Constellation Architecture Team-Lunar Habitation Concepts

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Abstract

This paper will describe lunar habitat concepts that were defined as part of the Constellation Architecture Team-Lunar (CxAT-Lunar) in support of the Vision for Space Exploration. There are many challenges to designing lunar habitats such as mission objectives, launch packaging, lander capability, and risks. Surface habitats are required in support of sustaining human life to meet the mission objectives of lunar exploration, operations, and sustainability. Lunar surface operations consist of crew operations, mission operations, EVA operations, science operations, and logistics operations. Habitats are crewed pressurized vessels that include surface mission operations, science laboratories, living support capabilities, EVA support, logistics, and maintenance facilities. The challenge is to deliver, unload, and deploy self-contained habitats and laboratories to the lunar surface.

This paper will describe an overview of the various CxAT-Lunar trade study habitat concepts and their functionality. The Crew Operations area includes basic crew accommodations such as sleeping, eating, hygiene and stowage. The EVA Operations area includes additional EVA capability beyond the suitlock function such as suit maintenance, spares stowage, and suit stowage. The Logistics Operations area includes the enhanced accommodations for 180 days such as enhanced life support systems hardware, consumable stowage, spares stowage, interconnection to the other habitation elements, a common interface mechanism for future growth, and mating to a pressurized rover or Pressurized Logistics Module (PLM). The Mission & Science Operations area includes enhanced outpost autonomy such as an IVA glove box, life support, medical operations, and exercise equipment.

I. Introduction

The CxAT-Lunar surface mission scenario (campaign) analysis focused on three primary scenarios or Analysis-of-Alternatives (AoA). The first CxAT-Lunar trade-set one (now known as Lunar Scenario 1.0.0—LS1) investigated sustaining a crew of four for six months with full outpost capability and the ability to perform long surface mission excursions using large mobility systems. Figure 1 and 2 depicts the notional outpost configurations for this trade set. CxAT-Lunar trade-set two (now known as Lunar Scenario 2.0.0—LS2) investigated a mobile architecture approach with the scenario focused on early exploration using two small pressurized rovers and a mobile logistics support capability. CxAT-Lunar trade-set three (now known as Lunar Scenario 3.0.0—LS3) investigated a variation of the LS1 scenario with an emphasis on initial core habitation capability. LS2 and LS3 are an attempt to align early

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functionality as constrained by affordability. The scenarios assume on average two missions per year that alternate between crewed and cargo missions. The buildup is structured in such a way that it can pause at any time to accommodate contingencies or a change in emphasis to a sortie mode. The outpost functionality is allocated so that a loss of any one element will not result in significant loss of outpost capabilities. The modular nature of the notional outpost build-up enhances the ability of international partners to contribute elements and systems. A crewed sortie to the outpost location is initiated before the delivery of the primary cargo flight to reduce risk of the cargo lander delivering surface elements.

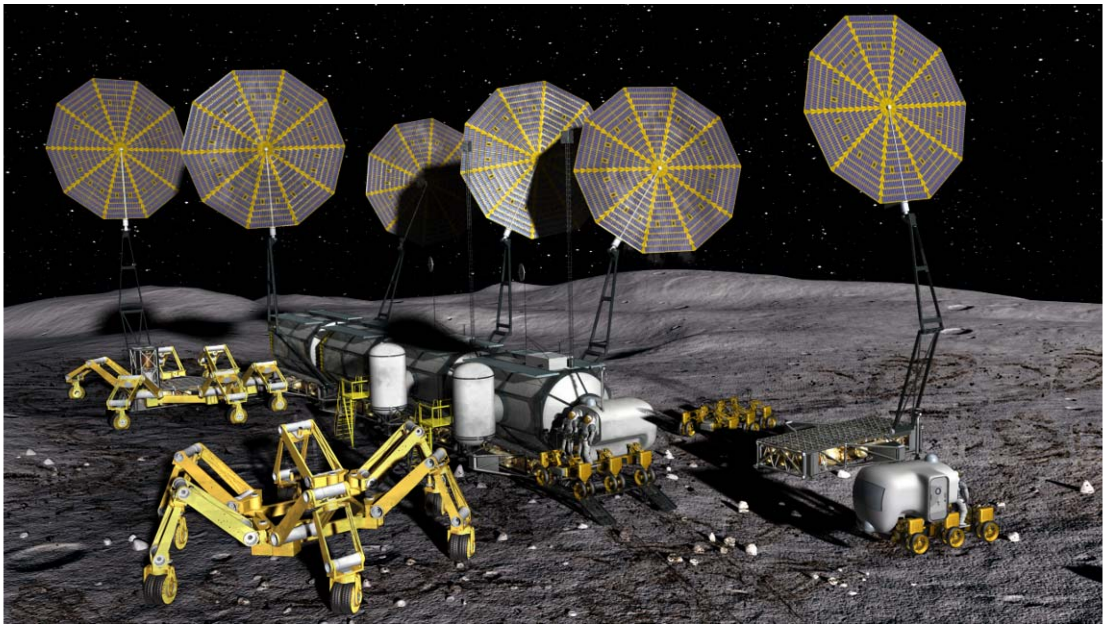


Figure 1. LS1 Horizontal Cylindrical Habitat Outpost

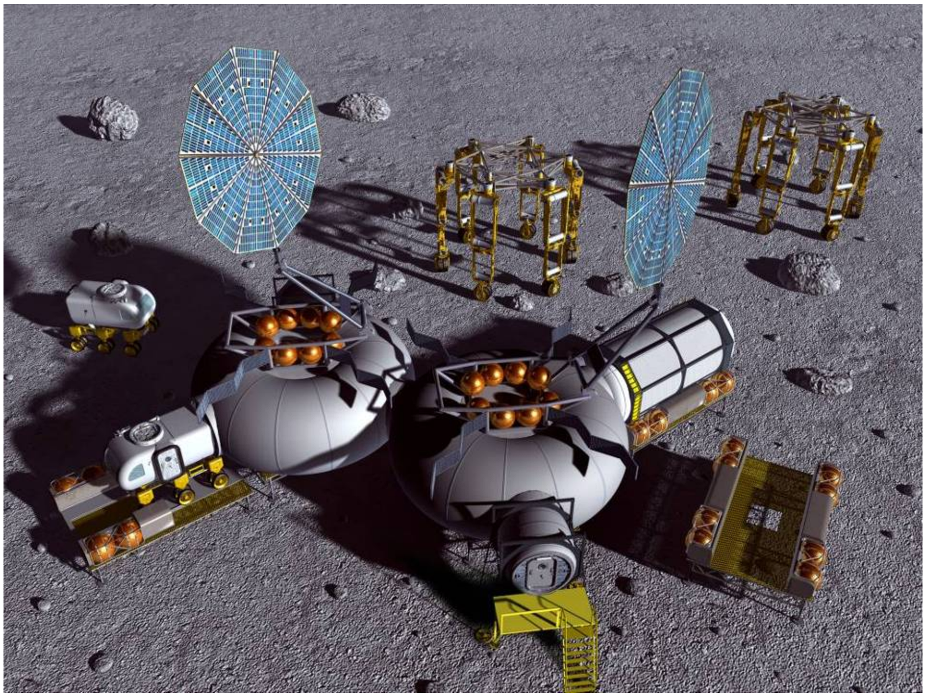


Figure 2. LS1 Alternative Inflatable Torus Habitat Outpost

For both scenarios, a minimum functional outpost is deployed in a single cargo flight that either features a mobility emphasis (LS2) or a core habitation emphasis (LS3). The option for putting off the remainder of the outpost functionality until either international participation or available budget permits is now available for a minimum up-front cost while still having the ability to accommodate a four person crew for 14-28 day missions during this outpost build-up "hold" opportunity. Both approaches build up to a capability similar to LS1 but with slightly less habitation volume and no ability to accommodate a crew during long eclipse periods. The outpost build-up manifests through LS2 and LS3 end at a similar state with redundant habitats, the ability to sustain a crew for 180 days, and support long distance and duration surface roving. Trade set three (LS3) investigated delivery of a "core" habitation capability in support of an early outpost that would mature into the full outpost capability (figure 3). The scenarios referenced a common top-loaded flat-deck lander sized to fit in a 10-meter shroud—resulting in a ~ 8.8 meter diameter octagonal lander by ~ 6.3 meter height of lander deck to surface. Other assumptions are a crew of four, mission duration varies at the beginning of the scenario with the goal being 180 day surface stays at outpost complete; and the scenario begins with a Sortie mission and "boots-on-the-Moon" in 2020. As previously stated the CxAT-Lunar studies have transitioned in nomenclature and are now referred to as Lunar Scenarios (LS). Lunar Scenario 1.0 is now called LS1, LS2, and LS3 respectively. The paper will use describe TS-1 and TS-3 as LS1 and LS3. ***LS2 exploration concept will not be described in this paper.***

The outpost build-up also incorporates design philosophies that enhance supportability. Application of lightweight materials coupled with multi-function structures and packaging reduce the needed mass of systems. Reuse or recycling of elements, systems, components or basic structural material reduce the need to bring mass to the outpost. All systems are conceptualized with this design philosophy, especially the Lunar Lander which offers substantial logistics reduction potential if its systems could be used as spares and its structure for resource needs of the outpost. However reuse of the lander descent stage is not fully developed and thus is not incorporated into this paper.

The objectives of the Constellation Architecture Team–Lunar habitation studies were to 1) identify promising habitation options that meet the mission architecture objectives, 2) identify desirable habitation features, 3) begin to understand the operational constraints based on different habitation options, and 4) understand the cost and risks of different habitation options. The habitation system is designed to support two mission modes 1) initial habitation mode and 2) outpost-complete mode with mobile exploration capability.

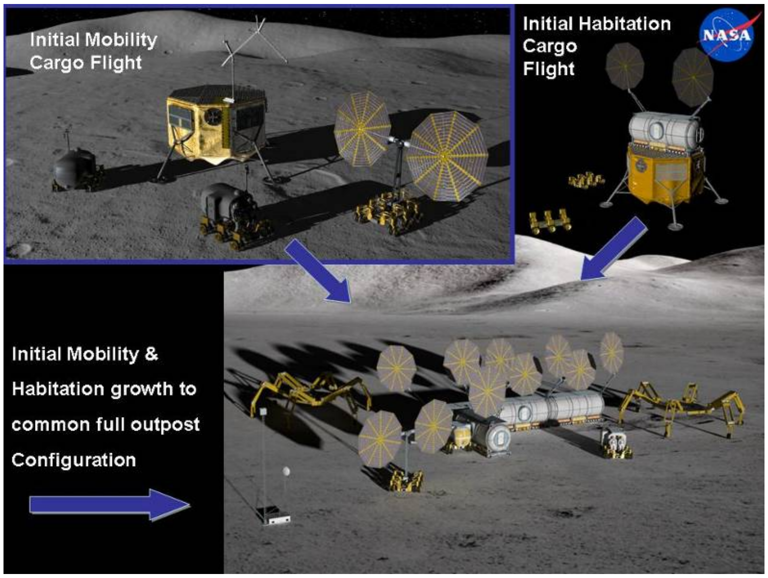


Figure 3. Initial Mobility (LS2) & Habitation Emphasis (LS3) to a Common Full Outpost

I. Description of Architecture Lunar Scenario 1.0.0—Horizontal Habitat Concept

This Lunar Scenario is the first study of the CxAT lunar surface architecture known as LS1. LS1 was guided by recommendations from the second ESMD-sponsored Lunar Architecture Team (LAT) and constrained by the Altair Lander configuration currently under consideration. The Altair Lander configuration features a large octagonal descent module with a flat-deck that the crewed ascent module attaches to, or in cargo mode, that accommodates the lunar surface system payloads. Since the Lander deck is about six meters from the lunar surface, access to and removal of payloads from the deck becomes a major architecture driver. The Altair Lander configuration along with the LAT-2 recommendations of pre-integration of lunar systems, mobility of lunar surface systems, and multiple habitat elements—but no more than three—resulted in an outpost that utilizes fewer but larger self-sufficient elements as compared to the LAT-2 outpost options.

LS1 mission objective was to develop a fully functional outpost as early as possible. This scenario assumes two missions per year that alternate between crewed and cargo missions. Although LS1 is initially being sized to operate at a polar location, the robust energy storage capabilities delivered on each cargo flight combined with the ability to move or relocate any outpost element enable a path to potential outpost deployment at any lunar location. The modular nature of LS1 enhances the ability of international partners to contribute elements and systems. The mobility capabilities can be tailored to science objectives as needed. Two alternative habitat concepts of a <u>hard metallic horizontal cylinder</u> and a larger <u>inflatable torus concept</u> were investigated as options in response to the surface exploration architecture scenario analysis.

A. Concept Description—Horizontal Hard Shell Habitat

The habitat elements provide a pressurized environment for the crewmembers to live in and work while performing mission tasks on the lunar surface. There are a number of architecture-level requirements that must be met by the habitat elements: reduce risk, reduce cost, achieve a basic level of crewed lunar surface stays as early as possible, and support outpost operations with a habitat element while meeting the initial habitation functionality and volume goals. Outpost operations consist of Crew Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations. These high-level requirements map to the following primary habitat element functions, interfaces and constraints.

Habitation System Functionality:

- <u>Crew Operations:</u> enable sustainability of 4 crew on lunar surface for 7-180 days
- <u>EVA Operations:</u> enable redundant EVA function & enhanced EVA capability
- <u>Mission Operations:</u> enable enhanced mission operations capability
- <u>Science Operations:</u> enable enhanced IVA biological & geological science capability
- <u>Logistics Operations:</u> enable resupply & spares cache

The LS1 horizontal habitation element is a 3-port horizontal cylindrical hard-shell integrally attached to the Power and Supply Unit (PSU). The hab unit is removed from the lander for surface emplacement (figure 5). The Outpost configuration consist of 3 Habitation Elements (1 Laboratory and 2 Hab units) mated together. A common mating mechanism is used to mate the modules together and for docking of the pressurized rover (figure 6). The Lab, 2 Hab units, and pressurized logistics modules (PLM) have the same pressure shell configuration and port locations. However the PLM only has 2 ports—one each end. The first PLM is retrofitted into the medical operations and biological science unit. The Lab and Hab are design to operate independently. The Lab with connection to the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) can demate and perform long excursions away from the outpost.

When hard-shell habitat elements are used in the outpost or mobile laboratory operations modes, the configurations are for two modes of operations. In the outpost mode, each habitat element is integrated with a PSU and the habitat/PSU unit is emplaced on the lunar surface and attached via a pressurized interface to other habitat elements to collectively form the outpost. In the mobile laboratory operations mode, the Lab-1 habitat element/PSU unit is attached to the ATHLETE and decoupled from the remaining elements of the outpost. The ATHLETE then moves the Lab-1/PSU unit to a new lunar surface location, where the crew stays and performs science operations for variable durations.

The Lab-1 unit is the first delivered since it provides the airlock function and is needed for the initial science mission and to begin the outpost emplacement phase. The Hab-2 and Hab-3/PLM units have a full-up capability delivered on a cargo lander. They have the crew ops and Closed ECLS on Hab-1. Hab-3 is the PLM and is retrofitted into the full-up medical ops system, exercise area, and biological science lab. The Lab-1 has the geological science lab (as allocated for lunar exploration). At this point the habitation complex, or Outpost, is Operational for long-term outpost use. Power is provided by an external solar array power generation system.

The thermal radiators are integrated to the top of the pressure shell frame. The shell is covered with multi-layer insulation (MLI) for passive thermal protection. The pressure shell is protected by a composite fabric micrometeoroid and surface ejecta protection barrier. An external deployable aluminum iso-grid open-grated dust porch and stairs allow surface access to and from the habitats. One of the design goals is to minimize the distance from the Hab to the surface. The habitat shown in figure 5 would be lowered to the maximum extent possible—not as shown in this artist image.

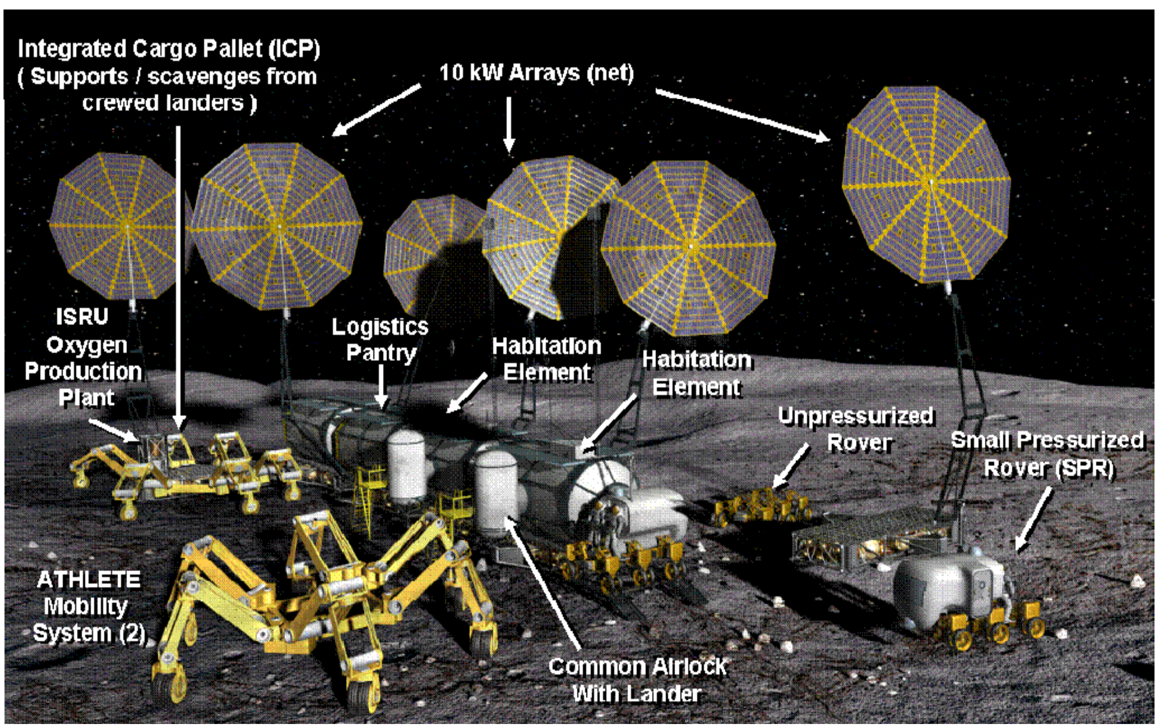


Figure 4. Outpost Emphasis Habitation Elements—Plan View

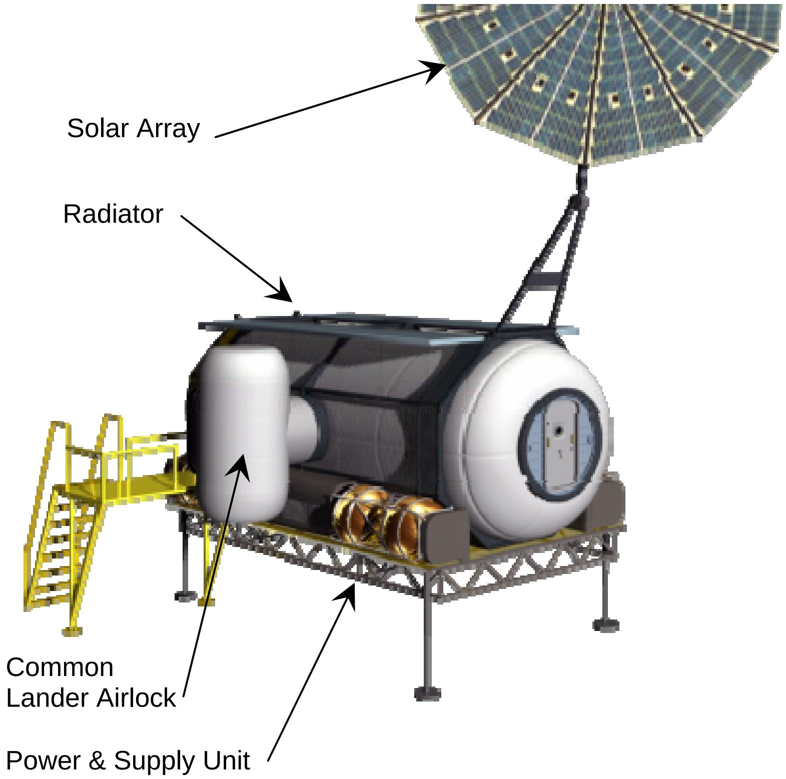


Figure 5. Common Habitation Element

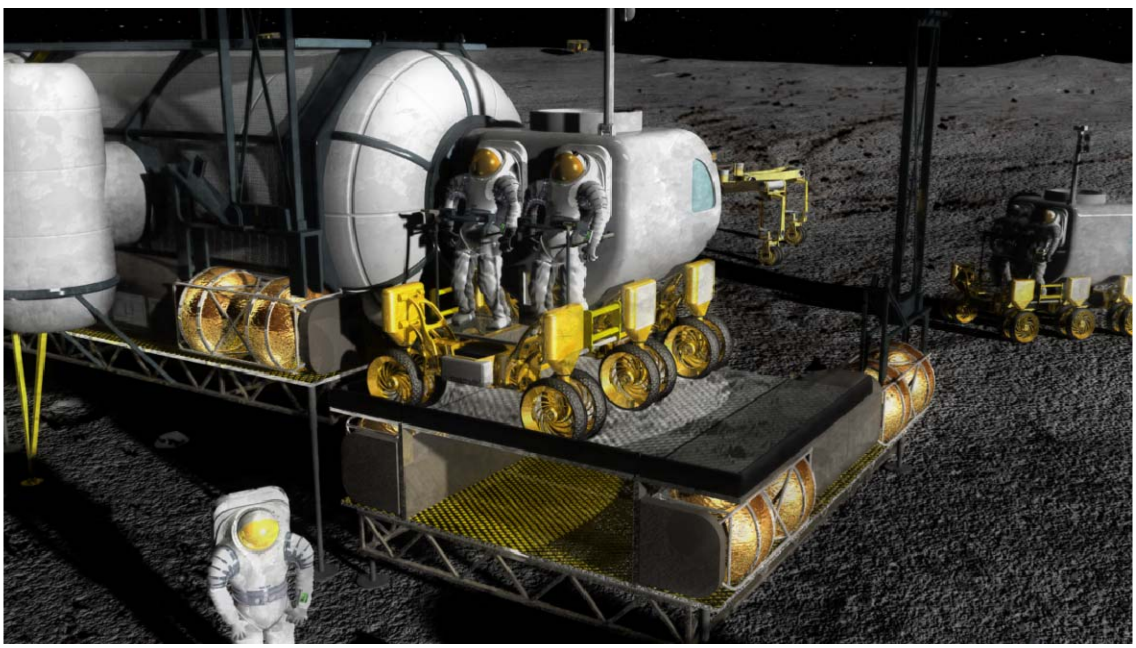


Figure 6. Small Pressurized Rover Docking with Lab Module

The Crew Operations in the Hab-1 unit includes basic crew accommodations such as sleeping, eating, hygiene and stowage. The EVA Operations includes additional EVA capability beyond the initial airlock function such as redundant airlock on the 2nd unit, suit maintenance, spares stowage, and suit stowage. Logistics Operations includes the enhanced accommodations for 180 days such as closed loop life support systems hardware, consumable stowage, spares stowage, interconnection to the other Hab units, and a common interface mechanism for future growth and mating to a pressurized rover. The Mission & Science Operations unit includes enhanced outpost autonomy such as an IVA glove box, life support, and medical operations.

<u>Outpost Habitat Elements Summary</u>

- Lab-1: Geological Science Lab, Airlock, EVA Ops & Maintenance, Subsystems
  3.5 m internal diameter x 8.17 m internal length, ~ 78 m3, 3-ports
- Hab-1: Crew Ops, Mission Ops, Airlock, Galley, Wardroom, Crew Sleep Area, Subsystems
  3.5 m internal diameter x 8.17 m internal length, ~ 78 m3, 3-ports
- Hab-3: Retrofitted PLM, Medical Ops, Biological Science, Exercise, Storage, limited subsystems
  3.5 m internal diameter x 8.17 m internal length, ~ 78 m3, 3-ports
- PLM: Logistics and Supplies, minimal subsystems
  3.5 m internal diameter x 8.17 m internal length, ~ 78 m3, 2-ports

Each habitat element is a 3.5 m internal diameter x 8.17 m internal length (providing ~ 78 m^3 volume in each element) aluminum-lithium hard-shell cylinder. This configuration has a total volume = ~234 m^3 total volume (all 3 habitat elements), which = ~58.5 m^3 / crewmember. The floor area = 21.3 m^2/habitat element = ~63.9 m^2 total (all 3 elements). The PLM adds another 78 m3 of stowage and supplies volume for a total volume of 312 m3 for 4-crew on a 180 day mission. This equates s to 78 m3 per crewmember for 180 day stays. The first Habitat element deployed to the surface would be supported and powered by its integrated PSU and have communications capability provided by an integrated LCT, figure 7. The habitation system has two airlocks. These two airlocks have commonality with and are the same as the Lander airlock. Internal to the Hab is the dust containment system and dust lock to minimize the amount to lunar regolith and dust that gets into the habitable volume. Each airlock is 5.5 m^3 of volume. An analysis was performed on reusing the lander airlock. The analysis showed that reusing (disconnecting, removal, transport, reconnection, and verification) was not cost effective due to the additional design changes required to make it relocatable, the additional crew and missions risks, and the crew time and training that would be required to implement. However, the study did show cost saving and reduced risk by using duplicates of the lander airlock pre-integrated with the habitat elements.

Each hard-shell habitat element is delivered with logistics supplies to enable a 14, 28, 45, 0r 180 crew-day missions. Consideration is given to crew accessibility to stowed items during outpost buildup missions. Hab-1 has sufficient volume to carry up to 2,912 kg (~224 CTBs) of pressurized consumables. Lab-1 has sufficient volume to carry up to 1,979 kg (~1542 CTBs) of pressurized consumables. After initial habitat element delivery, the outpost uses a PLM for delivery of supplies. The PLM attaches to Hab-2.

The Core Habitat external hatches are 1.0 m wide x 1.52 m tall submarine style doors that are pressure assisted opening inward. The mating mechanism is under design definition, but will encompass the external hatch and will be approximately 1.8 m outside diameter. The current mating mechanism concept incorporates both active and passive aspects.

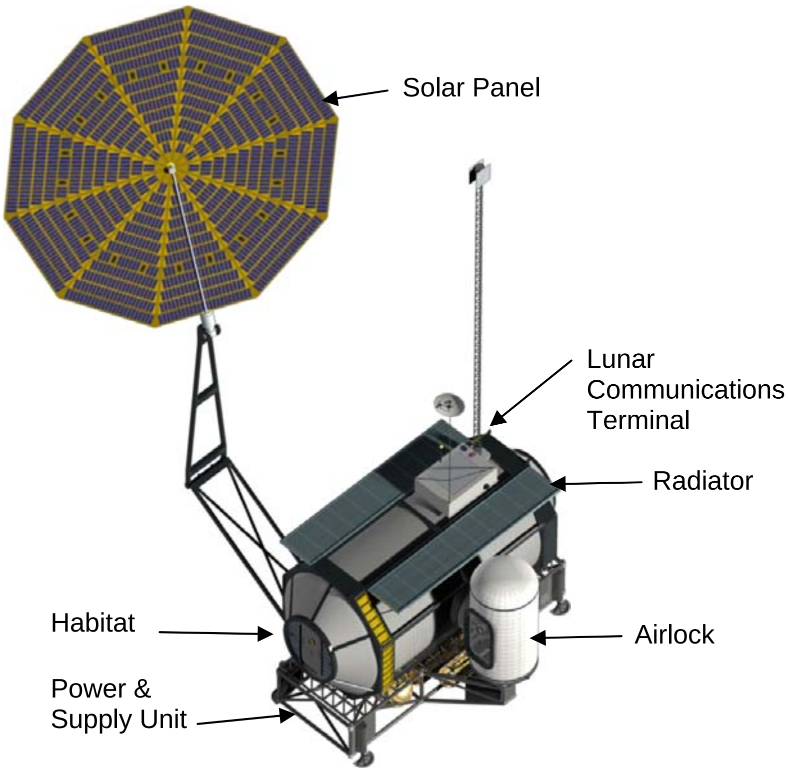


Figure 7. Initial Outpost Unit—Lab Module

The ECLS strategy for LS1 is to provide a distributed redundant system. The Lab provides a partially-closed ECLS for the initial habitation and when it is in the mobile lab mode. The primary habitat (Hab-1) provides the "closed" life support capability. The Lab or Hab has the ELCS redundancy in case one or the other module fails. The ECLS system consists of pressure control system, air revitalization, water recovery and management, waste management, fire detection and suppression, and emergency equipment. Air revitalization includes CO2 removal and reduction, O2 generation, trace contaminant control, ventilation and fans, airborne particulate control and monitoring, and atmosphere composition monitoring. The water recovery system includes H20 recovery of humidity condensate, waste hygiene and urine storage and distribution, and quality monitoring. The waste management system includes the urine collection and pre-treat, fecal collection, and trash collection. The waste and hygiene unit is located within the Hab-1 near the water recovery system.

Each habitat element has an internal Power Management & Distribution System (PMAD) that manages distribution of power to systems internal to habitat elements. The power storage system is external to the habitat in the PSU. The PMAD interfaces with the external power system in the PSU. The power storage system is external to the habitat in the PSU. The PMAD in the Lab and Hab each have two DC to 28v DC converters, two power distribution units, two 50-switch power switching units, two portable equipment panels, and appropriate primary and secondary wiring.

Each habitat element has an Active Thermal Control System (ATCS). The ATCS is the primary system for dissipating the thermal loads from the habitat element. The ATCS gathers the thermal loads from within the habitat and passes this load to the external body-mounted radiator panel integrated on top of the habitat element. The ATCS is designed to support the thermal loads and for the polar location environment. It has a primary and secondary loop. The fluid loops use a 60/40 mixture of propylene glycol/water and are stainless steel lines. The hardware is a mixture of Exploration Technology Development Program (ETDP) and ISS Thermal Control System (TCS) heritage. The hard shell cylinder habitat element outpost power and thermal loads are presented in Table 1.

The avionics (communication, control, and data management) subsystem has strong commonality with the Altair Lander avionics. A wireless communications system is used throughout the habitation complex. The habitat avionics uses primary and secondary operating computers and communications system (including antennas). The Habitats avionics has distributed crew utility panels, the EVA suitlock interface panel, workstations, the network server, networking bus cabling and interface. The outpost avionics assembly includes S-band software-defined radios, operational computers, bus interface units, antenna electronics, Redundancy Management Units, (RMUs), and data recorders.

The Lab-1 and Hab-1 habitat elements have three pressurized hatches/docking ports each and Hab-2 (the retrofitted PLM #1) has two hatches/docking ports. A parametric mass estimate is being allocated for the mating mechanism based on a preliminary assessment using ISS hardware. Additional definition is required to optimize a low-risk low-mass solution. In outpost mode, one hatch/docking port in each habitat element connects the three habitat elements longitudinally (Lab-1 is connected to Hab-1 which is connected to Hab-2) and provides a pass-through between the elements (normally open during operations). Lab-1 and Hab-1 each devote a docking port/hatch to the airlocks/suitlocks. The remaining hatch/docking port in Lab-1 is used by the SPR and the remaining hatch/docking port in Hab-2 is used by the PLM, Figure 8. The Lab and Hab-1 can operate independently (ECLS, Thermal, Comm, etc) so that the ATHLETE can reconnect to the Lab/PSU for long-distance exploration excursions, figure 9. Crewmembers use individual sleep bunks in Hab-1 when in outpost mode. Recumbent seat/workstations are used in Lab-1 when operating in mobile laboratory operations mode.

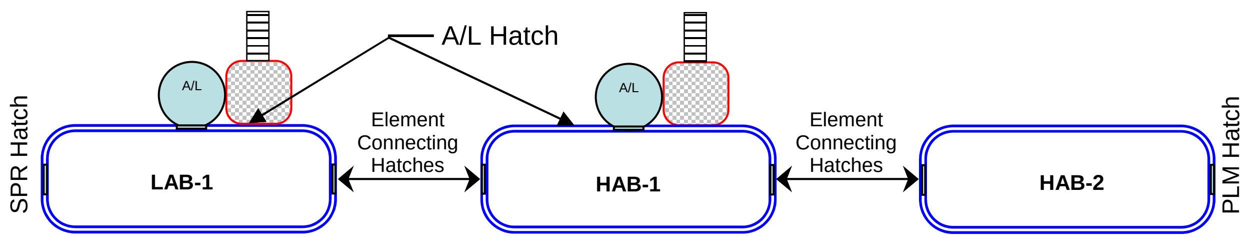


Figure 8. Outpost Interconnect Topology

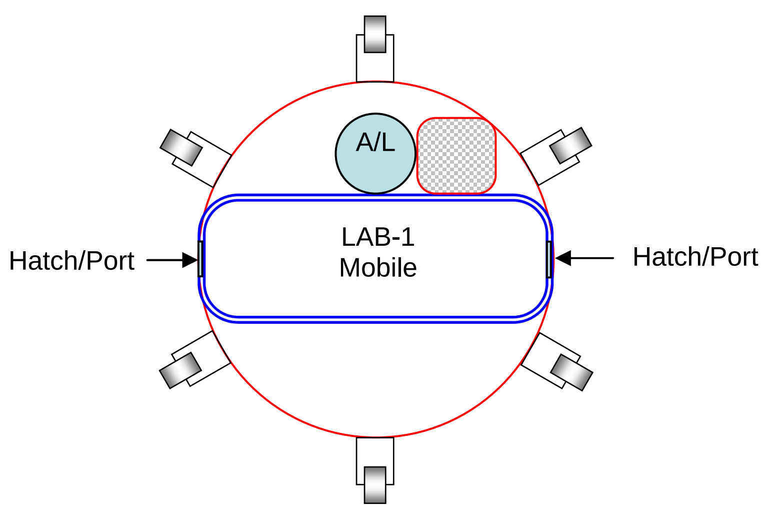
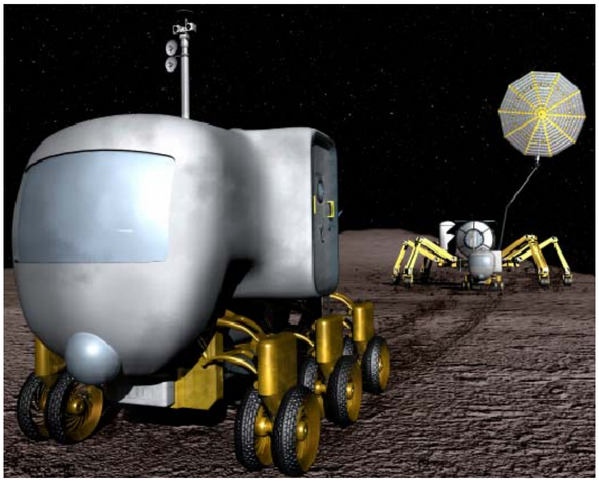
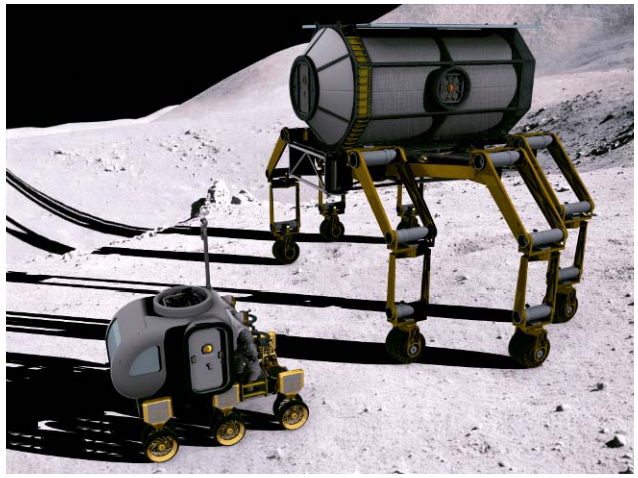


Figure 9a. Mobile Lab with Small Pressurized Rover





(b) (c)

Figure 9. Mobile Lab with Small Pressurized Rover

The Passive Thermal Control System (PTCS) reduces the thermal load in the habitat element by use of multi-layered insulation (MLI). Radiation protection is provided for Solar Proton Event (SPE-Solar Flare) using by a compartmentalized water wall capable of surrounding the crew sleep area. The water wall is filled with ~1000 kg of water, figure 10. The crew is not protected from Galactic Cosmic Radiation (GCR) radiation other than the supply tanks, structure, and subsystems. Further radiation analysis is required to determine the proper GCR protection.

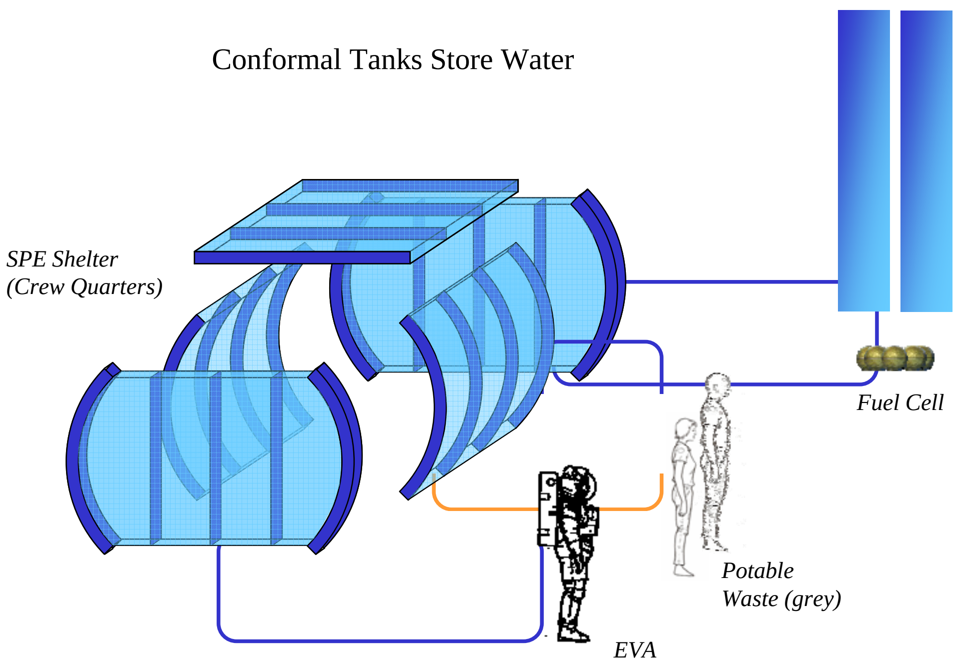


Figure 10. SPE Habitat Water Wall Concept

B. Hard Shell Internal Architecture

The habitation module units, as previously described, are cylindrical horizontal shells—smaller than the ISS 4.4 m diameter modules. The internal architectural layout is zoned by function separating the working Lab (noisy/dirty) from the living Hab (quiet/clean) areas. From a manufacturing and cost perspective, having these shell identical amortized the cost among units. The PLM is a derivative of them as well. Figure 11 depicts the internal architecture in the end-stated connected outpost mode. Shown in the lower left of figure 11 is the detached mobile lab element.

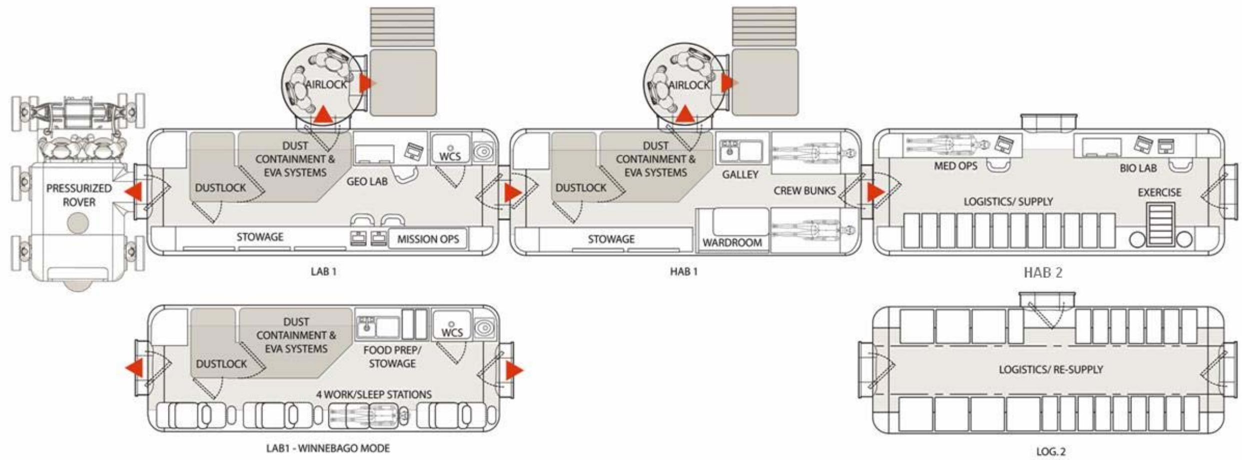


Figure 11. Outpost Hard-Shell Habitation Topology

The outpost habitation system is comprised of the Lab-1, Hab-1, and PLM #1 that is retrofitted to become Hab-2 (with outfitting from Lab-1, including medical operations/crew healthcare, exercise, and pantry/spares stowage). The habitat elements are delivered to the lunar surface in the following order: Lab-1, then Hab-1, then PLM #1 retrofitted to Hab-2. Each hard-shell habitat element is delivered fully outfitted.

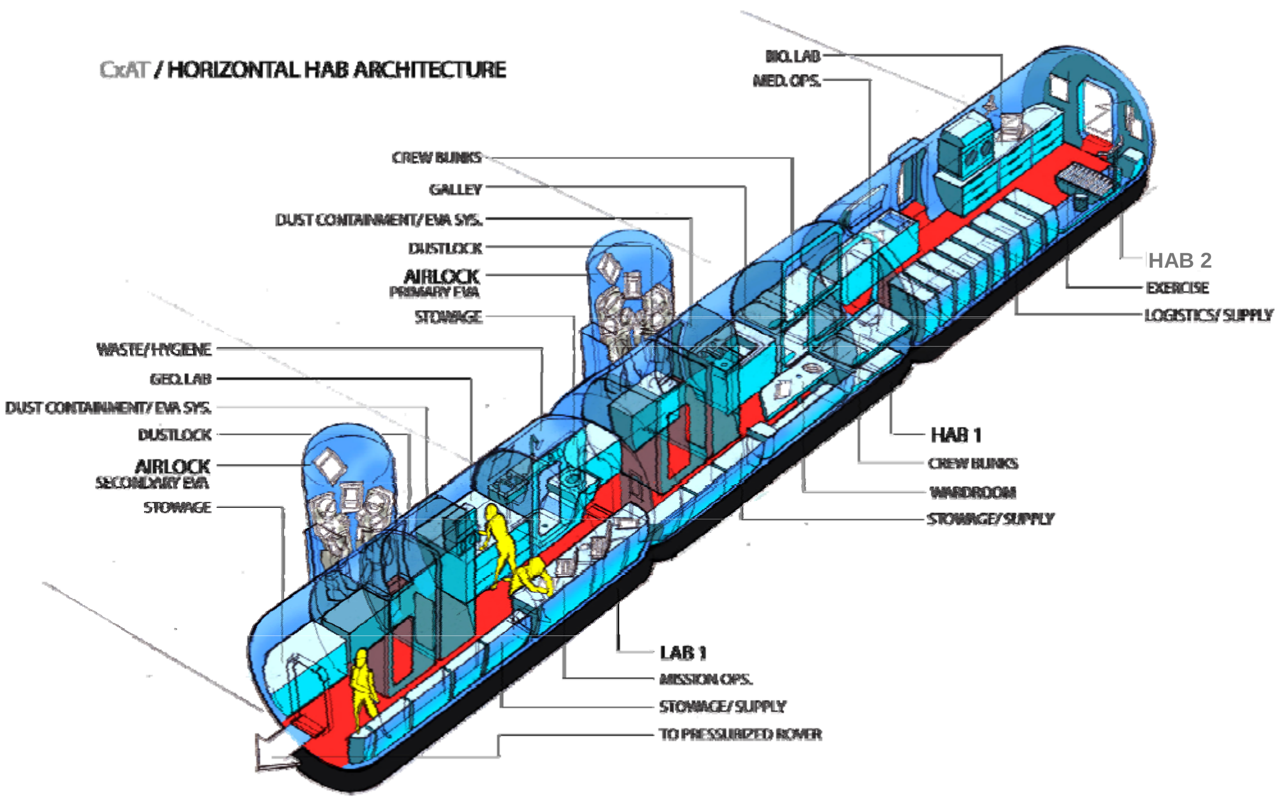


Figure 12. Hard-Shell Habitat Internal Architecture

Lab-1, the Lab module, contains the airlock, mission ops, and the geological science ops. The airlock is for two EVA suits, the hatch doors, and science pass-through lock for samples and equipment. The science ops area is the laboratory to support biological and geological science equipment, glove boxes, and storage. The EVA ops area has an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. By isolating the EVA function into a module by use of a dust containment area the dust and noise can be reduced throughout the rest of the habitation zones.

Hab-1 is the crew ops area and contains the sleep area bunks and the waste and hygiene function. As with each module the subsystems are dispersed among them as volume permits. Some of the subsystems, such as the closed life support are concentrated into one specific module. However avionic and power management is distributed. It is also the mission ops unit with the base operations and primary systems controls, the galley and wardroom functions. The crew ops area includes the basic crew accommodations of sleeping, eating, hygiene and stowage. Due to limitation on size, privacy curtains are utilized when necessary.

Hab-2 is the retrofitted pressurized logistics module—after the supplies have been used and distributed to the other units—it is turned into the bioscience lab, medical ops, exercise, and stowage area. Future PLMs will mate to the end of this unit with some supplies and spare relocated as appropriate. In most cases the additional PLM will be utilized as supplies are used and replaced with waste products for future disposal or recycling.

C. LS1 Hard-Shell Resource Summary

The power required (table 1) for nominal outpost operations is ~ 10.2 kW. The power required for the outpost while crew is not on board during a quiescent mode is ~ 2.0 kW. The thermal conditioning required for air-cooled and cold-plated cooling is ~ 4.6 and 7.2 kW respectively. The mass properties are shown in table 2. The outpost configuration total mass to the surface is ~ 18.7 mt for the 3 outpost habitation units. The Mobile Lab is ~ 8.5 mt.

Table 1. Hard-Shell Habitat Element Power and Thermal Loads

	Hab-1	**Lab-1**	**Hab-2**	Total Power & Thermal, W
Outpost Power Active, We	5115	4556	533	10204
Outpost Quiescent Power, We	1066	625	323	2014
Outpost Air-Cooled Thermal, W_t	1025	3226	391	4642
Outpost Cold-Plated Thermal, W_t	4090	1330	142	7231
Lab-1 in Mobile Laboratory Mode, W	n/a	4556	n/a	4556

Table 2. **Hard-Shell Habitat Element Mass Properties**

Habitat Subsystem	**Hab-1** Mass, Kg	**Lab-1** Mass, Kg	**Hab-2** Mass, Kg	**Total Outpost Mass, Kg**
Structures	2204	2204	1676	6084
Protection	331	233	233	797
Power	295	295	113	703
Thermal	243	222	45	510
Avionics	108	104	5	217
Life Support	1278	1621	146	3045
Airlock/Suitport	600	600	N/A	1200
Outfitting	136	1260	424	1820
Total Dry Mass	5195	6539	2642	14376
30% Growth	1559	1962	793	4313
Total Mass with 30% Growth	6754	8501	3435	18689

The lunar habitat interfaces with a number of external elements. Whether the habitat is a hard shell module or an inflatable module the interface are similar. Figure 13 shows an interface diagram of a habitat and its interfaces. Of note is this diagram shows an airlock attached to the exterior of the habitat rather than an internal suitlock. Figure 14 shows a habitat interface diagram with a suitlock.

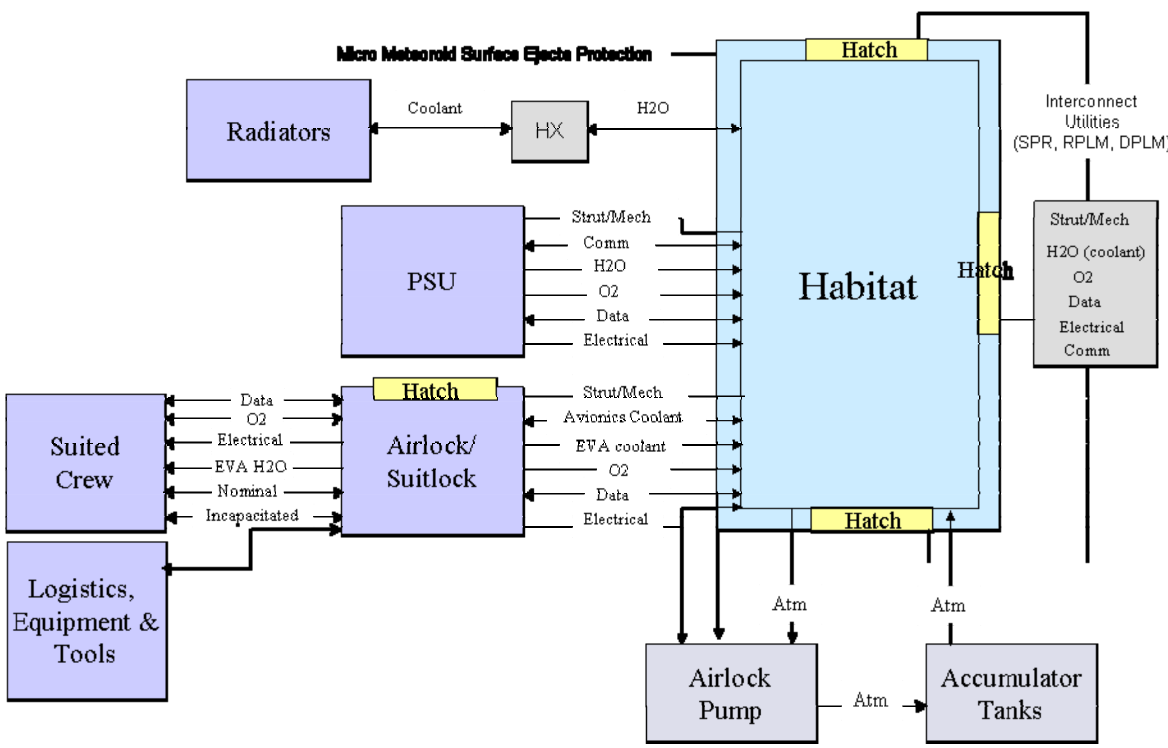


Figure 13. Surface Habitat Interface Diagram for LS1

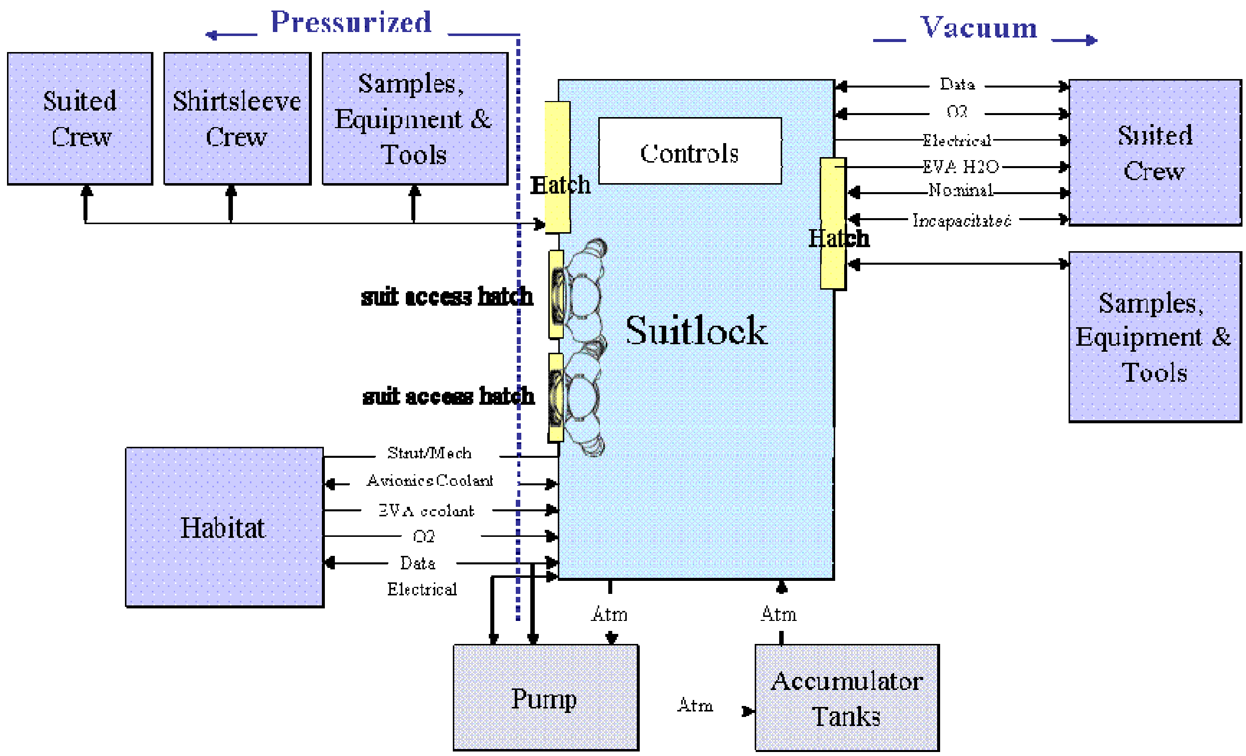


Figure 14. Suitlock Interface Diagram for LS3

D. LS1 Hab Summary

The habitation strategy for the LS1 surface outpost focused on assembling the Outpost capability as soon as possible; unloading the habitat(s) and emplacing them on the surface; and designing the Lab to be mobile. Unloading the habitats has the desirable feature of being close to the surface, being accessible for maintenance and repair, the capability to ad in-situ materials to protect from radiation (not addressed by this study), and the ability to dock a pressurized rover to the habitats. The final dimension for the horizontal cylindrical hard-shell is under investigation. As shown in LS1 analysis, three module are required plus the PLM in order to meet the needed functional and performance requirements, and pressurized volume for a crew of four staying on a long-duration (~180 days) lunar mission. As an alternative of horizontal cylindrical hard-shells inflatable torus habitation elements were studied.

II. Description of Architecture Lunar Scenario 1.0—Inflatable Habitat Concept

The inflatable habitat elements provides the same pressurized environment for the crewmembers to live and work while performing mission tasks on the lunar surface as the horizontal hard shell concept. The outpost operations are the same as the horizontal habs and consist of Crew Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations. These high-level requirements map to the same primary habitat element functions, interfaces and constraints as the hard shell. The primary difference is that the inflatable habitat delivers more volume per unit mass. However due to the nature of an inflatable structure and the need to have redundant pressure vessels, two inflatable modules are required.

Habitation System Functionality:

- <u>Crew Operations:</u> enable sustainability of 4 crew on lunar surface for 7-180 days
- <u>EVA Operations:</u> enable redundant EVA function & enhanced EVA capability

- <u>Mission Operations:</u> enable enhanced mission operations capability
- <u>Science Operations:</u> enable enhanced IVA biological & geological science capability
- <u>Logistics Operations:</u> enable resupply & spares cache

The LS1 inflatable torus shaped habitation element option provides ~174 m3 pressured volume in each unit. Subsequently, the total pressurized volume of the 2 units is 348 m3, which equates to 87 m3/crew. The PLM adds another 78 m3 of stowage and supplies volume for a total volume of 426 m3 for 4-crew on a 180 day mission. This equates s to 106 m3 per crewmember for 180 day stay. .Each unit is 8.5 m internal diameter inflated torus x 3.6 m internal height at the structural core. The eight longeron structural core is integrated via the support frame to the Power and Supply Unit (PSU). The deflated hab unit is removed from the lander by the ATHLETE attaching to the PSU for surface emplacement. The Outpost configuration consists of two Inflatable Habitation Elements (1 Laboratory & 1 Hab unit) and a PLM mated together, figure 15. A common mating mechanism is used to mate the modules together and for docking of the pressurized rover. The Lab and Hab each have an inflatable airlock pre-integrated with the unit. The Lab and Hab are design to operate independently. The Lab, when connected to the ATHLETE, can demate and perform long excursions away from the outpost.

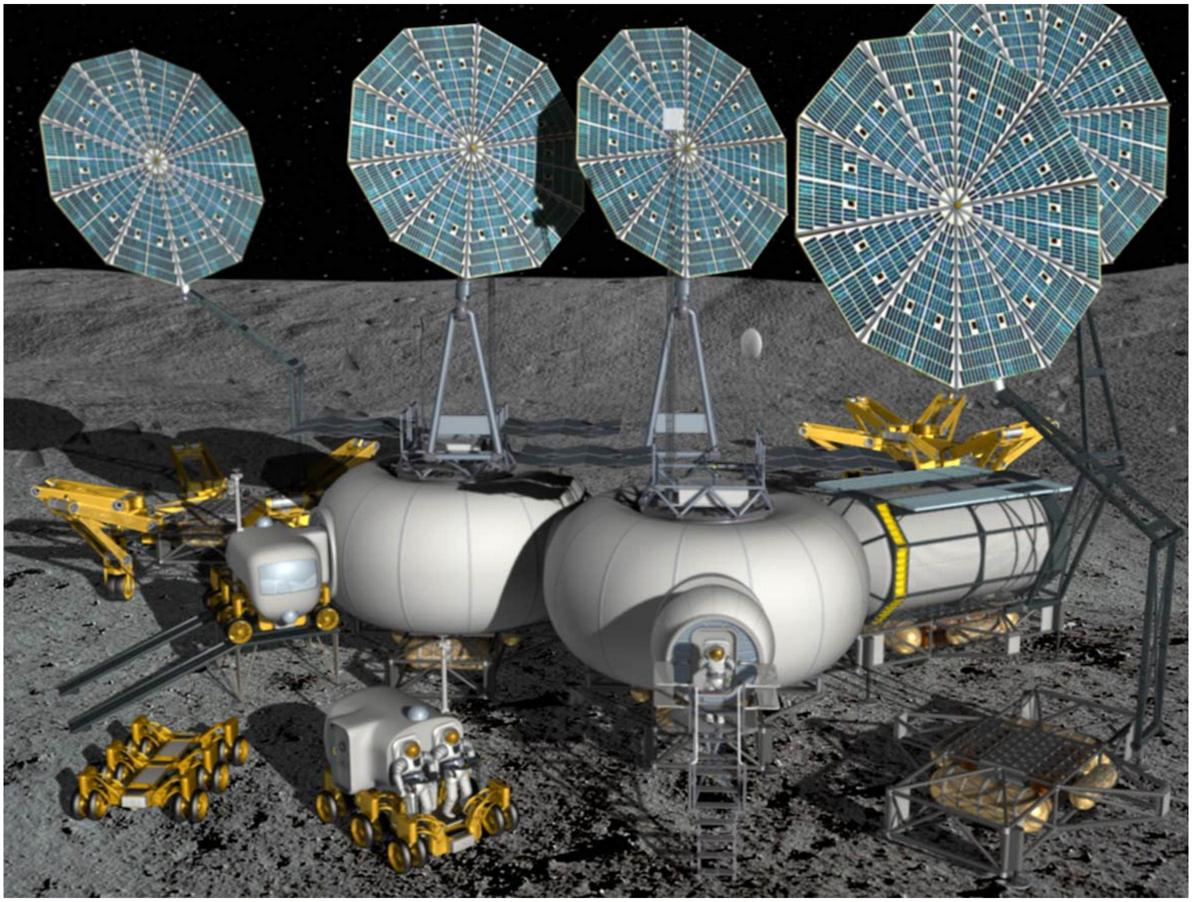


Figure 15. LS1 Inflatable Habitat & Laboratory Outpost Configuration

A. Concept Description—Inflatable Habitat

The completed habitat is comprised of 2 torus units, each with 3 docking ports. One port mates the two units together, another accommodates a pre-integrated inflatable airlock mated to each unit, and the remaining two ports provide attachment for the SPR and/or the PLM. The Hab element is delivered to the lunar surface first and then the

Lab element. Attached to the external top structure of the core are deployable radiator panels and solar arrays. The Hab and Lab elements are delivered to the lunar surface integrated with the PSU and are emplaced on the lunar surface as a single pre-integrated habitat/PSU unit. Each inflatable torus has an interface structure for integrating the habitat element to the PSU (mass = ~57 kg), figure 16 & 17. Each habitat element is delivered with all the required outfitting. The hab element outfitting includes crew operations, some initial mission operations, EVA, some initial science until the lab arrives, logistics stowage and handling, internal systems, and crew accommodations.

Outpost Habitat Elements Summary

- Lab: Inflatable Airlock, EVA Ops, Mission Ops, Medical Ops, Geological Science Lab, Biological Science Lab, Exercise, Storage, Maintenance, and Subsystems
  8.5 m internal dia x 3.6 m internal core height, ~ 174 m3, 3-ports
- Hab: Inflatable Airlock, Crew Ops, Galley, Wardroom, Individual Crew Quarters, Storage, and Subsystems
  8.5 m internal dia x 3.6 m internal core height, ~ 174 m3, 3-ports
- PLM: Logistics and Supplies, minimal Subsystems
  3.5 m internal dia x 8.17 m internal length, ~ 78 m3, 1-port

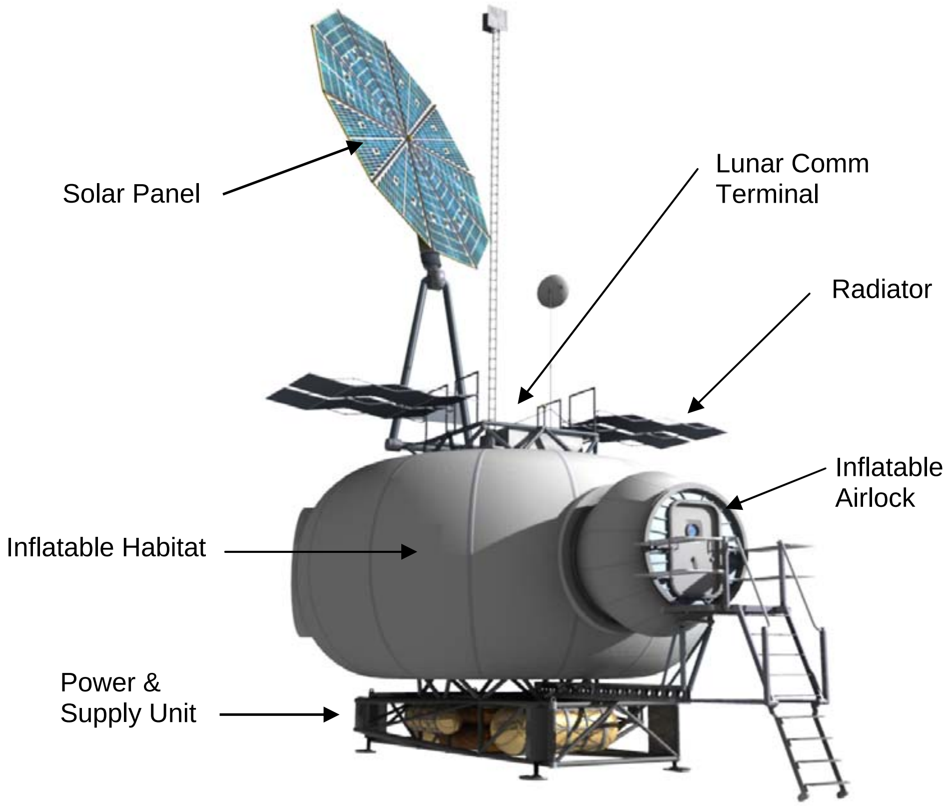


Figure 16. Inflatable Hab Element on the PSU

Each inflatable habitat is delivered unpressurized integrated with a PSU that provides the structural connection to the lander and ATHLETE, electrical power storage and jack stands for ground support and leveling. In the mobile laboratory operations mode, the Lab element/PSU unit is decoupled from the other hab unit and the ATHLETE mobility system is attached. The Lab element is used for the mobile laboratory operations, figure 18. The ATHLETE moves the mobile lab to a new lunar surface location, where the crew stays and performs science operations for variable durations.

The inflatable habitat is torus shaped with an internal hard structural core. The concept is a derivative of the “TransHab” structural concept developed at NASA circa 1998. The hard core combines shear panels and columns—also know as longerons, figure 19. There is a slightly curved bulkhead at the top and bottom attached to the longerons. Attached around the edge of the plate and longerons intersection is the interface ring where the clevis pins are mounted and the internal bladder is sealed. The inflatable fabric is a multi-layered system optimized based on the function required. It is comprised of the external micrometeoroid/secondary ejecta protection, multi-layer insulation thermal protection, the structural restraint layer, the pressure bladders, and the internal scuff protection. The restraint layer will likely be Vectran or Kevlar. The habitat subsystems and most of the deployable crew accommodations are packed in the core and the inflatable fabric system is packaged around it. The flooring system uses a combination of flooring panels with floor beams and struts to deploy the floor as the unit fills with air, figure 20. The port and hatch are integrated as part of the floor system and attached to the structural core. The inflatable fabric is integrated around the port & hatch much like it is at the top and bottom of the core. The packaged inflatable is secured around the core and a protective covering put on for shipment and integration onto the lander. It is then integrated onto the Power and Supply Unit for integration onto the cargo lander. Once inflated the core components can be deployed as shown in Figure 21 & 22. No pressurized consumables are carried in the inflatable core as currently envisioned.

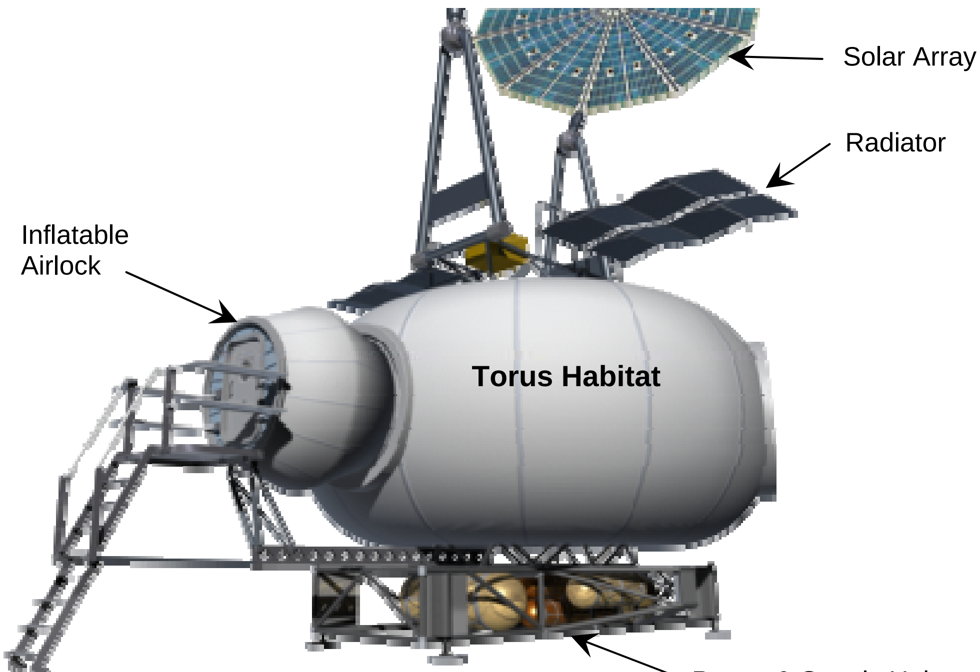


Figure 17. Inflatable Lab Element on the PSU

Figure 18. Mobile Lab Element

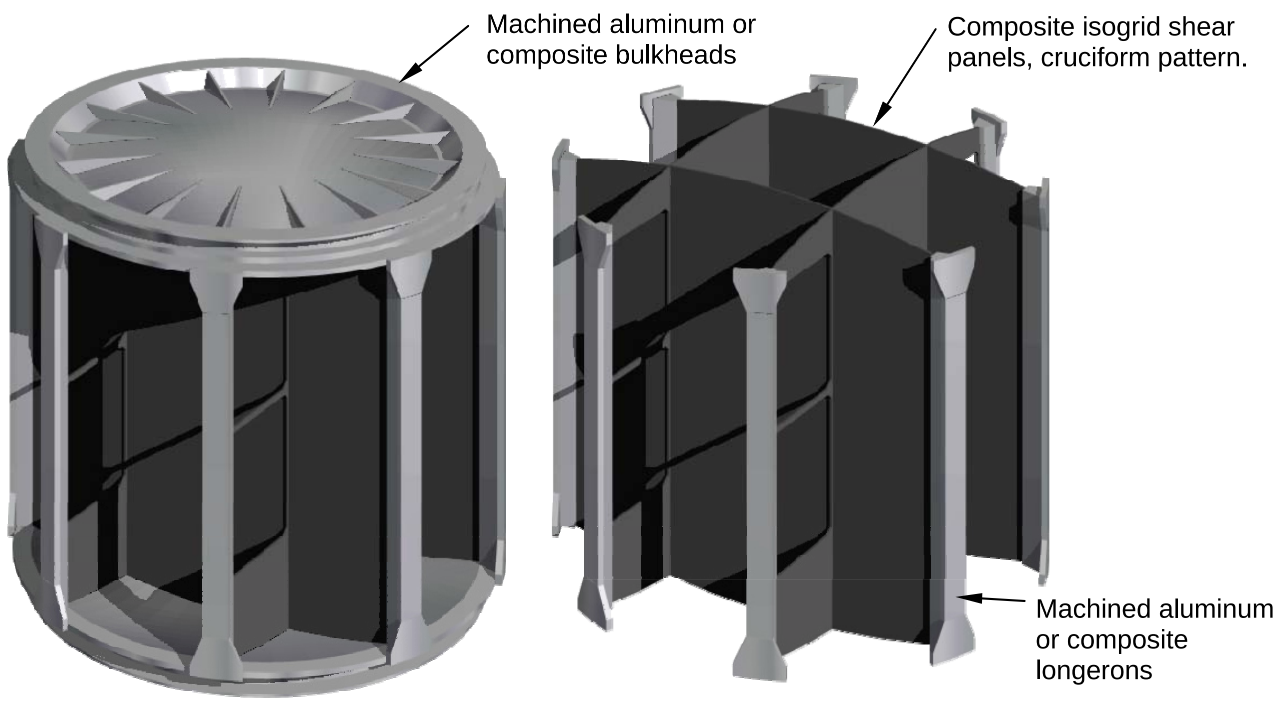
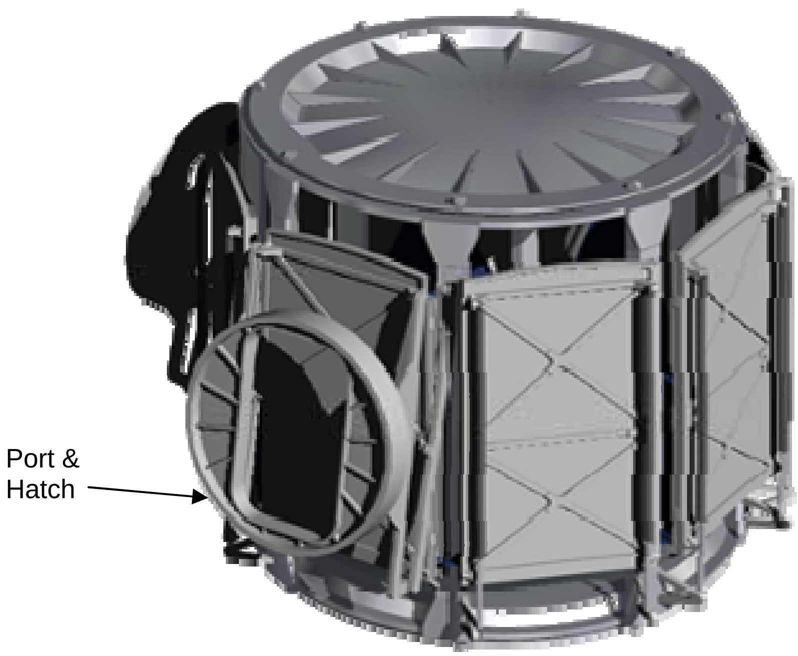
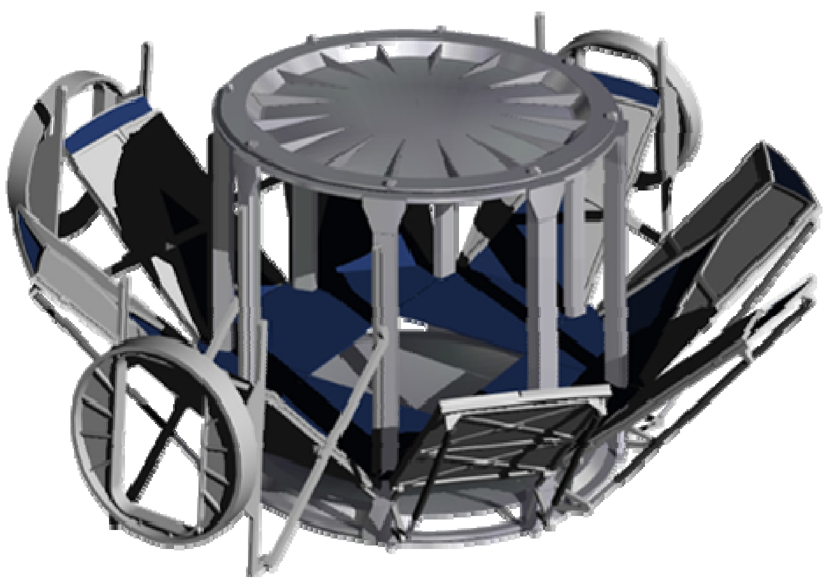


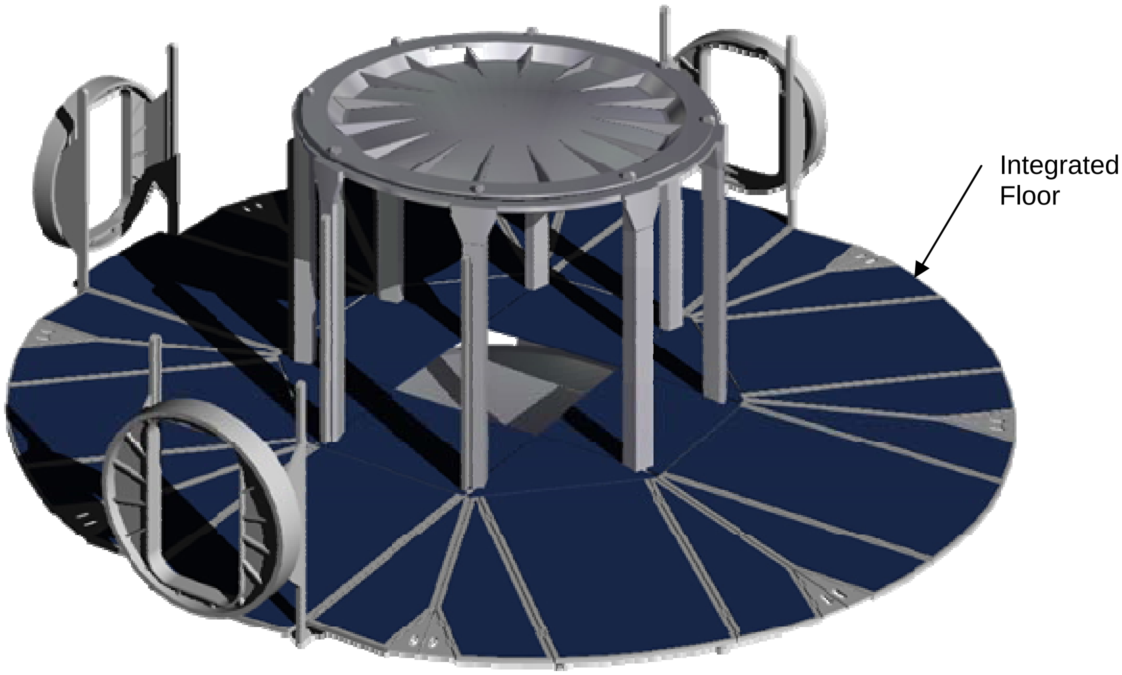
Figure 19. Inflatable Habitat Structural Core



(a) Inflatable Habitat Element Core



(b) Inflatable Habitat Element Core- Deploying



(c) Inflatable Habitat Element Core- Deploying

Figure 20. Inflatable Habitat Element Core Deployment Sequence

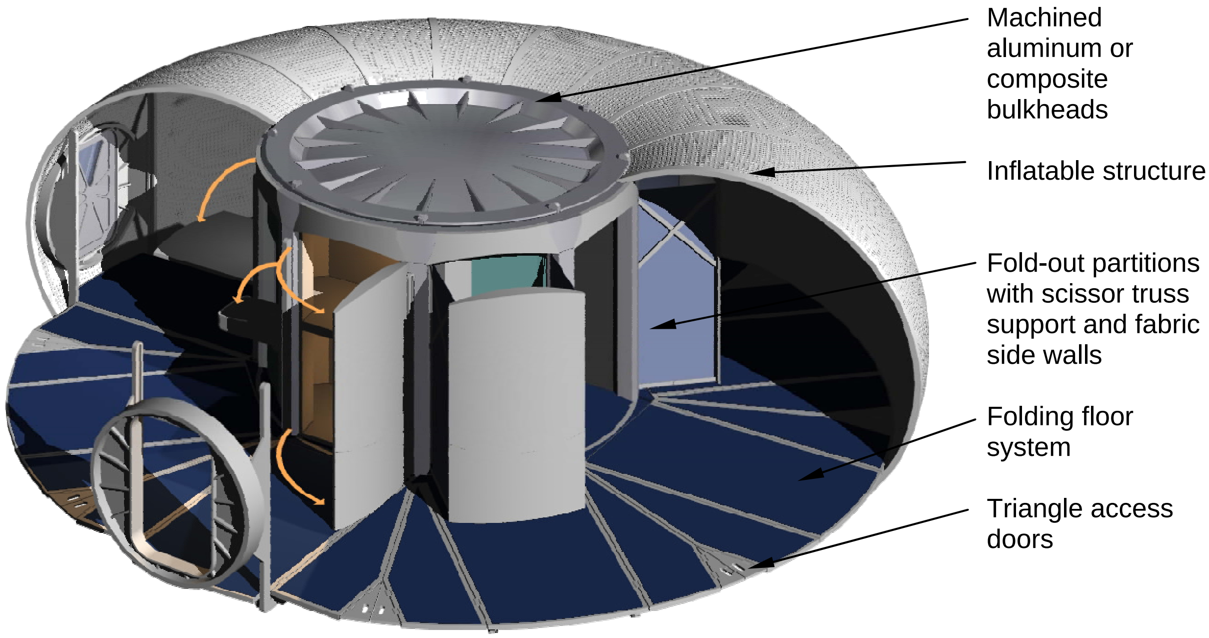


Figure 21. Cutaway View of Inflatable Habitat Element

In order to deliver pressurized logistics with the inflatable element Small Logistics Carriers (SLCs) are required. Up to eight SLCs can be carried in the core and additional SLCs are delivered on the cargo landers. After delivery of the habitat elements, the PLM is used for delivery of logistics supplies for the 180 day mission. The PLM can attach to either the Hab or Lab. The Hab contains the following habitation systems: four initial crew bunks with integral SPE radiation protection, galley, wardroom, pantry, airlock with dustlock and dust containment system, waste and hygiene, habitat systems, and stowage. The Lab contains the following habitation systems: bioscience lab, medical and crew healthcare, exercise, geosciences lab, mission operations, habitat systems, waste and hygiene, stowage and maintenance, and airlock with dustlock and dust containment system.

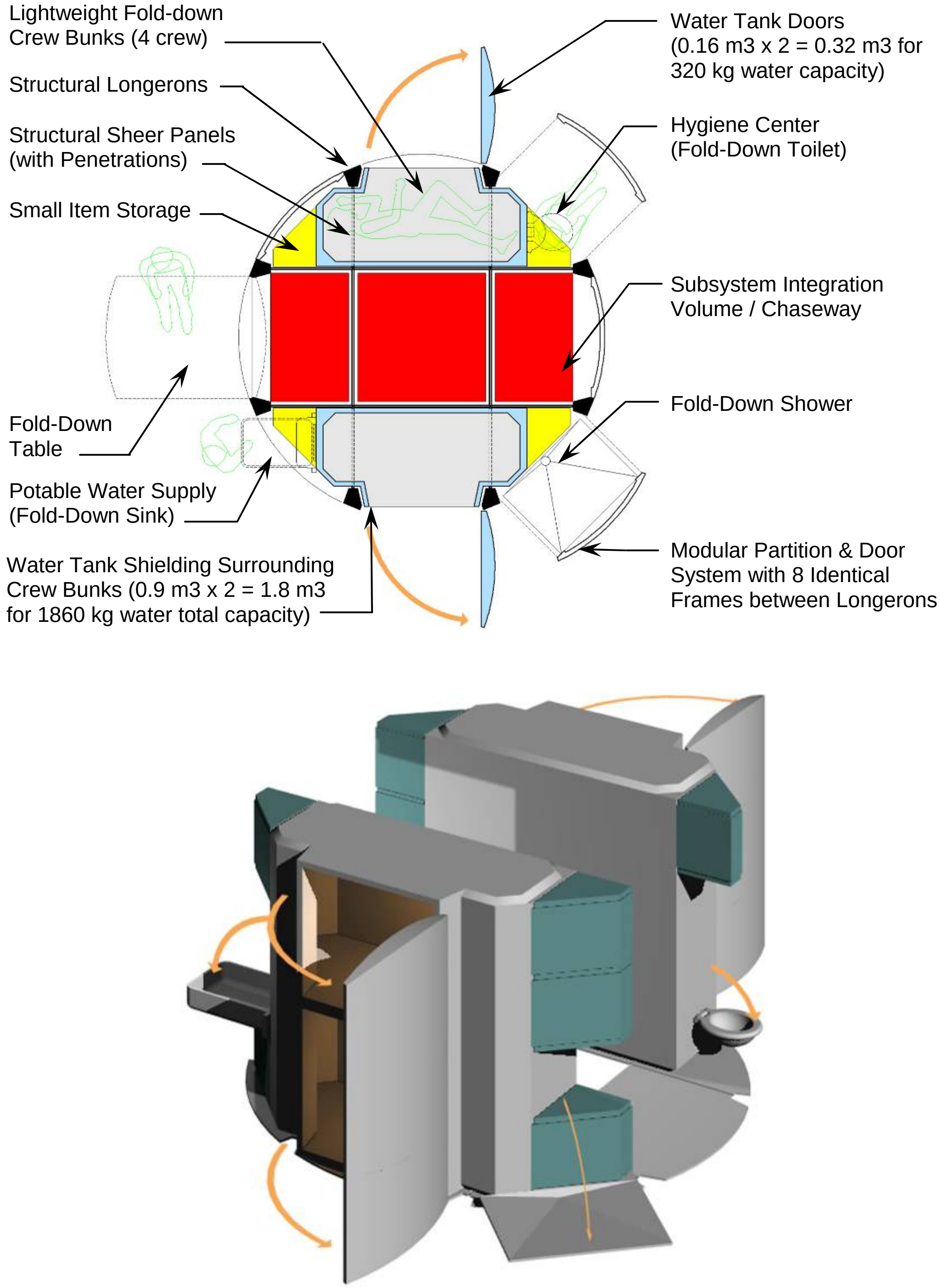


Figure 22. Inflatable Habitat Core Packaging

The ECLS strategy for the two inflatable elements is to provide a distributed redundant system. The Lab provides a partially-closed ECLS for when it is in the mobile lab mode. The primary habitat (Hab) provides the "closed" life support capability. The Lab or Hab has the ELCS redundancy in case one or the other module fails. The ECLS system consists of pressure control system, air revitalization, water recovery and management, waste management, fire detection and suppression, and emergency equipment. Air revitalization includes CO2 removal and reduction, O2 generation, trace contaminant control, ventilation and fans, airborne particulate control and monitoring, and atmosphere composition monitoring. The water recovery system includes H20 recovery of humidity condensate, waste hygiene and urine storage and distribution, and quality monitoring. The waste management system includes the urine collection and pre-treat, fecal collection, and trash collection. The waste and hygiene unit is located within the Hab near the water recovery system.

Each habitat element has an internal Power Management & Distribution System (PMAD) that manages distribution of power to systems internal to habitat elements. The power storage system is external to the habitat in the PSU. The PMAD interfaces with the external power system in the PSU. The power storage system is external to the habitat in the PSU. The PMAD in each Lab and Hab element has two DC to 28v DC converters, two power distribution units, two 50-switch power switching units, two portable equipment panels, and appropriate primary and secondary wiring.

Each habitat element has an Active Thermal Control System (ATCS). The ATCS is the primary system for dissipating the thermal loads from the habitat element. The ATCS gathers the thermal loads from within the habitat and passes this load to the external body-mounted radiator panel integrated on top of the habitat element. The ATCS is designed to support the thermal loads and for the polar location environment. It has a primary and secondary loop. The fluid loops use a 60/40 mixture of propylene glycol/water and are stainless steel lines. The hardware is a mixture of Exploration Technology Development Program (ETDP) and ISS Thermal Control System (TCS) heritage. The hard shell cylinder habitat element outpost power and thermal loads are presented in Table 3.

The avionics (communication, control, and data management) subsystem has strong commonality with the Altair Lander avionics. A wireless communications system is used throughout the habitation complex. The habitat avionics uses primary and secondary operating computers and communications system (including antennas). The Habitats avionics has distributed crew utility panels, the EVA suitlock interface panel, workstations, the network server, networking bus cabling and interface. The outpost avionics assembly includes S-band software-defined radios, operational computers, bus interface units, antenna electronics, Redundancy Management Units, (RMUs), and data recorders.

The Passive Thermal Control System (PTCS) reduces the thermal load in the habitat element by use of multi-layered insulation (MLI). Radiation protection is provided for Solar Proton Event (SPE-Solar Flare) using by a compartmentalized water wall capable of surrounding the crew sleep area in the core. The water wall is filled with ~1000 kg of water, figure 10. The crew is not protected from Galactic Cosmic Radiation (GCR) radiation other than the supply tanks, structure, and subsystems. Further radiation analysis is required to determine the proper GCR protection.

B. Inflatable Habitat Internal Architecture

The outpost habitation system is comprised of the Hab, Lab, and PLM #1, figure 23. Each habitation element is delivered with most of the outfitting. The inflatable habitation elements meet the same functional needs for an outpost as the hard shell habs. They are the Crew Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations. There are two external inflatable airlocks/suitlocks, one integrated with each of the two habitat elements. These two airlocks/suitlocks have dust containment systems and dust locks in the interior of the habitat.

The Hab element is the crew ops area and contains individual crew quarters (as required for long-duration habitation), galley, wardroom, and the waste and hygiene unit, figure 24. The subsystems are dispersed among habitation units for redundancy. Redundant mission ops capability is in both elements with base operations capability in either. The Crew Operations is in the Hab unit includes basic crew accommodations such as sleeping, eating, hygiene and stowage. The EVA Operations includes additional EVA capability beyond the airlock function such as a redundant airlock on the Lab unit, dust containment area, dust lock, suit maintenance, spares stowage, and suit stowage. The Logistics Operations includes the enhanced accommodations for 180 days such as consumable stowage, spares stowage, interconnection to the Hab unit, and a common interface mechanism for future growth and mating to a pressurized rover.

The Lab element contains the airlock, mission ops, medical ops, biological and geological science ops, figure 25. The airlock is for two EVA suits, the hatch doors, and science pass-through lock for samples and equipment. The Mission & Science Operations in the Lab includes enhanced outpost autonomy, geological science lab, biological science lab, IVA glove boxes, medical operations equipment, and exercise apparatus. The EVA ops area has an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. By isolating the EVA function into a module by use of a dust containment area the dust and noise can be reduced throughout the rest of the habitation zones.

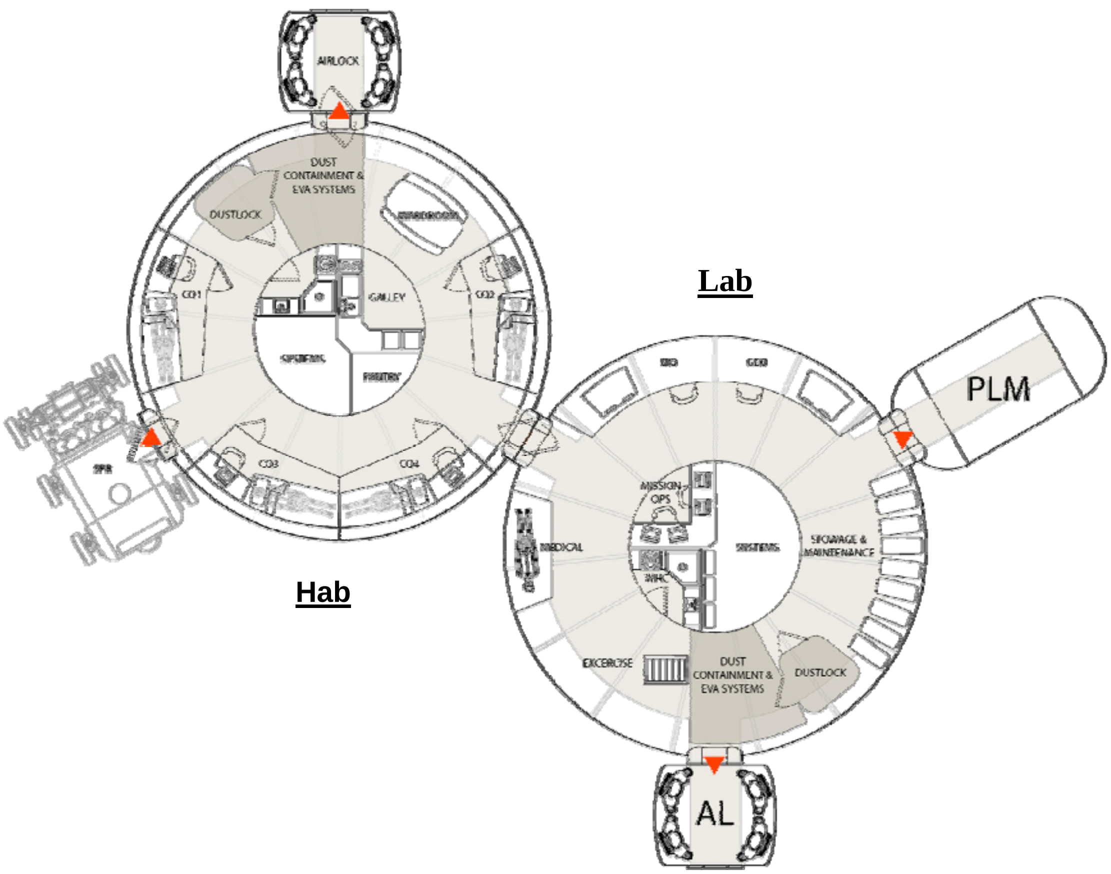


Figure 23. Outpost Inflatable-Shell Habitation Topology

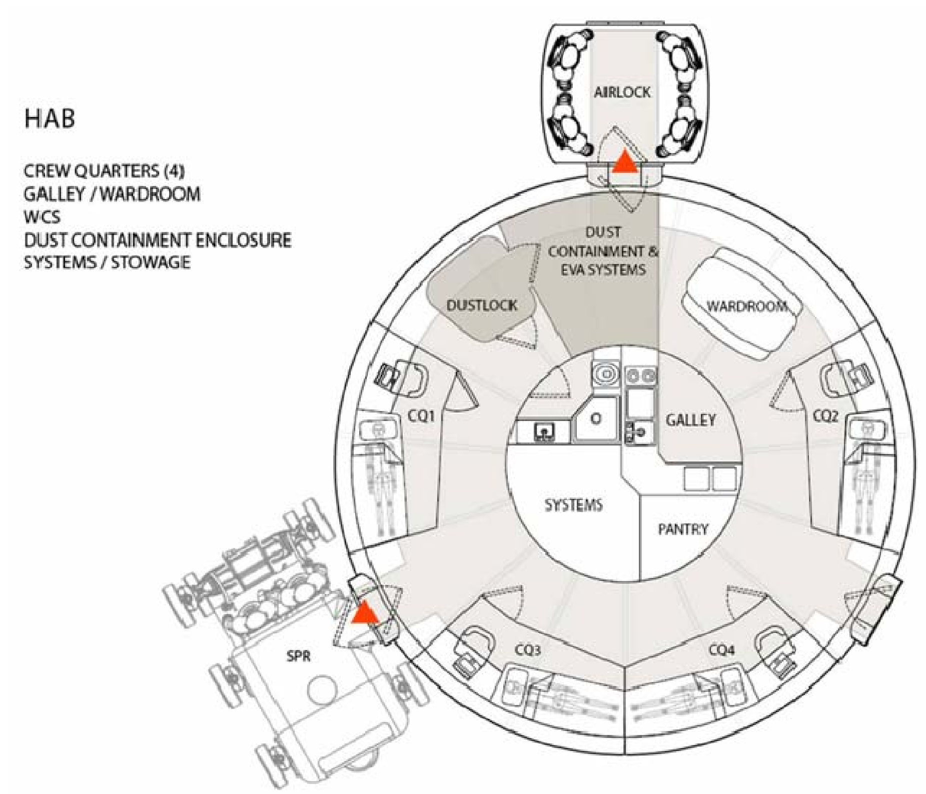


Figure 24. Inflatable Hab Topology

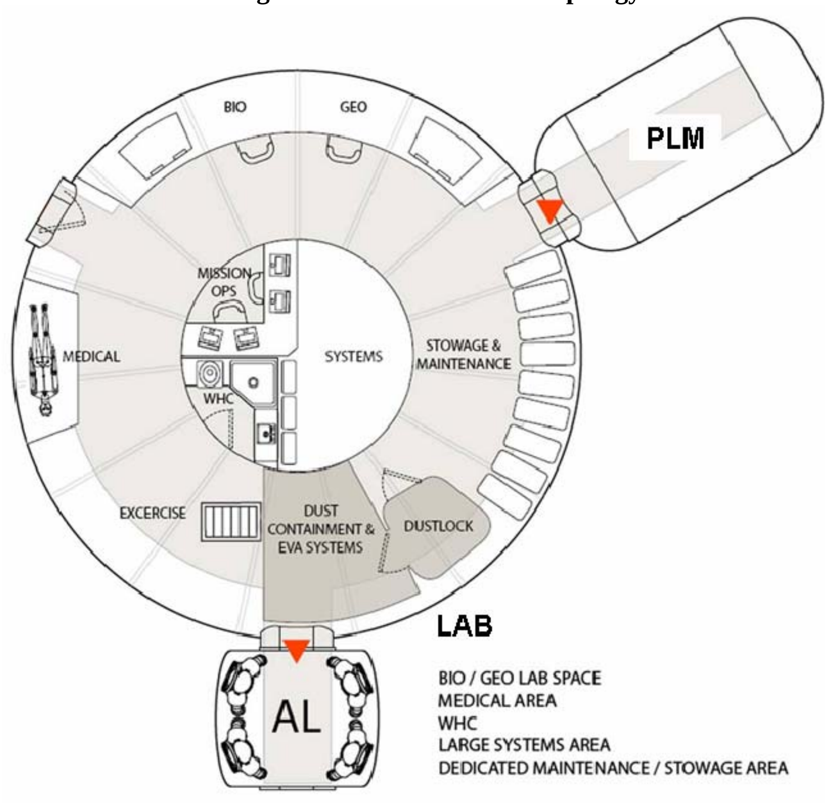


Figure 25. Inflatable Lab Topology

C. LS1 Inflatable Habitat Resource Summary

The power required (table 3) for the inflatable habitats nominal outpost operations is ~ 9.5 kW. The power required for the outpost while crew is not on board during a quiescent mode is ~ 1.1 kW. The thermal conditioning required for air-cooled and cold-plated cooling is ~ 4.2 and 5.2 kW respectively. The mass properties are shown in table 4. The outpost configuration total mass to the surface is ~ 18.0 mt for the two inflatable habitation units. The Mobile Lab is ~ 9.9 mt.

Table 3. Inflatable Habitat Element Power and Thermal Loads

	Hab	Lab	Subsystem Total Power & Thermal, W
Outpost Power Active, W_e	5028	4471	9499
Outpost Quiescent Power, W_e	568	535	1103
Outpost Air-Cooled Thermal, W_t	1028	3223	4251
Outpost Cold-Plated Thermal, W_t	4000	1248	5248

There is a closed-loop Life Support System in Hab and an open-loop Life Support System in Lab. 30% margin power growth not included.

Table 4. Inflatable Habitat Element Mass Properties

HABITAT SYSTEM	**Hab mass, kg**	**Lab mass, kg**	**OUTPOST TOTAL mass, kg**
Structures	2621	2621	5242
Protection	566	459	1025
Power	295	295	590
Thermal	363	331	694
Avionics	131	127	258
Life Support	1278	1622	2900
Initial Inflation System	276	276	552
Airlock/Suitport	600	600	1200
Outfitting	136	1270	1406
Total Dry Mass	6266	7601	13867
30 % growth	1880	2280	4160
Total with 30% growth	8146	9881	18027

III. Description of Architecture Lunar Scenario 3.0.0—Core Habitat Concept

This lunar scenario is the third iteration of the CxAT lunar surface architecture(s) known as Lunar Scenario 3.0.0 (LS3). LS3 is a functional variation of the LS1 scenario that emphasizes initial habitation functionality. LS3 is also constrained by the Altair Lander configuration currently under consideration. The Altair Lander configuration features a large descent module with a ~ 8.8 meter diameter octagonal flat “deck” that the crewed ascent module attaches to, or in cargo mode, that accommodates the lunar surface system cargo. Since the Lander deck is about six meters from the lunar surface, access to and removal of cargo from the deck is done by the ATHLETE for large cargo (habitat) or a lunar crane for the smaller cargo.

LS3 is an attempt to temper early functionality as constrained by affordability. A crewed sortie to the outpost location was inserted before the delivery of the primary cargo mission to reduce risk of delivering surface elements and to delay the cost of those elements by approximately 6 months. Then a minimum functional outpost is deployed in a single cargo mission that features a core habitation element. The option for putting off the remainder of the outpost functionality until either international/commercial participation or available budget permits is now available for a minimum up-front cost. The option also retains the ability to accommodate a four person crew for 14-28 day missions during this outpost build-up to initial surface capability of operations from the lander, figure 26, or from the surface, figure 27. The Core Habitat element is supported and powered by an integrated Power & Support Unit (PSU) and has communications capability provided by an integrated Lunar Communications Tower (LCT). Initially, the Core Habitat will remain on the Lander for multiple crewed missions (over a period of approximately two years) until the Heavy Lift Mobility System is delivered on a cargo flight.

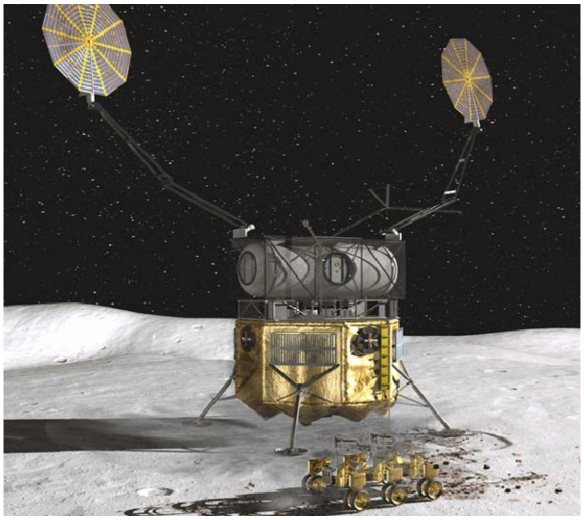


Figure 26. Initial Core Habitat Integrated on Altair Lander

Figure 27. Pressurized Rover Docked to Surface Habitat

The LS3 approach builds up to a full outpost capability similar to LS1 but with less habitation volume and no ability to accommodate a crew during long eclipse periods. The outpost build-up manifests end at a similar LS1 end-state with redundant habitats, the ability to sustain a crew for 180 days, and support long distance and duration surface roving, figure 28. The scenario assume on average two missions per year that alternate between crewed and cargo missions. Lunar Scenario 4.0.0 Analysis of Alternatives is assessing LS3 with an increase flight rate of two crew and two cargo flights per year. The LS3 buildup is structured in such a way that it can pause at any time to accommodate contingencies or a change in emphasis to a sortie mode. The modular nature of the outpost build-up enhances the ability of international and commercial partners to contribute elements and systems. The core lunar surface system technologies and outpost operations concepts have applicability to Mars exploration. Additionally, the mobility capabilities can be tailored to science objectives as needed.

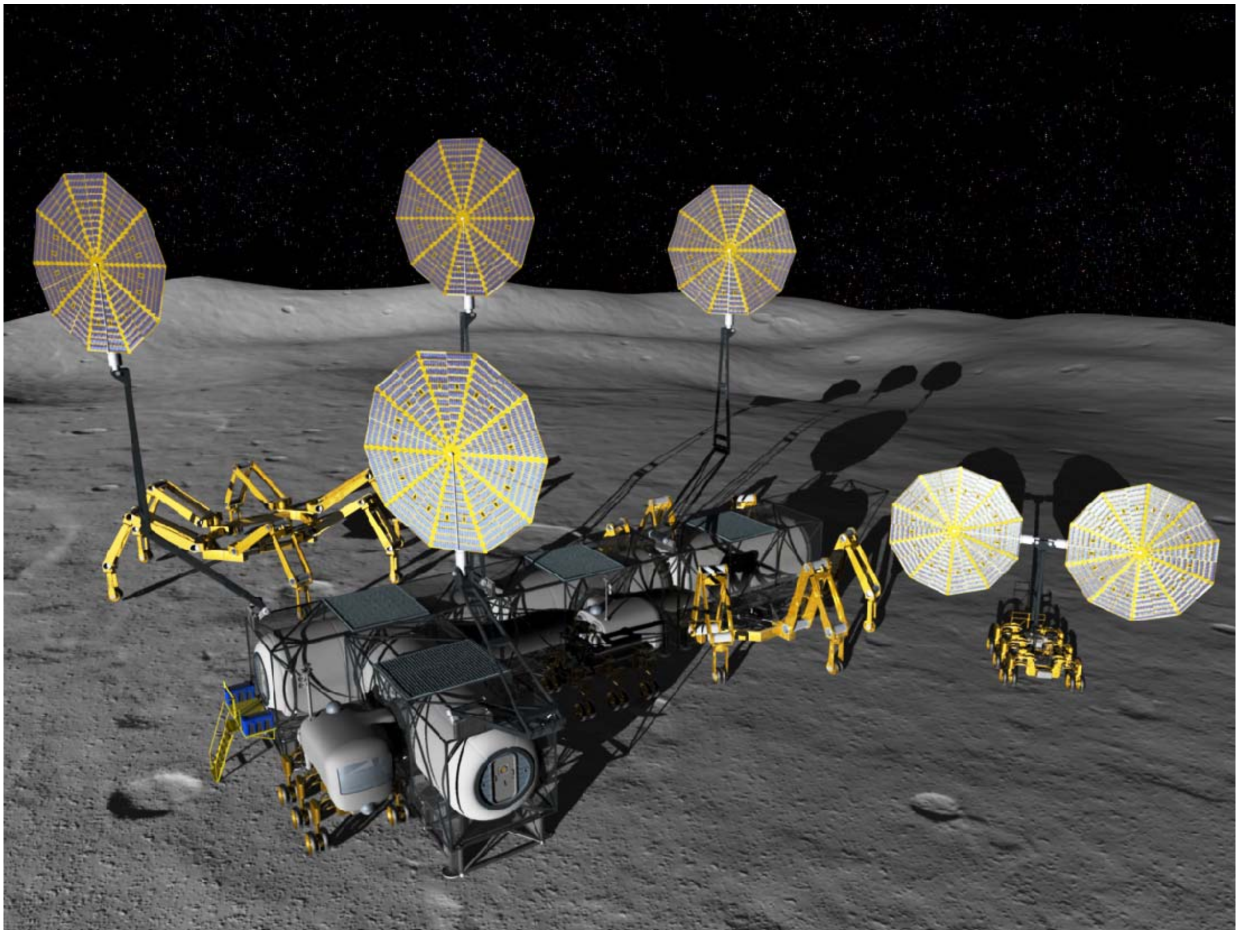


Figure 28. Lunar Scenario 3.0 Outpost Complete

A. Concept Description—Hard Shell "Core Habitat"

The Constellation Architecture Lunar (CxAT-Lunar) Lunar Scenario 3.0.0 outpost habitation system is comprised of three hard-shell cylinder habitat elements: a Core Habitat, a Reusable Pressurized Logistics Module #1 (RPLM-1), and a RPLM-2, figure 29. The RPLMs are retrofitted into living and working areas providing minimum functionality and volume required for long-duration crewed surface stays. The habitat elements are delivered to the lunar surface in the following order: Core Habitat, then RPLM-1, then RPLM-2. Disposable Pressurized Logistics Modules (DPLM) are periodically attached to the outpost habitation system to provide logistics resupply. Three "core habitat" concepts were defined for this scenario analysis. One concept had a 4-port core habitat, another with a 2-port core habitat, and the third investigated a 3-port core habitat. The assessment showed that a 3-port habitat met the growth, safety, and flexibility requirements while adhering to strict mass and volume constraints. A common mating mechanism and hatch size are used to mate the modules together and for docking of the pressurized rover as shown in figure 27.

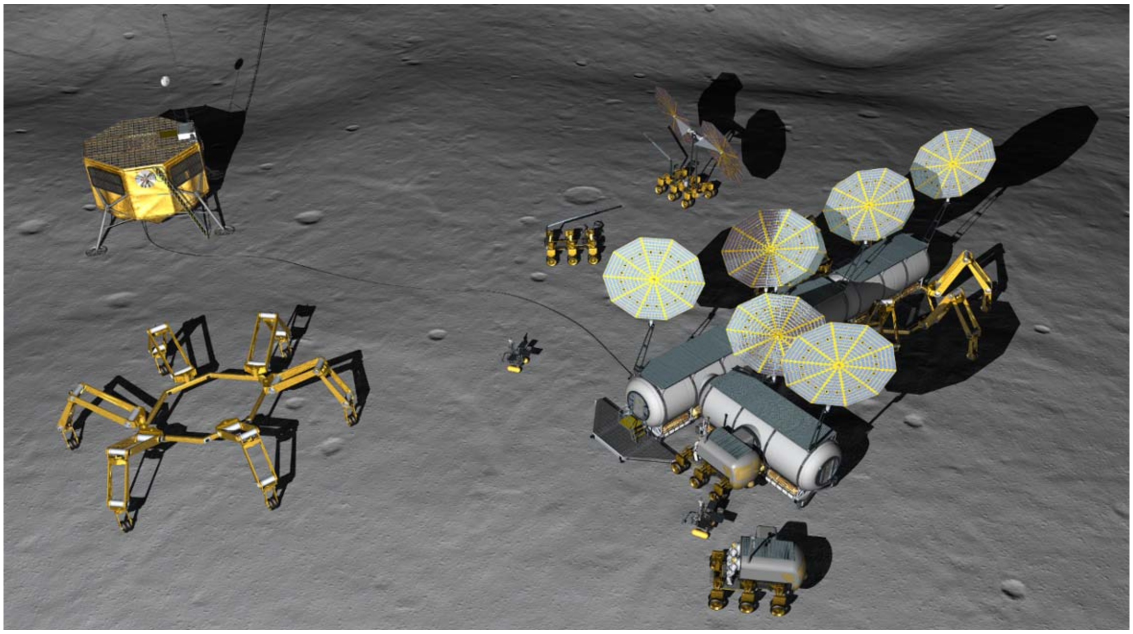


Figure 29. RC 3.0 Outpost Complete: View B

Each hard-shell habitat element is delivered with its mission logistics supplies and the respective outfitting required for retrofitting the modules. The RPLMs will require setup and outfitting once the supplies are used and space available. Outpost complete port growth and SPR docking options are shown in figure 30.

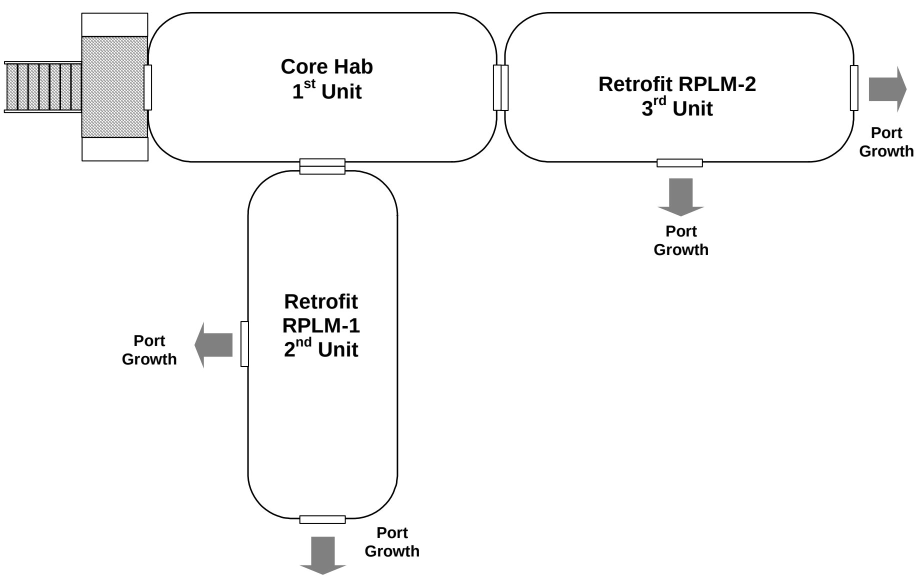


Figure 30. Outpost Complete Port Growth Options

The habitat elements provide the pressurized environment for the crewmembers to live in and work while performing mission tasks on the lunar surface and. Outpost operations are the same as LS1 which consist of Crew

Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations. These high-level requirements map to the following primary habitat element functions, interfaces and constraints.

Habitation System Functionality:

- Crew Operations: enable sustainability of 4 crew on lunar surface for 7-180 days
- EVA Operations: enable redundant EVA function & enhanced EVA capability
- Mission Operations: enable enhanced mission operations capability
- Science Operations: enable enhanced IVA biological & geological science capability
- Logistics Operations: enable resupply & spares cache

The LS3 horizontal habitation elements provides ~55 m3 pressured volume in each hard-shell module. Each unit is 3-port 3.0 m internal diameter x 8.35 m internal length aluminum-lithium (Al-Li) hard shell pressure vessel with an integral support frame attached to the Power and Supply Unit (PSU), figure 31. The hab element is removed from the lander for surface emplacement. The core habitat element has three ports to allow multi-directional expansion of the outpost while providing two ports open for docking of the pressurized rovers. The thermal radiators are integrated to the top of the pressure shell frame. The shell is covered with multi-layer insulation (MLI) for passive thermal protection. The pressure shell is protected by a composite fabric micrometeoroid and surface ejecta protection barrier. An external deployable aluminum iso-grid open-grated dust porch and stairs allow surface access to and from the core habitats. One of the design goals is to minimize the distance from the Hab to the surface. The habitat would be lowered to the maximum extent possible. The floor area ~2.3 m x ~7.75 m = ~17.83 m^2/habitat element = ~53.48 m^2 total floor area (all three elements). This outpost configuration has a total volume = ~165 m^3 total volume (all three habitat elements without the two SPRs), which = ~ 41.25 m^3 / crewmember.

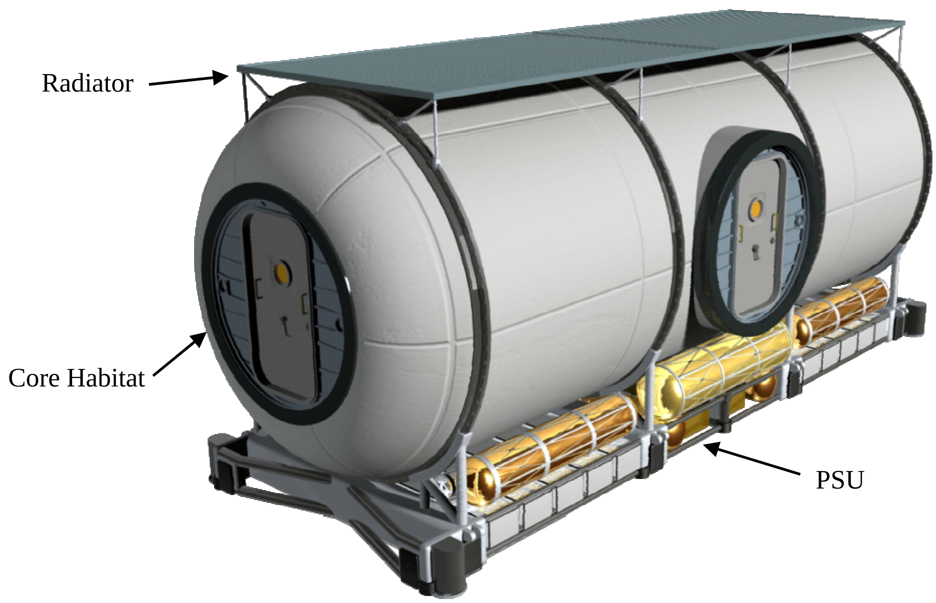


Figure 31. 3-Port Core Habitat on Power & Supply Unit

The Power and Supply Unit (PSU) is a core frame structure with detachable wing structures that is designed to incorporate the power system, modular logistics tank payloads, communications, and other systems. Two versions of the PSU design are briefly described below. The first structure is designed to internally accommodate growth of the power system into a regenerative fuel cell-based system, figure 32. The second option focuses solely on battery-based power systems, figure 33. Aside from mass and overall height, all other characteristics and systems are consistent. The PSU provides interfaces to attach payloads for launch, offloading, and transport on the lunar surface.

The PSU mates through 12 Lander hard points without wings installed or 16 hard points with wings to optimize load distribution of the cargo. Each side of the PSU, with wings installed, provides four mating interfaces to accept the unloading mobility system (a tri-ATHLETE on each side) figure 34. The PSU incorporates jack legs to support and level cargos on the surface.

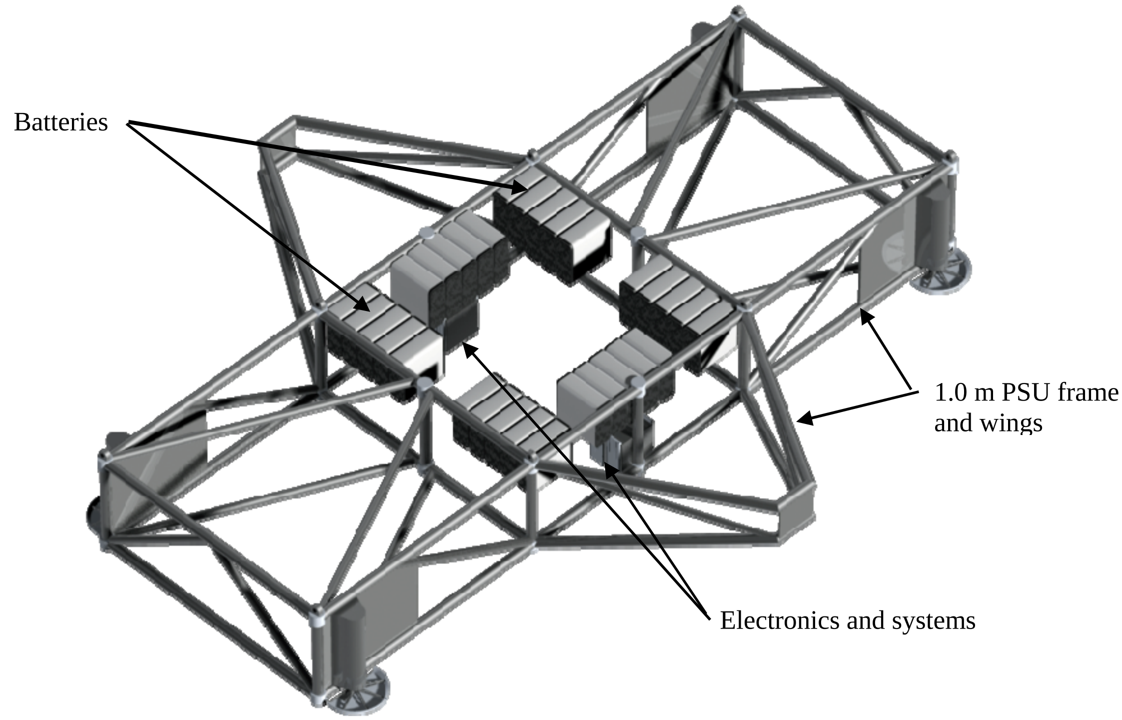


Figure 32. 1m Thick Power & Supply Unit with Wings

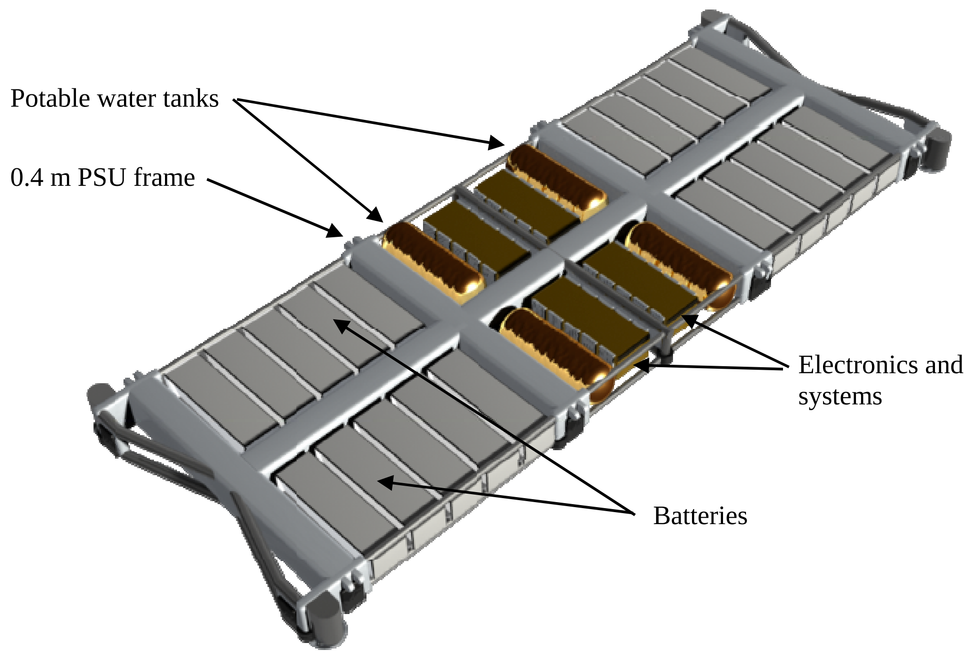


Figure 33. 0.4m Thin Power & Supply Unit without Wings

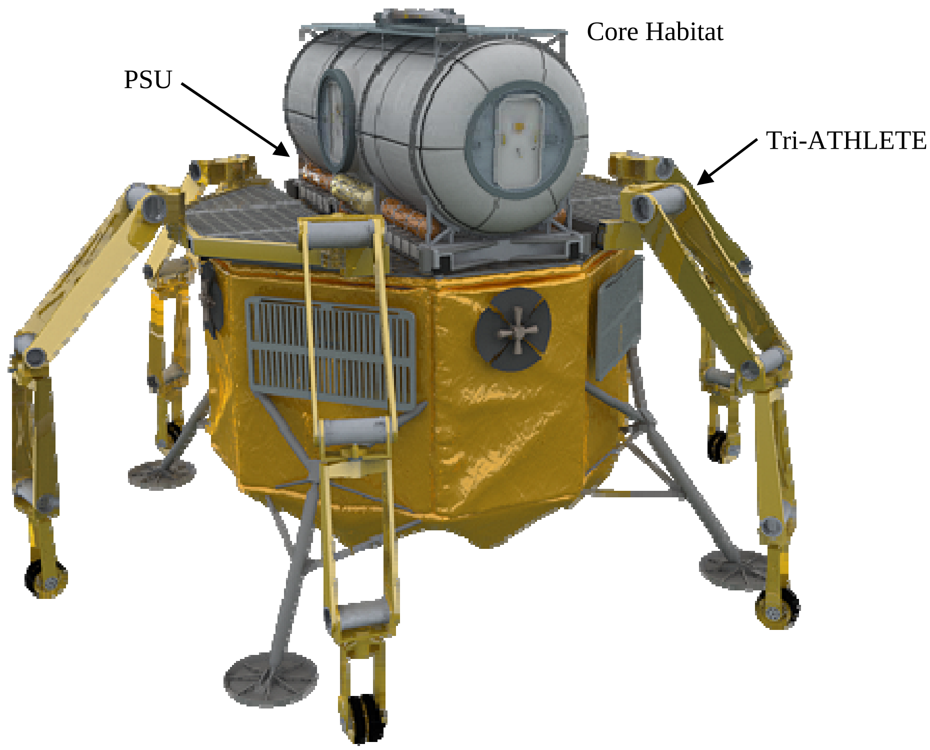


Figure 34.   Tri-ATHLETE Attached to a RPLM/PSU

Core Habitat initially contains the following minimum habitation systems: four crew bunks with SPE water wall, waste and hygiene, stowage, habitat subsystems, suitlock with dust containment area, and 28 days of crew supplies. The Core Habitat is then retrofitted into an EVA Operations & Geosciences Unit, containing the geosciences lab, the waste and hygiene, suitlock with dust containment system, and the added EVA suit maintenance area. RPLM-1 initially contains the logistics supplies and spares and pre-integrated hardware, such as the galley. When retrofitted, it becomes the Crew Operations Unit, containing the following habitation systems: Crew Ops, stowage, habitat systems, four crew bunks w/ SPE protection water wall, galley and wardroom. RPLM-2 initially contains the logistics supplies and spares and pre-integrated hardware, such as the exercise equipment. When retrofitted, it becomes the Science & Medical Operations Unit, containing the following habitation systems: biomedical/life sciences lab, crew health care, exercise, logistics/supply, and habitat systems. The outpost complete internal architecture is shown in figure 35.

Outpost End-State Habitat Elements Summary

- Core Hab: Crew Ops, Mission Ops, Suitlock, Galley, Wardroom, Initial Crew Sleep Area (relocated), Subsystems
  3.0 m internal dia x 8.35 m internal length, ~ 55 m3, 3 ports
- RPLM-1: Retrofitted PLM, Geological Science Lab, Airlock, EVA Ops & Maintenance, limited Subsystems
  3.0 m internal dia x 8.35 m internal length, ~ 55 m3, 3 ports
- RPLM-2: Retrofitted PLM, Medical Ops, Biological Science, Exercise, Storage, limited Subsystems
  3.0 m internal dia x 8.35 m internal length, ~ 55 m3, 3 ports
- DPLM: Disposable PLM, Logistics and Supplies, minimal subsystems
  3.0 m internal dia x 8.35 m internal length, ~ 55 m3, 1 port

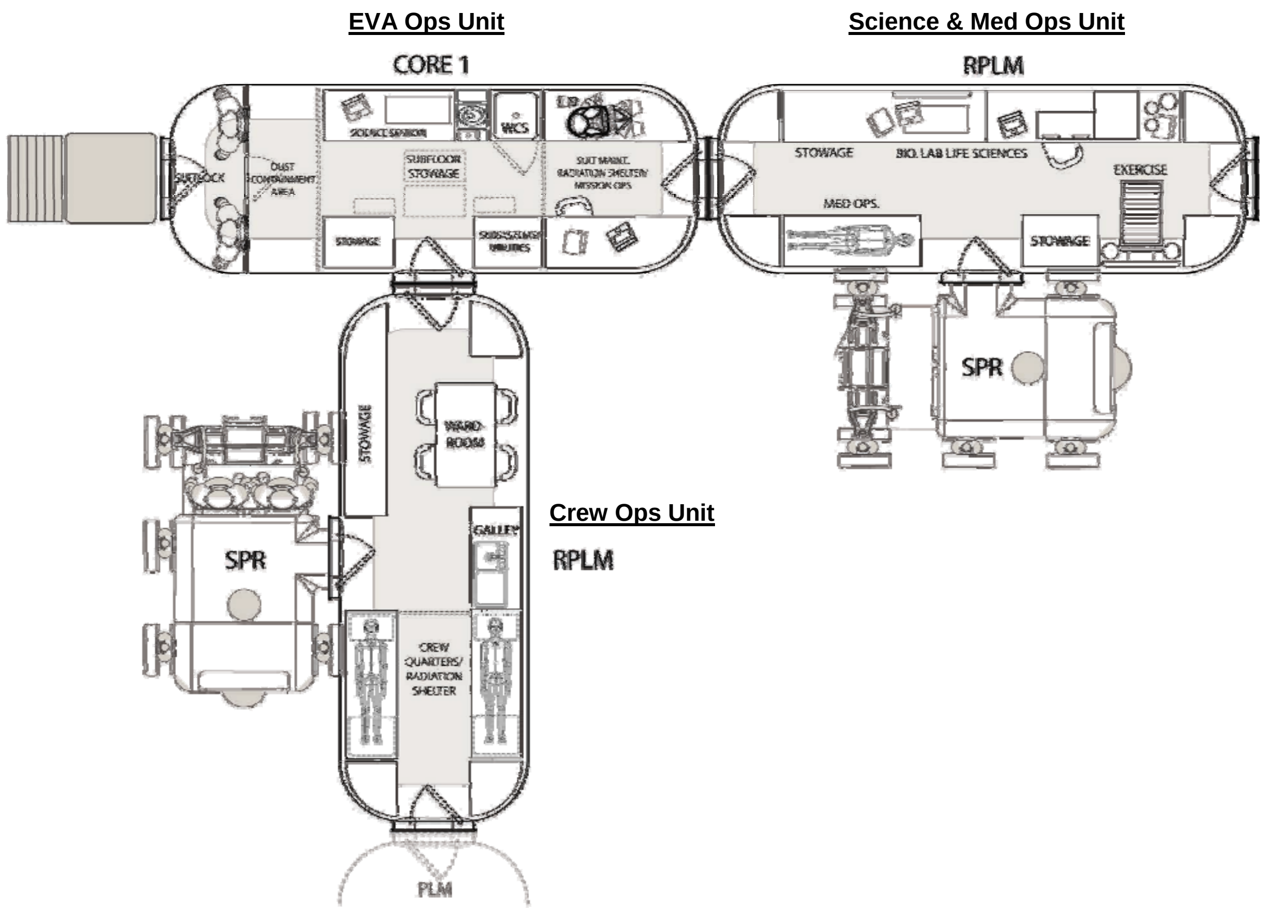


Figure 35. Outpost Complete: Internal Architecture Layout

The Core Habitat subsystems are sized based on the full-up outpost capability incorporating the outpost expansion using the two RPLMs. The Core Habitat will host all of the primary operating systems. Redundancy is provided by the subsystem's design. The initial Core Habitat will be delivered with the initial crew logistics and spares to support the first outpost crewed mission, figure 36. As shown in Figure 37, 12 M02 bags are integrated where the geoscience lab will be set up, and 44 CTBEs are integrated under the floor. A total of ~92 Crew Transfer Bas Equivalents (CTBE) of logistics is sent with the Core Habitat element.

The habitation system has one suitlock in the Core Habitat that accommodates two suits at one time, figure 34. The second and redundant suitlock capability is provided by the SPRs. The suitlock has dust containment area in the interior of the habitat. The suitlock provides 6.5 m^3 of volume. A suit maintenance area and work surface is emplaced in the core final configuration.

The Core Habitat external hatches are 1.0 m wide x 1.52 m tall submarine style doors that are pressure assisted opening inward. The mating mechanism is under design definition, but will encompass the external hatch and will be approximately 1.8 m outside diameter. The current mating mechanism concept incorporates both active and passive aspects. Additional definition of a surface mating mechanism is in development.

The passive thermal MLI and MM/SE protection cocoons the Core Habitat hard shell structure. The SPE radiation protection of the crew is provided by a water wall in the crew bunk area, same LS1 as shown in figure 10.

Whereas a long-term GCR protection is required, none is shown with this concept. Additional study is required to select a long-term GCR protection solution.

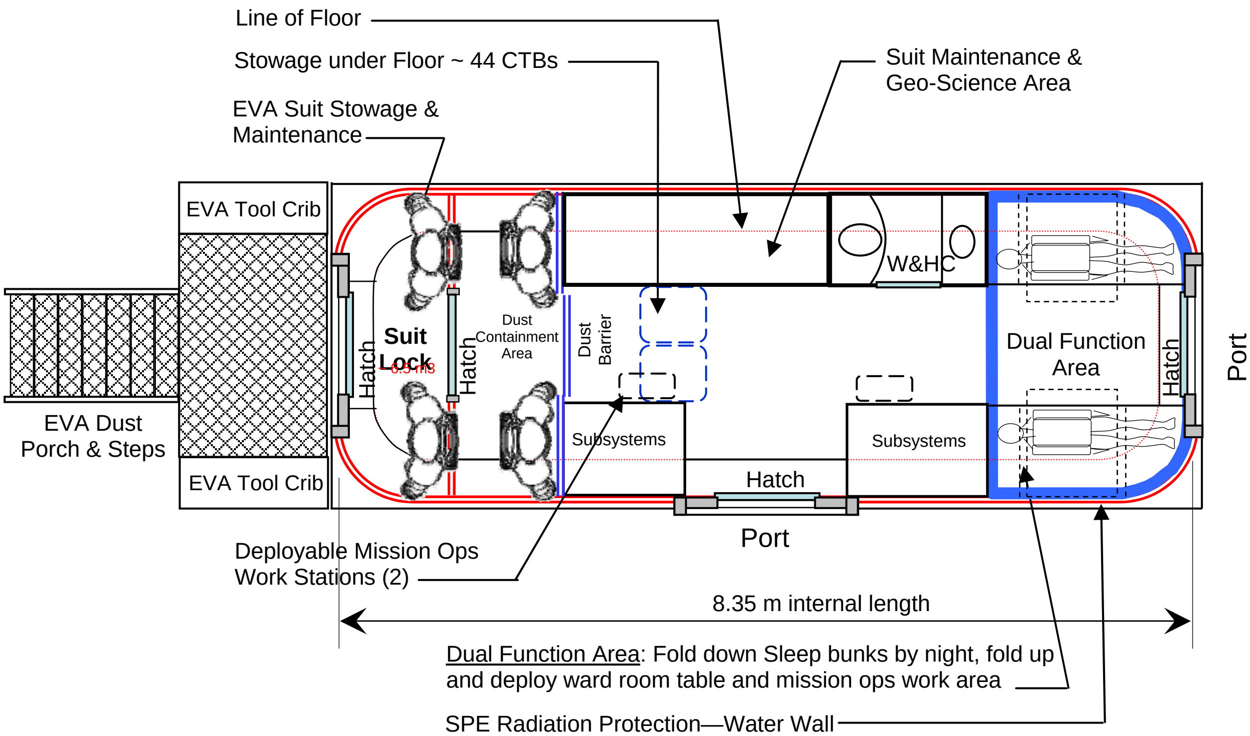


Figure 36. Initial Core Habitat Internal Architecture

The Core Habitat element has the primary Power Management & Distribution System (PMAD) that manages distribution of power to the core habitat subsystems and to the RPLM/DPLM elements. The PMAD interfaces with the external power system in the PSU. The power storage system is external to the habitat in the PSU. The PMAD in the Core Habitat has two DC to 28v DC converters, two power distribution units, two 50-switch power switching units, two portable equipment panels, and appropriate primary and secondary wiring.

The Core Habitat has an Active Thermal Control System (ATCS). The ATCS is the primary system for dissipating the thermal loads from the element. The ATCS gathers the thermal load from within the habitat and passes this load to the external ATCS, a body-mounted ~18m2 radiator panel placed on top of the element. The Passive Thermal Control System (PTCS) reduces the thermal load in the habitat element by use of multi-layered insulation (MLI). The ATCS is designed to support the thermal loads and for the polar location environment. It has a primary and secondary loop. The fluid loops use a 60/40 mixture of propylene glycol/water and are stainless steel lines. The hardware is a mixture of Exploration Technology Development Program (ETDP) and ISS Thermal Control System (TCS) heritage.

There is a partially closed-loop Life Support System in the Core Habitat that supports the minimal-capability Life Support Systems in the RPLMs and the DPLMs. The core hab provides the primary life support capability such as the pressure control system, air revitalization, water recovery and management, waste management, fire detection and suppression, and emergency equipment. Air revitalization includes CO2 removal and reduction, O2 generation, trace contaminant control, ventilation and fans, airborne particulate control and monitoring, and atmosphere composition monitoring. The water recovery system includes H20 recovery of humidity condensate, waste hygiene and urine storage and distribution, and quality monitoring. The waste management system includes the urine collection and pre-treat, fecal collection, and trash collection. The waste and hygiene unit is located within the Core Habitat near the water recovery system.

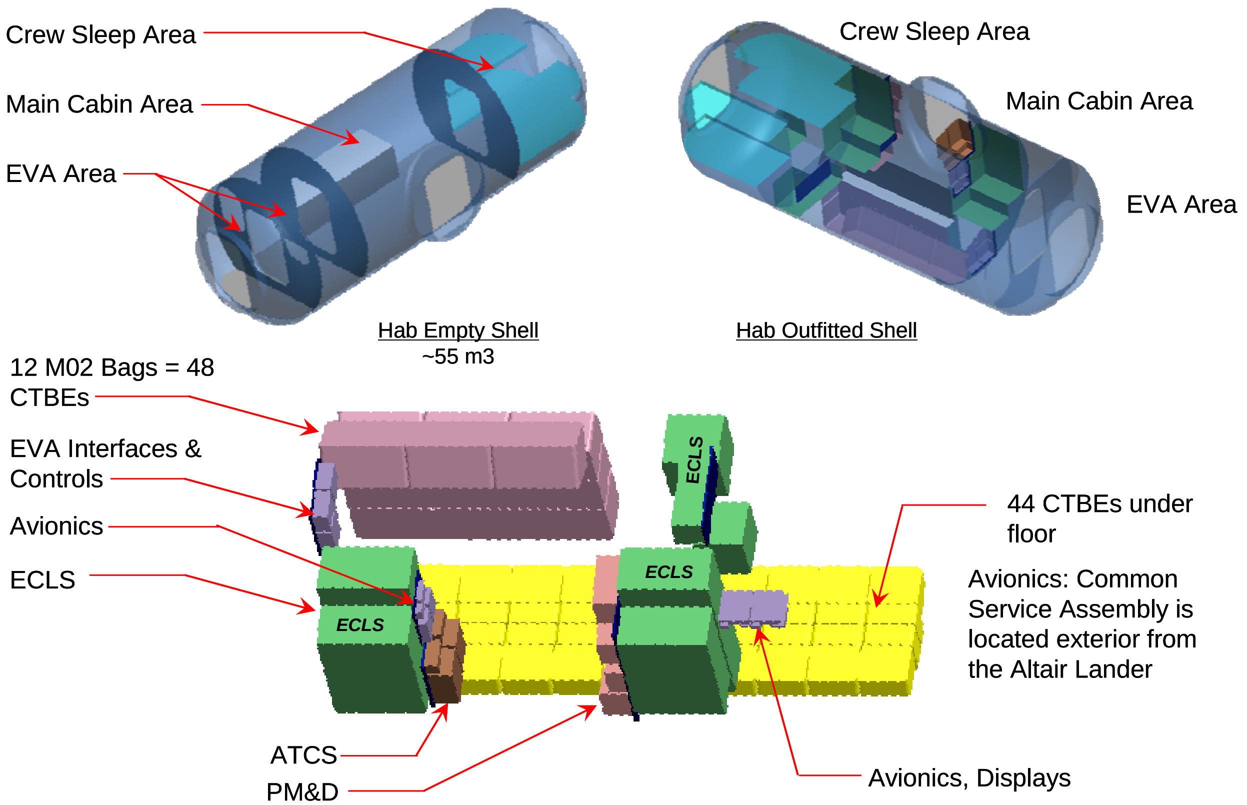


Figure 37.   Initial Core Habitat Integrated Subsystems

The avionics (communication, control, and data management) subsystem has strong commonality with the Altair Lander avionics. A wireless communications system is used throughout the habitation complex. The habitat avionics re-uses the Lander avionics Common Service Assembly after landing. It will be relocated to the PSU/habitat post-landing and will provide the secondary operating computers and communications system (including antennas). The Core Habitat avionics has two crew utility panels, the EVA suitlock interface panel, two workstations, the network server, networking bus cabling and interface. The Lander avionics assembly includes two S-band software-defined radios, two operational computers, two bus interface units, antenna electronics, three Redundancy Management Units, (RMUs), and a data recorder.

Outfitting is provided within the habitation element being delivered. Outfitting will be modular deployable furnishings. The Core Habitat geoscience laboratory equipment will be stowed and will require deployment, setup and verification of operational status. Crewmembers use individual sleep bunks in the Core Habitat during the initial outpost missions, then move into the RPLM-1 Crew Ops Unit for their permanent location. Privacy curtains provide visual privacy when crewmembers desire privacy when in outpost mode.

B. Reusable Pressurized Logistics Module (RPLM)

The RPLM is a duplicate of the core hab shell and port configuration for commonality and to amortize design, development, testing, and engineering (DDT&E) and production costs. It will be delivered on a cargo Lander with the heavy lift mobility system (ATHLETE) pre-integrated with the PSU/RPLM, as shown in figure 38. The RPLM habitat element has three ports to allow multi-directional expansion of the outpost while providing two ports for docking of the pressurized rovers. Upon delivery, RPLM-1 is off-loaded from the Lander and attached to the Core Habitat on the lunar surface, similar to figure 34.

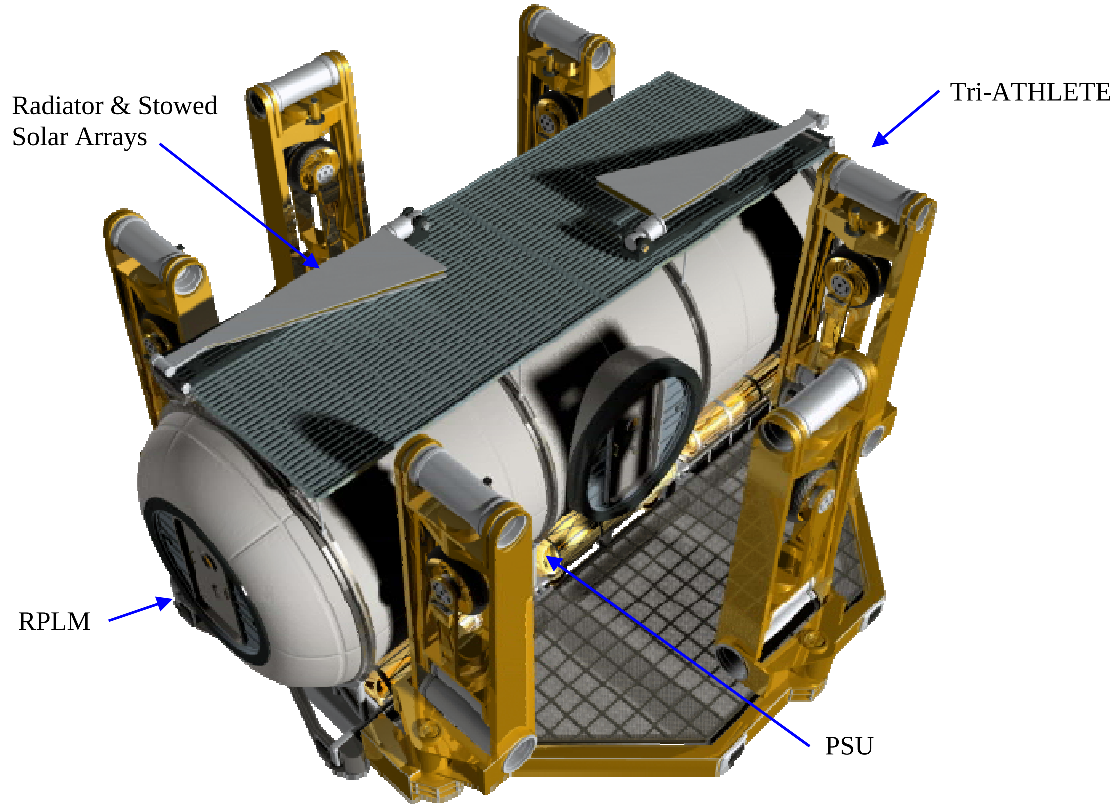


Figure 38. tri-ATHLETE Pre-integrated with RPLM/PSU

The passive thermal MLI and MM/SE protection cocoons the RPLM-1 hard shell structure. The SPE radiation protection of the crew is provided by a water wall in the crew bunk area. No long-term GCR protection is provided.

The core habitat element has a primary Power Management & Distribution System (PMAD) that manages distribution of power to the RPLM and its subsystems. The RPLM PMAD each has two converters, power distribution units, power switching units, and appropriate wiring.

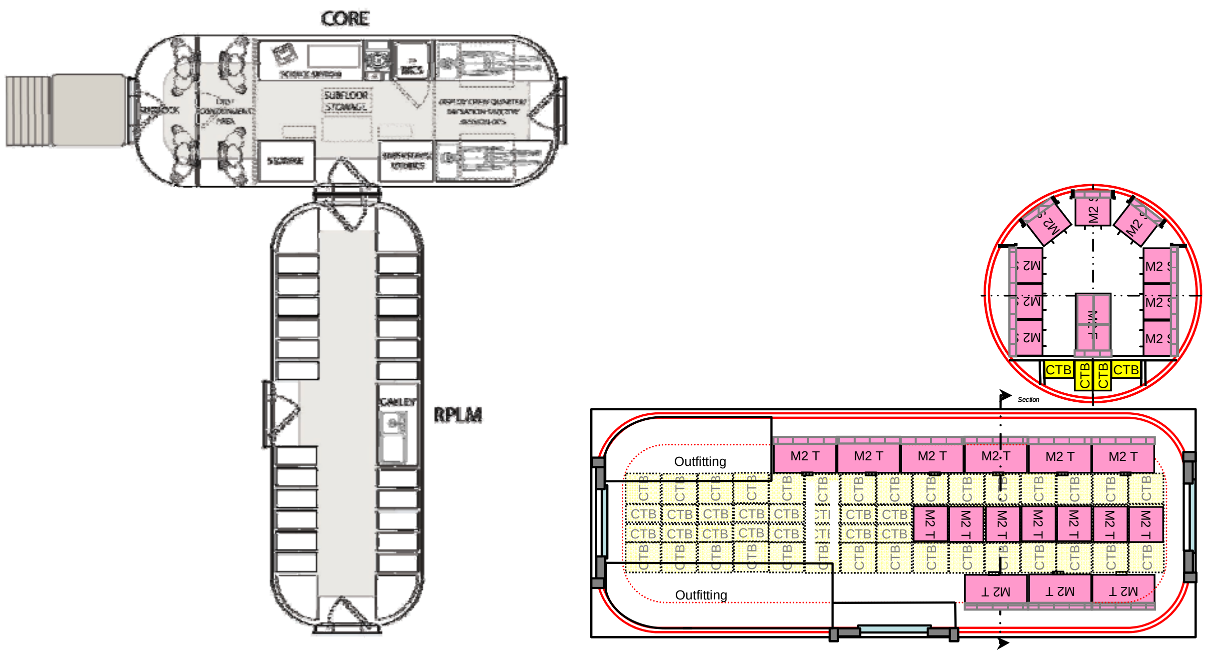
Each RPLM has a separate Active Thermal Control System (ATCS) for managing the thermal loads of this habitat element. The ATCS gathers the thermal load from within the habitat and passes this load to the external ATCS, body-mounted radiators placed on top of the element.

The Life Support System in the Core Habitat supports the minimal Life Support in the RPLMs, and has the capability to support the DPLMs. Pressure control is provided. Air distribution and collection ducting is provided into the RPLMs via inter-module ducting, cabin fan package, and fans within the unit. Sensors provide O2, CO2, and trace contaminate control. Fire detection and suppression equipment is provided.

The avionics (communication, control, and data management) primary subsystem is in the Core Habitat. A wireless communications system is used through out the habitation internal system. The RPLM-1 avionics includes crew utility panels, a work station capability, and a networking bus interface.

C. LS3 Outpost Internal Architecture

Each RPLM is delivered filled with 40 M02 bags are on the exterior, 7 MO2 bags are placed in the temporary aisle, and 60 CTBEs are stowed below deck, for a total of 248 CTBEs crew logistics and spares to support the crewed missions, figure 39. After retrofitting, RPLM-1 becomes the Crew Operations Unit that provides the crew living functions of eating, sleeping, recreation, and mission ops/meeting gatherings, as shown in figure 38. RPLM-1 retrofitting operations includes first relocating sleep stations to RPLM-1/Crew Operations Unit. Other outfitting steps are setting up the EVA Maintenance area in the Core Habitat; completing the Geo-Science Lab in Core Habitat; relocating the food warmer to the Crew Ops area. RPLM-1 includes the Telemedicine Workstation (temporarily set up in the Crew Operations Unit until arrival of RPLM-2). The wardroom table is set up. The logistic framework of struts, cable and fabric shelves are reused to create furniture, walls, tables, and other internal furnishings. The SPE Water Wall in Crew Operations Unit is filled for the sleep area to be protected.



(a) (b)

Figure 39. RPLM-1 with Logistics

RPLM-2 is delivered on a cargo Lander with the heavy lift mobility system (ATHLETE) pre-integrated with the PSU/RPLM, similar to RPLM-1. Upon delivery, RPLM-2 is off-loaded from the Lander and attached to the Core Habiat/RPLM-1 habitation complex, as shown in Figure 41. RPLM-2 is delivered filled with crew logistics and spares to support the crewed missions. After retrofitting, RPLM-2 becomes the Medical and Bioscience Operations Unit that provides the bioscience lab operations, medical care capability, exercise, and local stowage, as shown in figure 42. RPLM-2 retrofitting operations include relocating the Telemedicine Workstation (from the Crew Operations Unit); set up the Bio-Science and Medical Operations area; and set up the crew exercise area.

The Medical Ops subsystem consists of medical kits, environmental contingency kits, exercise/countermeasures equipment and biomedical research equipment. Operative Capability/Functionality- Provides the capability to proved crew health maintenance and medical and environmental contingency management; crew exercise to provide aerobic capacity and muscular strength and endurance for post-flight performance maintenance; life sciences research to reduce uncertainties and risk for longer duration and Mars missions. The system allows the crew to relatively autonomously or with consultatative telemedicine maintain or restore crew health, and preserve mission objectives in the face of medical or environmental surface contingencies or traumatic mishaps/anomalies.

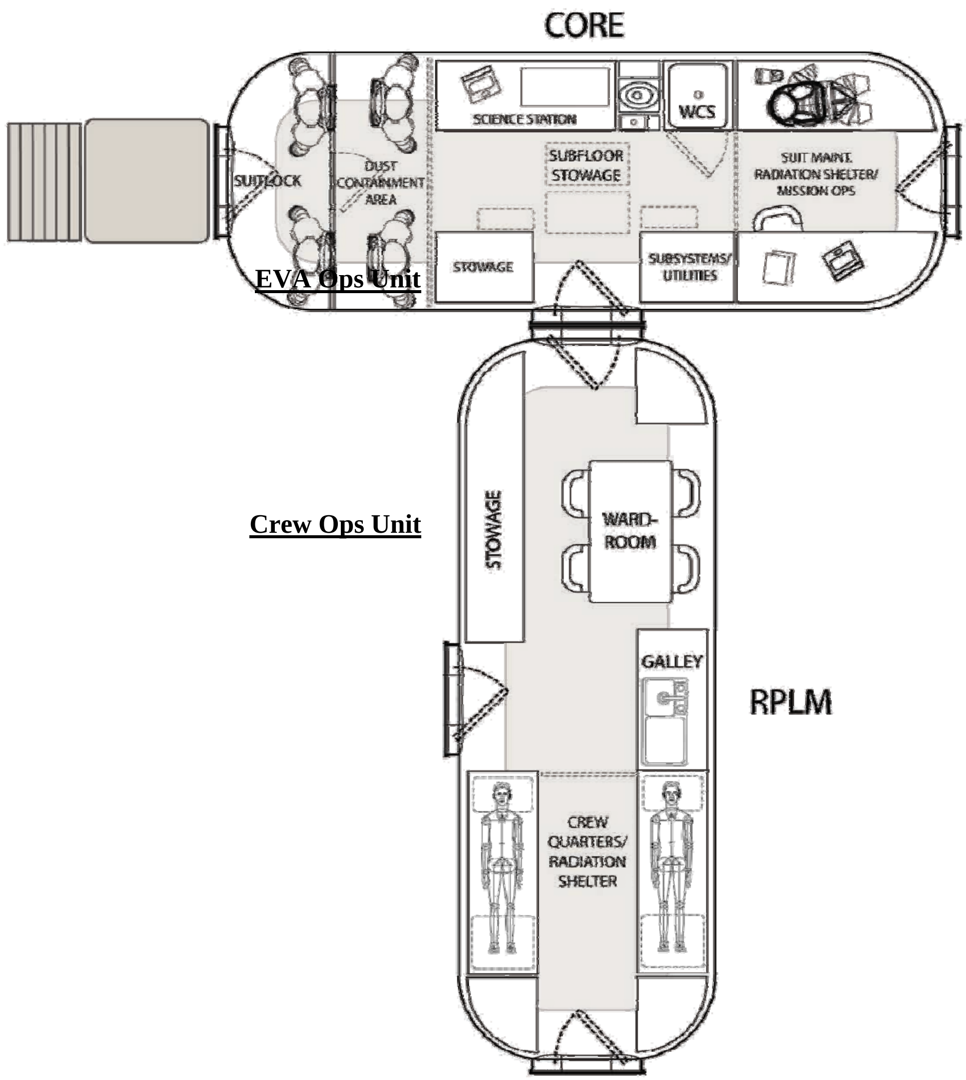


Figure 40. RPLM-1 Retrofitted into Crew Ops & Core Hab into EVA/Geoscience Ops

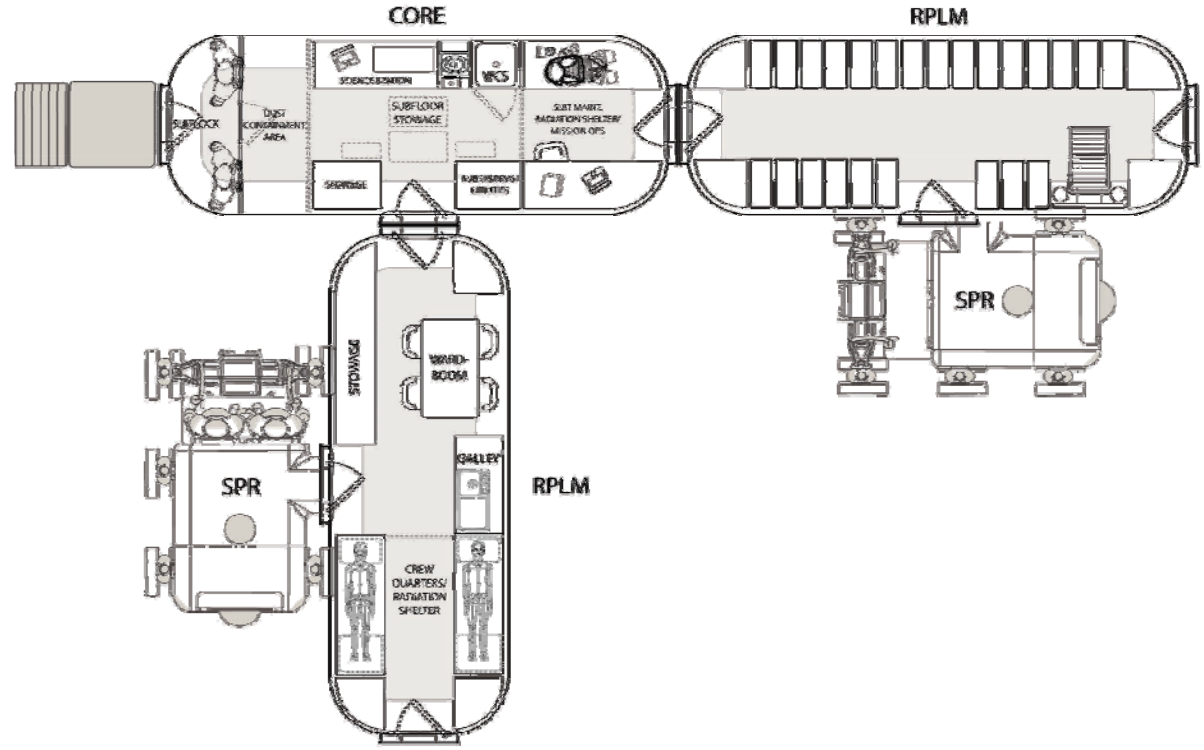


Figure 41. Core Habitat & RPLM-1 after RPLM-2 Delivery and Attachment

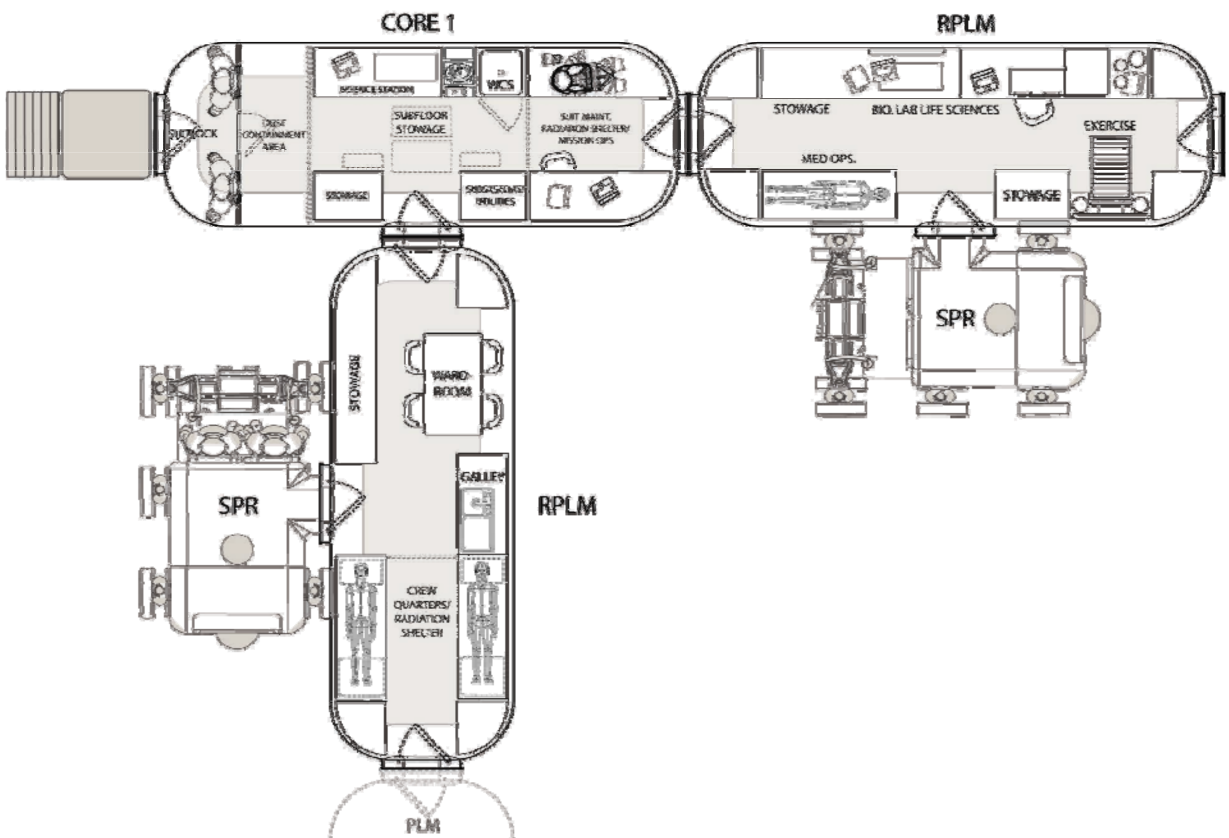


Figure 42. RPLM-2 Retrofitted into Medical Ops & Biological Science

D. RC 3.0 Outpost Summary

The power required (table 5) for nominal outpost operations is ~ 9.6 kW. The power required for the outpost while crew is not on board during a quiescent mode is ~ 2.8 kW. The thermal conditioning required for air-cooled and cold-plated cooling is ~ 4.2 and 5.4 kW respectively. The mass properties are shown in table 6. The outpost configuration total mass to the surface is ~ 17.3 mt for the three outpost habitation units.

Table 5. LS3 Outpost Power & Thermal Loads

Note: with out the 30% growth	Core Hab	RPLM-1	RPLM-2	Total Power & Thermal, W
Outpost Power Active, We	5748	1122	2772	9642
Outpost Quiescent Power, We	1133	836	836	2805
Outpost Air-Cooled Thermal, W_t	1655	510	2047	4212
Outpost Cold-Plated Thermal, W_t	3980	725	725	5430

Table 6. RC-3 Outpost Habitation Elements Mass Properties

HABITAT SUBSYSTEM	**Core Hab** mass, kg	**RPLM-1** mass, kg	**RPLM-2** mass, kg	**TOTAL OUTPOST MASS, kg**
Structures	1866	1937	1937	5740
Protection	300	300	300	900
PM&D	277	268	268	813
ATCS	346	159	224	729
Avionics [1]	84	57	57	198
Life Support	2025	146	146	2317
Airlock/Suitport	462	0	0	462
Outfitting	217	1020	936	2173
Total Dry Mass	5577	3887	3868	13332
30% Growth	1673	1165	1160	3998
Total Mass w/ 30%	7250	5052	5027	17330

Note 1: Avionics reuses the Altair Lander Avionics Common Service Assembly; thus, the mass is not book kept here.

IV. Summary of CxAT-Lunar Habitat Concepts

This paper has provided an executive summary of the habitation concepts defined during the Constellation Architecture Team-Lunar study. This study was performed by a multi-center team of subject matter experts from September 2008 – June 2009 in preparation for the Constellation milestone of the Lunar Capability Concept Review. The purpose was to define feasible habitation concepts that would be compatible with the Lunar Capability transportation system of Ares V and Altair lander. The concepts presented herein are not the final choice or baseline of a Lunar Scenario. Additional Lunar Scenarios will continue to be defined to drive out figures of merit, technical performance measures, desired features, functionality, operational concepts, risks, and cost considerations. Numerous Lunar Scenarios will be analyzed over the next 18-20 months in preparation for the Constellation Lunar Surface Concept Review. Additional details of these CxAT-Lunar Scenarios can be found in the CXAT-Lunar Surface Architecture Reference Documents (SARD). During this CxAT-Lunar and LAT2 study cycle several surface habitat technologies were identified. A list of these needs have been integrated into the Constellation Technology Prioritization Process and to the Exploration Technology Development Program.

Considerations of how to protect the habitat from radiation with several meters of regolith, accessibility for maintenance, and repair need further definition. The ATHLETE heavy lifting mobile robotic system mitigates the risks associated with moving the habitat off the lander and ensuring the structural integrity of the pressure shell while it is being moved and emplaced at the outpost site location. When determining which habitation strategy to pursue, considerations of the mission objectives, risk, cost and safety of the crew are required. After which, each strategy should be traded-off to determine which approach best satisfies the requirements and performance challenges. Depending on the scenario objectives one or a combination of habitat strategies may be used or phased as the outpost matures.

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