Lunar Architecture Team-Phase 2 Architecture Option-4 Habitation Concepts

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Abstract

This paper will describe an overview of the Lunar Architecture Team phase 2 (LAT-2) Option-4 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. The option 4 architecture focuses on the mobility aspects of a lunar outpost. Each habitation unit is 3.0 meters diameter by 8.5 meters long. Each is an aluminum-lithium pressure shell integrated with the lander and mobility system. Each habitat unit contains 55 cubic meters of volume and 3 habitats are used to make up the 165 m3 outpost. As part of the outpost architecture a mobile habitat and laboratory was defined to provide the long range mobile exploration capability. 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 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

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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-two 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 three mission modes: 1) sortie mode, 2) outpost mode, and 3) long-range exploration mode.

Description of Architecture Option-4 Habitation

The primary concept feature of LAT-2 Architecture Option-4 was its mobility. The integrated lander-habitat would include an ATHLETE (All-Terrain Hex-Legged Extra-Terrestrial Explorer) wheel-on-limb mobility system. After landing each lander would move to a desired lunar feature for exploration purposes. Upon the landing of additional units such a lab and pressurized logistics, the mobile base concept would connect together for an extended outpost operations. Once an area had been explored thoroughly for several months or so, the outpost habitation units would disconnect and travel to a new location. This allows for expanding the surface exploration. Also an individual “excursion” type hab unit would disconnect for shorter excursion near the outpost location without having to move the entire outpost. Accompanying the larger hab units at the outpost are small pressurized rovers for local exploration excursions. Figure 1 and 2 depicts the outpost with the “Excursion” unit separated and in excursion mode respectively.

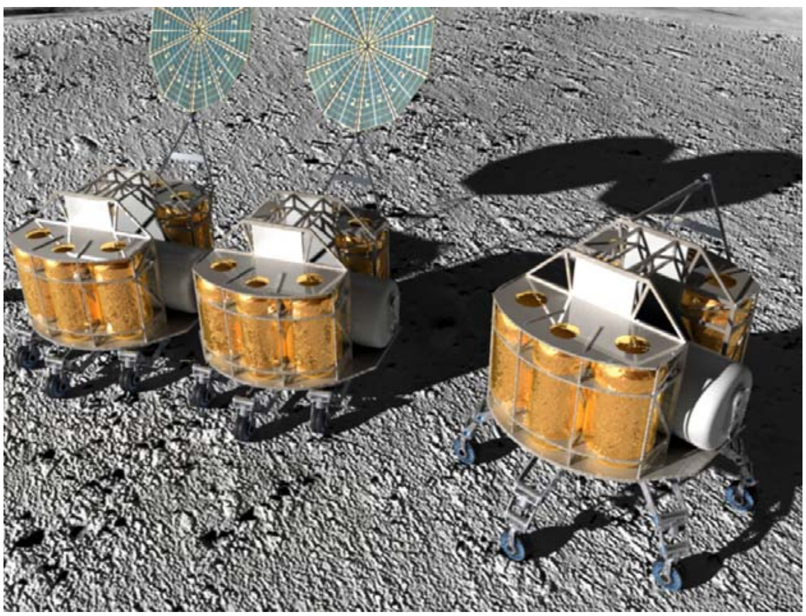

Figure 1, Mobile Lander-Habitation Elements

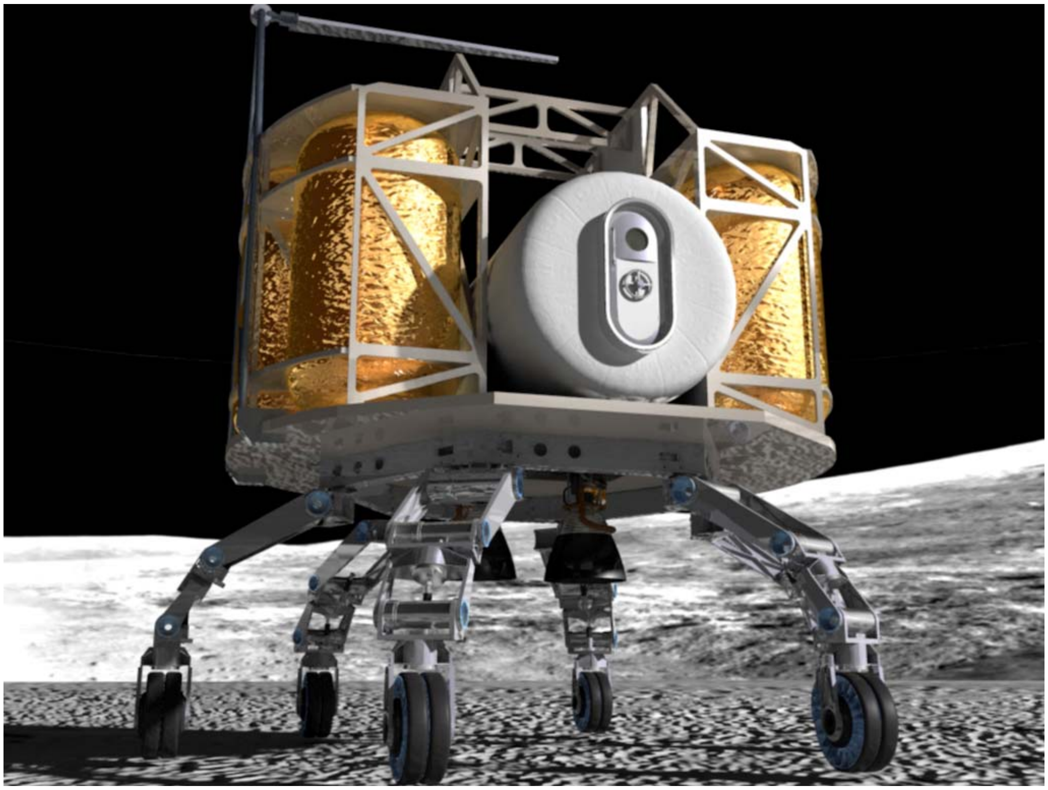

Figure 2, Lander-Habitation Element on ATHLETE Mobility System

Concept Description:

This Mobile Hab Element provides ~55 m3 pressured volume each. It is 3 m dia x 8.5 m long Al-Li Hard Shell pressure vessel pre-integrated with the Lander that will remain on the lander for surface operation. The Outpost configuration consist of three Hab Elements (Hab, Lab, and Logistic) linked together. The 2 Sortie-Excursion Habs are used for remote Hab/Lab operation visited by 2 or 4 crew members. The reference concept shown depicts an example of a Lunar Outpost consisting of 3-Option 4 Hab units that remain on the mobile [ATHLETE] landers. Figure 3 shows an ATHLETE prototype (one-third scale for the applications described here) in testing at the Jet Propulsion Laboratory (JPL). The Habitat units are landed on the lunar surface as pre-integrated units that will be moved via the lander, connected, and checked out remotely. The subsystems, utilities, and outfitting are pre-integrated into the hab units. The 1st Pressurized Logistics Module is reused and retrofitted for exercise and Medical Ops as a permanent part of the Outpost. The Outpost has a capability to disconnect and move the base to a new location.

<u>Habitat Elements</u>

1) 24 hr Sortie Hab:3 x dia x 4 m long
2) Sortie / Excursion Hab/Lab #1 & #2: 3 m dia x 8.5 m long, ~ 55 m3
3) Outpost Habitat #3: 3 m dia x 8.5 m long, ~ 55 m3
4) Outpost Laboratory #1: 3 m dia x 8.5 m long, ~ 55 m3
5) Outpost Retrofitted Logistic #1: 3 m dia x 8.5 m long, ~ 55 m3

Figure 3, ATHLETE Mobility System

Figure 4, Lander-Habitation Element on ATHLETE Mobility System

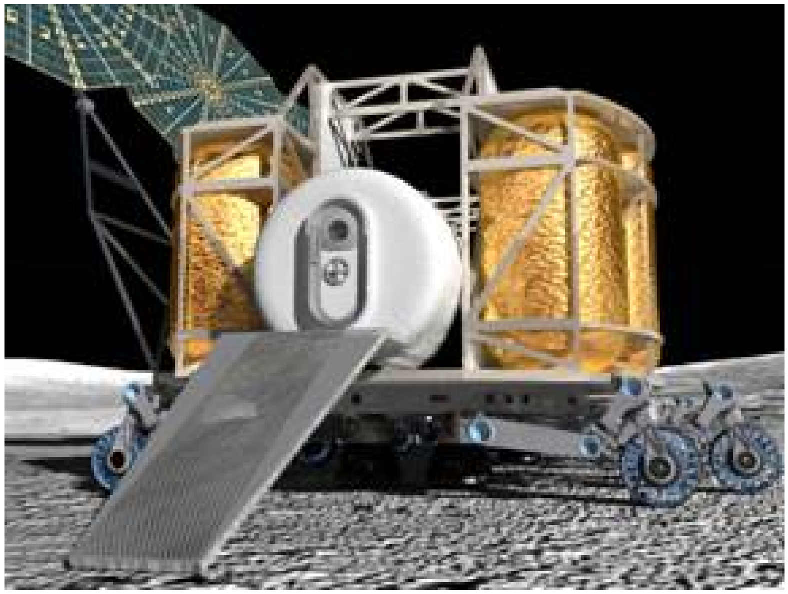

Figure 5, Lander-Habitation Element on ATHLETE Mobility System

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:

- <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

<u>Operational Capability</u>

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 routine extravehicular activity (EVA) operations, lunar science, and technology evaluations of Mars forward systems.

The habitats (Hab-1, Hab-2, Hab-3, Lab-1, and Log-1) are pre-integrated with lander and not off-loaded to the surface—figure 6. Since they not off-loaded, the Sortie Hab requires the ATHLETE system to "crouch" down for EVA surface access—as shown in figure 5. The lander provides ascent module plume impingement protection, power and some PMAD. The thermal radiator is deployed on top of descent stage tanks. However, the radiator may need to retract and store for protection from ascent module plume impingement. Hab-3 and Lab-1 are delivered on cargo missions fully-outfitted. Log-1 is used to bring the initial logistic supplies and is then retrofitted as Life Sciences, Med Ops, and Exercise volume for long-duration crew occupancy. A pressurized tunnel that would connect the ascent module directly to Sortie Hab-1 & Hab-2 is under consideration. However this will increase the already mass challenged Habs and overall lander configuration.

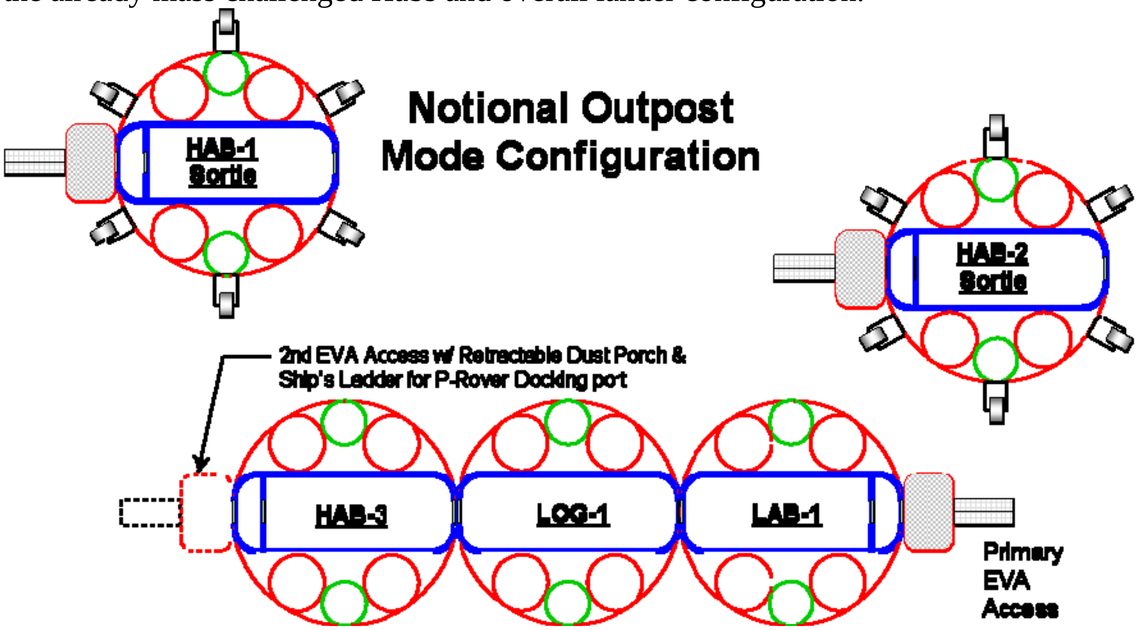

Figure 6, Lander-Habitation Outpost Configuration

Thermal protection is provided multi-layer insulation. Radiation protection is provided for Solar Proton Event (SPE-Solar Flare) only by a water wall capable of surrounding the crew sleep area. The water wall is filled with ~1000 kg of water. The crew is not protected from GCR radiation other than the lander tanks, structure, and subsystems. No micrometeoroid protection is provided other than the surrounding lander tank system—which was assessed as being sufficient. The lander batteries and fuel cells are shared with the hab and integrated with lander power system.

The habitat does not provide for private crew quarters due to the volume limitation. However it does provide recumbent seat/work station/sleep units for the exploration mobile habitat and lab. Sortie Hab 1 and 2 are landed on the Crew Lander with minimal system allocation mass constraint of ~4230 kgs. Together, or separately, they can perform exploration excursions, figure 6. However, additional post-landing outfitting is required to enable the sortie habs to be fully functional for habitation and laboratory excursion exploration elements.

The Hab-3 unit has a full-up capability delivered on a cargo lander. It has a Crew Lock and Closed ECLS. Lab-1 has the full-up medical ops system, exercise, biological and geological science labs (as allocated for lunar exploration), but not the volume needed for medical and exercise equipment to be deployed and used effectively. Therefore, the initial Log-1 is retrofitted into permanent outpost habitation volume for this purpose. The Log-1 unit delivers outfitting systems for the Sortie 1 & 2, and to retrofit Log-1 for additional habitation vol (Med ops, exercise, and Life Science). The crew relocates subsystems and outfitting into their permanent respective locations. Then the crew installs and performs checkout of installed subsystems. At this point the Hab or Lab is Operational for long-term outpost use. The primary Outpost is a Stationary Outpost consisting of a Hab-3, Log-1 (retrofitted), & Lab-1 as shown in figure 6 and 7.

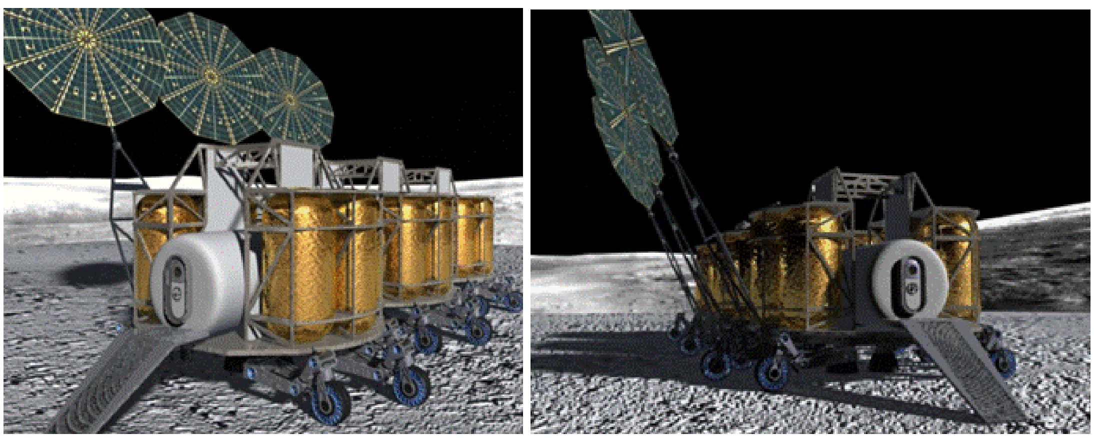

Figure 7, Lander-Habitation Element on ATHLETE Mobility System

Internal Architecture

The habitation module units, as previously described, are cylindrical horizontal shells that are 3.0 m dia x 8.5 m long. 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 the hab and lab. 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 connected outpost mode.

The Hab module contains the EVA ops, some mission ops, and crew ops. The EVA ops area has the suit lock for two EVA suits, the hatch doors, an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. The crew ops area includes basic crew accommodations such as sleeping, eating, hygiene and stowage. Due to limitation on size, privacy curtains are utilizing when necessary. The recumbent sleep units are used as a dual function for mission ops, reading, working, and in recumbent mode—sleeping.

The Lab module contains the EVA ops, mission ops, and science ops. The EVA ops area is the same as the Hab unit with a suit lock for two EVA suits, the hatch doors, an EVA maintenance area with stowage and spares, appropriate tools, cleaning and repair equipment. The science ops area is the laboratory to support biological and geological science equipment—such as glove boxes—and storage. It also contains a hygiene compartment.

The retrofitted logistics module—after the supplies have been used and distributed to the other units—is turned into the medical ops area. The medical equipment, treatment table, exercise equipment and stowage are placed herein.

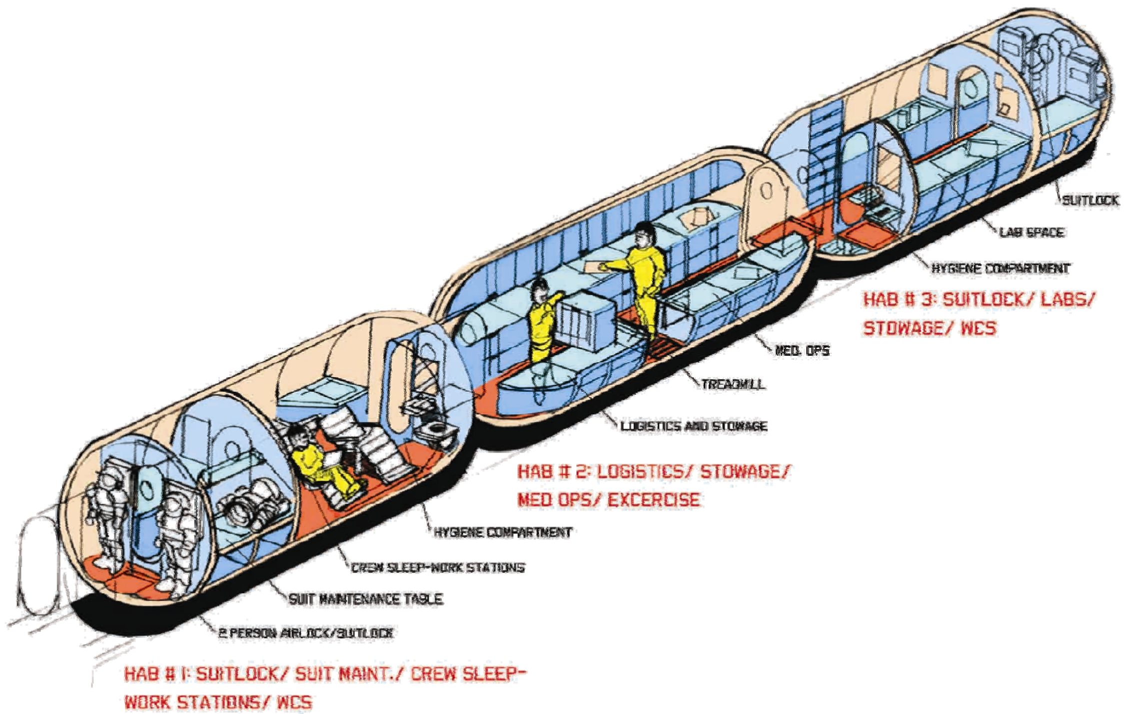

Figure 8, Habitation Element Interior Architecture

Figure 9, Habitation Element Interior (EVA Ops (left), Mission Ops (rgt))

Resource Summary

The mass properties are shown in table 1. The outpost configuration total mass to the surface is ~ 15.5 mt for the 3 modules. The Sorties habs are ~ 3.8 mt and the smaller shorter Sortie Hab is ~ 2 mt.

The power required for nominal outpost operations is ~ 13.2 kW. The power required for the outpost while crew is not on board during a quiescent mode is ~ 1.5 kW. The thermal conditioning required for air-cooled and cold-plated cooling is ~ 4 and 8.7 kW respectively. Power is provided by a single large 'UltraFlex' solar array that will also functions as a sun shade.

		Outpost Configuration				
	Outpost Only Masses (kgs)	#2: Hab-3: EVA, Crew Ops	#4: Lab-1: EVA, Med Ops, Mission Ops, Science	#3: Log-1: Pressurized Logistics Module	#5: 4m Sortie Hab	#1: Sortie Hab-1&2
Structures	5264	1781	1772	1712	979	1304
Protection	360	185	87	87	45	87
Power PM&D	702	295	295	113	114	188
Thermal	622	363	218	41	108	414
Avionics	191	93	93	5	54	85
Life Support	2592	1654	708	230	373	541
Suit-Lock Sys	1191	596	596	0	0	463
Outfitting	2030	304	1708	18	29	76
20% Growth	2590	1054	1095	441	340	632
Total	15543	**6325**	**6571**	**2647**	**2042**	**3790**

Table 1, Habitation Elements Mass Properties Statement

		OUTPOST: Hab-3, Log-1, Lab-1		
	Subsystem Total Power & Thermal w/ 20% growth	#2: Hab-3: EVA, Crew Ops	#4: Lab-1: EVA, Med Ops, Mission Ops, Science	#3: Log-1: Pressurized Logistics Module
Outpost Power	13202	7311	3383	308
Outpost Quiescent Power	1482	597	539	99
Outpost Air-cooled Thermal	4057	1459	1688	234
Outpost Cold plated Thermal	8772	5697	1540	74

Table 2, Habitation Elements Power & Thermal Allocations

Summary

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; and 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 add in-situ materials to protect from radiation, 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.

Leaving the habitat on the lander has desirable features of being fully integrated, checked-out on Earth, and sent knowing it is ready to be activated and moved into by the crew. Also, the habitat-lander may be able to provide a larger open volume which is desirable for long-duration missions. On the other hand, there are considerations such as the limitations of the lander, how big they can be, and how to bring two units (a hab and a lab) together for connection.

Other considerations are how to protect the habitat from radiation when it is several meters on top of the lander, accessibility for maintenance and repair, and how to segment the internal volume so incase of a pressure breach the entire habitat volume is not lost. Mobile habitats provide the capability to perform more exploration and move the outpost from site to site. In this case the mobile habitat has size limitations depending on the mobility system. There are risks associated with moving the habitat of which a few are ensuring the structural integrity of the pressure shell while it is moving about the surface, the risk of getting stuck or impassable terrains—to mention a few. 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.