Lunar Architecture Team-Phase 2 Architecture Option-2 Habitation Concepts

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Abstract

This paper will describe an overview of the Lunar Architecture Team phase 2 (LAT-2) Option-2 architecture surface habitation definition performed during LAT-2. The LAT-2 architecture study focused on three primary habitation strategies. The three strategies are 1) habitats that are small, modular, and unloaded from the lander to create an outpost, 2) a monolithic habitat strategy that remained on the lander, and 3) habitats that remain on the lander and are mobile. This paper will describe the 2.75 meter diameter by 5 meter long mini-habitats that were defined for the Option 2 architecture. Each mini-hab is an aluminum-lithium pressure shell with an integrated cargo frame used for handling, integration with the lander, and surface emplacement. Each mini-hab contains 27.5 cubic meters of volume and 5 mini-habs are used to make up the outpost. The modular mini-habs allows for flexibility and adaptability to the lander integration and emplacement on the surface. This paper will describe the mass and master equipment list of the systems. The internal architecture and configuration will be described.

Introduction

Habitation as defined in Webster's New World dictionary comes from the word Habitat. Habitat is defined as [1] the region where a plant or animal naturally grows or lives, and [2] the place where a person or thing is ordinarily found. Therefore Habitation is [1] the act of inhabiting; occupancy, [2] a place in which to live; dwelling; home, [3] a colony or settlement. Understanding the psychological and physiological needs of humans to create habitable spaces for the crew to live and

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work on the Moon is paramount. Many studies of historical space craft volumes per crew member per mission duration have been performed. The mission durations for the purposes of gross volume estimates are defined as short duration [a few days to a week or so]; medium duration [a few weeks to a couple of months]; and long duration [six months or greater]. Numerous studies have been completed on the isolation and confinement of humans in hostile environments including jails, off-shore oil platforms, submarines and Antarctic facilities.

Objectives

The objectives of the Lunar Architecture Team phase-2 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) sortie mode, and 2) outpost mode with local-range mobile exploration capability.

Description of Architecture Option-2 Habitation

The primary concept feature of LAT-2 Architecture Option-2 was its small modular habitat units that could be delivered on a crewed or cargo lander. At the time of the design conceptualization, the lander constrained the habitat units to a payload bay size of 3 meters x 3 meters x ~5 meters long and a mass allocation of 6 mt for the crewed mode. The goal was to deliver a habitat on the crewed lander. Of course in cargo mode (no crew) the mass allocation to the surface is more since there is no ascent module. In the cargo lander case two hab units with cargo could be delivered for the 16 mt capability. The distinguishing feature of these habitation units is that they are preintegrated and designed to be removed from the lander and emplaced on the lunar surface to create a static outpost operational end-state. The advantage of this approach is its modularity, robustness, flexibility to adapt to various missions, and the ability to “pay as you go” through the life cycle.

The Outpost consists of 5 mini-Habs. Due to the small size of the mini-habs (27.5 m3 each) five units were required to house all the functionality and volume for a minimal outpost capability. This created manifesting challenges as to which unit to bring first, second, third, and so on. The first hab unit delivered needed to have an airlock (suit-lock integrated into the mini-hab) in order for the crew to enter and begin the initial setup. However, the mini-hab could also be used in Sortie mode by remaining on the lander.

The reference concept shown in figure 1 depicts an example of a Lunar Outpost consisting of 5 mini-Hab units removed from the landers and emplaced on the lunar surface. The Habitat Modules are landed on the lunar surface as pre-integrated pressurized units not to exceed 6 mt. The Outpost configuration provides pressurized mating attachment for 2 pressurized rovers and a pressurized logistics module. For commonality, manufacturing, and cost considerations the pressurized logistics module (PLM) is a duplicate of the mini-hab shell and integrated cargo frame (fig 2). The 1st Pressurized Logistics Module (Pantry Hab) is reused and retrofitted for exercise, Medical Ops, and for storage/spares as a permanent part of the Outpost.

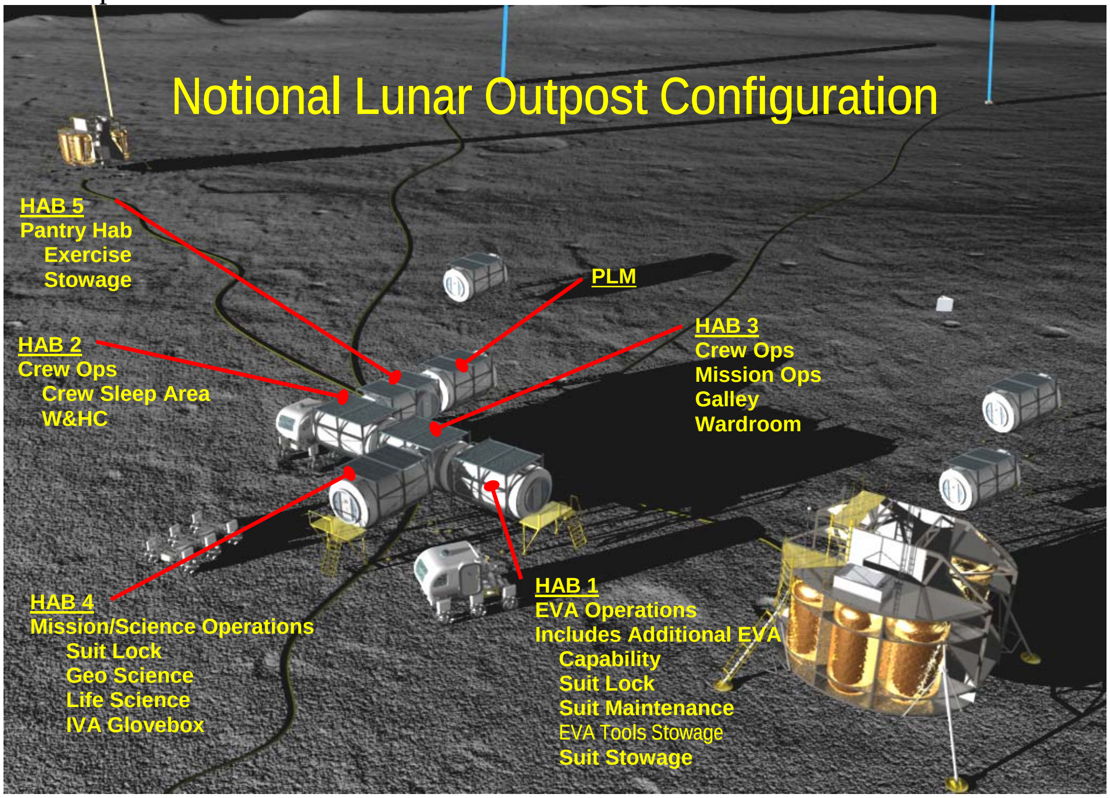

Figure 1, Option-2 Outpost End-State

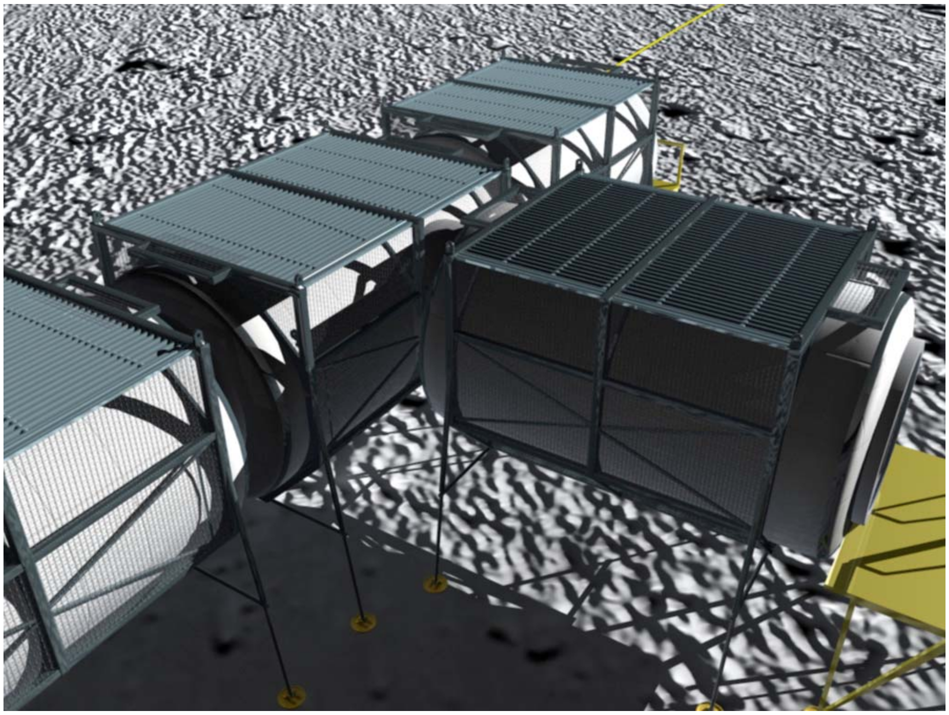

Figure 2, Option-2 Mini-Habitation Elements

Concept Description:

This Mini-Hab Element provides ~27.5 m3 pressured volume each. Each mini-Hab is 2.75 m diameter x 5 m long aluminum-lithium (Al-Li) hard shell pressure vessel with a truss-type integral exo-structure cargo frame. The hab unit is removed from the lander for surface emplacement (figure 3). The Outpost configuration consist of five Hab Elements (2 Habs, EVA, Lab, and Pantry Hab units) mated together. A common mating mechanism is used to mate the modules together and for docking of the pressurized rover (figure 4). The thermal radiators are integrated to the top of the shell cargo frame. The top and sides are protected by a composite fabric micrometeoroid and surface ejecta protection barrier (not shown). The outer shell of the module is covered with multi-layer insulation for passive thermal protection. An external deployable aluminum iso-grid open grated dust porch and stairs allow surface access to and from the habitats (two alternative concepts shown in fig. 3 and 5). One of the design goals is to minimize the distance from the Hab to the surface. The habitat shown in figure 3 should be lowered to the maximum extent possible—not as shown in this artist image.

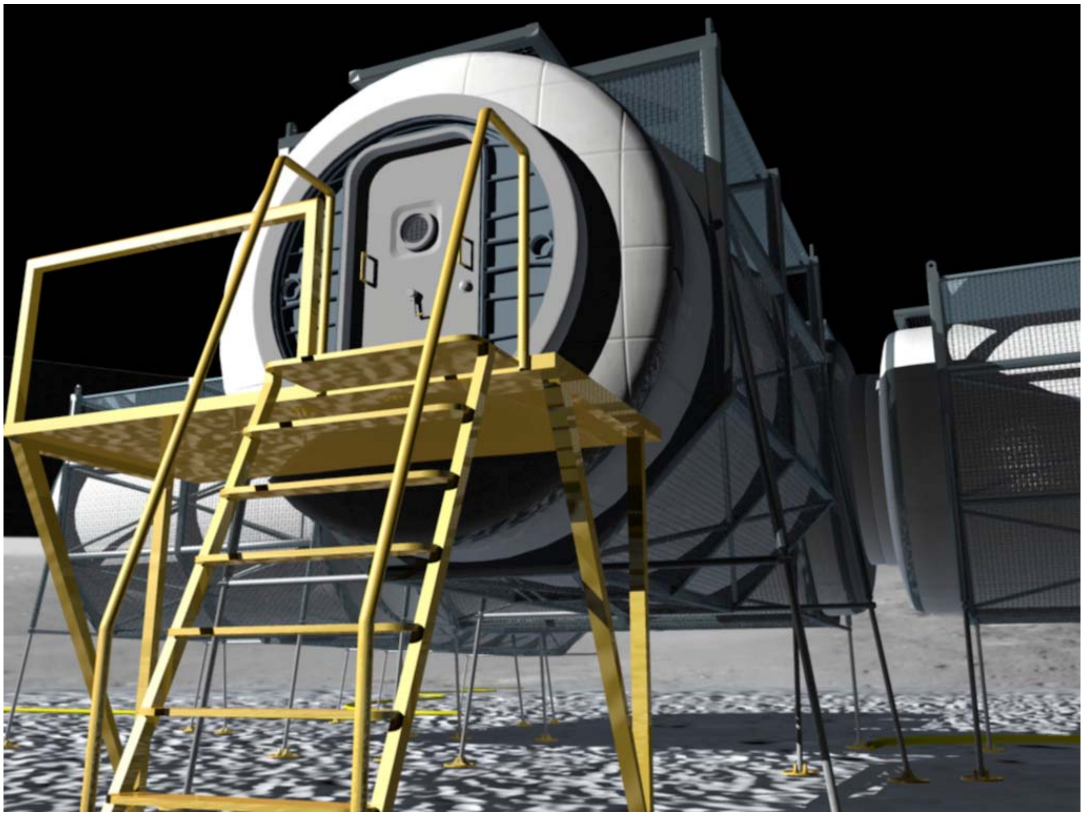

Figure 3, Mini-Hab

The functional needs for an outpost can be divided into five achievable segments. They are the Crew Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations. The Crew Operations unit includes basic crew accommodations such as sleeping, eating, hygiene and stowage. The EVA Operations unit includes additional EVA capability beyond the suit-port airlock function such as redundant airlock(s), suit maintenance, spares stowage, and suit stowage. The Logistics Operations unit 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.

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

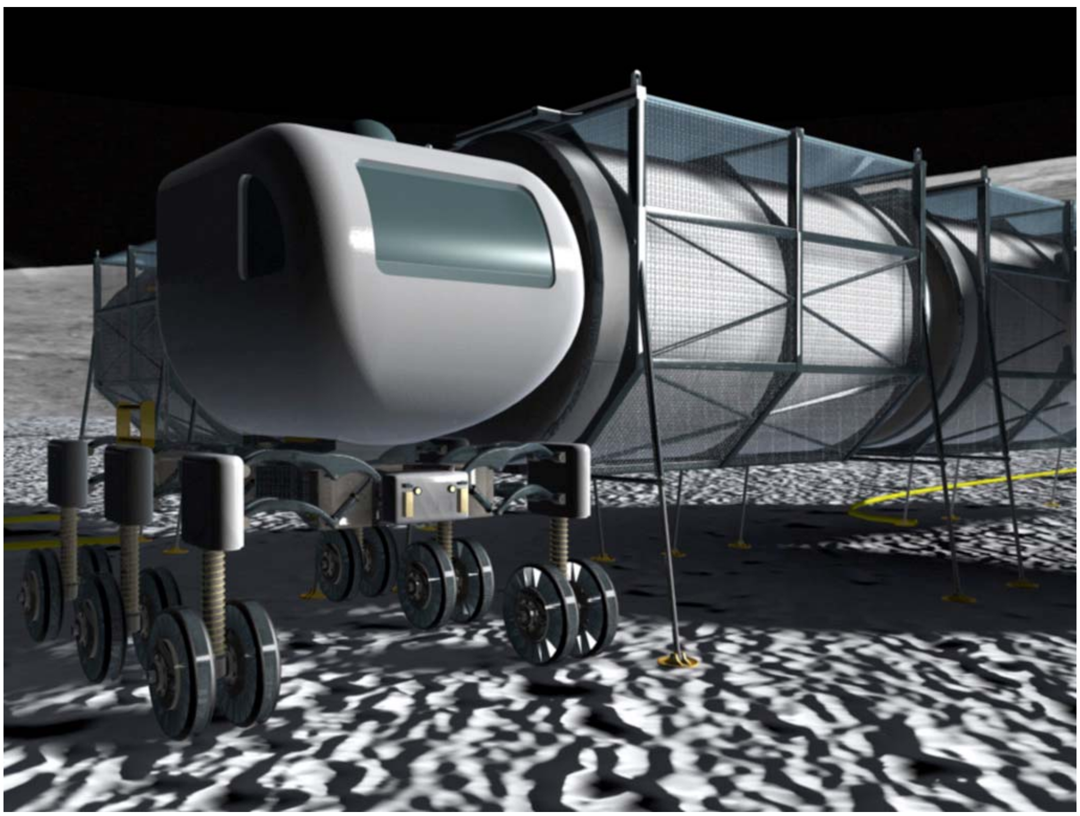

Figure 4, Small Pressurized Rover docked to a Mini-Hab

Figure 5 depicts the modular structural shell “kit” approach with use of integratable modular subsystems. The module kit approach provides good manufacturability and sharing of components to create PLMs, Sortie units, hybrid expandables, and habitats. Modularity of subsystems will provide more commonality and flexibility for reconfiguration across habitats and other elements. Two integrated suit locks are provided in two hab units. The integrated suit lock provide for two EVA suit ports, dust control, and airlock functionality.

<u>Habitat Elements</u>

1) Hab-1: EVA Ops & Maintenance Hab Element, 2.75 m dia x 5 m long, ~ 27.5 m3
2) Hab-2: Crew Ops, Crew Sleep Area, 2.75 m dia x 5 m long, ~ 27.5 m3
3) Hab-3: Mission Ops, Galley / Wardroom, 2.75 m dia x 5 m long, ~ 27.5 m3
4) Hab-4: EVA Ops, Med Ops & Science Labs, 2.75 m dia x 5 m long, ~ 27.5 m3
5) Hab-5: Pantry Hab / Retrofit Med Ops-Exercise, 2.75 m dia x 5 m long, ~ 27.5 m3

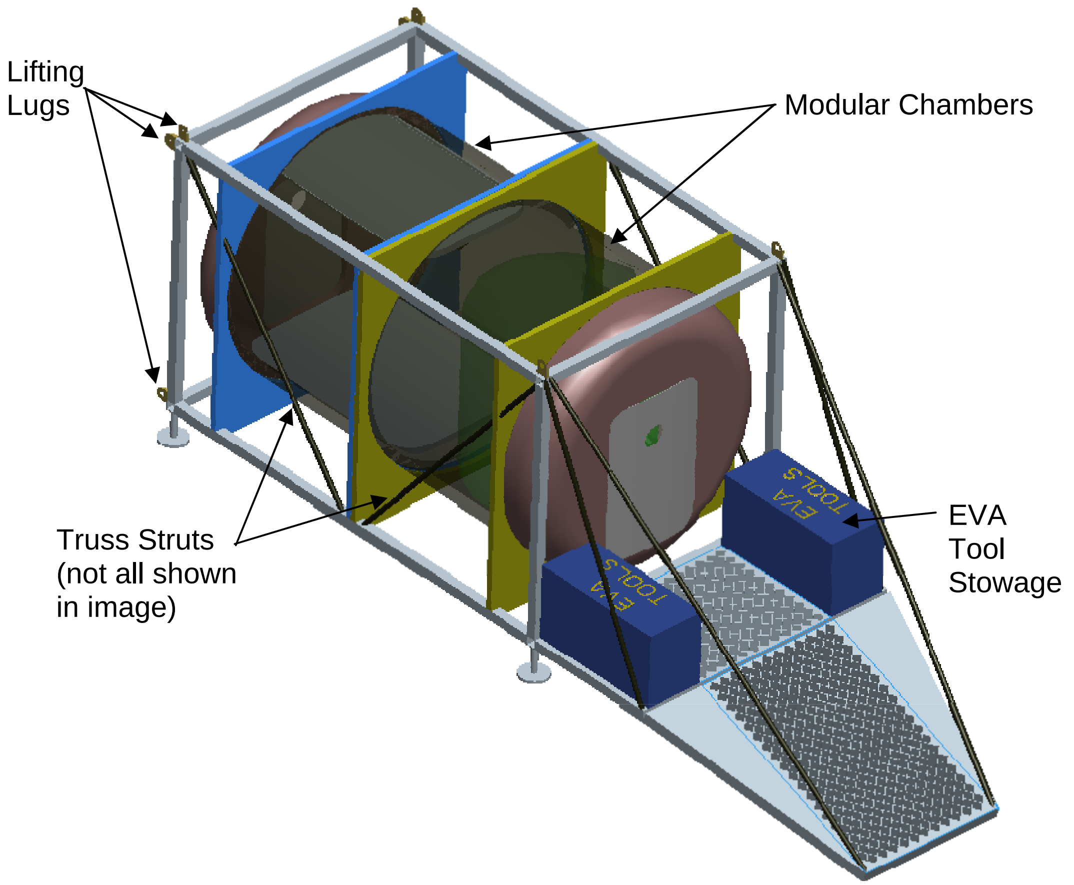

Figure 5, Mini-Hab Concept Features

Lunar habitation provides a pressurized “shirt-sleeve” environment within which the lunar surface crew members can live and work. The lunar habitat’s operational capabilities include supporting a crew of four’s life support, habitability, and medical requirements for six-month intervals, including supporting crew change-out operations with a full crew of eight. The lunar habitat will also support exploration extravehicular activity (EVA) operations, lunar science, and technology evaluations of Mars forward systems.

Thermal protection is provided by multi-layer insulation. Radiation protection is provided for Solar Proton Event (SPE-Solar Flare) using by a water wall capable of surrounding the crew sleep area. The water wall is filled with ~1000 kg of water (figure 6). The crew is not protected from GCR radiation other than the supply tanks, structure, and subsystems.

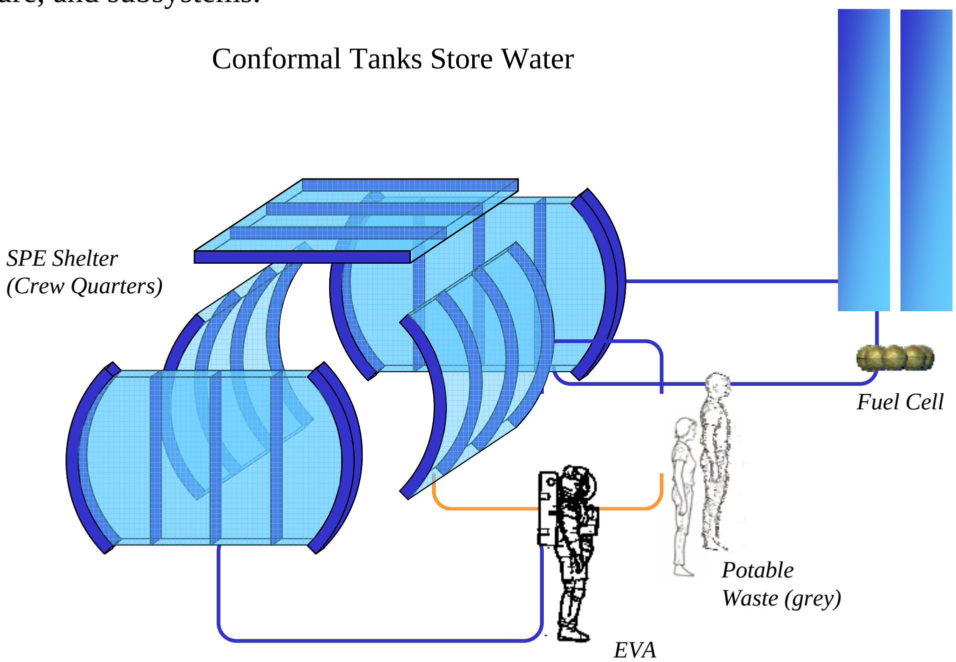

Figure 6, Habitat Water Wall Concept

The Hab-1 unit is the first delivered since it provides the airlock function and is needed for the initial sortie mission to begin the outpost emplacement phase. The Hab-2 and Hab 3 units have a full-up capability delivered on a cargo lander. They have the crew ops and Closed ECLS. Hab-4 is the Lab and has the full-up medical ops system, exercise, biological and geological science labs (as allocated for lunar exploration), but it does not have the volume required for medical and exercise equipment to be deployed and used effectively. Therefore, the initial Log-1 is retrofitted into the Hab-5 Pantry Hab for permanent outpost habitation volume and use. At this point the habitation complex or Outpost is Operational for long-term outpost use. Power is provided by an external generation solar array system.

Internal Architecture

The habitation module units, as previously described, are cylindrical horizontal shells—smaller than the ISS modules. The internal architectural layout is zoned by function separating the working Lab (noisy/dirty) from the living Hab (quiet/clean) areas. However due to volume and mass constraints a suit lock was integrated into the end of two units. From a manufacturing and cost perspective, having these shell identical amortized the cost among units. The PLM was a derivative of them as well. Figure 8 depicts the internal architecture in the end-stated connected outpost mode.

The Hab-1 is the dedicated EVA ops unit. It contains the EVA ops area (fig 9) with a suit lock for two EVA suits, the hatch doors, dust control, an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. By isolating the EVA function into a module the dust and noise can be reduced throughout the rest of the habitation zones.

Hab-2 is the crew ops area and contains the sleep area bunks (fig 10) 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.

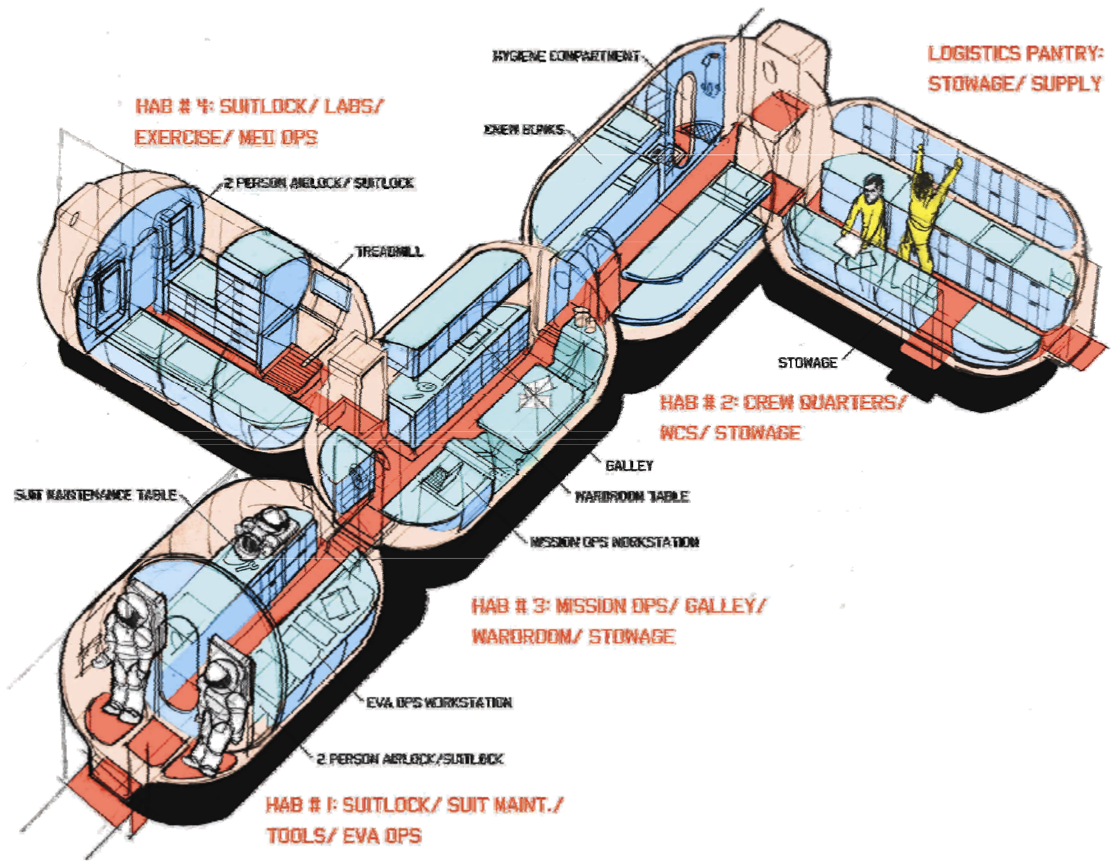

Figure 8, Habitation Element Interior Architecture

Hab-3 is the mission ops unit with the base operations and primary systems controls, the galley and wardroom functions. The crew ops area is split between Hab 2 and 3, which includes the basic crew accommodations of sleeping, eating, hygiene and stowage. Due to limitation on size, privacy curtains are utilized when necessary.

Hab-4, the Lab module, contains the second suit-lock, mission ops, and science ops. The suit lock is for two EVA suits, the hatch doors, and science pass through for samples and equipment. The science ops area (fig 11) is the laboratory to support biological and geological science equipment—such as glove boxes—and storage.

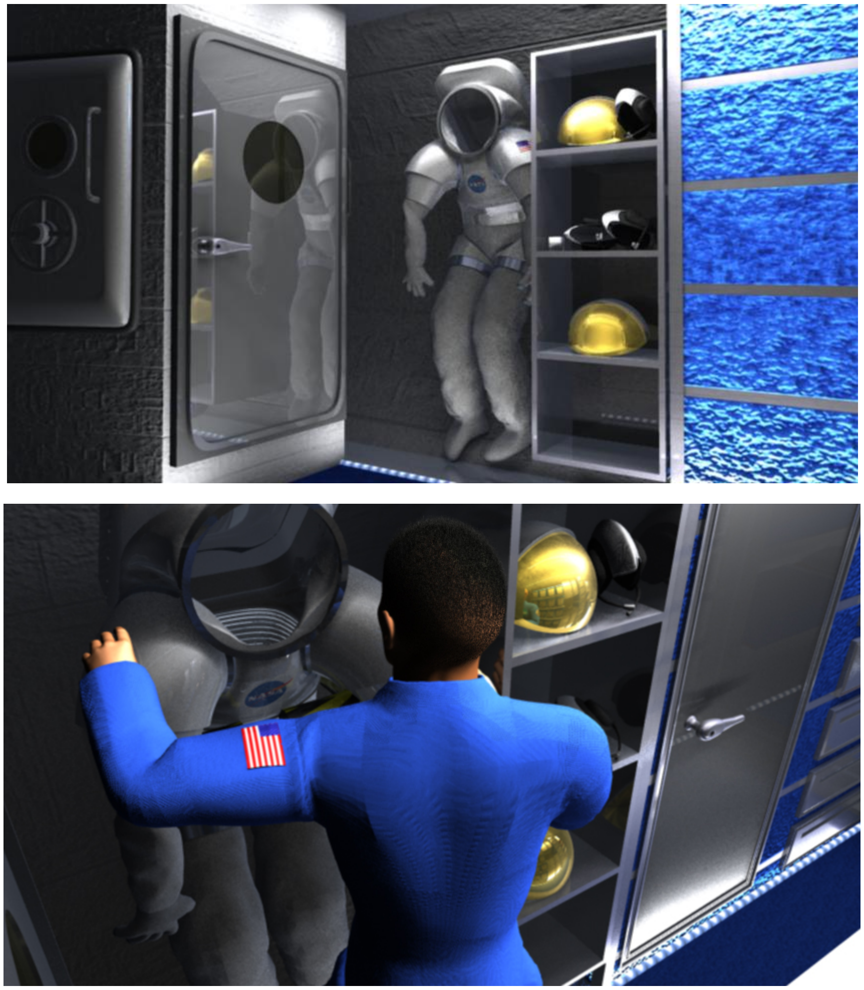

Figure 9, Habitation Element Interior: EVA Ops

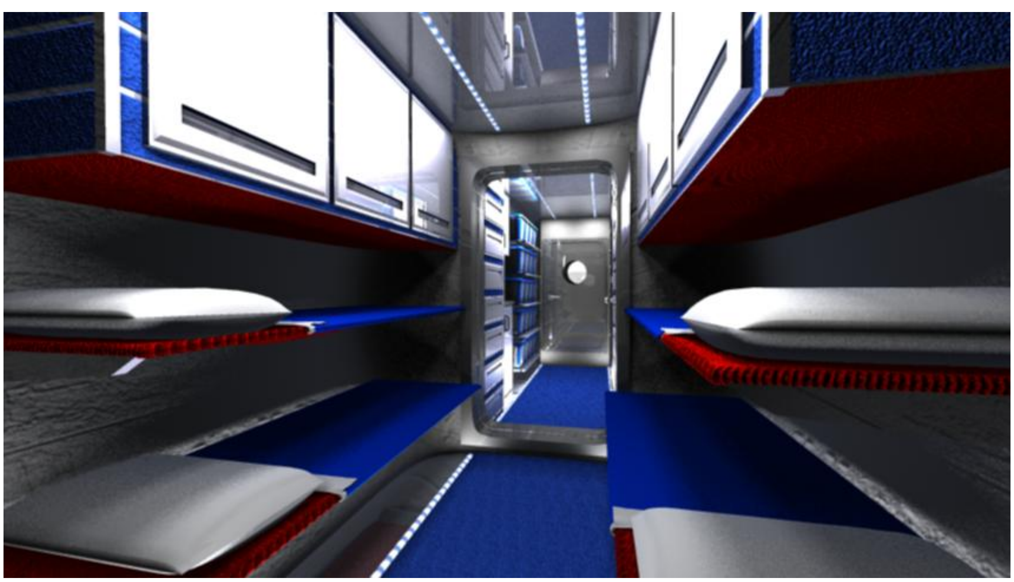

Figure 10, Habitation Element Interior: Crew Ops—Sleep Area

Hab-5 (Pantry Hab) is the retrofitted logistics module—after the supplies have been used and distributed to the other units—it is turned into the 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.

Figure 11, Habitation Element Interior: Science Ops

Resource Summary

The mass properties are shown in table 1. The outpost configuration total mass to the surface is ~ 20.4 mt for the 5 hab units. The Sortie habs are ~ 3.5 mt.

The power required (table 2) for nominal outpost operations is ~ 12.5 kW. The power required for the outpost while crew is not on board during a quiescent mode is ~ 2.6 kW. The thermal conditioning required for air-cooled and cold-plated cooling is ~ 4.3 and 8.3 kW respectively.

Mini-Hab Mass Properties: Al-Li Hard Shell

	Outpost Configuration						
	Subsystem Tab Hardware Only Masses (kgs)	#1: EVA, Maintenance & Spares	#2: Sleep & Hygiene	#3: Mission Ops, Galley, Wardroom	#4: EVA, Science Lab, Med Ops	#5: Pantry Hab	Sortie Hab
Structures	7460	1263	1651	1798	1116	1632	999
Protection	491	79	177	79	79	79	79
Power Mangt & Distr	1882	422	422	422	422	195	392
Thermal	643	272	77	136	104	54	146
Avionics	261	79	34	81	46	21	86
Life Support	3386	1169	556	1048	429	184	548
Suit-Lock	1201	601	0	0	601	0	601
Outfitting	1656	57	59	71	1457	12	31
20% Growth	3396	788	595	727	851	435	576
Total	20375	4729	3570	4361	5104	2611	3459

Table 1, Habitation Elements Mass Properties Statement

	Subsystem Total Power & Thermal	#1: EVA, Maintenance & Spares	#2: Sleep & Hygiene	#3: Mission Ops, Galley, Wardroom	#4: EVA, Science Lab, Med Ops	#5: Pantry Hab
Power	12439	4995	912	2464	1558	438
Quiescent Power	2638	830	402	410	363	193
Aircooled Thermal	4379	1040	492	466	1296	355
Coldplated Thermal	8326	3955	420	1998	262	82

Table 2, Habitation Elements Power & Thermal Allocations

Mini-Hab Summary

The habitation strategies for a surface outpost include unloading the habitat(s) and emplacing them on the surface; leaving the habitat(s) on the lander thus becoming the initial outpost; or designing the habitat(s) to be mobile. Of course a combination of all three approaches could be employed as well. Unloading the habitats has some desirable features such as 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. They also may need to be segmented into smaller manageable units so they can be unloaded, transported, and emplaced on the surface. Below is a summary of the advantages and disadvantages of the mini-hab habitation strategy.

<u>Advantages:</u>

1. The mass and size are more compatible with other payloads (power units, ISRU, rovers, PLM) for handling, thus not imposing additional requirements on handling and mobility systems.
2. The incorporation of regolith for radiation and micrometeoroid protection may be easier due to its close proximity to surface.
3. Surface access for EVA ingress/egress is easy due to their close proximity to surface.
4. Carry items to and from lunar surface will be easier for astronauts due to close proximity of the habs to the lunar surface.

5. The handling of payloads and equipment for logistics, re-supply and repair will be easier due to close proximity to the lunar surface.
6. Exterior inspections and repairs performed by astronauts will be easier due to close proximity to the lunar surface.
7. It is easier to add habitat elements and build up base beyond Initial Outpost Capability (IOC).
8. The integrated hab cargo frame can also serve as the launch integration structure as well as payload handling structure and alignment structure (for mating).
9. The mini-Habs have a lower recurring cost because they can amortize the design and development costs over multiple units.
10. The mini-Habs will be less costly to build a spare.
11. The mini-Habs have commonality with NEEMO and related underwater analogs.
12. The mini-Habs are designed for manufacturability by utilizing the “kit of parts” concept.

<u>Disadvantages</u>:
1. As habitats become smaller, the structural mass becomes dominated by non-pressure shell items (such as doors, frames, windows), increasing area mass.
2. Site preparation or capability for leveling must be provided by each habitat element.
3. Modules must be aligned and mated, requiring additional hardware and operations.
4. Requires some mobility and payload handling capability (may or may not be additional).
5. There is an increased subsystems mass due the distribution among multiple habs.
6. Small interior volume portrays a closed-in feeling to inhabitants. .
7. Increased time to get to full IOC mission capability.
8. Increased number of interfaces & connections.
9. Increased operational complexity.

Other considerations are how to protect the habitat from radiation with several meters of regolith, accessibility for maintenance, and repair. There are risks associated with moving the habitat off the lander and ensuring the structural integrity of the pressure shell while it is being moved to the surface. 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 campaign objectives one or a combination of habitat strategies may be used or phased as the outpost matures.

During the conceptual investigation of the mini-hab approach, an alternative habitat concept was derived. It is a mid-section expandable hybrid concept based in-part on the “kit of parts” manufacturing approach. Included here in is a brief description. This concept was not evaluated by the Lunar Architecture Team at large due to time constraints of the study.

Alternative Option-2 Mid-Expandable Habitat Concept

Concept Description:

The Mid-X Hab Element provides 63 m3 pressured volume each. It is 2.75 m diameter x 10 m long (fully expanded) Al-Li Hard-End Caps with multi-layered tensile fabric pressure shell (fig 12). Three units comprise the Lunar Outpost configuration. The lander packaged configuration is a 3m x 3m x 5m payload, and after expanding some outfitting is required.

Reference Concept

The reference concept shown depicts an example of a Lunar Outpost consisting of 3 midX-Hab units removed from the landers and emplaced on the lunar surface. The Habitat Modules are landed on the lunar surface as pre-integrated unpressurized units that will be deployed, expanded, and outfitted. The subsystems, utilities, and outfitting are pre-integrated into the hard end caps to allow easy ground processing and deployment. The Outpost configuration allows the pressurized mating to 2 pressurized rovers and a pressurized logistics module. As with the mini-hab, the hard end-caps are Al-Li with preintegrated subsystems. The functional needs are same as for the mini-Hab outpost; the Crew Operations, EVA Operations, Mission Operations, Science Operations, and Logistics Operations.

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

Habitat Elements

1. Hab-1: Crew Ops: Crew Sleep Area, Galley and Wardroom, 2.75 m dia x 10 m long, ~ 63 m3
2. Hab-2: EVA Ops: Crew lock, EVA, & Maintenance, Mission Ops, WCS, 2.75 m dia x 10 m long, ~ 63 m3
3. Hab-3: Science Ops: Crew lock, Med Ops, & Science Labs, 2.75 m dia x 10 m long, ~ 63 m3

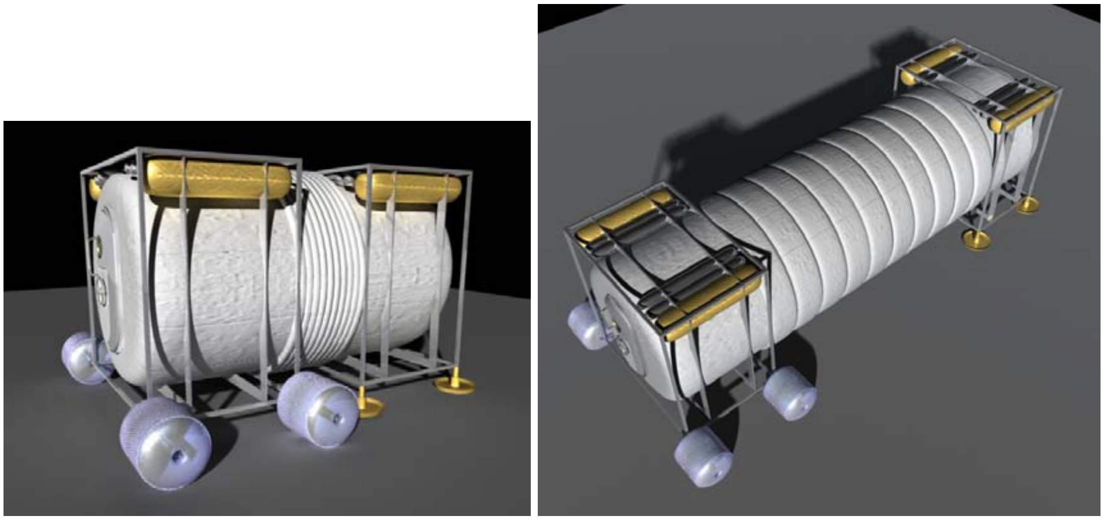

Figure 12, Mid-Expandable Hybrid Habitat Concept

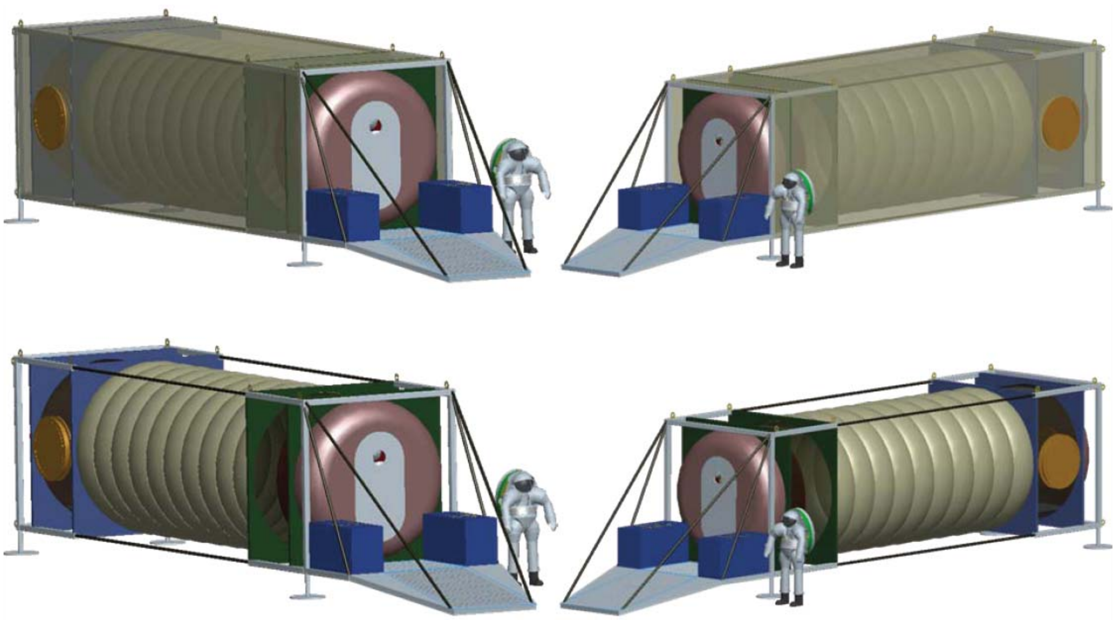

Figure 13, Mid-X Habitat External Views w and w/o MMSE Shield

Internal Architecture

The habitation module units, as previously described, are cylindrical horizontal shells—with a mid-expandable section. 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. Figure 14 depicts the internal architecture in the end-stated connected outpost mode.

Hab-1 is the crew ops area and contains the sleep area bunks, some mission ops with the base operations, the galley, and wardroom functions. The crew ops area is primarily contained in this unit, which includes the basic crew accommodations of sleeping, eating, and stowage. Due to limitation on size, privacy curtains are utilized when necessary. Each module has the subsystems 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.

The Hab-2 is the dedicated EVA ops unit. It contains the EVA ops area with a suit lock for two EVA suits, the hatch doors, dust control, an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. By isolating the EVA function into a module the dust and noise can be reduced throughout the rest of the habitation zones. It also contains the hygiene function.

Hab-3, the Lab module, contains the second suit-lock, mission ops, and science ops. The suit lock is for two EVA suits, the hatch doors, and science pass-through for samples and equipment. The science ops area is the laboratory to support biological, life science, and geological science equipment—such as glove boxes—and storage.

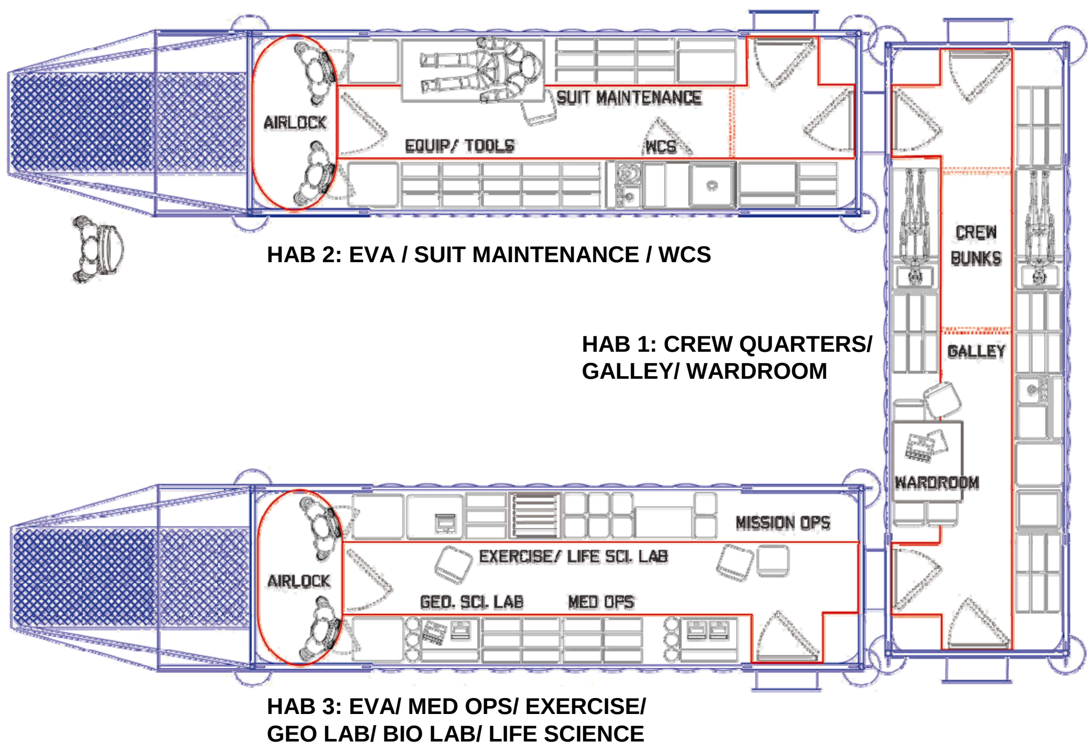

Figure 14, Mid-X Habitat Internal Architecture

Resource Summary

The mass properties are shown in table 3. The outpost configuration total mass to the surface is ~ 18.4 mt for the 3 midX hab units.

	Subsystem Tab Hardware Only Masses (kgs)	Hab-1: Crew Ops, CQ Galley, Wardrm	Hab-2: EVA Ops, Maintenance	Lab-1: Mission Ops, EVA, Med, Geo, Bio Science
Structures	5927	2262	1832	1832
Protection	377	191	93	93
Power PM&D	1183	394	394	394
Thermal	1088	363	363	363
Avionics	315	107	98	111
Life Support	3105	647	1794	664
Suit-Lock Sys	1201	0	596	596
Outfitting	2124	297	111	1716
20% Growth	3064	852	1056	1154
Total	18384	**5113**	**6336**	**6923**

Table 3, Mid-X Hab Elements Mass Properties Statement

Parameter	3 x 5 mini-Habs Al-Li Hard Shell	3 x 10 (deployed) Hybrid Hab Mid-Section Expandable
Total Pressurized Volume	137 m3	189 m3
Total Floor Area	~ 2 m x 4.75 m = 9.5 m2 Total of 5 = 47.5 m2	~ 2 m x 9.75 m = 19.5 m2 Total of 3 = 97.5 m2
Total Mass Summary	5 units = 20375 kg	3 units = 18384 kg
Power Summary	12.44 kW	12.6 kW
Number of Free Hatches	3	4
Outfitting	Pre-Integrated	Some Outfitting Required
Technology Required	minimal	Inflatable Systems

Table 4, Option 2 Habitat Concepts Comparison

Mid-X Hab Summary

The expandable mid-section gives the needed additional volume for the long-term habitation functionality of an outpost. The advantage of this hybrid (hard shell and inflatable) habitat is that the packed volume is the same as the mini-hab, but the expanded volume is ~ 2.3 times greater. Thus in fewer deliveries you get more pressurized volume and floor space (table 4).