.89</td>
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<tr>
<td></td>
<td>Delete standoff fans</td>
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<td></td>
<td></td>
<td>+35.6</td>
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<td>Remove half water storage and associated hardware</td>
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<td></td>
<td>Delete obsolete hardware components (RO-old data)</td>
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<td>Delete water vent</td>
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<td>-98.4</td>
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<td>Delete tank pressurization hardware</td>
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<td>Reduce tank mass (remove bellows)</td>
<td>Delta-2</td>
<td>-21.6</td>
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<td></td>
<td>Delete STS interface hardware</td>
<td>Delta-1</td>
<td>-13.7</td>
</tr>
<tr>
<td></td>
<td>Delete 8” duct delta for extended module</td>
<td>Delta-1</td>
<td>-2.6</td>
</tr>
<tr>
<td></td>
<td>Remove urine fan/seperator</td>
<td>Delta-2</td>
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<td></td>
<td>-907.8</td>
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<tr>
<td><strong>Adjustments to Lunar Outpost ECLSS</strong></td>
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<td></td>
<td><strong>-1317.0</strong></td>
</tr>
</tbody>
</table>

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 (CO₂ 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

<table>
<thead>
<tr>
<th>SSF Modules</th>
<th>Lunar Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical orientation</td>
<td>Horizontal orientation</td>
</tr>
<tr>
<td>Launched on Shuttle</td>
<td>Launches on HLLV-derived vehicle</td>
</tr>
<tr>
<td>Launch loads</td>
<td>Launch loads</td>
</tr>
<tr>
<td>Axial: 0.2 g's</td>
<td>Axial: 4.0 g's</td>
</tr>
<tr>
<td>Lateral: 2.5 g's</td>
<td>Lateral: 2.7 g's</td>
</tr>
<tr>
<td>Modules mounted on trunnions</td>
<td>Modules required to survive an abort landing</td>
</tr>
<tr>
<td>Landing loads</td>
<td>Landing loads</td>
</tr>
<tr>
<td>Axial: 1.7 g's</td>
<td>Axial:</td>
</tr>
<tr>
<td>Lateral: 3.6 g's</td>
<td>Lateral:</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Axis</th>
<th>Load factor (g)</th>
<th>Total static load (lbf)</th>
<th>No. of reaction points</th>
<th>Maximum static reaction (lbf)</th>
<th>Maximum dynamic reaction (lbf)</th>
<th>Dynamic amplification factor</th>
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<tr>
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<td>1</td>
<td>38600</td>
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<td>4</td>
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Abort landing

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Lunar Hab Configuration 51000

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Lunar Hab Configuration 44000

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<td>44000</td>
<td>74227</td>
<td>1.69</td>
</tr>
</tbody>
</table>

* 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.

<table>
<thead>
<tr>
<th>Design limit load factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nx</td>
</tr>
<tr>
<td>Hab</td>
</tr>
<tr>
<td>Racks</td>
</tr>
</tbody>
</table>

* 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

<table>
<thead>
<tr>
<th></th>
<th>Nonhyperbaric Mass (kg)</th>
<th>Hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ref (A)</td>
<td>(G)nh</td>
</tr>
<tr>
<td>Basic module structural weight</td>
<td>3175</td>
<td>3175</td>
</tr>
<tr>
<td>STS airlock weight</td>
<td>454</td>
<td>726</td>
</tr>
<tr>
<td>SSF crewlock structural weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airlock-to-module adapter</td>
<td>113</td>
<td>227</td>
</tr>
<tr>
<td>New bulkhead structural weight</td>
<td>415</td>
<td>576</td>
</tr>
<tr>
<td>New cylinder skin</td>
<td>284</td>
<td></td>
</tr>
<tr>
<td>New bulkhead/skin installation</td>
<td>129</td>
<td>68</td>
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<tr>
<td>Existing bulkhead structural mod</td>
<td>1111</td>
<td>1111</td>
</tr>
<tr>
<td>Existing skin mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunnion modification</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>3742</td>
<td>3719**</td>
</tr>
<tr>
<td>Percent Change from Ref. (A)</td>
<td>0%</td>
<td>-1%</td>
</tr>
</tbody>
</table>

** 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 (Δ1) is shown in figure 5-2, and the detailed breakdown is included in appendix F. The major differences from the reference included the following:
<table>
<thead>
<tr>
<th>Item</th>
<th>Connected Load</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDS/DMS/PI/IAV</td>
<td>1428</td>
<td>884</td>
</tr>
<tr>
<td>TCS/THC/ACS</td>
<td>2499</td>
<td>2085</td>
</tr>
<tr>
<td>Galley/Wardroom</td>
<td>4334</td>
<td>504</td>
</tr>
<tr>
<td>Science</td>
<td>2952</td>
<td>895</td>
</tr>
<tr>
<td>Crossover - cabin air</td>
<td>1404</td>
<td>512</td>
</tr>
<tr>
<td>Water stor./Proc.</td>
<td>1125</td>
<td>292</td>
</tr>
<tr>
<td>Air Revit. System</td>
<td>1299</td>
<td>1194</td>
</tr>
<tr>
<td>Crew Health</td>
<td>911</td>
<td>91</td>
</tr>
<tr>
<td>Fire Det./Suppression</td>
<td>838</td>
<td>40</td>
</tr>
<tr>
<td>Waste Management</td>
<td>455</td>
<td>46</td>
</tr>
<tr>
<td>RPC Modules</td>
<td>312</td>
<td>312</td>
</tr>
<tr>
<td>M/S Hygiene</td>
<td>1642</td>
<td>242</td>
</tr>
<tr>
<td>Hab Growth</td>
<td>393.5</td>
<td>393.5</td>
</tr>
<tr>
<td>Gas Cond. Assembly</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Heat Pump - Day</td>
<td>3749</td>
<td>3749</td>
</tr>
<tr>
<td>- Night</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Totals: - Day</td>
<td>23582 W</td>
<td>11480 W</td>
</tr>
<tr>
<td>- Night</td>
<td>20133 W</td>
<td>8031 W</td>
</tr>
</tbody>
</table>

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

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

Figure 5-2. Lunar Campsite Overall Power Budget Summary - Δ1
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, H2O 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 A1 case was further revised to reflect the removal of standoff fans and water/air separators (not required in gravity field). The final revision, A2, is summarized in figure 5-3; as with the reference and A1 case, the detailed breakdown is included in appendix G. The A2* case is simply the A2 case with multiple lunar day fuel cell recharge. The reduction in average power for the A2 configuration was roughly 300 - 500 W. Major differences from the A2 case included the following:
   a. Some components removed/modified as follows:
      1. TCS - removed standoff fans.
      2. Crew systems - removed all H2O/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 night-time 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).

<table>
<thead>
<tr>
<th>Item</th>
<th>All Loads in Watts</th>
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<tr>
<td></td>
<td>Connected Load</td>
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<td>EPDS/DMS/SP/IA</td>
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</tr>
<tr>
<td>TCS/TH/ACS</td>
<td>1552</td>
</tr>
<tr>
<td>Galley/Wardroom</td>
<td>1629</td>
</tr>
<tr>
<td>Science</td>
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<tr>
<td>Waterstor:Proor</td>
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<tr>
<td>Air Revit System</td>
<td>12986</td>
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<tr>
<td>Crew Health</td>
<td>911</td>
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<tr>
<td>Fire Det./Suppression</td>
<td>838</td>
</tr>
<tr>
<td>RPC Modules</td>
<td>312</td>
</tr>
<tr>
<td>Waste Management</td>
<td>205</td>
</tr>
<tr>
<td>MS Hygiene</td>
<td>516</td>
</tr>
<tr>
<td>Hab Growth</td>
<td>328</td>
</tr>
<tr>
<td>Gas Cond. Assembly</td>
<td>240</td>
</tr>
<tr>
<td>Heat Pump - Day</td>
<td>14836 W</td>
</tr>
<tr>
<td>- Night</td>
<td>12452 W</td>
</tr>
</tbody>
</table>

**Figure 5-3. Lunar Campsite Overall Power Budget Summary - A2**

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
<table>
<thead>
<tr>
<th>Item</th>
<th>Connected Load</th>
<th>Duty Cycle (%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control/sel.</td>
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<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>A/L ACS</td>
<td>11.6</td>
<td>100</td>
<td>11.6</td>
</tr>
<tr>
<td>Flame detector</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>Smoke sensors</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>A/L audio</td>
<td>84.6</td>
<td>10</td>
<td>8.5</td>
</tr>
<tr>
<td>A/L video</td>
<td>43.5</td>
<td>10</td>
<td>4.4</td>
</tr>
<tr>
<td>SPCU</td>
<td>1240</td>
<td>27</td>
<td>335</td>
</tr>
<tr>
<td>CMDM</td>
<td>106</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>RPCMs</td>
<td>45</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>Depress D&amp;C Panels (2)</td>
<td>20</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Pumps (config Av/G)</td>
<td>1684/3150</td>
<td>10</td>
<td>236/441</td>
</tr>
<tr>
<td>Heat Pump Delta</td>
<td>327/418 W (Avg)</td>
<td>491/627 W (Peak)</td>
<td>1069/1365 W</td>
</tr>
<tr>
<td><strong>D NONHYPERBARIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabin air fan</td>
<td>292</td>
<td>100</td>
<td>292</td>
</tr>
<tr>
<td>Cab air - electrical I/F</td>
<td>25</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Cab air temp. ctrl.</td>
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<td>1.7</td>
<td>0.57</td>
</tr>
<tr>
<td>Cab air - H2O sep.</td>
<td>43</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td>Control/sel.</td>
<td>9.6</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>A/L ACS</td>
<td>11.6</td>
<td>100</td>
<td>11.6</td>
</tr>
<tr>
<td>Flame detector</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>Smoke sensors</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>A/L audio</td>
<td>84.6</td>
<td>10</td>
<td>8.5</td>
</tr>
<tr>
<td>A/L video</td>
<td>43.5</td>
<td>57</td>
<td>24.6</td>
</tr>
<tr>
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</tr>
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<td>50</td>
<td>53</td>
</tr>
<tr>
<td>RPCMs</td>
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<td>100</td>
<td>45</td>
</tr>
<tr>
<td>O2-N2 control/vent</td>
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<td>11.1</td>
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<tr>
<td>Depress D&amp;C Panels (2)</td>
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<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Pumps (config D/G)</td>
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<td>236/441</td>
</tr>
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<td>500/530 W (Avg)</td>
<td>750 W (Peak)</td>
<td>1633/1928 W</td>
</tr>
<tr>
<td><strong>D&amp;G HYPERBARIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabin air fan</td>
<td>292</td>
<td>100</td>
<td>292</td>
</tr>
<tr>
<td>Cab air - electrical I/F</td>
<td>25</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Cab air temp. ctrl.</td>
<td>34</td>
<td>1.7</td>
<td>0.57</td>
</tr>
<tr>
<td>Cab air - H2O sep.</td>
<td>43</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td>Control/sel.</td>
<td>9.6</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>A/L ACS</td>
<td>11.6</td>
<td>100</td>
<td>11.6</td>
</tr>
<tr>
<td>Flame detector</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>Smoke sensors</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>A/L audio</td>
<td>84.6</td>
<td>10</td>
<td>8.5</td>
</tr>
<tr>
<td>A/L video</td>
<td>43.5</td>
<td>57</td>
<td>24.6</td>
</tr>
<tr>
<td>SPCU</td>
<td>1240</td>
<td>27</td>
<td>335</td>
</tr>
<tr>
<td>CMDM</td>
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<td>50</td>
<td>53</td>
</tr>
<tr>
<td>RPCMs</td>
<td>45</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>O2-N2 control/vent</td>
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<td>100</td>
<td>11.1</td>
</tr>
<tr>
<td>Depress D&amp;C Panels (2)</td>
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<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Pumps (config D/G)</td>
<td>1684/3150</td>
<td>14</td>
<td>236/441</td>
</tr>
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<td>Hyperbaric audio I/F unit</td>
<td>28.6</td>
<td>2</td>
<td>0.452</td>
</tr>
<tr>
<td>Hyperbaric gas and press ctrl. assembly</td>
<td>100</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Hyperbaric environ. ctrl. assembly</td>
<td>1175</td>
<td>10</td>
<td>118</td>
</tr>
<tr>
<td>Hyperbaric lighting assembly</td>
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<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Heat Pump Delta</td>
<td>561/478 6* W (Avg)</td>
<td>841/718 W (Peak)</td>
<td>1833/1956 W</td>
</tr>
<tr>
<td>Total</td>
<td>5081/6547 W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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 H₂ and O₂ 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 180-day 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 (1-inch 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
"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.

<table>
<thead>
<tr>
<th>Item</th>
<th>Min A/L</th>
<th>Nonhyperbaric</th>
<th>Hyperbaric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ref</td>
<td>Δ1</td>
<td>Δ2</td>
</tr>
<tr>
<td>(A) STS A/L</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>(D) Crew Lock</td>
<td></td>
<td>X*</td>
<td>X*</td>
</tr>
<tr>
<td>(G) Int. Bulkhead</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Power System Overall Mass Matrix (all masses in kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Min A/L</th>
<th>Nonhyperbaric</th>
<th>Hyperbaric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ref</td>
<td>Δ1</td>
<td>Δ2</td>
</tr>
<tr>
<td>(A) STS A/L</td>
<td>5183</td>
<td>4136</td>
<td>3947</td>
</tr>
<tr>
<td>(D) Crew Lock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(G) Int. Bulkhead</td>
<td>4298</td>
<td>4109</td>
<td>5603</td>
</tr>
</tbody>
</table>

*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

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

Figure 5-7. Power System Mass Summary
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 (PbV/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.
<table>
<thead>
<tr>
<th>Item</th>
<th>Assumption</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power level</td>
<td>Varies w/o pt and A/L combination</td>
<td>System Requirements</td>
</tr>
<tr>
<td>Discharge cycle time</td>
<td>354 hrs</td>
<td>Lunar Night</td>
</tr>
<tr>
<td>Total number of cycles</td>
<td>5+</td>
<td>System more sens. to miss. length</td>
</tr>
<tr>
<td>Solar cell selection</td>
<td>CLEVEL/GaAs/CIS</td>
<td>Several leading candidates</td>
</tr>
<tr>
<td>Reactant storage press.</td>
<td>3000 psi</td>
<td>Minimize high press vol.</td>
</tr>
<tr>
<td>Reactant storage temperature</td>
<td>300°K</td>
<td>Typical outer surface equil. temp.</td>
</tr>
<tr>
<td>Tank type</td>
<td>Filament wound composite</td>
<td>Lower tank mass</td>
</tr>
<tr>
<td>Tank yield strength</td>
<td>~125 ksi</td>
<td>Derived from vendor data</td>
</tr>
<tr>
<td>Tank safety factor</td>
<td>1.5</td>
<td>Typical press vessel s f</td>
</tr>
<tr>
<td>Array supplied power</td>
<td>~25 to 33 kW</td>
<td>Day power fuel cell recharge, and margin (varies w/o opt)</td>
</tr>
</tbody>
</table>

**Figure 5-9. Power System Assumptions and Options**

\[
\text{PbV/W (in } \times 10^{6} \text{)}
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Spherical</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>2219-T87 Al</td>
<td>324 - 360</td>
<td>243 - 270</td>
</tr>
<tr>
<td>6AL-4V Ti</td>
<td>533 - 594</td>
<td>400 - 445</td>
</tr>
<tr>
<td>Kevlar-49 Titanium</td>
<td>800 - 900</td>
<td>NA</td>
</tr>
<tr>
<td>Graphite Titanium</td>
<td>800 - 1000</td>
<td>NA</td>
</tr>
<tr>
<td>Kevlar-49 Aluminum</td>
<td>550 - 700</td>
<td>550 - 700</td>
</tr>
<tr>
<td>Graphite/Aluminum*</td>
<td>800 - 1000</td>
<td>800 - 1000</td>
</tr>
</tbody>
</table>

* Aerospace/commercial

**Figure 5-10. Typical Performance Factors**

A brief example is shown below to illustrate this point:

\[
\text{PbV/W} = 360000 \text{ in (Aluminum); PbV/W} = 900000 \text{ in (typical of composite)}
\]

The mass of the tank is proportional to working stress, \( \sigma \), which is, in turn, proportional to performance factors:

\[
\frac{m_{\text{Al tank}}}{m_{\text{comp tank}}} \propto \frac{\sigma_{\text{Al}}}{\sigma_{\text{comp}}} \cdot \frac{P_{\text{V/W}}_{\text{Al}}}{P_{\text{V/W}}_{\text{comp}}} \propto \frac{360000}{900000} = 0.4
\]

Either of two tank sizing options give same results:

a. Size as for aluminum, with scaled \( \sigma \) and above ratio (ex: 50 ksi/0.4 = 125 ksi)
b. Scale tank mass by above ratio \([m_{\text{tank (comp)}} = m_{\text{tank (Al)}} \times 0.4]\)
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.

<table>
<thead>
<tr>
<th>Item</th>
<th>Min A/L ref</th>
<th>Δ1</th>
<th>Δ2</th>
<th>Nonhyperbaric ref</th>
<th>Δ1</th>
<th>Δ2</th>
<th>Hyperbaric ref</th>
<th>Δ1</th>
<th>Δ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) STS A/L</td>
<td>4365</td>
<td>3480</td>
<td>3323</td>
<td>3341*</td>
<td>4625</td>
<td>3736</td>
<td>3578</td>
<td>4717</td>
<td>3827</td>
</tr>
<tr>
<td>(D) Crewlock</td>
<td>3615</td>
<td>3457</td>
<td>4761</td>
<td></td>
<td></td>
<td></td>
<td>4773</td>
<td>3705</td>
<td>3548</td>
</tr>
<tr>
<td>(G) Int. Bulkhead</td>
<td>3615</td>
<td>3457</td>
<td>4761</td>
<td></td>
<td></td>
<td></td>
<td>4773</td>
<td>3705</td>
<td>3548</td>
</tr>
</tbody>
</table>

*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;

\[ q = \varepsilon a (T_{surf}^4 - T_{sink}^4) \]
Where \( q \) is the heat rejection per unit area, and \( \varepsilon \) and \( \alpha \) 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 affects 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:

1. SSF-derived internal heat acquisition/transport system design.
2. Vertical unshielded radiator utilized; heat-pump augmented rejection.
3. Electrolyzer rejects its own heat passively.
5. Compressor isentropic efficiency = 0.6 (from terrestrial systems data).
6. Heat-pump system mass \( \sim 31.83 \times Q \) (from terrestrial systems data).
7. Heat-pump power provided by main arrays.
8. \( \alpha_{\text{rad}} = 0.25 \) (absorptivity) \( \varepsilon_{\text{rad}} = 0.8 \) (emissivity) \( Q_{\text{nominal}} = 132 \) W/person x 4 crew.
9. Compressor specific mass \( \sim 5.2 \text{ kg/m}^2 \)
10. Radiator sized for \( 1.5 \times Q_{\text{nominal}} \) at lunar day "worst case".

Radiator surface properties were taken from SSF End Of Life (EOL) data. More favorable EOL surface property data (higher \( \varepsilon \), lower \( \alpha \)) 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:

1. SSF-derived internal heat acquisition/transport design.
2. Electrolyzer rejects its own heat passively.
4. Compressor isentropic efficiency = 0.6.
e. Heat-pump system mass \( -31.83 \times Q_{\text{rej}} \).
f. Heat-pump power provided by main arrays.
g. \( \alpha_{\text{rad}} = 0.25 \)  
f in efficiency = 0.85  
\( \varepsilon_{\text{rad}} = 0.8 \)  
radiator rej. temp. = 360 K  
specific mass \( \sim 5.2 \text{ kg/m}^2 \)
h. Radiator sized for \( 1.5 \times Q_{\text{nominal}} \) at lunar day "worst case".
i. \( Q_{\text{metabolic}} = 132 \text{ W/person} \times 4 \text{ crew} \).

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.

### Table 5-12: Heat-Rejection System External Mass Summary Matrix (all masses in kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Min A/L</th>
<th></th>
<th></th>
<th>Non Hyperbaric</th>
<th></th>
<th></th>
<th>Hyperbaric</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ref</td>
<td>( \Delta 1 )</td>
<td>( \Delta 2 )</td>
<td>ref</td>
<td>( \Delta 1 )</td>
<td>( \Delta 2 )</td>
<td>ref</td>
<td>( \Delta 1 )</td>
<td>( \Delta 2 )</td>
</tr>
<tr>
<td>(A) STS A/L</td>
<td>466</td>
<td>383</td>
<td>368</td>
<td>400</td>
<td>386</td>
<td>407</td>
<td>391</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D) Crewlock</td>
<td>399</td>
<td>377</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(G) Int. Bulkhead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Multi-day recharge case.

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

### Table 5-13: Heat-Rejection System Top-Level Mass Breakdown

<table>
<thead>
<tr>
<th>Item</th>
<th>Rej. Load (kW)</th>
<th>Rad Area (m(^2))</th>
<th>Rad Mass (kg)</th>
<th>Support Mass (kg)</th>
<th>Heat Pump Mass (kg)</th>
<th>Heat Exch. Mass (kg)</th>
<th>Total Ext. Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference case</td>
<td>13.2</td>
<td>43.2</td>
<td>225</td>
<td>45</td>
<td>134</td>
<td>62.4</td>
<td>466</td>
</tr>
<tr>
<td>( \Delta 1 ) case</td>
<td>10.45</td>
<td>34.1</td>
<td>177</td>
<td>35.4</td>
<td>120</td>
<td>50.4</td>
<td>383</td>
</tr>
<tr>
<td>( \Delta 2 ) case</td>
<td>9.94</td>
<td>32.5</td>
<td>169</td>
<td>34</td>
<td>117</td>
<td>48</td>
<td>368</td>
</tr>
<tr>
<td>( \Delta 2^* ) case same as ( \Delta 2 ) case (sized for peak loads)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.

**Image Description**

- **Radiation Sources**
  - Solar proton events
  - Galactic cosmic rays
  - Geomagnetically trapped particles

- **Design Requirements**
  - NCRP No. 98
  - ICRP 26
  - NASA approved limits

- **Design and Analysis Review**

**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 $2\pi$ (specifically for surface operations; otherwise normally $4\pi$) 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

![Differential Lunar Spectra Comparison Feb '56, Aug '72, Oct '89 SPEs](image)
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/cm³) 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

<table>
<thead>
<tr>
<th>Rack Location</th>
<th>Mass (kg)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>292.1</td>
<td>0.156</td>
</tr>
<tr>
<td>C2</td>
<td>671.4**</td>
<td>a</td>
</tr>
<tr>
<td>C3</td>
<td>689.7*</td>
<td>b</td>
</tr>
<tr>
<td>C4</td>
<td>579.3</td>
<td>0.310</td>
</tr>
<tr>
<td>C5</td>
<td>436.0</td>
<td>0.233</td>
</tr>
<tr>
<td>C6</td>
<td>332.1</td>
<td>0.177</td>
</tr>
<tr>
<td>S1</td>
<td>623.9*</td>
<td>c</td>
</tr>
<tr>
<td>S2</td>
<td>368.1</td>
<td>0.196</td>
</tr>
<tr>
<td>S3</td>
<td>596.5**</td>
<td>d</td>
</tr>
<tr>
<td>S4</td>
<td>648.1</td>
<td>0.346</td>
</tr>
<tr>
<td>S5</td>
<td>410.0</td>
<td>0.219</td>
</tr>
<tr>
<td>S6</td>
<td>313.2</td>
<td>0.167</td>
</tr>
<tr>
<td>F1</td>
<td>463.3*</td>
<td>e</td>
</tr>
<tr>
<td>F2</td>
<td>295.0</td>
<td>0.158</td>
</tr>
<tr>
<td>F3</td>
<td>501.4</td>
<td>0.268</td>
</tr>
<tr>
<td>F4</td>
<td>618.2</td>
<td>0.330</td>
</tr>
<tr>
<td>F5</td>
<td>503.7</td>
<td>0.269</td>
</tr>
<tr>
<td>F6</td>
<td>350.3</td>
<td>0.187</td>
</tr>
<tr>
<td>P1</td>
<td>297.9*</td>
<td>f</td>
</tr>
<tr>
<td>P2</td>
<td>313.3</td>
<td>0.167</td>
</tr>
<tr>
<td>P3</td>
<td>418.0</td>
<td>0.223</td>
</tr>
<tr>
<td>P4</td>
<td>235.0</td>
<td>0.125</td>
</tr>
<tr>
<td>P5</td>
<td>329.3</td>
<td>0.176</td>
</tr>
<tr>
<td>P6</td>
<td>419.6</td>
<td>0.224</td>
</tr>
<tr>
<td>E1</td>
<td>417.7</td>
<td>0.223</td>
</tr>
</tbody>
</table>

* Indicates racks used to form storm shelter
* Includes mass for STS EMUs
** Includes 79.4 kg of water
* Includes 238.3 kg of water
a-f: Refer to following chart for detailed density description

Figure 6-3. Rack Densities Specified in Solid Model SSF Habitat Module Retrofit
Figure 6-4. NASA Shelter Concept - Rack Densities SSF Habitat Module Retrofit

a. 0.359 g/cc - 1.00 g/cc - Water Tank
   0.359 g/cc

b. 0.368 g/cc - 1.00 g/cc - Water Tank
   0.368 g/cc

c. 0.171 g/cc - 0.732 g/cc - EMU Backpack**
   0.171 g/cc

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

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

<table>
<thead>
<tr>
<th>Structure</th>
<th>Density (g/cm³)</th>
<th>Material</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure vessel</td>
<td>2.86</td>
<td>2219 A1</td>
<td>0.318</td>
</tr>
<tr>
<td>Debris shield</td>
<td>2.71</td>
<td>6061 A1</td>
<td>0.127</td>
</tr>
<tr>
<td>MLI blanket</td>
<td>0.192*</td>
<td>*</td>
<td>0.352</td>
</tr>
<tr>
<td>Modeled racks</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

* Space station MLI is configured in 21 layers. Sheldahl catalog data was used to calculate the nominal area of the layers at 0.68 g/cm². 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 0.35 cm, leading to an average density of 0.192 g/cm³. 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
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.

---

<table>
<thead>
<tr>
<th>Time Period</th>
<th>BFO*</th>
<th>Lens of Eye</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 day</td>
<td>25</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Annual</td>
<td>50</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Career</td>
<td>See table below</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>

* 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%

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>35</td>
<td>175</td>
<td>250</td>
</tr>
<tr>
<td>45</td>
<td>200</td>
<td>320</td>
</tr>
<tr>
<td>55</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>

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

Figure 6-10. Lunar Habitat Radiation Assessment Configuration

- Detector locations 2 and 14 represent positions of maximum and minimum dose rates respectively
- Shield distribution established for 21 points with 256 rays over 4π steradians.
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.
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.
Dose equivalent to simulated BFO (rem/event)

August 2, 1972 SPE

Current 30-day limit

Dose equivalent to simulated BFO (rem/event)

October 19, 1989 SPE

Current 30-day limit

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

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

<table>
<thead>
<tr>
<th>Area</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Quarters</td>
<td>36.0 m²</td>
</tr>
<tr>
<td>Wardroom</td>
<td>20.0 m²</td>
</tr>
<tr>
<td>Galley</td>
<td>4.0 m²</td>
</tr>
<tr>
<td>WMF/hygiene</td>
<td>4.0 m²</td>
</tr>
<tr>
<td>Laundry</td>
<td>1.0 m²</td>
</tr>
<tr>
<td>Recreation/exercise</td>
<td>10.0 m²</td>
</tr>
<tr>
<td>Medical</td>
<td>3.0 m²</td>
</tr>
<tr>
<td>EVA</td>
<td>10.0 m²</td>
</tr>
<tr>
<td>Operations: 2 workstations</td>
<td>4.0 m²</td>
</tr>
<tr>
<td>Life sciences lab</td>
<td>6.0 m²</td>
</tr>
<tr>
<td>Geochemistry and Petrology lab</td>
<td>6.0 m²</td>
</tr>
<tr>
<td>Circulation (15%)</td>
<td>16.0 m²</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td>120.0 m²</td>
</tr>
</tbody>
</table>

Figure 7-2. Biconic MEV/Habitat Internal Arrangement
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:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity (E)</td>
<td>1.103E11 Pa</td>
</tr>
<tr>
<td>Modulus of Rigidity (G)</td>
<td>0.427E11 Pa</td>
</tr>
<tr>
<td>Poisson's Ratio ((\nu))</td>
<td>0.310</td>
</tr>
<tr>
<td>Density ((\rho))</td>
<td>4.429E03 kg/m³</td>
</tr>
<tr>
<td>Ult. Tensile Stress ((F_{tu}))</td>
<td>11.030E8 Pa</td>
</tr>
<tr>
<td>Comp. Yield Stress ((F_{cy}))</td>
<td>10.617E8 Pa</td>
</tr>
<tr>
<td>Ult. Shear Stress ((F_{su}))</td>
<td>11.030E8 Pa</td>
</tr>
</tbody>
</table>
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.
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:

<table>
<thead>
<tr>
<th></th>
<th>Aero Loading (6 g)</th>
<th>Thermal Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Displacement</td>
<td>26 cm</td>
<td>11 cm</td>
</tr>
<tr>
<td>Max Disp. to Max Dimension Ratio</td>
<td>0.87%</td>
<td>0.35%</td>
</tr>
<tr>
<td>Max Principal Stress</td>
<td>2.31e08 Pa</td>
<td>6.80e08 Pa</td>
</tr>
<tr>
<td>Stress Margin of Safety</td>
<td>389%</td>
<td>62%</td>
</tr>
</tbody>
</table>
Figure 7-7. Maximum Deformations Due to Thermal Loads

Figure 7-8. Exaggerated Deformation Plot
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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.
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.
REFERENCES


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)

- 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

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

  **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 CO2 removal, TCCS, and ACMA (w/ critical ORU for CRM & MCA)
  - CO2 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"

• 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)*
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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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### Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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### Notes

- SSF HAB A Mass Properties Report (12/15/91) (PEP is an unknown - mass not identified in this report?)

### AvTwo1

- **Av Air/ Crossover/ PEP**
- **Pack**
  - Rack structure: 102.10 kg
    - 5-28%

### AvTwo2

- **EPDS**
  - Rack attachments: 29.68 kg
    - 5-105%
  - Cable Assy.: 3.96 kg
  - RPC: 7.03 kg
  - RPDA: 1.80 kg
  - TCS:
    - Flow control assy.: 6.81 kg
    - Cold plate: 3.15 kg
    - Regenerative heat: 10.72 kg
    - Plumbing: 4.42 kg
    - Fluid(water): 2.72 kg
## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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<tr>
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<th>Name</th>
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<th>Subsystem</th>
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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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| PHC1     | Personal Hygiene Compartment 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            | 3.97  |       |                                                     |
|          |                                      | 22.56           | 14.06 |       |                                                     |
|          |                                      | RCC             | 4.53  |       |                                                     |
|          |                                      | TCS             | 3.37  |       |                                                     |
|          |                                      | ECLSS-THC       | 1.31  |       |                                                     |
|          |                                      | ECLSS-FDS       | 1.95  |       |                                                     |

<p>| PHC2     | Man-Systems Waste Mgmt Compartment | 115.32 Handwash | 61.92 |       |                                                     |
|          |                                      | Handrails | 47.63 |       |                                                     |
|          |                                      | Closeouts | 0.70  |       |                                                     |
|          |                                      | Sub        | 235.02|       |                                                     |</p>
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## Lunar Outpost Hab Module Reference Configuration A Mass Breakdown

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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.77</td>
<td>Closeout</td>
<td>5.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td></td>
<td></td>
<td>417.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ops1</td>
<td>Ops storage (located in endcone of Outpost)</td>
<td>9680.71</td>
<td></td>
<td></td>
<td>SSF HAB A Mass Properties Report (12/15/91) (All mass in consumables below)</td>
<td></td>
</tr>
<tr>
<td>Rack-based</td>
<td>Sub</td>
<td></td>
<td></td>
<td>17534.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation Protection</td>
<td>Sub</td>
<td></td>
<td></td>
<td></td>
<td>ANALYSIS NEEDED (In Progress)</td>
<td></td>
</tr>
<tr>
<td>Airlock</td>
<td>AL1</td>
<td>STS airlock - Configuratio</td>
<td>450.00</td>
<td></td>
<td>STS data for airlock structure and systems (additional reinforcements may be needed ?)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AL2</td>
<td>Hab-to Airlock Adapter</td>
<td>113.40</td>
<td>Estimated</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Tools and Toolbox</td>
<td>553.20</td>
<td>From SSF WP02 Mass Properties Report (toolbox itself masses 344.7 kg and is definitely oversized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td></td>
<td></td>
<td>1116.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Name</td>
<td>System</td>
<td>Subsystem</td>
<td>Mass (kg)</td>
<td>SSF Growth</td>
<td>Comment/Sources</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------</td>
<td>--------------</td>
<td>------------------------------------</td>
<td>-----------</td>
<td>----------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>External Support Systems</td>
<td>ExtISA</td>
<td>Surface access</td>
<td></td>
<td>200.00</td>
<td></td>
<td>Guess for stairs, platforms, etc. (dust control and removal systems and approaches TBD)</td>
</tr>
<tr>
<td>ExtC&amp;T</td>
<td>C&amp;T</td>
<td></td>
<td></td>
<td>100.00</td>
<td></td>
<td>Guess for antennas, etc. (based on earlier studies)</td>
</tr>
<tr>
<td>ExtTCS</td>
<td>Thermal Control System</td>
<td></td>
<td></td>
<td>466.00</td>
<td></td>
<td>Sized for using a heat pump during the lunar day</td>
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<tr>
<td>ExtEPS1</td>
<td>Power</td>
<td>Reactants</td>
<td></td>
<td>1507.68</td>
<td></td>
<td>High pressure (3000 psi) stored O2/H2 reactants for regenerable fuel cell operation</td>
</tr>
<tr>
<td>ExtEPS2</td>
<td></td>
<td>Tanks</td>
<td></td>
<td>2739.21</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Arrays, fuel cells, etc.</td>
<td></td>
<td>935.95</td>
<td></td>
<td>All power and thermal masses based on needs of reference layout (thermal includes metabolic load from crew as well)</td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td></td>
<td></td>
<td>5182.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td></td>
<td></td>
<td>5948.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td>ConsH2O</td>
<td>Crew water</td>
<td></td>
<td></td>
<td></td>
<td>Closed system needs included in above ECLSS</td>
</tr>
<tr>
<td></td>
<td>ConsFood</td>
<td>Food</td>
<td></td>
<td>360.00</td>
<td></td>
<td>4 people for 45 days (2 kg/p.d)</td>
</tr>
<tr>
<td></td>
<td>ConsGW</td>
<td>Galley/ Wardroom (non-food)</td>
<td></td>
<td>103.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ConsECLS1</td>
<td>ECLSS expendables</td>
<td>AR</td>
<td>20.90</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ConsECLS2</td>
<td>WM</td>
<td></td>
<td>151.00</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>ConsECLS3</td>
<td>WM</td>
<td></td>
<td>15.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ConsECLS4</td>
<td>THC</td>
<td></td>
<td>47.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub</td>
<td></td>
<td></td>
<td>234.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Name</td>
<td>System</td>
<td>Subsystem</td>
<td>Mass (kg)</td>
<td>SSF Growth</td>
<td>Comment/Sources</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------</td>
<td>---------------------------------------------</td>
<td>------------------------------------------------</td>
<td>-----------</td>
<td>------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ConsGas</td>
<td>Make-up gas</td>
<td>Repress, Airlock loss, module leakage</td>
<td></td>
<td>516.20</td>
<td></td>
<td>2 represses, 10% airlock loss, standard leakage (including hi-pressure tankage)</td>
</tr>
<tr>
<td>ConsO2</td>
<td>Metabolic oxygen</td>
<td></td>
<td></td>
<td>188.00</td>
<td></td>
<td>This assumes cryo storage (high pressure storage would mass at 331 kg). These numbers include</td>
</tr>
<tr>
<td>ConsEVAH2O</td>
<td>EVA sublimator water</td>
<td></td>
<td></td>
<td>160.00</td>
<td></td>
<td>16 lbs/EVA for 2 people for 7 hours (22 EVAs per mission)</td>
</tr>
<tr>
<td>ConsEMU</td>
<td>Suit spares, etc.</td>
<td></td>
<td></td>
<td>241.10</td>
<td></td>
<td>Assumed part of crew lander? based on JSC's 3/6/92 value</td>
</tr>
<tr>
<td>ConsCHC</td>
<td>CHECS</td>
<td></td>
<td></td>
<td>23.30</td>
<td></td>
<td>From WP02 Mass Report?</td>
</tr>
<tr>
<td>ConsPH</td>
<td>Personal Hygiene</td>
<td></td>
<td></td>
<td>45.80</td>
<td></td>
<td>From HAB A Mass Report?</td>
</tr>
<tr>
<td>ConsOps</td>
<td>Ops storage</td>
<td>Camera, cleaning, etc.</td>
<td></td>
<td>182.80</td>
<td></td>
<td>From HAB A Mass Report?</td>
</tr>
<tr>
<td>ConsOther</td>
<td>Other crew accommodations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>See 2/5/92 report from JSC</td>
</tr>
<tr>
<td>ConsCloth</td>
<td>Clothing</td>
<td></td>
<td></td>
<td>245.00</td>
<td></td>
<td>3 lbs per person-day</td>
</tr>
<tr>
<td>Sub</td>
<td></td>
<td></td>
<td></td>
<td>2300.50</td>
<td></td>
<td>Unknowns remain for complete consumables number</td>
</tr>
<tr>
<td>Growth</td>
<td></td>
<td></td>
<td></td>
<td>2309.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>29209.97</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Airlock Mass Breakdown
## Airlock Mass Summary

<table>
<thead>
<tr>
<th>Option</th>
<th>Airlock Mass (kg)</th>
<th>Configuration</th>
<th>Non-hyperbaric Mass (kg)</th>
<th>Hyperbaric Mass (kg)</th>
<th>Support/attach/Hab mods</th>
<th>Airlock sys. total, w/o tools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reference</td>
<td>Configuration &quot;A&quot; STS Airlock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>STS Airlock</td>
<td>450</td>
<td>420</td>
<td>-</td>
<td>113.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Configuration &quot;D&quot; SSF Crewlock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hyperbaric</td>
<td>1188.8</td>
<td>428.9</td>
<td>192.8</td>
<td>293.2 incl. rack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-Hyperbaric</td>
<td>1188.8</td>
<td>337.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Configuration &quot;G&quot; Internal bulkhead, standard hab module length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hyperbaric</td>
<td>1728.2</td>
<td>420</td>
<td>192.8</td>
<td>293.2 incl. rack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-Hyperbaric</td>
<td>415.5</td>
<td>420</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Configuration &quot;F&quot; Internal bulkhead, extended hab module length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hyperbaric</td>
<td>1728.2</td>
<td>TBD</td>
<td>192.8</td>
<td>293.2 incl. rack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-Hyperbaric</td>
<td>576.1</td>
<td>TBD</td>
<td>420</td>
<td>-</td>
</tr>
</tbody>
</table>

## Primary Structure Weight Comparison

### Outpost Airlock Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Non-hyperbaric Mass (kg)</th>
<th>Hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref (A) Basic Module Structural Weight</td>
<td>3175</td>
<td>3175</td>
</tr>
<tr>
<td>STS Airlock Weight</td>
<td>454</td>
<td></td>
</tr>
<tr>
<td>SSF Crewlock Structural Weight</td>
<td>726</td>
<td></td>
</tr>
<tr>
<td>Airlock-to-Module Adapter</td>
<td>113</td>
<td>227</td>
</tr>
<tr>
<td>New Bulkhead Structural Weight</td>
<td>415</td>
<td>576</td>
</tr>
<tr>
<td>New Cylinder Skin</td>
<td>284</td>
<td></td>
</tr>
<tr>
<td>New Bulkhead/Skin Installation</td>
<td>129</td>
<td>68</td>
</tr>
<tr>
<td>Existing Bulkhead Structural Mod</td>
<td></td>
<td>1111</td>
</tr>
<tr>
<td>Existing Skin Mod</td>
<td>850</td>
<td></td>
</tr>
<tr>
<td>Trunnion Modification</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>3742</td>
<td>3719**</td>
</tr>
</tbody>
</table>

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

Crewlock Mass Breakdown
Includes Assumptions Based on WP02 and JSC Data (cont)

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

Utilities Subtotal                             428.9                337.3
### Crewlock Mass Breakdown
*Includes Assumptions Based on WP02 and JSC Data (cont)*

<table>
<thead>
<tr>
<th>Crewlock Hyperbaric Support:</th>
<th>Hyperbaric Mass (kg)</th>
<th>Assumed Non-hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crewlock Rack</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rack structure</td>
<td>58.3</td>
<td>0</td>
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<tr>
<td>rack support structure</td>
<td>4.5</td>
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<tr>
<td>hyperbaric ltg support structure</td>
<td>8.8</td>
<td>0</td>
</tr>
<tr>
<td>HECA</td>
<td>78.4</td>
<td>0</td>
</tr>
<tr>
<td><strong>Other</strong></td>
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<td></td>
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<tr>
<td>hyperbaric lighting assembly</td>
<td>42.8</td>
<td>0</td>
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</table>

**Hyperbaric Support Subtotal**

<table>
<thead>
<tr>
<th>Items not included in WP02 Mass Properties Report</th>
<th>Hyperbaric Mass (kg)</th>
<th>Assumed Non-hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HGPCA CL O&amp;C panel</td>
<td>?</td>
<td>0</td>
</tr>
<tr>
<td>CHeCS breathing mask interface</td>
<td>?</td>
<td>0</td>
</tr>
<tr>
<td>CHeCS equip utility interface panels</td>
<td>?</td>
<td>0</td>
</tr>
<tr>
<td>CHeCS restraint system mounting assy</td>
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</tbody>
</table>

**CREWLOCK TOTALS**

<table>
<thead>
<tr>
<th></th>
<th>Hyperbaric Mass (kg)</th>
<th>Assumed Non-hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2371.5</td>
<td>2087.1 (includes 561 kg of tools, R&amp;MA)</td>
</tr>
</tbody>
</table>

### Hab Burden for Crewlock Mass Breakdown
*Includes Assumptions Based on WP02 and JSC Data*

<table>
<thead>
<tr>
<th>1st SPCU Rack *:</th>
<th>Hyperbaric Mass (kg)</th>
<th>Assumed Non-hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPCU - suit drying assy #1</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>SPCU - rack ventilation assy #1</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>SPCU - don/doff assy #1</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>SPCU - cable set</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>depress/repress console</td>
<td>8.5</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**1st SPCU Subtotal**

<table>
<thead>
<tr>
<th>2nd SPCU Rack *:</th>
<th>Hyperbaric Mass (kg)</th>
<th>Assumed Non-hyperbaric Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPCU - power supply and battery charger</td>
<td>18.1</td>
<td>18.1</td>
</tr>
<tr>
<td>SPCU - battery storage locker</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>SPCU - oxygen reg and distr</td>
<td>25.5</td>
<td>25.5</td>
</tr>
<tr>
<td>SPCU - H2O reg and distr</td>
<td>74.8</td>
<td>74.8</td>
</tr>
<tr>
<td>SPCU - rack ventilation assy #2</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>SPCU - umbilical I/F panel</td>
<td>36.9</td>
<td>36.9</td>
</tr>
<tr>
<td>SPCU - hose set</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>SPCU - cable set</td>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>SPCU - suit dryer assy #2</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>SPCU - don/doff assy #2</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>SPCU - maintenance kit</td>
<td>19.9</td>
<td>19.9</td>
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<td>NSTS EMU launch fixtures</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>umbilical set</td>
<td>19.6</td>
<td>19.6</td>
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**2nd SPCU Subtotal**

---

B-4
# Hab Burden for Crewlock Mass Breakdown

Includes Assumptions Based on WP02 and JSC Data (cont)

<table>
<thead>
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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 reqts 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
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Appendix D

Habitat Modifications Δ2
Habitat Modifications: Δ2

Δ2 Strategy: modifications made to SSF hardware because of known lunar outpost requirements or due to the lunar environment

Δ2 contains all modifications made in Δ1, 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 Δ2 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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Appendix E

Outpost Internal Systems Power
Budget Summary - Reference
# Lunar Campsite Internal Systems Power

## Budget Summary - Reference

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
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</thead>
</table>

### Electrical Power Distribution System (EPDS)

<table>
<thead>
<tr>
<th>Component</th>
<th>Continuous Load</th>
<th>Duty Cycle</th>
<th>Avg. Load</th>
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</thead>
<tbody>
<tr>
<td>Lights</td>
<td>360</td>
<td>50</td>
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<tr>
<td>Cable power losses</td>
<td>228</td>
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**Data Management System (DMS)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Continuous Load</th>
<th>Duty Cycle</th>
<th>Avg. Load</th>
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<tbody>
<tr>
<td>Ring concentrators</td>
<td>48</td>
<td>100</td>
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<tr>
<td>C&amp;W control panel</td>
<td>7.5</td>
<td>100</td>
<td>7.5</td>
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<tr>
<td>EMADS</td>
<td>10</td>
<td>100</td>
<td>10</td>
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<tr>
<td>Multiplexer-demultiplexer (MDM)</td>
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### Signal Processor Interface

<table>
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<tr>
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<th>Duty Cycle</th>
<th>Avg. Load</th>
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</thead>
<tbody>
<tr>
<td>Data acquisition signal proc.</td>
<td>40</td>
<td>100</td>
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### Internal Audio & Video

<table>
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<tr>
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<th>Continuous Load</th>
<th>Duty Cycle</th>
<th>Avg. Load</th>
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</thead>
<tbody>
<tr>
<td>Crew wireless unit batt.</td>
<td>22.5</td>
<td>10</td>
<td>2.25</td>
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<tr>
<td>Camera body</td>
<td>34.3</td>
<td>10</td>
<td>3.5</td>
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<tr>
<td>Zoom lens</td>
<td>9.2</td>
<td>2</td>
<td>0.18</td>
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<tr>
<td>Audio bus couplers (3)</td>
<td>39.9</td>
<td>40</td>
<td>16</td>
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<tr>
<td>Video switching unit</td>
<td>104.5</td>
<td>10</td>
<td>10.5</td>
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<tr>
<td>Audio terminal units (2)</td>
<td>56</td>
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<tr>
<td>Portable video monitor</td>
<td>155</td>
<td>5</td>
<td>7.75</td>
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**Totals:**

1428 W  884 W

---

# Lunar Campsite Internal Systems Power

## Budget Summary - Reference (Cont.)

- All Loads in Watts -

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<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
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</table>

### Thermal Control System (TCS)

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<th>Duty Cycle</th>
<th>Avg. Load</th>
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<tbody>
<tr>
<td>Rack flow control assy.</td>
<td>91</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Crossover assy.</td>
<td>56</td>
<td>0</td>
<td>0</td>
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<tr>
<td>ITCS pump assy.</td>
<td>575</td>
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<td>System flow ctrl. assy.</td>
<td>14</td>
<td>50</td>
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### Temp. & Humidity Ctrl. (ECLSS-THC)

<table>
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<tr>
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<th>Continuous Load</th>
<th>Duty Cycle</th>
<th>Avg. Load</th>
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</thead>
<tbody>
<tr>
<td>Isolation valves</td>
<td>100</td>
<td>0</td>
<td>0</td>
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<tr>
<td>IMV fan</td>
<td>55</td>
<td>100</td>
<td>55</td>
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<tr>
<td>Isolation valves - IMV</td>
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<td>0</td>
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<tr>
<td>Rack air ctrl. valves</td>
<td>28</td>
<td>0.025</td>
<td>0.01</td>
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<td>Avionics air fan</td>
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<td>Av. air - I/F box</td>
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<td>Cabin air - electrical I/F</td>
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<tr>
<td>Cabin air fan</td>
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<td>Cabin air - Temp. ctrl.</td>
<td>34</td>
<td>1.6</td>
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<td>Fan, ceiling ventilation</td>
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<tr>
<td>Standoff fan</td>
<td>220</td>
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**Totals:**

2477 W  2063 W

---

*power dak/pv/18Mg92*

E-2
### Lunar Campsite Internal Systems Power
#### Budget Summary - Reference (Cont.)

- All Loads in Watts -

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<th>Av. Load</th>
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<td>O2/N2 discharge diffuser</td>
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<td>Vent &amp; relief subassembly</td>
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<td>1</td>
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<td><strong>Galley / Wardroom</strong></td>
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<td>6</td>
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<td>Temp. meas.</td>
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<td>0.5</td>
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<td>H2O / air separator</td>
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### Lunar Campsite Internal Systems Power
#### Budget Summary - Reference (Cont.)

- All Loads in Watts -

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<td>70</td>
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E-3
## Lunar Campsite Internal Systems Power
### Budget Summary - Reference (Cont.)

<table>
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<th>Water Processing</th>
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<th>Duty Cycle(%)</th>
<th>Av. Load</th>
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<td>Water processor</td>
<td>600</td>
<td>33</td>
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<td>Process ctrl. H2O quality</td>
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<td>~0</td>
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<td>Urine processing</td>
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<td>Fluid pump ORU</td>
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<td>Purge pump</td>
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<table>
<thead>
<tr>
<th>Air Revitalization System (ECLSS - ARS)</th>
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<tbody>
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<td>CO2 vent valve</td>
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<td>THC supply valve</td>
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<td>Heater</td>
<td>150</td>
<td>100</td>
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<td>TCCS - elec. I/F assy.</td>
<td>10</td>
<td>100</td>
<td>10</td>
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</table>

Totals: 2337 W 1455 W

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

<table>
<thead>
<tr>
<th>Air Revitalization System -Cont.- (ECLSS - ARS)</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCCS - flow ctrl. assy.</td>
<td>15.4</td>
<td>100</td>
<td>15.4</td>
</tr>
<tr>
<td>Flow meter &amp; cable</td>
<td>1.6</td>
<td>100</td>
<td>1.6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Science / DMS / Comm. / Workstation</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>996</td>
<td>59</td>
<td>59</td>
<td>995</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Crew Health (CHeCS)</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>911</td>
<td>10</td>
<td>10</td>
<td>91</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fire Detection / Suppression</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame detector</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>CO2 release valve</td>
<td>800</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>Sensors, smoke - duct &amp; area</td>
<td>23.8</td>
<td>100</td>
<td>23.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste Management</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commode/urinal assy.</td>
<td>50</td>
<td>2.5</td>
<td>1.25</td>
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<tr>
<td>C/U - commode fan</td>
<td>130</td>
<td>0.55</td>
<td>0.72</td>
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<tr>
<td>Compactor</td>
<td>250</td>
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<td>19</td>
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<td>User panel</td>
<td>25</td>
<td>100</td>
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Totals: 3217 W 789 W

E-4
### Lunar Campsite Internal Systems Power
#### Budget Summary - Reference (Cont.)

- **All Loads in Watts** -

<table>
<thead>
<tr>
<th>M/S Hygiene</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste mgt. &amp; pers hygiene compartments (2)</td>
<td>60</td>
<td>70</td>
<td>42</td>
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<tr>
<td>Cabin air fans</td>
<td>60</td>
<td>70</td>
<td>42</td>
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<tr>
<td>Cabin air heaters</td>
<td>200</td>
<td>8</td>
<td>16</td>
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<td>Cabin air temp. sensors</td>
<td>20</td>
<td>100</td>
<td>20</td>
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<tr>
<td>Lighting systems</td>
<td>60</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>Local controllers</td>
<td>54</td>
<td>100</td>
<td>54</td>
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<tr>
<td>Handwashes (2)</td>
<td>3.6</td>
<td>4.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Diverter motors</td>
<td>3.2</td>
<td>100</td>
<td>3.2</td>
</tr>
<tr>
<td>Local controls</td>
<td>12</td>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>Temp. meas.</td>
<td>4.2</td>
<td>100</td>
<td>4.2</td>
</tr>
<tr>
<td>H2O supply</td>
<td>618</td>
<td>9</td>
<td>56</td>
</tr>
<tr>
<td>H2O / air separators</td>
<td>610</td>
<td>4.2</td>
<td>25.4</td>
</tr>
<tr>
<td><strong>Hab Growth</strong></td>
<td>393.5</td>
<td>100</td>
<td>393.5</td>
</tr>
</tbody>
</table>

**Totals:**

- **Day/Night** 2035 W 635 W

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

- **All Loads in Watts** -

<table>
<thead>
<tr>
<th>Gas Conditioning Assembly (GCA)</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCA - N2</td>
<td>113.6</td>
<td>100</td>
<td>113.6</td>
</tr>
<tr>
<td>N2 cond. assy.</td>
<td>9.1</td>
<td>100</td>
<td>9.1</td>
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<tr>
<td>N2 growth</td>
<td>108.8</td>
<td>100</td>
<td>108.6</td>
</tr>
<tr>
<td>O2 cond. assy.</td>
<td>8.7</td>
<td>100</td>
<td>8.7</td>
</tr>
<tr>
<td>O2 growth</td>
<td>312</td>
<td>100</td>
<td>312</td>
</tr>
</tbody>
</table>

**Totals:**

- **Day/Night** 4301/852 W 4301/852 W
**Lunar Campsite Overall Power Budget**

**Summary - Reference**

- All Loads in Watts -

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

Outpost Internal Systems Power
Budget Summary - Δ1
## Lunar Campsite Internal Systems Power

### Budget Summary - A1

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Systems</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Power Distribution System (EPDS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lights</td>
<td>360</td>
<td>50</td>
<td>180</td>
</tr>
<tr>
<td>Cable power losses</td>
<td>228</td>
<td>100</td>
<td>228</td>
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<tr>
<td><strong>Data Management System (DMS)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ring concentrators</td>
<td>48</td>
<td>100</td>
<td>48</td>
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<tr>
<td>C&amp;W control panel</td>
<td>7.5</td>
<td>100</td>
<td>7.5</td>
</tr>
<tr>
<td>EMADS</td>
<td>10</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Multiplexer-demultiplexer (MDM)</td>
<td>313</td>
<td>100</td>
<td>313</td>
</tr>
<tr>
<td><strong>Signal Processor Interface</strong></td>
<td></td>
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<tr>
<td>Data acquisition signal proc.</td>
<td>40</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td><strong>Internal Audio &amp; Video</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew wireless unit batt.</td>
<td>22.5</td>
<td>10</td>
<td>2.25</td>
</tr>
<tr>
<td>Camera body</td>
<td>34.3</td>
<td>10</td>
<td>3.5</td>
</tr>
<tr>
<td>Zoom lens</td>
<td>9.2</td>
<td>2</td>
<td>0.18</td>
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<tr>
<td>Audio bus coupler</td>
<td>39.9</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Video switching unit</td>
<td>104.5</td>
<td>10</td>
<td>10.5</td>
</tr>
<tr>
<td>Audio terminal units</td>
<td>56</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>Portable video monitor</td>
<td>155</td>
<td>5</td>
<td>7.75</td>
</tr>
<tr>
<td><strong>Thermal Control System (TCS)</strong></td>
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<td></td>
</tr>
<tr>
<td>Rack flow control assy.</td>
<td>91</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Crossover assy.</td>
<td>56</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>ITCS pump assy.</td>
<td>300</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>System flow ctrl. assy.</td>
<td>14</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td><strong>Temp. &amp; Humidity Ctrl. (ECLSS-THC)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolation valves</td>
<td>100</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Rack air ctrl. valves</td>
<td>28</td>
<td>0.025</td>
<td>0.01</td>
</tr>
<tr>
<td>Avionics air fan</td>
<td>520</td>
<td>100</td>
<td>520</td>
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<tr>
<td>Av. air - I/F box</td>
<td>10</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Cabin air - electrical I/F</td>
<td>25</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Cabin air fan</td>
<td>360</td>
<td>100</td>
<td>360</td>
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<tr>
<td>Cabin air/H2O separator</td>
<td>43</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td>Cabin air temp. ctrl.</td>
<td>34</td>
<td>1.6</td>
<td>0.57</td>
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<tr>
<td>Fan, ceiling ventilation</td>
<td>22</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Standoff fan</td>
<td>220</td>
<td>100</td>
<td>220</td>
</tr>
<tr>
<td><strong>Atmosphere control (ECLSS-ACS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolation valve</td>
<td>2.4</td>
<td>100</td>
<td>2.4</td>
</tr>
<tr>
<td>Line press. sensor</td>
<td>1.8</td>
<td>100</td>
<td>1.8</td>
</tr>
<tr>
<td>Line temperature sensor</td>
<td>0.02</td>
<td>100</td>
<td>0.02</td>
</tr>
<tr>
<td>O2/N2 discharge diffuser</td>
<td>6.8</td>
<td>100</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Totals: 1428 W 884 W

---

**Lunar Campsite Internal Systems Power**

**Budget Summary - A1 (Cont.)**

- All Loads in Watts -

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

Totals: 1834W 1520 W
# Lunar Campsite Internal Systems Power Budget Summary - Δ1 (Cont.)

All Loads in Watts

<table>
<thead>
<tr>
<th>System</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECLSS - ACS (Cont.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCA firmware controller</td>
<td>14</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>Vent &amp; relief subassembly</td>
<td>1</td>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>

| 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      |

| 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    |

F-3
## Lunar Campsite Internal Systems Power Budget Summary - A1 (Cont.)

### - All Loads in Watts -

<table>
<thead>
<tr>
<th>Air Revitalization System (ECLSS - ARS)</th>
<th>Continuous Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 vent valve</td>
<td>40</td>
<td>0.001</td>
</tr>
<tr>
<td>Atmos. comp. monitor</td>
<td>531 (nt/day) 25/100</td>
<td>133/531</td>
</tr>
<tr>
<td>CO2 removal assy.</td>
<td>523.4 100</td>
<td>523.4</td>
</tr>
<tr>
<td>Converter</td>
<td>7.2</td>
<td>100</td>
</tr>
<tr>
<td>THC supply valve</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Heater</td>
<td>150</td>
<td>57</td>
</tr>
<tr>
<td>TCCS - elec. I/F assy.</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>TCCS - flow ctrl. assy.</td>
<td>15.4</td>
<td>100</td>
</tr>
<tr>
<td>Flow meter &amp; cable</td>
<td>1.6</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science / DMS / Comm. / Workstation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>996</td>
<td>59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crew Health (CHeCS)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Health</td>
<td>911</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fire Detection / Suppression</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame detector</td>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>CO2 release valve</td>
<td>800</td>
<td>0.25</td>
</tr>
<tr>
<td>Sensors, smoke - duct &amp; area</td>
<td>23.8</td>
<td>100</td>
</tr>
</tbody>
</table>

**Totals:**

- 4043 W
- 1522 / 1920 W

## Lunar Campsite Internal Systems Power Budget Summary - A1 (Cont.)

### - All Loads in Watts -

<table>
<thead>
<tr>
<th>Waste Management</th>
<th>Continuous Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commode/urinal assy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/U - commode fan</td>
<td>50</td>
<td>2.5</td>
</tr>
<tr>
<td>Compactor</td>
<td>130</td>
<td>0.55</td>
</tr>
<tr>
<td>Fan/separator</td>
<td>250</td>
<td>7.5</td>
</tr>
<tr>
<td>User panel</td>
<td>25</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>M/S Hygiene</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste management compartment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabin air fan</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Cabin air heater</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Cabin air temp. sensor</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Lighting system</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Local controller</td>
<td>27</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Handwash</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverter motors</td>
<td>1.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Local control</td>
<td>1.6</td>
<td>100</td>
</tr>
<tr>
<td>Signal cond.</td>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>Temp. meas.</td>
<td>0.5</td>
<td>100</td>
</tr>
<tr>
<td>H2O supply</td>
<td>309</td>
<td>9</td>
</tr>
<tr>
<td>H2O / air separator</td>
<td>305</td>
<td>4.3</td>
</tr>
</tbody>
</table>

**Totals:**

- 1276 W
- 179.4 W

F-4
### Lunar Campsite Overall Power Budget Summary - Δ1

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Load</th>
<th>Continuous</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDS/DMS/SP/IAV</td>
<td>1428</td>
<td>884</td>
</tr>
<tr>
<td>TCS/THC/ACS</td>
<td>1849</td>
<td>1535</td>
</tr>
<tr>
<td>Galley / Wardroom</td>
<td>1934</td>
<td>456</td>
</tr>
<tr>
<td>Science</td>
<td>1769</td>
<td>702</td>
</tr>
<tr>
<td>Water stor. / Proc.</td>
<td>1125</td>
<td>292</td>
</tr>
<tr>
<td>Air Revit. System</td>
<td>1298.6</td>
<td>796</td>
</tr>
<tr>
<td>Crew Health</td>
<td>911</td>
<td>91</td>
</tr>
<tr>
<td>Fire Det. / Suppression</td>
<td>838</td>
<td>40</td>
</tr>
<tr>
<td>RPC Modules</td>
<td>312</td>
<td>312</td>
</tr>
<tr>
<td>Waste Management</td>
<td>455</td>
<td>46</td>
</tr>
<tr>
<td>M/S Hygiene</td>
<td>821</td>
<td>133</td>
</tr>
<tr>
<td>Hab Growth</td>
<td>345</td>
<td>345</td>
</tr>
<tr>
<td>Gas Cond. Assy.</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Heat Pump - Day</td>
<td>2840</td>
<td>2840</td>
</tr>
<tr>
<td>- Night</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

Grand Totals:  
- Day: 16166 W  
- Night: 13626 W

### Lunar Campsite Internal/External Systems

Power Budget Summary - Δ1 (Cont.)

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Load</th>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hab Growth (scaled from SSF: ~5.4% Favg)</td>
<td>345</td>
<td>100</td>
<td>345</td>
</tr>
<tr>
<td>Gas Conditioning Assembly (GCA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCA - N2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2 cond. assy.</td>
<td>113.6</td>
<td>100</td>
<td>113.6</td>
</tr>
<tr>
<td>N2 growth</td>
<td>9.1</td>
<td>100</td>
<td>9.1</td>
</tr>
<tr>
<td>GCA - O2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O2 cond. assy.</td>
<td>108.8</td>
<td>100</td>
<td>108.8</td>
</tr>
<tr>
<td>O2 growth</td>
<td>8.7</td>
<td>100</td>
<td>8.7</td>
</tr>
<tr>
<td>RPC Modules</td>
<td>312</td>
<td>100</td>
<td>312</td>
</tr>
<tr>
<td>Rad. Ht Pump (for avg.+10%)</td>
<td>2840 / 300</td>
<td>100</td>
<td>2840 / 300</td>
</tr>
</tbody>
</table>

Totals: 3409 / 869 W 3409 / 869 W
Appendix G

Outpost Internal Systems Power
Budget Summary - Δ2
### Lunar Campsite Internal Systems Power  
**Budget Summary - Δ2**

- **All Loads in Watts** -

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

**Totals:**  
1428 W  
884 W

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

- **All Loads in Watts** -

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

**Totals:**  
1552 W  
1271 W
## Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

### - All Loads in Watts -

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

### Science/workbench (Cont.)

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press. transducers / sensors</td>
<td>31.5</td>
<td>33</td>
</tr>
<tr>
<td>Temp. sensors</td>
<td>0.4</td>
<td>40</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>237.5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Science/Glovebox

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

### Water Storage

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>20</td>
<td>14</td>
</tr>
</tbody>
</table>

### Water Processing

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water processor</td>
<td>600</td>
<td>33</td>
</tr>
<tr>
<td>Process ctrl. H2O quality</td>
<td>100</td>
<td>~0</td>
</tr>
<tr>
<td>Urine processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation assy.</td>
<td>175</td>
<td>16.5</td>
</tr>
<tr>
<td>Embedded ctrl.</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Fluid ctrl. assy.</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Fluid pump ORU</td>
<td>70</td>
<td>17</td>
</tr>
<tr>
<td>Pressure ctrl.</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Purge pump</td>
<td>70</td>
<td>1.4</td>
</tr>
</tbody>
</table>

### Totals:

- 3527 W
- 836 W

G-3
# Lunar Campsite Internal Systems Power Budget Summary - Δ2 (Cont.)

## - All Loads in Watts -

<table>
<thead>
<tr>
<th>Continuous Duty Cycle(%)</th>
<th>Avg. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air Revitalization System (ECLSS - ARS)</strong></td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2} vent valve</td>
<td>40</td>
</tr>
<tr>
<td>Atmos. comp. monitor</td>
<td>531 (nt/day) 25/100</td>
</tr>
<tr>
<td>CO\textsubscript{2} removal assy.</td>
<td>523.4</td>
</tr>
<tr>
<td>Converter</td>
<td>7.2</td>
</tr>
<tr>
<td>THC supply valve</td>
<td>20</td>
</tr>
<tr>
<td>Heater</td>
<td>150</td>
</tr>
<tr>
<td>TCCS - elec. I/F assy.</td>
<td>10</td>
</tr>
<tr>
<td>TCCS - flow ctrl. assy.</td>
<td>15.4</td>
</tr>
<tr>
<td>Flow meter &amp; cable</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Science / DMS / Comm. / Workstation</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>996</td>
</tr>
<tr>
<td><strong>Crew Health (CHeCS)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>911</td>
</tr>
<tr>
<td><strong>Fire Detection / Suppression</strong></td>
<td></td>
</tr>
<tr>
<td>Flame detector</td>
<td>14</td>
</tr>
<tr>
<td>CO\textsubscript{2} release valve</td>
<td>800</td>
</tr>
<tr>
<td>Sensors, smoke - duct &amp; area</td>
<td>23.8</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td>4043 W</td>
</tr>
</tbody>
</table>

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

## - All Loads in Watts -

<table>
<thead>
<tr>
<th>Continuous Duty Cycle(%)</th>
<th>Avg. Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waste Management</strong></td>
<td></td>
</tr>
<tr>
<td>Commode/urinal assy.</td>
<td></td>
</tr>
<tr>
<td>C/U - commode fan</td>
<td>50</td>
</tr>
<tr>
<td>Compactor</td>
<td>130</td>
</tr>
<tr>
<td>User panel</td>
<td>25</td>
</tr>
<tr>
<td><strong>M/S Hygiene</strong></td>
<td></td>
</tr>
<tr>
<td>Waste management compartment</td>
<td></td>
</tr>
<tr>
<td>Cabin air fan</td>
<td>30</td>
</tr>
<tr>
<td>Cabin air heater</td>
<td>100</td>
</tr>
<tr>
<td>Cabin air temp. sensor</td>
<td>10</td>
</tr>
<tr>
<td>Lighting system</td>
<td>30</td>
</tr>
<tr>
<td>Local controller</td>
<td>27</td>
</tr>
<tr>
<td><strong>Handwash</strong></td>
<td></td>
</tr>
<tr>
<td>Diverter motors</td>
<td>1.8</td>
</tr>
<tr>
<td>Local control</td>
<td>1.6</td>
</tr>
<tr>
<td>Signal cond.</td>
<td>6</td>
</tr>
<tr>
<td>Temp. meas.</td>
<td>0.5</td>
</tr>
<tr>
<td>H2O supply</td>
<td>309</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td>721 W</td>
</tr>
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G-4
### Lunar Campsite Internal/External Systems

#### Power Budget Summary - Δ2 (Cont.)

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Duty Cycle(%)</th>
<th>Av. Load</th>
</tr>
</thead>
</table>

**Hab Growth (scaled from SSF: -5.4% Pave):**

| 328 | 100 | 328 |

**Gas Conditioning Assembly (GCA):**

<table>
<thead>
<tr>
<th>Component</th>
<th>Continuous</th>
<th>Duty Cycle</th>
<th>Av. Load</th>
</tr>
</thead>
</table>

| GCA - N2 | 113.6 | 100 | 113.6 |
| N2 cond. assy. | 9.1 | 100 | 9.1 |
| N2 growth | 108.8 | 100 | 108.6 |
| O2 cond. assy. | 8.7 | 100 | 8.7 |
| O2 growth | 312 | 100 | 312 |

**RPC Modules:**

| 2684 / 300 | 100 | 2684 / 300 |

**Totals:**

| 3236 / 852 W | 3236 / 852 W |

### Lunar Campsite Overall Power Budget Summary - Δ2

- All Loads in Watts -

<table>
<thead>
<tr>
<th>Component</th>
<th>Continuous</th>
<th>Av. Load</th>
</tr>
</thead>
</table>

| EPDS/DMS/SP/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 dish/rw/18Mar92

G-5
Appendix H

Power System Summary
### Power System Top Level Area, Mass, & Power Breakdown

**Configuration A - Min A/L -**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>reference case</td>
<td>33.25</td>
<td>144</td>
<td>12.6</td>
<td>9.1</td>
<td>4.08</td>
<td>10</td>
</tr>
<tr>
<td>Δ1 case</td>
<td>26.2</td>
<td>113</td>
<td>9.8</td>
<td>7.24</td>
<td>3.17</td>
<td>10</td>
</tr>
<tr>
<td>Δ2 case</td>
<td>24.9</td>
<td>107.7</td>
<td>9.3</td>
<td>6.9</td>
<td>3.01</td>
<td>10</td>
</tr>
<tr>
<td>Δ2* case same as Δ2 case (sized for 1 day contingency)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 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 -**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<tr>
<td>Non hyp. A/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ1 case</td>
<td>27.9</td>
<td>121</td>
<td>10.4</td>
<td>7.8</td>
<td>3.34</td>
<td>10</td>
</tr>
<tr>
<td>Δ2 case</td>
<td>26.6</td>
<td>115</td>
<td>9.9</td>
<td>7.5</td>
<td>3.2</td>
<td>10</td>
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<tr>
<td>Hyperbaric A/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ1 case</td>
<td>28.5</td>
<td>123.5</td>
<td>10.6</td>
<td>8.0</td>
<td>3.4</td>
<td>10</td>
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<tr>
<td>Δ2 case</td>
<td>27.2</td>
<td>118</td>
<td>10.1</td>
<td>7.7</td>
<td>3.24</td>
<td>10</td>
</tr>
</tbody>
</table>

* 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 G -**

<table>
<thead>
<tr>
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<td></td>
</tr>
<tr>
<td>Δ1 case</td>
<td>27.1</td>
<td>117</td>
<td>10.1</td>
<td>7.6</td>
<td>3.3</td>
<td>10</td>
</tr>
<tr>
<td>Δ2 case</td>
<td>25.8</td>
<td>112</td>
<td>9.6</td>
<td>7.2</td>
<td>3.1</td>
<td>10</td>
</tr>
<tr>
<td>Hyperbaric A/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ1 case</td>
<td>27.7</td>
<td>120</td>
<td>10.3</td>
<td>7.7</td>
<td>3.32</td>
<td>10</td>
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<tr>
<td>Δ2 case</td>
<td>26.4</td>
<td>114</td>
<td>9.8</td>
<td>7.4</td>
<td>3.2</td>
<td>10</td>
</tr>
</tbody>
</table>

*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 Mass Summary
**Configuration A - Min. A/L**

<table>
<thead>
<tr>
<th>Component</th>
<th>Reference</th>
<th>Δ1</th>
<th>δ2</th>
<th>Δ2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td>137 kg</td>
<td>109 kg</td>
<td>104 kg</td>
<td>104 kg</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>165 kg</td>
<td>131 kg</td>
<td>126 kg</td>
<td>126 kg</td>
</tr>
<tr>
<td>Radiator</td>
<td>49 kg</td>
<td>39 kg</td>
<td>37 kg</td>
<td>37 kg</td>
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<tr>
<td>Hydrogen Reactant</td>
<td>130 kg</td>
<td>103 kg</td>
<td>99 kg</td>
<td>99 kg</td>
</tr>
<tr>
<td>Hydrogen Residual</td>
<td>37 kg</td>
<td>30 kg</td>
<td>28 kg</td>
<td>37 kg</td>
</tr>
<tr>
<td>Oxygen Reactant</td>
<td>1042 kg</td>
<td>829 kg</td>
<td>791 kg</td>
<td>791 kg</td>
</tr>
<tr>
<td>Oxygen Residual</td>
<td>298 kg</td>
<td>237 kg</td>
<td>226 kg</td>
<td>291 kg</td>
</tr>
<tr>
<td>Hydrogen Tank(s)</td>
<td>1883 kg</td>
<td>1503 kg</td>
<td>1434 kg</td>
<td>1373 kg</td>
</tr>
<tr>
<td>Oxygen Tank(s)</td>
<td>856 kg</td>
<td>686 kg</td>
<td>655 kg</td>
<td>499 kg</td>
</tr>
<tr>
<td>Water Tank</td>
<td>59 kg</td>
<td>47 kg</td>
<td>44 kg</td>
<td>44 kg</td>
</tr>
<tr>
<td>Solar Array</td>
<td>240 kg</td>
<td>198 kg</td>
<td>191 kg</td>
<td>191 kg</td>
</tr>
<tr>
<td>Support Equipment (cables, etc.)</td>
<td>287 kg</td>
<td>224 kg</td>
<td>212 kg</td>
<td>212 kg</td>
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</table>

Total: 5183 kg  4136 kg  3947 kg  3803 kg
### Power System Mass Summary
#### Configuration D - Non-hyp. A/L

<table>
<thead>
<tr>
<th>Component</th>
<th>Δm (kg)</th>
<th>Δm2 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td>117</td>
<td>112</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>142</td>
<td>136</td>
</tr>
<tr>
<td>Radiator</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>Hydrogen Reactant</td>
<td>112</td>
<td>107</td>
</tr>
<tr>
<td>Hydrogen Residual</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>Oxygen Reactant</td>
<td>894</td>
<td>855</td>
</tr>
<tr>
<td>Oxygen Residual</td>
<td>255</td>
<td>244</td>
</tr>
<tr>
<td>Hydrogen Tank(s)</td>
<td>1618</td>
<td>1549</td>
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<tr>
<td>Oxygen Tank(s)</td>
<td>738</td>
<td>707</td>
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<tr>
<td>Water Tank</td>
<td>50</td>
<td>48</td>
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<tr>
<td>Solar Array</td>
<td>208</td>
<td>201</td>
</tr>
<tr>
<td>Support Equipment (cables, converters, etc.)</td>
<td>236</td>
<td>225</td>
</tr>
</tbody>
</table>

Total: 4445 kg 4255 kg

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Δm (kg)</th>
<th>Δm2 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td>113</td>
<td>108</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>137</td>
<td>131</td>
</tr>
<tr>
<td>Radiator</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>Hydrogen Reactant</td>
<td>108</td>
<td>103</td>
</tr>
<tr>
<td>Hydrogen Residual</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Oxygen Reactant</td>
<td>863</td>
<td>825</td>
</tr>
<tr>
<td>Oxygen Residual</td>
<td>246</td>
<td>235</td>
</tr>
<tr>
<td>Hydrogen Tank(s)</td>
<td>1564</td>
<td>1495</td>
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<tr>
<td>Oxygen Tank(s)</td>
<td>713</td>
<td>682</td>
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<tr>
<td>Water Tank</td>
<td>49</td>
<td>46</td>
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<tr>
<td>Solar Array</td>
<td>203</td>
<td>196</td>
</tr>
<tr>
<td>Support Equipment (cables, converters, etc.)</td>
<td>231</td>
<td>219</td>
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</tbody>
</table>

Total: 4298 kg 4109 kg

H-4
## Power System Mass Summary
### Configuration D - Hyperbaric A/L

<table>
<thead>
<tr>
<th>Component</th>
<th>Δ1</th>
<th>Δ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td>120 kg</td>
<td>115 kg</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>145 kg</td>
<td>139 kg</td>
</tr>
<tr>
<td>Radiator</td>
<td>43 kg</td>
<td>41 kg</td>
</tr>
<tr>
<td>Hydrogen Reactant</td>
<td>115 kg</td>
<td>110 kg</td>
</tr>
<tr>
<td>Hydrogen Residual</td>
<td>33 kg</td>
<td>32 kg</td>
</tr>
<tr>
<td>Oxygen Reactant</td>
<td>917 kg</td>
<td>878 kg</td>
</tr>
<tr>
<td>Oxygen Residual</td>
<td>262 kg</td>
<td>251 kg</td>
</tr>
<tr>
<td>Hydrogen Tank(s)</td>
<td>1659 kg</td>
<td>1590 kg</td>
</tr>
<tr>
<td>Oxygen Tank(s)</td>
<td>756 kg</td>
<td>725 kg</td>
</tr>
<tr>
<td>Water Tank</td>
<td>52 kg</td>
<td>49 kg</td>
</tr>
<tr>
<td>Solar Array</td>
<td>211 kg</td>
<td>204 kg</td>
</tr>
<tr>
<td>Support Equipment (cables, converters, etc.)</td>
<td>241 kg</td>
<td>230 kg</td>
</tr>
</tbody>
</table>

**Total:** 4554 kg 4365 kg

## Power System Mass Summary
### Configuration G - Hyperbaric A/L

<table>
<thead>
<tr>
<th>Component</th>
<th>Δ1</th>
<th>Δ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cells</td>
<td>116 kg</td>
<td>111 kg</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>141 kg</td>
<td>135 kg</td>
</tr>
<tr>
<td>Radiator</td>
<td>41 kg</td>
<td>39 kg</td>
</tr>
<tr>
<td>Hydrogen Reactant</td>
<td>111 kg</td>
<td>106 kg</td>
</tr>
<tr>
<td>Hydrogen Residual</td>
<td>32 kg</td>
<td>30 kg</td>
</tr>
<tr>
<td>Oxygen Reactant</td>
<td>886 kg</td>
<td>848 kg</td>
</tr>
<tr>
<td>Oxygen Residual</td>
<td>253 kg</td>
<td>242 kg</td>
</tr>
<tr>
<td>Hydrogen Tank(s)</td>
<td>1604 kg</td>
<td>1536 kg</td>
</tr>
<tr>
<td>Oxygen Tank(s)</td>
<td>732 kg</td>
<td>701 kg</td>
</tr>
<tr>
<td>Water Tank</td>
<td>50 kg</td>
<td>48 kg</td>
</tr>
<tr>
<td>Solar Array</td>
<td>206 kg</td>
<td>199 kg</td>
</tr>
<tr>
<td>Support Equipment (cables, converters, etc.)</td>
<td>235 kg</td>
<td>224 kg</td>
</tr>
</tbody>
</table>

**Total:** 4407 kg 4218 kg
Appendix I

Heat Rejection Summary
## Heat Rejection System Top Level
### Mass Breakdown

### - Configuration A - Min A/L -

<table>
<thead>
<tr>
<th></th>
<th>Rej. load (kW)</th>
<th>Rad area (m²)</th>
<th>Rad mass (kg)</th>
<th>Support mass (kg)</th>
<th>Heat pump mass (kg)</th>
<th>Heat exch. mass (kg)</th>
<th>Total Ext. mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference case</td>
<td>13.2</td>
<td>43.2</td>
<td>225</td>
<td>45</td>
<td>134</td>
<td>62.4</td>
<td>466</td>
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<td>Δ1 case</td>
<td>10.45</td>
<td>34.1</td>
<td>177</td>
<td>35.4</td>
<td>120</td>
<td>50.4</td>
<td>383</td>
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<tr>
<td>Δ2 case</td>
<td>9.94</td>
<td>32.5</td>
<td>169</td>
<td>34</td>
<td>117</td>
<td>48</td>
<td>368</td>
</tr>
</tbody>
</table>

Δ2* Case same as Δ2 case (sized for peak loads)

---

### Heat Rejection System Top Level
### Mass Breakdown (Cont.)

### - Configuration D -

<table>
<thead>
<tr>
<th></th>
<th>Rej. load (kW)</th>
<th>Rad area (m²)</th>
<th>Rad mass (kg)</th>
<th>Support mass (kg)</th>
<th>Heat pump mass (kg)</th>
<th>Heat exch. mass (kg)</th>
<th>Total Ext. mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non hyp. A/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ1 case</td>
<td>11.04</td>
<td>36</td>
<td>187</td>
<td>37.4</td>
<td>123</td>
<td>53</td>
<td>400</td>
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<tr>
<td>Δ2 case</td>
<td>10.53</td>
<td>34.4</td>
<td>179</td>
<td>36</td>
<td>120</td>
<td>51</td>
<td>386</td>
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<td>Hyperbaric A/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Δ1 case</td>
<td>11.26</td>
<td>36.7</td>
<td>191</td>
<td>38</td>
<td>124</td>
<td>54</td>
<td>407</td>
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<tr>
<td>Δ2 case</td>
<td>10.73</td>
<td>35</td>
<td>182</td>
<td>36</td>
<td>121</td>
<td>52</td>
<td>391</td>
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Heat Rejection System Top Level  
Mass Breakdown (Cont.)

- Configuration G -

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