Common Habitat Base Camp for Moon and Mars Surface Operations

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The Common Habitat uses the SLS Core Stage Liquid Oxygen tank as the primary structure (similar to Skylab) and has an internal architecture compatible with microgravity, lunar gravity, and Mars gravity, such that identical versions of the same design can be used in all three environments. Applying the large dimensions and eight-person crew size of the Common Habitat to a surface architecture leads to a unique base camp configuration. A notional such base camp is described in this analysis. The base camp includes four distributed zones – habitation, landing, power, and resource production. The base camp is deployed and assembled in three phases: site preparation, element staging, and habitat delivery, each of which are briefly discussed. Crew arrival and departure is discussed, including variations caused by orbital mechanics-induced differences between the Moon and Mars base camps. Trash and logistics operations are described. Finally, crew operations within the base camp are described.

I. Nomenclature

ARED	=	Advanced Resistive Exercise Device
ATHLETE	=	All-Terrain Hex-Limbed Extra-Terrestrial Explorer
BAM	=	Biological and Medical
CEVIS	=	Cycle Ergometer with Vibration Isolation System
DADH	=	Disabled and Decommissioned Hardware
EGM	=	Excess Goods and Materials
GBE	=	Glovebox Equivalent
HCM	=	Hazardous Controlled Hardware
ISRU	=	In-Situ Resource Utilization
LANCE	=	Lunar Attachment Node for Construction and Excavation
LM	=	Logistics Module
LOX	=	Liquid Oxygen
LSMS	=	Lightweight Surface Manipulator System
LTV	=	Lunar Terrain Vehicle
MDLE	=	Mid-Deck Locker Equivalent
MGAAMA	=	Multi-Gravity Active-Active Mating Adapter
PAM	=	Packaging and Miscellaneous
PR	=	Pressurized Rover
PUP	=	Portable Utility Pallet
RASSOR	=	Regolith Advanced Surface Systems Operations Robot
T2	=	2^{nd} Generation Treadmill with Vibration Isolation System
TCAN	=	Two-Chamber Airlock Node
VIPER	=	Vibratory Impacting Percussive Excavator for Regolith

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II. Introduction

The Common Habitat is a conceptual long-duration habitation element based on the use of the SLS Core Stage Liquid Oxygen Tank as the pressure vessel. [1] A uniqueness of the Common Habitat is that it is designed with a single architecture that is equally functional in a variety of different gravity environments – microgravity, lunar gravity, Mars gravity, Earth gravity, and artificial gravity. The Common Habitat is not currently part of any active NASA reference mission or human spaceflight program. This paper is part of an ongoing feasibility study to assess the viability of the Common Habitat and associated architectures, elements, and operations. Should such feasibility be determined, NASA would then be positioned to make a programmatic decision about whether to incorporate any aspects of these studies into current or future programs.

Given the existence of such a habitat, it is possible to define a surface habitation concept centered around its use. This resulting base camp can be used for human operations on both the Moon and Mars, in keeping with the commonality nature of the Common Habitat.

In the construction of this base camp concept, other spacecraft elements are incorporated, some of which are variants of elements used in other NASA, commercial, or international programs or studies. These variants may diverge in various ways from their use in this paper. This architecture was created specifically to apply to the Common Habitat and has no existence beyond the Common Habitat study. Where it makes use of existing spacecraft or spacecraft from other development studies it makes no commitment to remain consistent with the current designs of those elements and no programmatic intent is implied by any such divergences.

III. Base Camp Overview

For purposes of this paper, the term base camp identifies the immediate region that the surface crew makes their base of operations. This is inclusive of habitation, logistics, and sustaining operations support, but does not include surface exploration/research activity, which may occur both within and beyond the base camp. It is, essentially, the "home base" of a long-duration surface expedition.

Because the Common Habitat architecture is not tied to a specific NASA reference mission there are no explicit constraints as to the location of the base camp on the lunar surface. In the lunar case, primarily for thermal control reasons it is generally intended as a polar base camp, but there is at this point no greater degree of specificity. The Common Habitat lunar base camp is considered to be located somewhere within 50 kilometers of 90 degrees north or south latitude, as measured along a known traverse path with no slope greater than 20 degrees between the Common Habitat and the pole coordinates. For the Mars base camp, there is no inherent assumption as to where on the planetary surface the Mars base camp is located. It is compatible with any location on the planet, from polar to equatorial. In other words, a Common Habitat base camp could be placed at many of the locations on the Moon or Mars discussed in various NASA, international, and commercial concepts proposed over the past several decades but is not constrained to any of these locations. It is beyond the intent of this work to specify a location.

IV. Base Camp Zones

As implied in the preceding section, the surface base camp denotes more than just the immediate land the Common Habitat is emplaced upon, but instead is the general region where infrastructure has been emplaced. It is further divided into four distinct operational zones.

Habitation Zone

The Habitation Zone includes the Common Habitat, as well as elements that are docked or connected to it. Mobility assets are also based in the Habitation Zone when not in use. Finally, an interferometry array of nine 1.5-meter telescopes surrounds the Habitation Zone with diameter of ~2 km. In the case of the lunar base camp location, the Habitation Zone is further constrained such that this telescope array experiences line of sight visibility to Earth at least one third of the time. This enables the lunar base camp to conduct Earth science remote sensing as well as astronomy and heliophysics research. The Habitation Zone includes surface preparation, leveling a 60-meter diameter (~0.7 acre) region to a ground slope of less than or equal to five degrees. The Habitation Zone must have a regolith depth of 1.6 meters or greater after leveling.

The central element within the Habitation Zone is the Common Habitat, shown in Fig. 1. The Common Habitat is 8.41 meters in diameter and 15 meters in length, providing living and working space for an eight-person crew. It includes four docking ports, one at each longitudinal end and two radial docking ports midships. Each docking port includes a 40-inch wide by 60-inch tall hatch and is compatible with the 6x6 Multi-Gravity Active-Active Mating Adapter (MGAAMA) docking system. [2]

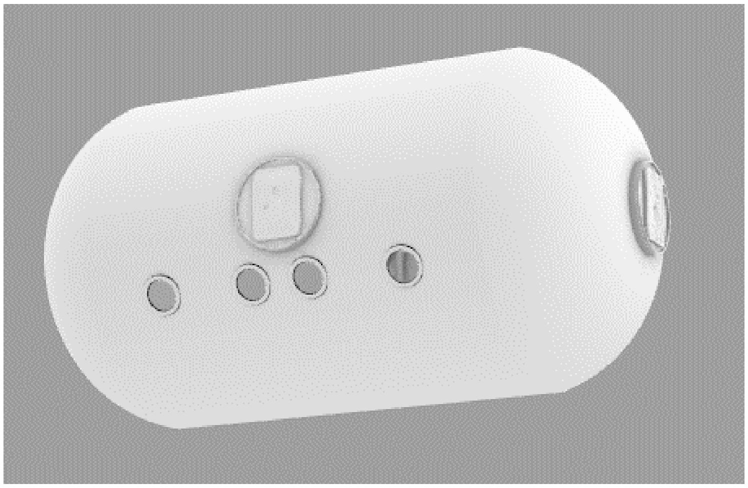

Fig. 1 Common Habitat

The Upper Deck, shown in Fig. 2, is the primary social and group operations volume of the habitat. It includes a galley with plant growth chambers, reconfigurable wardroom, panoramic projection screen, hygeine compartment, medical care facility, command and control center, and subsystems equipment.

Fig. 2 Common Habitat Upper Deck

The Mid Deck, shown in Fig. 3, is the primary working volume of the habitat. It includes an extensive exercise countermeasures facility with ISS-compatible exercise equipment (two each of ARED, CEVIS, and T2), a fabrication, maintenance, and repair facility, a life sciences laboratory including both space biology and human research, and a physical science laboratory including geology, remote sensing, and physics.

Fig. 3 Common Habitat Mid Deck

The Lower Deck, shown in Fig. 4, is the private volume of the habitat. It includes eight identical, private crew quarters, each with room for a horizontal bunk, personal work desk, limited floor space, and 10.5 mid deck locker equivalent stowage volume. The deck also includes four combined hygiene and waste management facilities. Each includes a private waste management compartment, private full body hygiene compartment, and a clothes changing/personal items stowage chamber that serves as the outer room to both hygiene and waste management.

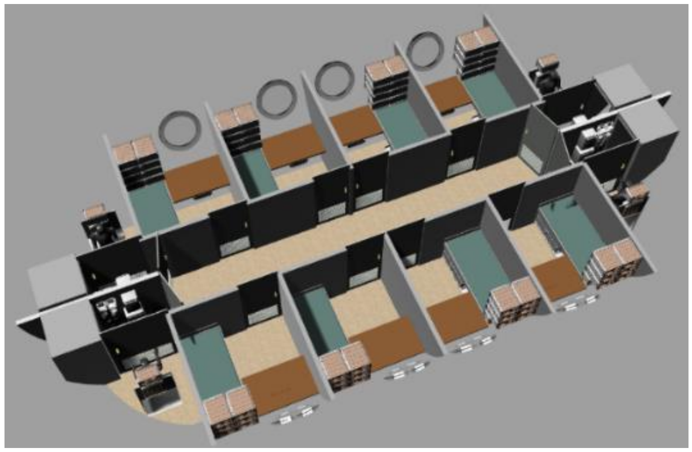

Fig. 4 Common Habitat Lower Deck

The habitat is partially buried, as shown in Fig. 12, emplaced in a 1.58-meter deep trench in order to place its docking ports at the proper height relative to docked elements. The previously mentioned MGAAMA is attached to each docking port: a 4x6 MGAAMA docked to the Common Habitat port near the exercise facility and 6x6 MGAAMAs [2] are docked to the other three ports. One Pressurized Rover (PR) is docked to the 4x6 MGAAMA. A second PR is docked to the first, connected by a 4x4 MGAAMA between them. Both rovers include Portable Utility Pallets (PUPs). The Two-Chamber Airlock Node (TCAN) [3] is docked to the port between life sciences and exercise. The two Logistics Modules (LMs) [4] are docked to the remaining ports. These individual elements are shown in Figures 5 - 9.

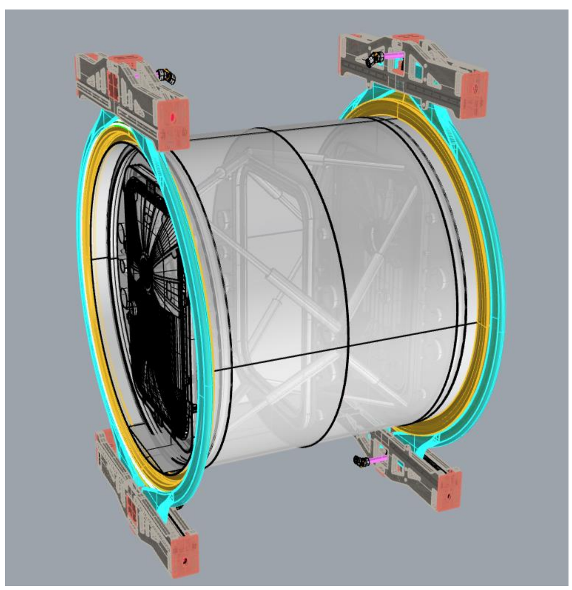

Fig. 5 6x6 Multi-Gravity Active-Active Mating Adapter (MGAAMA)

Fig. 6 Two-Chamber Airlock Node (TCAN)

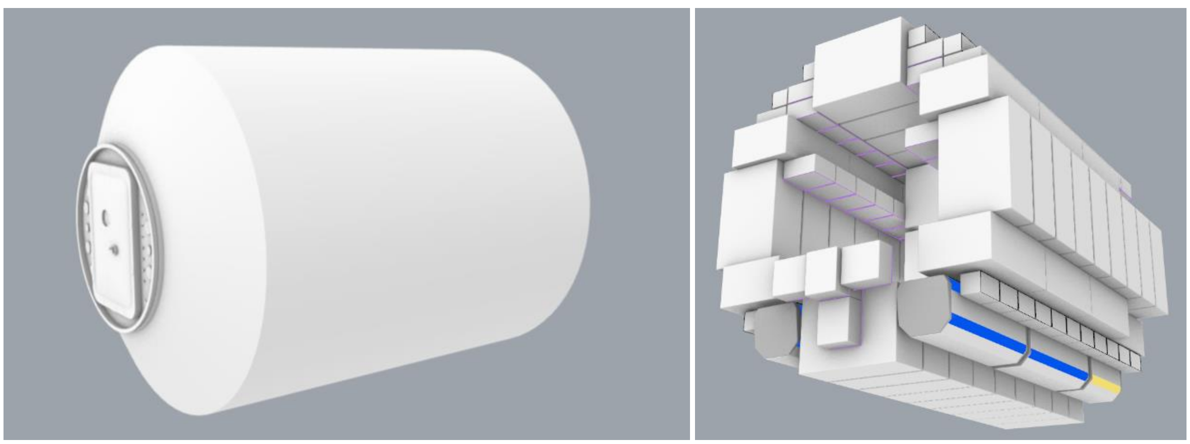

Fig. 7 Logistics Module (LM)

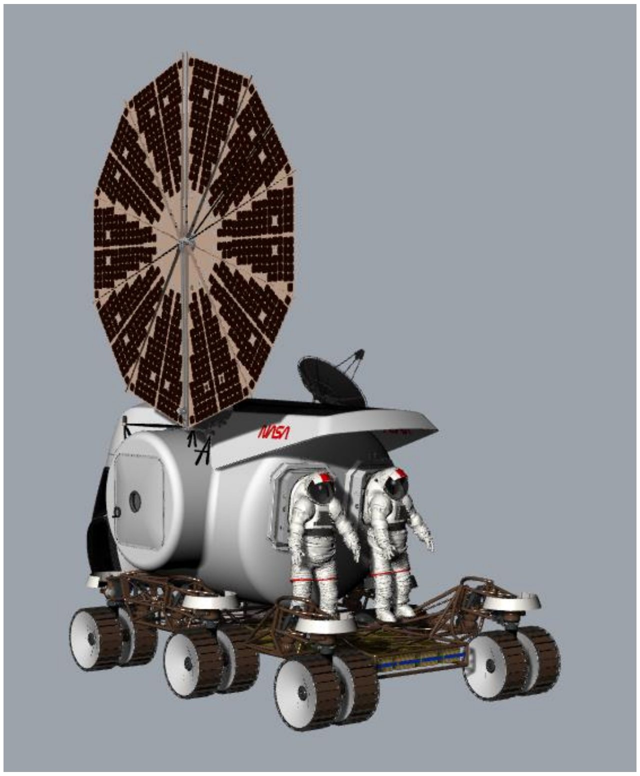

Fig. 8 Pressurized Rover (PR)

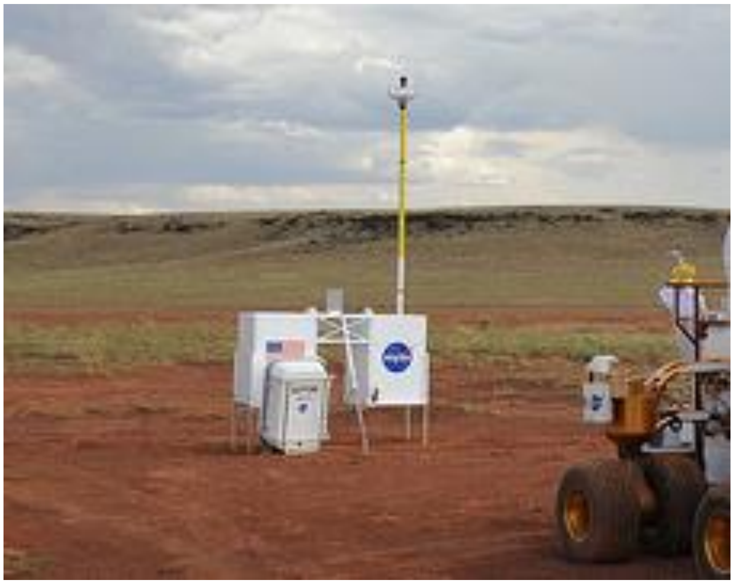

Fig. 9 Constellation Program Era Portable Utility Pallet (PUP) Prototype (Solar Array not Mocked Up)

Fig. 10 shows the configuration of these elements when docked. It is worth noting that the MGAAMAs can enable relocation of any element to any port, so should there be a mission advantage to doing so the relative locations of any docked modules can be swapped .

Fig. 10 Habitation Zone Docked Elements

The Common Habitat and docked elements rely on an external source for power generation and energy storage, communication transmission/reception, and heat rejection. This is provided by buried conduits attached to the Common Habitats. One conduit leads to a power terminal. The Power Terminal is the terminus of a buried cable leading to the Power Zone. The other conduit leads to the Radiator Field, shown in Fig. 11. The Radiator Field includes a radiator array that provides heat rejection for the Habitation Zone elements. It also includes communications towers to provide local area and surface to space communications.

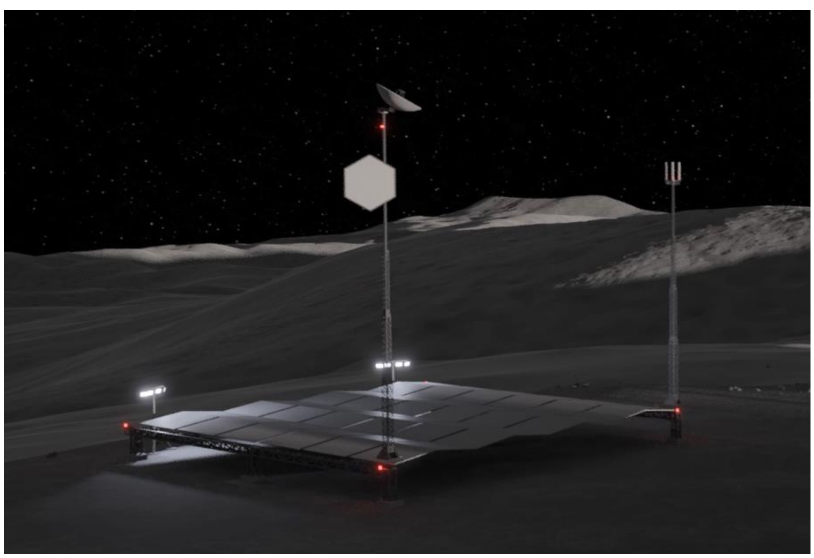

Fig. 11 Radiator Field

Mobile assets that are not in active use will be stationed at the Habitation Zone. Fig. 12 captures a point in time where two Lunar Terrain Vehicles (LTVs) and four All-Terrain Hex-Limed Extra-Terrestrial Explorers (ATHLETEs) are not in use and are shown parked at the Habitation Zone. Several fixed Light Stands are also positioned within the Habitation Zone to provide additional illumination due to low lighting conditions in the south pole vicinity. The entire Habitation Zone is shown in this image.

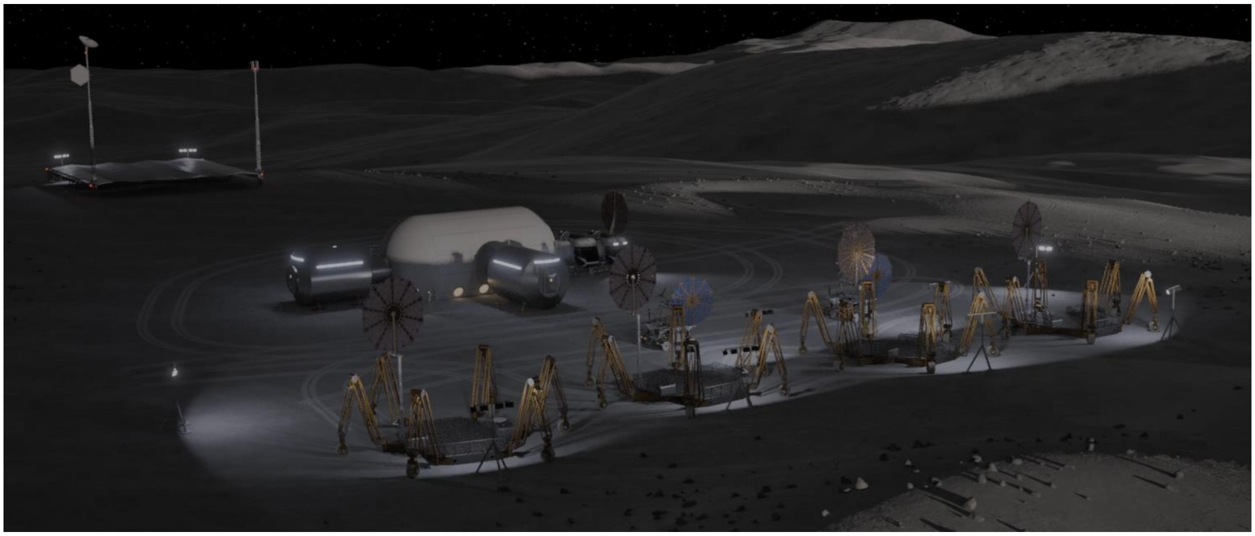

Fig. 12. Habitation Zone

Landing Zone

The Landing Zone is a dedicated region for repeated landings. The level of site preparation and maintenance is a forward work trade study, but it is assumed that navigation aids are made available in the Landing Zone after the first landing has been completed, at some point before the second landing occurs. The Landing Zone is at least two kilometers downhill from the Habitation Zone, linked by at least one traverse path with an average slope of less than 10 degrees and a maximum slope of less than twenty degrees. The Landing Zone includes non-overlapping landing areas, each of which is 100 meters in diameter (~1.94 acres) with a slope of less than or equal to five degrees. Five such landing areas constitute a landing cluster. If additional landing areas are needed, one or more additional clusters can be established.

Due to presently ongoing HLS competition sensitivities, only limited information is discussed regarding the Landing Zone. A Power Terminal is positioned near the center of the landing cluster along with several cable carts that can each deploy up to 200 meters of cable to connect to a lander, providing power while it is active on the surface. The JPL Axel rover [5], shown in Fig. 13, is an example of a prototype mobility system that could perform this function. The cable cart would retract this cable and take shelter under a protective housing prior to launch of any reusable lander system. The housing would also protect it during lander arrival.

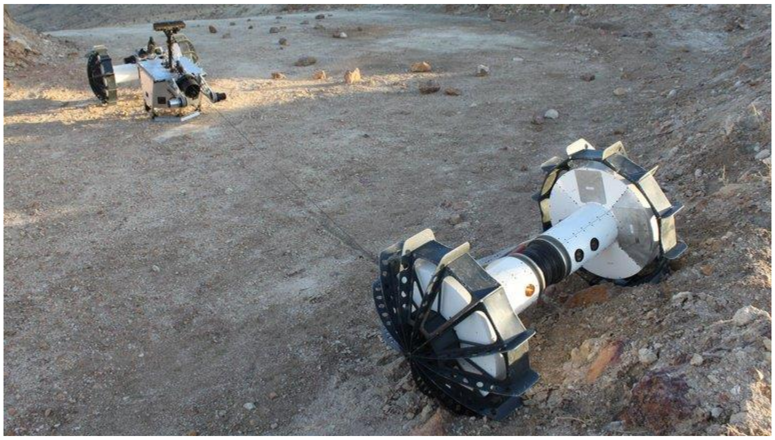

Fig. 13 JPL Axel Rover

If there is more than one landing cluster there will be a separate Power Terminal for each cluster. The Landing Zone will generally include one or more landers at any given time. This will include the crew lander for any crew on the surface at a particular point in time. It may also include cargo landers if those landers were not capable of launching from the lunar surface.

Resource Production Zone

The Resource Production Zone, shown in Fig. 14 is located based on its access to usable resources. It is linked to the Common Habitat by a known traverse path of less than eight kilometers. This site is host to in-situ resource utilization (ISRU) activities and equipment needed for propellant, water, and/or oxygen production. The Resource Production Zone includes permanently shadowed regions expected to contain ice.

The Power Terminal in the Resource Production Zone includes umbilical connections to fixed In-Situ Resource Utilization (ISRU) plants and recharging interfaces for mobile assets. The mobile assets include four ATHLETEs, each equipped with Vibratory Impacting Percussive Excavator for Regolith (VIPER) digging buckets, Lunar Attachment Node for Construction and Excavation (LANCE) bulldozer blades, and regolith payload bays. Three Regolith Advanced Surface Systems Operations Robot (RASSORs) digging robots are also present. A LOX tanker, Methane tanker, and water tanker (none shown) can all be carried by the ATHLETEs to transport locally produced resources to either the Habitation Zone or Landing Zone.

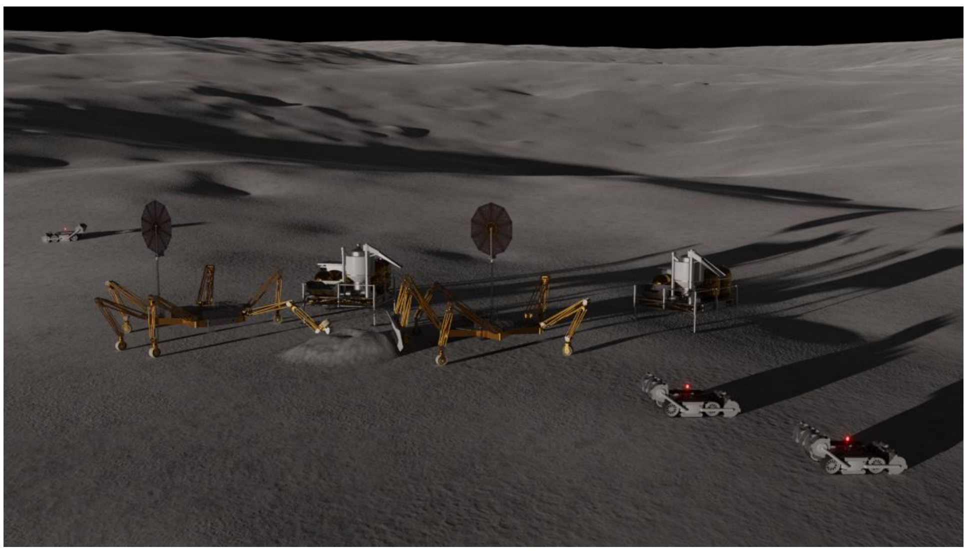

Fig. 14. Resource Production Zone

Unlike the other zones, the Resource Production Zone can be relocated if necessary, for instance to locations with more plentiful resources.

Power Zone

The Power Zone is a dedicated site for nuclear fission power production. Natural and prepared terrain are used to provide sufficient radiation shielding, including a crater of at least thirty meters depth and a slope of less than 30 degrees. The Power Zone is less than two kilometers from the Habitation Zone.

The central feature of the Power Zone is a nuclear fission reactor. The reactor is buried beneath meters of regolith and is therefore not visible in Fig. 15. Only the mound of regolith covering it can be seen. The regolith depth is intended as sufficient to enable unrestricted crew and equipment operation as close as 500 meters of the Power Zone center. Design sizing of the reactor and resulting regolith depth remain as forward work. The reactor mound is surrounded by lights and radiators, both of which can be seen in Fig. 15. A power distribution terminal splits off buried power cables leading to the Habitation, Landing, and Resource Production Zones.

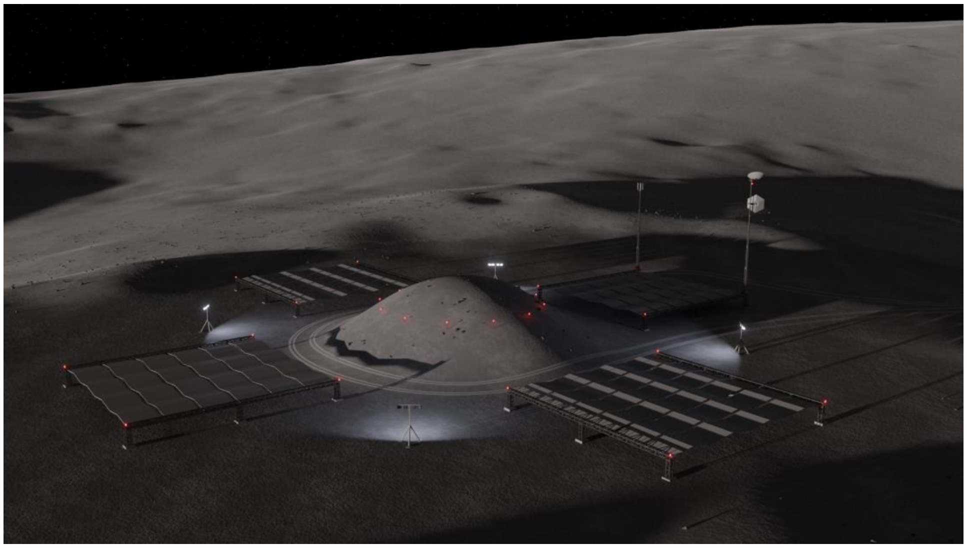

Fig. 15. Power Zone

In addition to the previously listed constraints, the Habitation, Resource Production, and Power Zones are each at least one and less than four kilometers from the Landing Zone. There is also at least one traverse path (average slope of less than 10 degrees and a maximum slope of less than twenty degrees) from the Power Zone and from the Landing Zone to all other Zones.

V. Phases of Delivery and Assembly

Spread out over several square kilometers, the base camp is assembled in three phases, each of which requires one or more lander flights to deliver surface infrastructure.

The first phase is Site Preparation. Lander missions are used to deliver the following surface elements:

- One Lightweight Surface Manipulation System (LSMS) (331 kN crane)
- One 4x4 MGAAMA
- Two PRs with Portable Utility Pallets
- Four ATHLETEs
- Three LANCE Bulldozer Blades
- Three Regolith 3D Printers
- 3D Printing Binder Material
- Nine Regolith Sintering Devices
- Three VIPER Digging Buckets
- Three RASSORs
- One Nuclear Power Element with Radiators
- One External Communications Array
- Two Lunar Terrain Vehicles (or Mars Terrain Vehicles for Mars base camp)

Once all cargo is offloaded, the first action is to prepare the Power Zone for the nuclear reactor. This may involve digging an appropriately sized pit in the bottom of a crater to emplace the reactor. The reactor is then transported and positioned in the pit. While protecting a path for thermal, power, and data cables leading from the reactor, the reactor is buried. The adjoining surface is prepared for radiator deployment with any needed grading or bulldozing. Radiators are then deployed and connected to the reactor thermal cables and the attached communications tower is raised. Buried cables are laid between the Power Zone and the Habitation, Landing, and Resource Production Zones.

With the Power Zone set up, site preparation focuses on the Habitation Zone. This will involve preparing the Habitation Zone by digging a 1.58-meter trench with the proper curvature to support the Common Habitat. The walls of the trench will be sintered or 3D printed to increase its stability. The surrounding surface will also be leveled up to a radius of 30 meters surrounding the trench. Local paths will also be prepared, using sintering for EVA paths and 3D printing for rover and ATHLETE paths and crane locations. The LSMS, MGAAMA, and PRs are staged near the Landing Zone a safe distance away from arriving landers.

The second phase is Element Staging. The following surface elements are delivered:

- One LSMS
- One 4x6 MGAAMA
- Three 6x6 MGAAMA
- One TCAN with support cradle
- Four ISRU Payloads
- Nine Interferometric Surface Telescopes
- Three External Science Payloads
- Four ATHLETEs
- One Habitation Zone Heat Rejection Assembly
- One External Communications Array

The ISRU payloads are deployed to the Resource Production Zone along with the RASSORs. Up to four ATHLETEs will assist in moving regolith in the Resource Production Zone when not occupied with other tasks. The LSMS crane will be staged alongside its predecessor in the Landing Zone. The MGAAMAs, airlock, and science payloads will be temporarily staged at the Habitation Zone. The telescopes will be deployed in a 2 km radius around the Common Habitat. The Habitation Zone Heat Rejection Assembly will be deployed at the edge of the Habitation Zone's leveled surface, with additional surface leveling at its location. The External Communications Array will be raised in position at the Heat Rejection Assembly.

The third and final phase is habitat delivery. The only surface elements delivered in this phase are the Common Habitat and a third LSMS. Once both are offloaded, ATHLETEs and LSMS cranes are used to transport the Common Habitat to the Habitation Zone and emplace it in the trench. With this completed, the three 6x6 and one 4x4 MGAAMAs are mated to the Common Habitat. The TCAN and PRs are then mated to the habitat via their respective MGAAMAs. The two remaining 6x6 MGAAMAs are already attached to the Common Habitat but will be unused until the Logistics Modules for the next crew mission arrive. Finally, power, thermal, and communications umbilicals are connected to the Common Habitat, linking it to both the Power Zone and the Habitation Zone's Heat Rejection Assembly.

VI. Crew Arrival and Departure

Crew arrival and departure is different for the Moon and Mars base camps due to orbital mechanics considerations. The lunar base camp is continuously occupied, so there is a handover period between arriving and departing crews. Because of the irregular Earth departure opportunities for Earth-Mars transit, the Mars base camp is crew tended and is unoccupied between human Mars expeditions.

In the lunar case, an arriving crew arrives while the departing crew is still on the surface and there is a 5.5-day period of overlap where both crews are present. The departing crew will prepare for departure by packing personal items and relocating their spacesuits to the airlock. When the arriving crew have landed, the PRs will be teleoperated to the Landing Zone where a pressurized crew transfer will enable the arriving crew to transfer from their spacecraft to the PR interior, along with their personal items and spacesuits. The arriving crew will drive the rovers to the Habitation Zone and dock with the Common Habitat.

The arriving crew will sleep in the PRs and in temporary cots set up in the Logistics Modules or Common Habitat mid deck. The arriving crew will primarily focus on adapting to surface gravity and on transitioning tasks from the departing crew. At the end of the overlap period, the departing crew will use the PRs to travel to their spacecraft while the arriving crew moves into the Common Habitat crew quarters.

Because the Mars base camp is not continuously occupied, there will be no crew handover. Just as in the lunar case, the PRs will be teleoperated to the landing site for pressurized crew transfer. Upon reaching the Common Habitat they will be able to immediately move into the crew quarters since no other crew are present. For departure, they will have to transition the base camp to an uncrewed mode as the entire base camp will need to function without human presence for more than 200 days before the next crew arrives.

While outside the scope of this paper, there are three options for the departing crew. Under one option, the crew will leave their spacesuits behind, allowing them to become spares for future contingencies. Under a second option, the crew will use the suits to perform transfer to the departing spacecraft that involves some level of EVA. Under a third option, the departing crew will bring their suits with them when they leave the surface but will bring them through a pressurized transfer that does not involve EVA. There are a number of implications of each option and decision paths that define which are available.

VII. Trash and Logistics Operations

Lander selection will have an impact on trash and logistics operations. One approach is to time the arrival of logistics as close to the crew arrival as possible. This minimizes shelf life concerns. The ultimate realization of this approach is to co-manifest logistics delivery with crew landing. This is possible with some, but not all, potential landers. If it is not possible to co-manifest logistics delivery, an alternate approach is to complete logistics delivery before committing the crew to a surface landing. This approach ensures that the crew do not arrive on the surface without needed supplies but does exacerbate shelf life concerns. This paper will not distinguish between the two approaches and will merely discuss the arrival of new logistics and disposition of trash, irrespective of how the timing sequences with crew arrival and departure.

Once a lander spacecraft has delivered a Logistics Module to the surface of the Moon or Mars (including offloading) it must be transported across the surface to the Common Habitat. On the Moon, three ATHLETEs are required to transport one fully loaded Logistics Module. This does require the ATHLETEs to reconfigure their limbs into a more compact arrangement. A LSMS may also be needed to position the Logistics Module onto the resulting platform and to remove the Logistics Module once positioned at its intended MGAAMA. On Mars, six ATHLETEs are required to transport the same Logistics Module. In both cases, this requires the AHLETEs to reconfigure into heavy cargo elements. Notional instances of this are shown in Fig. 16 and Fig. 17.

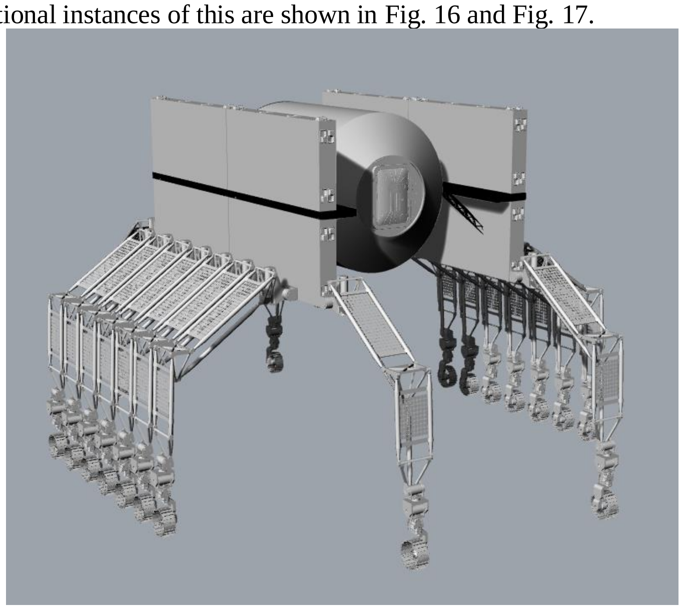

Fig. 16. Three-ATHLETE Logistics Module Lunar Surface Transportation

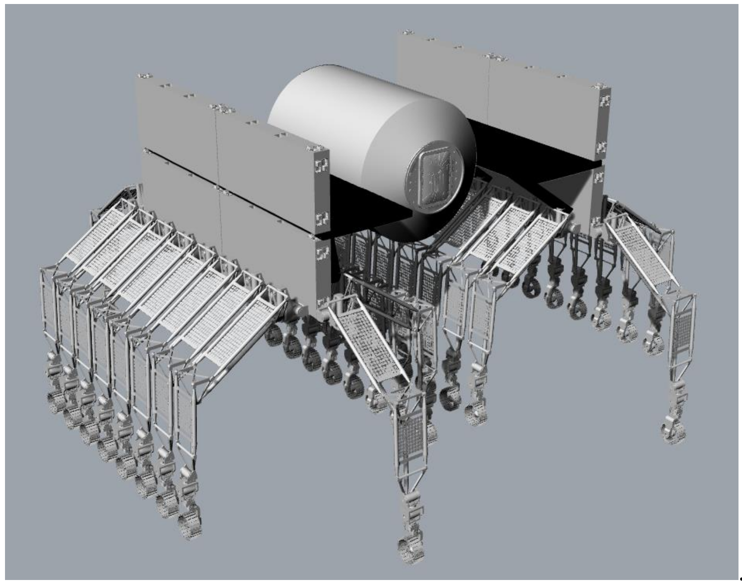

Fig. 17. Six-ATHLETE Logistics Module Mars Surface Transportation

The Logistics Module arrives fully loaded with supplies for the Common Habitat and airlock. Operationally, it is used as a warehouse. The crew does not retrieve items from the Logistics Module for daily use – instead items are stowed within the habitat, PRs, and TCAN at their respective points of use. Periodically, these locations are resupplied from the Logistics Module. Thus, the Logistics Module is unloaded at periodic increments throughout the surface mission.

Naturally, as supplies within the Common Habitat are consumed, there is a buildup in generated trash and this trash must have somewhere to go. Consequently, Logistics Modules transition over time from Logistics Modules to Trash Modules. Trash generated within the base camp pressurized elements is classified into five distinct types:

1. Biological and Medical (BAM) trash includes human waste, life science payloads including deceased specimens, biological samples, food trash, plant growth waste, expired medicines, or related trash with biological attributes.
2. Hazardous Controlled Hardware (HCM) trash includes non-biological solids, liquids, or gases that are hazardous to human health due to toxins, radiation, abrasives, or other physical attributes.
3. Disabled and Decommissioned Hardware trash (DADH) includes damaged or failed equipment and end of life hardware. DADH trash has potential scavenging value but is generally not fully operational.
4. Excess Goods and Material (EGM) trash includes equipment or unexpired consumables not used during the intended period, including equipment associated with completed mission objectives or aborted mission operations. EGM trash is generally fully functional.
5. Packaging and Miscellaneous (PAM) trash includes discarded launch packaging, release mechanisms, and otherwise uncategorized equipment.

As supplies are removed from the Logistics Modules, space is opened up to receive some trash. DADH, EGM, and PAM trash are stored in the docked Logistics Modules as the mission progresses. BAM and HCH trash are never stored long term in the Common Habitat or any docked elements.

In the lunar case, the first crew mission includes a Logistics Module that is never docked to the Common Habitat. This module houses all trash from the first crew mission, but for subsequent missions it houses BAM and HCM trash. The Mars base camp does not include this Logistics Module, thus for the first mission another location must be made available. Options include using propellant tanks of abandoned landers or 3D printed trash storage units. Starting with the second crew mission, used Logistics Modules from the first mission may be repurposed as trash modules.

Clearly a Trash Module cannot remain docked to the Common Habitat indefinitely. Whether to make room for an arriving Logistics Module or because the Trash Module is full, it must at some point be removed from the Habitation Zone. Two options exist for the long-term disposition of a Trash Module, influenced heavily by ISRU architecture and lander selection. One option is to establish a Trash Module boneyard, an out of the way area (potentially the bottom of a crater) where a Trash Module can be carried by an ATHLETE. The second option involves loading the Trash Module(s) onto a reusable lander that has been refueled. In such a case, the lander can deliver the Trash Module to another destination, whether a solar trajectory, a surface impact, a destructive Earth intercept trajectory, or a controlled return and landing on Earth. Some of the options involving launch from the surface may involve transferring the Trash Module across various spacecraft and entry vehicles. Given that some trash, EGM in particular, is still usable, there may be a combination of options pursued where the more useful trash is retained to the extent possible within the Habitation Zone while less useful trash is removed. DADH and PAM trash in particular, and to a lesser extent BAM and HCM trash may benefit from a return to Earth as terrestrial facilities may be able to recycle and repurpose this trash.

VIII. Crew Operations

Crews will live and work in the base camp during Moon and Mars surface missions ranging in duration from roughly 370 to 624 days. (This is only time on the surface and does not include in-space transit times.) This exceeds the current endurance record for a single-mission human stay of 438 days [6] even without considering the substantial additional in-space transit times.

The base camp's mobility capabilities allow for up to four crew to explore traverse paths in excess of 100 kilometers from the Common Habitat, using the Pressurized Rovers. The ATHLETEs and LTVs support the PR traverses with the ability to carry additional equipment for use during these traverses. In the event of a PR failure, the ATHLETEs also have the ability to recover a failed PR and bring it back to the base camp for repair. The PRs and LTVs also simplify crew EVA operations needed within the base camp zones.

Meanwhile, the habitat's laboratories provide more than 110 mid deck locker equivalent (MDLE) and eight glovebox equivalent (GBE) volumes to support space biology, human research, physics, remote sensing, and geology science. MELFI, Glacier, MERLIN, and CryoChiller freezer volumes provide conditioned samples stowage volumes under specific temperature requirements.

The extensive capabilities of the Fabrication, Maintenance, and Repair Facility on the mid deck include 58 MDLE, four GBE, multiple 3D printers, three work surfaces, and one large work volume. This enables the crew to maintain all of the surface elements and recover from failures that might otherwise result in loss of mission or even loss of crew.

Given the very long mission durations of the base camp, the Common Habitat pursues the conservative approach to field the ISS US operational segment suite of exercise devices, with two each of the ARED, CEVIS, and T2. This provides the best possible countermeasures to deconditioning experienced due to lower gravity. The T2s also help with crew adaptation to gravity during the first few days on the Moon or Mars.

The medical care facility enables caregivers to have complete 360-degree access to an injured crew member. Stowage volume within the facility allows for an increase in medical equipment and medicines beyond those flown on the International Space Station.

The combination of private and group social volumes in the Common Habitat allow the crew to maintain psychological health. The crew quarters are sufficiently large to enable a variety of private pursuits including yoga, meditating, computer-based activity, and even recreational model building enabled by the habitat's 3D printing fabrication capability. The wardroom table can be disassembled and stowed to create an open area on the upper deck to support movie watching and a variety of group gaming activities.

The number and separation of private hygiene and waste management compartments minimizes crew conflicts for access to those facilities. There is plentiful volume within each compartment for the crew to comfortably maneuver as they perform hygiene or waste management tasks and hygiene is kept separate from waste management.

There is no single "day in the life" typical of all days in the surface base camp – there are far too many options. There will be an initial surface adaptation period where crew activities will be limited, and rehabilitative exercises will be prescribed. As the crew transitions into nominal operations, there will be some periods of exclusive habitat IVA activity where all crew work entirely inside the Common Habitat. This will include both generalized and discipline-focused science activity. It will also include nominal maintenance and contingency fabrication and repair activities. There will be local EVAs within one or more of the base camp zones. There will be split crew periods where two, four, or six crew conduct excursions away from the base camp. And there will be select EVA days that involve the entire crew on EVA.

IX. Conclusion

It is clear that an effective base camp can be formed within the Common Habitat architecture, suitable for use on both the Moon and Mars. The science return of the base camp is multidisciplinary and unquestionably extensive, enabled by both internal laboratories and external science platforms. Its maintenance and fabrication capabilities increase habitat survivability and support other surface elements. Its medical care facility expands the range of conditions that can be treated without loss of crew or evacuation. The docking system is positioned for expansion with future commercial or international elements.

Forward work is needed, however, with respect to detailed design of most habitable elements, including subsystems and all IVA and EVA human interfaces. Cold stowage within the Logistics Modules, galley, and medical care facility should be investigated.

Several aspects of the base camps are directly influenced by lander selection and will be customized to the specific crew or cargo lander selected. Due to the HLS Option A protest in progress during the writing of this paper, those aspects are not described, though potential solutions have been identified. Forward work includes more closely integrating base camp operations with specific Moon and Mars lander spacecraft.

Forward work is needed in particular in the Resource Production Zone. Independent of any lander relevance, the ISRU capabilities lack any purpose beyond technology demonstration. But for the case of a reusable lander – which may or may not exist in a Common Habitat architecture – the ISRU capability could be scaled up to produce sufficient propellant to refuel lander spacecraft. This also drives the level of power that must be supplied by the Power Zone and may impact the number of initial cargo landings.

Lander selection also has implications for the habitat laboratories and surface mobility. The lander selection will ultimately determine the return sample capacity. The smaller the capacity, the more quickly it will be exceeded by both laboratory analysis and surface sample collection. Once that capacity is exceeded, crew activity will need to turn from activities that generate samples to those that either prioritize samples already collected, or those that conduct research without generating samples, or those that analyze samples collected without need to transport those samples to Earth. This will drive the ratio of crew time spent in the laboratory versus the Pressurized Rover and will drive the makeup of instruments within the laboratory.

Forward work somewhat unrelated to the lander includes the surface nuclear fission power. Power levels are expected to be significant and may be on a similar order as the low megawatt systems proposed for nuclear electric propulsion. A recent National Academy of Sciences report discussed surface power use of nuclear electric propulsion reactors and indicated that surface systems would need to account for the presence of atmosphere and dust, effects of gravity on coolant flow, and the impact of planetary surface on radiation heat rejection. [7] Once sized, the reactor will have implications for lander selection, so even the reactor does have some relevance to the lander.

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References

[1] Robert Howard. Opportunities and Challenges of a Common Habitat for Transit and Surface Operations, IEEE Aerospace 2019, Big Sky, MT, March 2-9, 2019.

[2] Robert Howard. A Multi-Functional Two Chamber Airlock Node for a Common Habitat Architecture. AIAA ASCEND 2021. November 15-17, 2021.

[3] Robert Howard. A Multi-Gravity Docking and Utilities Transfer System for a Common Habitat Architecture. AIAA ASCEND 2021. November 15-17, 2021.

[4] Robert Howard. Stowage Assessment of the Common Habitat Baseline Variants. AIAA ASCEND 2020. Virtual. November 16-18, 2020.

[5] The Axel Rover System. Last Accessed: June 13, 2021. https://www-robotics.jpl.nasa.gov/systems/system.cfm?System=16.

[6] David Harland. Mir Soviet-Russian Space Station. Brittanica. Last Accessed June 13, 2021. https://www.britannica.com/topic/Mir-Soviet-Russian-space-station.

[7] Robert Braun, Roger Meyers (Co-Chairs). Space Nuclear Propulsion for Human Mars Exploration. Space Nuclear Propulsion Technologies Committee. The National Academies of Sciences Engineering Medicine. Last Accessed: June 14, 2021. https://www.nap.edu/download/25977.