Stowage Assessment of the Common Habitat Baseline Variants

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Abstract— **This paper performs a stowage assessment of the four baseline variants of the Common Habitat, a SLS-derived long duration, multi-mission habitat. The Common Habitat can be utilized as a lunar surface outpost, a Mars surface outpost, or an in-space habitat for Mars transit flights. The paper will discuss the stowage philosophy applied to all baseline variants of the Common Habitat and will discuss the approaches taken to domain-specific stowage, bulk stowage, and fluid and gas stowage. Water and air stowage for the closed loop ECLS subsystem is described across the four variants. Stowage of other supplies, consumables, and equipment is also described across the four variants and based on logistics sizing studies, a self-contained mission endurance is predicted for each variant – e.g. how long a mission each can support without a docked logistics module. Finally, follow-on assessments, including a habitability virtual reality evaluation, are discussed along with specific stowage issues relevant to these assessments.**

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1. INTRODUCTION

Common Habitat Concept

The Common Habitat builds on an idea pioneered at NASA Marshall Space Flight Center known as the Skylab II concept. [1] Skylab II refers to the idea of using a Space Launch System (SLS) propellant tank as the primary structure for a space habitat. This is analogous to the original Skylab space station, which used the Saturn S-IVB stage's liquid hydrogen tank as the primary pressure vessel. [2] The advantage of this concept is that the pressure vessel is an expensive, long lead-time component of any habitat and using a pressure vessel that is already in production has the potential to save time and reduce expenses. The Common Habitat specifically uses the SLS Core Stage Liquid Oxygen (LOX) tank as its primary structure.

The aspect of the Common Habitat that adds to the Skylab II approach and makes it "common" is that the design is common across multiple missions in different gravity regimes. It is often assumed that a habitat for the lunar surface will inherently be different than one for use in deep space or on Mars. The Common Habitat challenges that notion and attempts a single design for the roles of lunar surface habitat, Mars surface habitat, Mars transit habitat, and Earth trainer. The Common Habitat is designed for mission durations up to 1200 days.

Common Habitat Variants

Two key architectural questions remain unresolved that significantly impact the design of the Common Habitat. Is a horizontal or vertical orientation preferable for living and working within the habitat? And does a crew size of four or eight provide the most effective human performance?

These questions have led to the development of four variants of the Common Habitat that represent the design space encompassed by these variables: a four-crew horizontal habitat, four-crew vertical habitat, eight-crew horizontal habitat, and eight-crew vertical habitat. The eight-crew variants use the entire SLS LOX tank while the four-crew variants use a modification of the tank where the structure is assembled using only half of the barrel section's length.

Initial data shows significant variations among the four Common Habitat variants with respect to stowage capacities. Each variant was designed with the goal to provide the best possible living and working conditions within the available volume to sustain the morale, safety, health, and performance of the crew, thereby directly affecting crew effectiveness.

This caused stowage capacity to become a variable driven by the differences between each variant.

Stowage Assessment Scope

This stowage assessment will document and categorize the extent of variation in stowage capacities across the four Common Habitat variants. The assessment does not attempt to associate a level of "goodness" based solely on stowage capacities. Instead, these variations in capacities are inputs to other studies that assess the crew's ability to live and work in the Common Habitat. It does also inform stack configuration, as the stowage capacity of each Common Habitat has an impact on the number of logistics modules that must be associated with each.

Stowage can be expressed in any number of different units, primarily those of mass and volume. This paper is focused on volumetric accommodation and will describe stowage primarily in terms of its volume. Stowage volumes will generally be described in terms of Cargo Transfer Bag Equivalents (CTBE), with Mid Deck Locker Equivalents (MDLE) used in a near-synonymous fashion, though there is a slight difference between the two. Mid Deck Lockers (MDLs) were introduced in the space shuttle program as standard stowage units on the Orbiter mid deck, hence the name. An MDL is a rigid locker that typically houses a drawer or smaller subdivisions of the standard drawer. Cargo Transfer Bags (CTBs) are lightweight, zippered, fabric bags used to transfer cargo from the shuttle (and subsequently various logistics modules) to the International Space Station (ISS). CTBs were sized such that a standard CTB can fit in a standard MDL. The Common Habitat utilizes both CTBs and MDLs in its internal architecture. CTBs are used for bulk stowage and MDLs are used for point of use stowage.

It should be noted that inventory management is not within the scope of the stowage assessment. Clearly, the large quantities of stowage associated with the Common Habitat demand an inventory management system, as does the multi-vehicle aspect of any Moon or Mars mission. However, the current assessment is geared towards resolving the questions related to habitat orientation and crew size. Notionally, the Common Habitat will employ radio frequency identification (RFID) as part of its inventory management system, potentially with three-dimensional position tracking, enabling an automated inventory management system. However, this system is likely to function identically across all four variants and thus is not expected to impact a study of crew size or internal orientation.

2. STOWAGE PHILOSOPHY

Habitability Focus

The stowage philosophy applied to the Common Habitat is that stowage accommodation is secondary to the primary mission of the habitat. Habitability considerations therefore drive stowage placement and capability. The primary function of the habitat is to provide living and working conditions necessary to sustain the morale, safety, health, and performance of the crew. Thus, each habitat variant was designed for the living and working functions to be performed by the crew [3] without regard to stowage. Stowage is placed unobtrusively within various work stations or crew functional areas, with the intent that it be used to contain equipment and supplies expected to be used for tasks associated with that area. Where the design allows, additional bulk stowage is placed in leftover volumes.

This philosophy is supported by more than a decade of human-in-the-loop analog testing. Test crews have generally noted concerns where stowage interferes with work volumes [4], [5], or too far from point of use [6]. The desire to avoid stowage encroachment in the habitat was most strongly expressed in the Gateway NextSTEP habitat evaluations where astronaut test subjects recommended that the habitat needs only one weeks' worth of consumables, frequently used items, and critical spares – with all other items stored in a logistics module. [7] The concern raised by the crew is that excessive stowage within the habitat interferes with living and working. When a habitat is designed to maximize stowage, the perception can be that it is like living in a storage closet.

While the Common Habitat does accommodate more than a week's worth of consumables, the design priority was to favor habitability with no consideration given to providing stowage accommodation other than point of use stowage for crew tasks. Additional stowage was then added to fill unused volumes with an attempt made to ensure no such stowage encroached on crew habitation.

Stowage Classification

Domain-specific stowage is the primary use of stowage within the Common Habitat. This is stowage volume within a specific living or working area, outfitted with stowage related to that area. Generally, stowed items should be reasonable accessible by an operator or operators within any given living or working area.

In all four variants of the Common Habitat, there is domain-specific stowage in the following areas: Galley (including wardroom table), Hygiene, Waste Management, Medical, Life Science, Physical Science, Maintenance, Exercise, Crew Quarters, and Command. The quantities vary from one variant to another.

Bulk stowage is intended to house infrequently used items or consumables to resupply domain-specific stowage. However, the Common Habitat design philosophy does not require the existence of bulk stowage. Essentially, bulk stowage is only allowable if there is "leftover" volume after all work areas, crew areas, and subsystems have been accounted for. That volume can be used for bulk stowage if it serves no other purpose. The eight-crew horizontal habitat is unique among the four variants in that it has no bulk stowage within its pressure vessel.

Fluids and gas consumables are generally stowed in dedicated containers, separately from bulk stowage or domain-specific stowage. The only fluid that has been identified to date requiring stowage is potable water. Potable water stowage is permanently installed within the Common Habitat. While the internal thermal control system will likely have some tanks for reserve thermal fluid, those are not presently modeled in the Common Habitat and are assumed to occupy portions of the volume between decks. Any fluids specific to maintenance, medical, or science other than water are stowed within the domain-specific stowage. Gases stowed in the Common Habitat are oxygen and nitrogen.

3. STOWAGE SYSTEMS

Water Stowage

A major driver for water (in addition to crew size) is the presence of plant growth chambers, the number of which varies across the Common Habitat variants. Thus, all four variants will require different levels of water stowage. The Common Habitat potable water system is sized as closed loop with open loop contingency capacity.

It is based on a closed air and water loop ECLS system, but it allows for a major contingency to render the recycling capability nonfunctional and retains the ability to operate open loop while repairs are made.

Nominally the habitat will recycle water captured from atmospheric humidity and urine waste. This water is recycled from a supply roughly equal to thirty days of nominal, open-loop consumption. However, in the event of a water system failure, the habitat can operate in an open-loop fashion, drawing from this water as well as an additional, sacrificial thirty-day supply.

The baseline nominal 30-day water is based on the following usage rates required by NASA-STD-3001, [8] with some increases as described below:

- Drinking: 2 kg / crew / day
- Eye irrigation: 0.5 kg total
- Medical: 5 kg / medical event; one medical event / 10 days
- Hygiene: 12.27 kg / crew / day
- EVA: 0.227 kg / EVA hour / EVA crew @ 17 two-person EVA days (272 EVA-hours total)
- Plant Growth: 4.985 kg / plant growth pallet / day

Because the Common Habitat is applied across microgravity and surface missions, water tank size is driven by the greatest need between surface and in-space applications. Both hygiene and EVA are driven by surface activities. Hygiene allocates sufficient water for "Navy showers," a very low water volume (as compared with typical civilian showers) hygiene technique intended to minimize water usage. EVA allocates sufficient water for the high-frequency EVAs that accompany small pressurized rover excursions along with limited local inspections and servicing.

The contingency water allocation is based on the scenario where a failure has rendered the closed loop ECLS system inoperable. This may be a failure within the ECLS system itself, water tank failures, or failures of other systems within the architecture that impair the ability of ECLS to recycle water. The crew will have to restore functionality before the onboard water is consumed. This may involve significant EVA activity if the incident involves damage to the exterior of the spacecraft. Thus, the additional, sacrificial 30-day water supply is added to account for water that is not necessarily recaptured for reuse upon completion of repairs. Repair must be completed within this time.

Contingency 30-day water is based on the following usage assumptions:

- Three external incidents (e.g. points of damage requiring EVA repair – example: one structural failure and two subsystem failures)
- Eight 8-hour, 2-person EVAs to repair each external incident:
  - 2 site inspection and diagnosis EVAs
  - 1 site preparation EVA
  - 3 repair attempt EVAs
  - 1 close-out EVA
  - 1 follow-up inspection EVA
- Increased eye irrigation resulting from exposure during repair activities – repair of each external incident consumes two nominal 30-day eye irrigation allocations
- Seven crew medical events associated with the initial contingency and subsequent recovery efforts
- Usage rates for Drinking, Hygiene, and Plant Growth are unchanged
- Usage rates for Eye irrigation, Medical, and EVA become:
  - Eye irrigation: 3 kg total
  - Medical: 5 kg / medical event @ 7 medical events
  - EVA: 0.227 kg / EVA hour / EVA crew @ 24 two-person EVA days (384 EVA-hours total)

The Common Habitat variants employ customized water tanks in order to better take advantage of otherwise unused volumes for water storage. These tanks are placed in locations that do not interfere with crew functions or subsystem placement.

A material selection is not assumed at this level of detail for the Common Habitat. However, an obvious consideration is that it must be material compatible with very long-term storage of water as the tank needs to remain usable for the life of the habitat. Using the International Space Station as an example, the ISS has had a human crew onboard since 1998. A twenty-year lifetime would be a minimum goal, but it is credible to conceive of the water tanks holding potable water for greater than thirty years.

Gas Stowage

Nitrogen Oxygen Recharge System (NORS) tanks are used for stowage of breathable gases. While the ECLSS is a closed-loop system, enough NORS tanks are provided to allow for an open-loop quantity of gas to provide a buffer in the event of an emergency that disables the air recycling loop. Using values from prior internal NASA studies, a minimum threshold of ten NORS tanks are baselined for the Common Habitat, though each variant was permitted to incorporate additional tanks if there was otherwise unused volume in the location allocated to NORS tank stowage.

Mid Deck Lockers

Stowage is primarily contained within shuttle-era Mid-Deck Lockers. Full size, half height, half width, and half depth lockers are used. Notionally, any cluster of two full lockers could be substituted for a double locker and a 4x4 cluster could be substituted for a quad locker. Trays within each locker may be sized to the full dimensions of the locker or may subdivide the locker into smaller storage volumes. Some additional custom-sized stowage cabinets are used within Medical and Hygiene to improve ease of access. Domain-specific stowage uses lockers or cabinets exclusively to improve usability for repeated-access.

Cargo Transfer Bags

Bulk stowage is contained within Cargo Transfer Bags (CTBs). CTBs are used exclusively for bulk stowage. Bulk stowage is only accessed for transfer of contents to domain-specific stowage. CTBs used in the Common Habitat study are 3rd generation CTBs produced under the ISS Cargo Mission Contract. [9] While they may include any of the CTB sizes within this contract, those primarily used in the Common Habitat are the 1.0 CTB and the 10.0 CTB.

Freezers

Cold stowage is contained within individual units derived from the ISS Minus Eighty Degree Laboratory Freezer's (MELFI) 75-liter cylindrical vacuum-insulated dewars. Each can operate at a different temperature to provide refrigeration or freezing at temperatures ranging from +4 °C to -80 °C. [10]

Docked Logistics Modules

Each Common Habitat reserves at least one docking port for a logistics module. No assumption is made on the type or size of module or total number of logistics modules needed. If more logistics modules are needed than there are ports available, the additional modules would be stored somewhere in the vicinity and swapped out as needed.

Trash and Waste

Waste stowage is primarily accomplished via temp stow trash bags that can be mounted in the relevant area during a particular task and then disposed of upon completion of the task. The only dedicated waste stowage volumes are wet and dry trash units in the galley and the waste cannisters contained within to toilets inside the Waste Management Compartment (WMC). All long-term trash stowage is contained within a docked logistics module or ejected. (All wet trash or waste is of course first processed through the ECLSS water recovery system prior to permanent disposal.)

4. STOWAGE IMPLEMENTATION

Four-Crew Horizontal Habitat

The four-crew horizontal habitat, shown in figure 1, is manufactured using only one barrel section of the SLS Core Stage LOX tank and is arranged with three internal decks, a lower deck, mid deck, and upper deck.

Stowage in the Galley includes six MDLs in the food preparation area, eight MDLs in the Wardroom table, one wet trash and one dry trash receptacle, and four MELFI-derived freezers. The four freezers only provide six MDLE stowage, so the intent is not to provide long-term cold stowage for prepackaged foods. Instead, the freezers enable short-term stowage of foods prepared in-flight that require cold stowage.

Each Hygiene Compartment includes three MDLE stowage distributed across multiple custom-sized compartments. The four-crew horizontal habitat includes three Hygiene Compartments for a total of nine MDLE hygiene stowage.

The Waste Management Compartment includes one half-height mid deck locker and one half-depth mid deck locker. There are two Waste Management Compartments for a total of two MDLE waste management stowage.

The Medical facility includes eight MDLE stowage distributed across multiple custom-sized compartments.

Life Science includes thirty-one MDLE stowage. These may be any mixture of mid deck lockers and science payloads. Four MELFI-derived freezers provide life science cold storage.

Physical science includes thirty-seven MDLE stowage. Similar to life science, this can include any combination of lockers and science payloads.

Maintenance includes forty-six MDLE stowage. This is primarily lockers but can also include powered payloads or other fixed equipment where needed.

Exercise stowage consists of three mid deck lockers located near the exercise devices.

Each of the four crew quarters features sixteen and a half MDLE. This is distributed throughout the crew quarters in the following manner: two mid deck lockers and two half-height lockers beneath the bunk, three half-height lockers and one half-depth locker beneath the desk, four mid deck lockers and two half-depth lockers above the side desk, and five mid deck lockers and three half-depth lockers above the foot of the bed / front desk

The Systems Monitoring and Commanding Workstation includes two MDLE, two half-depth lockers at each of the two consoles.

There are two bulk stowage locations on the lower deck, with 50 CTBE each using a combination of CTB sizes.

Water is stowed in three tanks located beneath the lower deck.

Thirteen NORS tanks are located on the upper deck, co-located with ECLSS subsystem pallets.

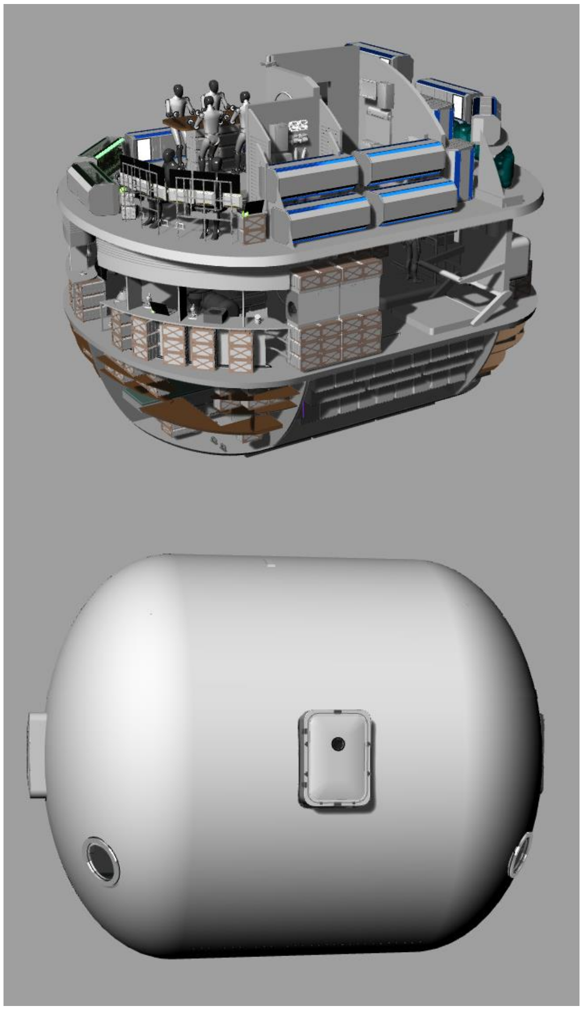

Figure 1. Four-Crew Horizontal Habitat

Four-Crew Vertical Habitat

Shown in figure 2, the four-crew vertical habitat uses the same primary structure as its horizontal counterpart but is instead oriented vertically with four internal decks, numbered one (lower dome) through four (upper dome).

Galley stowage is identical to that in the four-crew horizontal habitat, with the exception that the there are four 10-CTBE bulk food stowage bags located in the galley area.

Hygiene stowage within each Hygiene Compartment is identical to the four-crew horizontal habitat, however the four-crew vertical habitat has only two Hygiene Compartments for a total of six MDLE hygiene stowage.

Waste management stowage and medical stowage are both identical to that in the four-crew horizontal habitat.

Life Science stowage is similar to that of the four-crew horizontal habitat with the only exception being an MDL stowage capacity of twenty-six.

The Physical Science MDL capacity is twenty-eight.

The Maintenance stowage capacity is forty-five MDLs, almost the same capacity as the four-crew horizontal habitat.

Exercise stowage is identical to that in the four-crew horizontal habitat.

Each Crew Quarters contains ten and a half MDL stowage. This is configured with three MDLs above the desk, two MDLs under the left side of the desk, two MDLs under the right side of the desk, one half MDL under the center of the desk, and two half MDLs and two MDLs under the bunk.

The Systems Monitoring and Commanding Workstation stowage is identical to the four-crew horizontal habitat.

Deck one features a bulk stowage location containing five 10-CTBE bulk stowage bags.

Water is stowed in three tanks, one at the base of the lower dome, one at the top of the upper dome, and one in the ceiling of the deck three hallway.

Ten NORS tanks are located on deck one, co-located with ECLSS subsystem pallets.

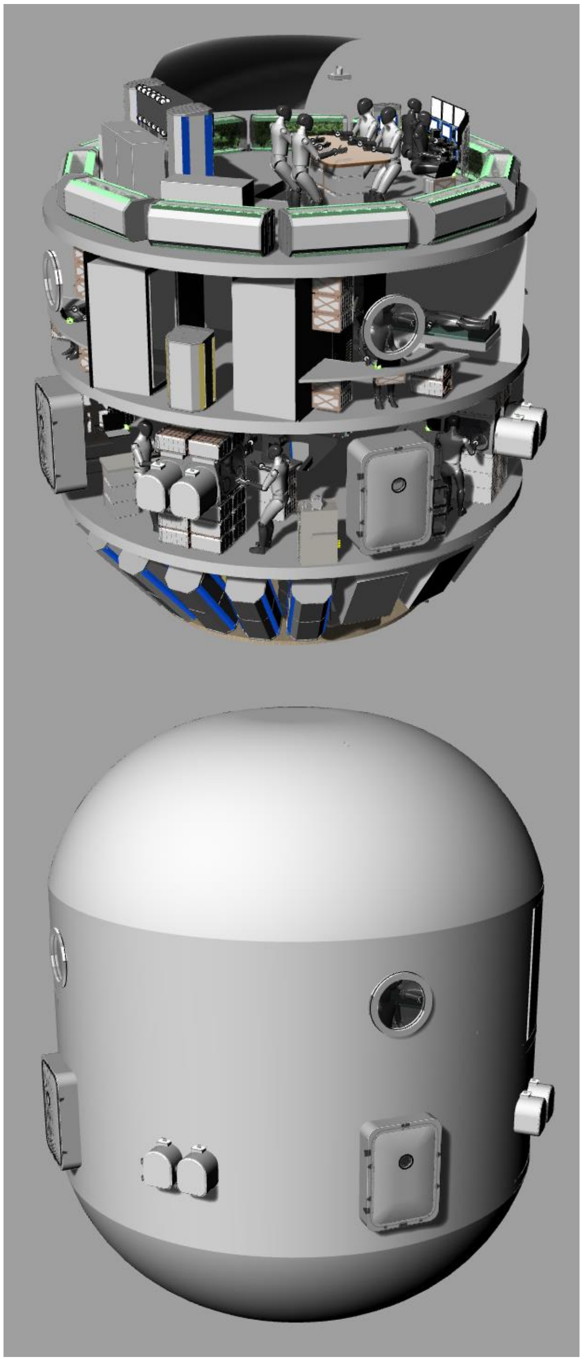

Figure 2. Four-Crew Vertical Habitat

Eight-Crew Horizontal Habitat

Figure 3 provides images of the eight-crew horizontal habitat. This variant uses the entire SLS Core Stage LOX tank as its pressure vessel and just like the four-crew variant is organized in three internal decks.

The Galley of the eight-crew horizontal habitat is a double of the versions in the four-crew habitats due to the increased crew size. Consequently, Galley stowage includes twelve MDLs in the food preparation area, two wet trash and two dry trash receptacles, and eight MELFI-derived freezers. There is no change to the stowage in the Wardroom table. There are three 10-CTBE bulk food stowage bags located in the galley area.

Each Hygiene Compartment contains the same three MDL stowage configuration as the four-crew variants, however the eight-crew horizontal habitat has five Hygiene Compartments.

The eight-crew horizontal habitat similarly retains the same single MDL Waste Management Compartment stowage configuration as the four-crew variants but doubles the number of compartments to a total of four.

Medical stowage is identical to that in the four-crew horizontal habitat.

The Life Science stowage capacity is increased to forty-seven MDLs but remains the same four MELFI freezers as the four-crew variants.

Physical Science stowage capacity increases in the eight-crew horizontal habitat to sixty-five MDL.

Maintenance stowage capacity is fifty-eight MDL.

Exercise stowage is doubled due to the additional exercise devices and is six MDL.

Each of the eight Crew Quarters features ten and a half MDLE. This is distributed in the following manner: two mid deck lockers and two half-height lockers beneath the bunk, one half-height locker beneath the desk, and six mid deck lockers and two half-depth lockers at / above the foot of the bed.

The Systems Monitoring and Commanding Workstation contains four MDLE stowage, four half-depth lockers at each of the two consoles.

The eight-crew horizontal habitat does not have any bulk stowage.

Like the four-crew horizontal habitat, water is stored in three large tanks beneath the lower deck.

NORS tank storage is identical to that of the four-crew horizontal habitat.

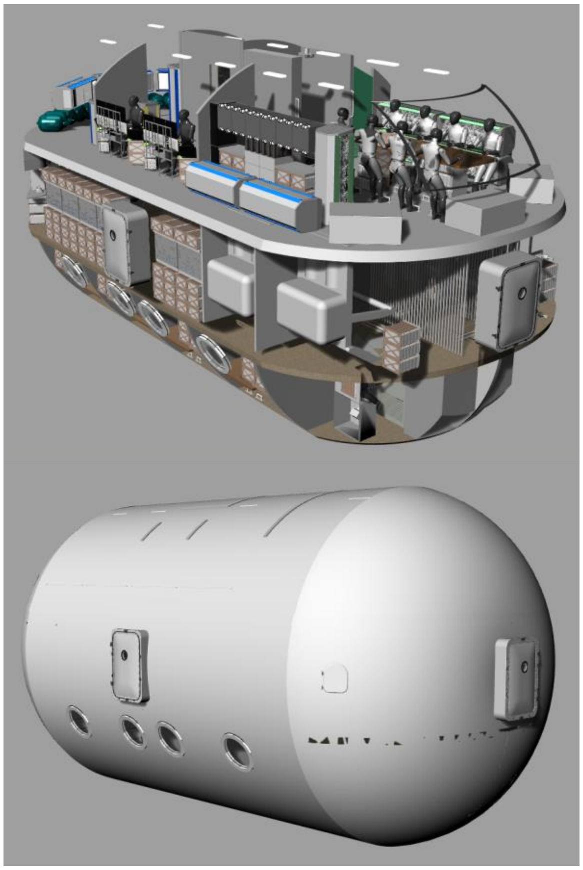

Figure 3. Eight-Crew Horizontal Habitat

Eight-Crew Vertical Habitat

The final Common Habitat variant, the eight-crew vertical habitat, is shown in figure 4. Like the eight-crew horizontal habitat it also uses the entire LOX tank, but like the four-crew vertical, it is oriented vertically, with decks numbered one (lower dome) to six (upper dome).

Galley stowage is identical to the eight-crew horizontal habitat, with the exception that the eight-crew vertical habitat also contains four 10-CTBE bulk food stowage bags.

Hygiene Compartment stowage is identical to the eight-crew horizontal habitat with the exception that there are four Hygiene Compartments in the eight-crew vertical.

Waste Management Compartment stowage is identical to the eight-crew horizontal habitat.

Medical stowage is identical to all of the other habitat variants.

Life Science stowage includes eight MELFI freezers and fifty-six MDLs.

Physical science stowage also includes fifty-six MDLs

Maintenance stowage capacity is forty-eight MDLs.

Exercise stowage is identical to the eight-crew horizontal habitat.

Each of the eight Crew Quarters are identical to their counterparts in the four-crew vertical habitat, with ten and a half MDL each.

Stowage in the Systems Monitoring and Commanding Workstation is identical to the eight-crew horizontal habitat.

Bulk stowage is identical to that in the four-crew vertical habitat.

Water stowage is similar to the four-crew vertical habitat, but is stowed in four tanks – one at the base of the lower dome, one at the top of the upper dome, and one each in the ceilings of the decks four and five hallways.

NORS tank stowage is identical to the four-crew vertical habitat.

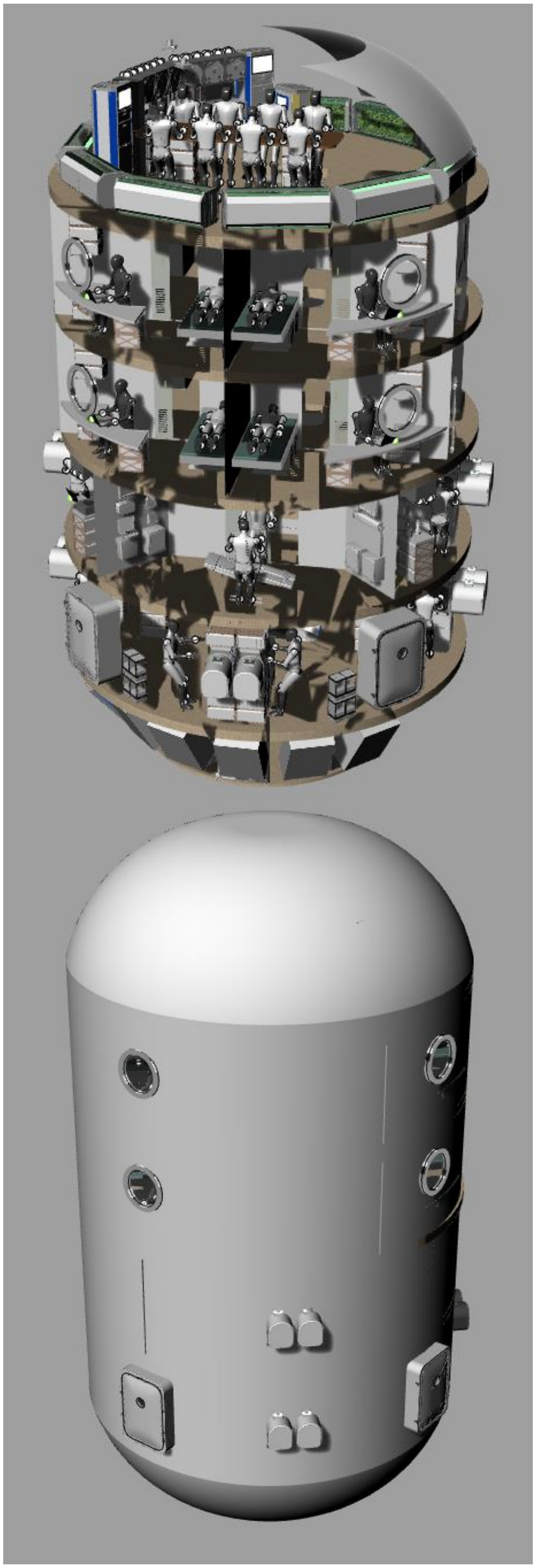

Figure 4. Eight-Crew Vertical Habitat

Logistics Module

A roughly MPLM-like element is notionally depicted in figure 5 as a logistics module and analyzed for stowage capacity. It is depicted as 4.5 meters in diameter and 7 meters in length, including a 5.2-meter barrel segment and 0.6-meter height endcones. This element would be used in both microgravity and planetary scenarios. It is depicted with two axial docking ports, though future design trades will trade this against a radial docking port. Initial subsystems assumptions include one NORS tank, three Gateway-style ECLSS pallets, one avionics pallet, and one power half-pallet. Thermal is assumed to be contained within these pallets and integrated in voids within the pressure vessel. Down-selection of a specific Common Habitat variant and in-space propulsion system selection may heavily influence the logistics module configuration. This logistics module has a stowage capacity of 766 CTBE, using a mixture of bag sizes to accommodate the maximum stowage possible.

The logistics module is used to resupply "point of use" stowage in the habitat and is not used for routine stowage access. Spares and other low frequency items are also stowed primarily in the logistics module.

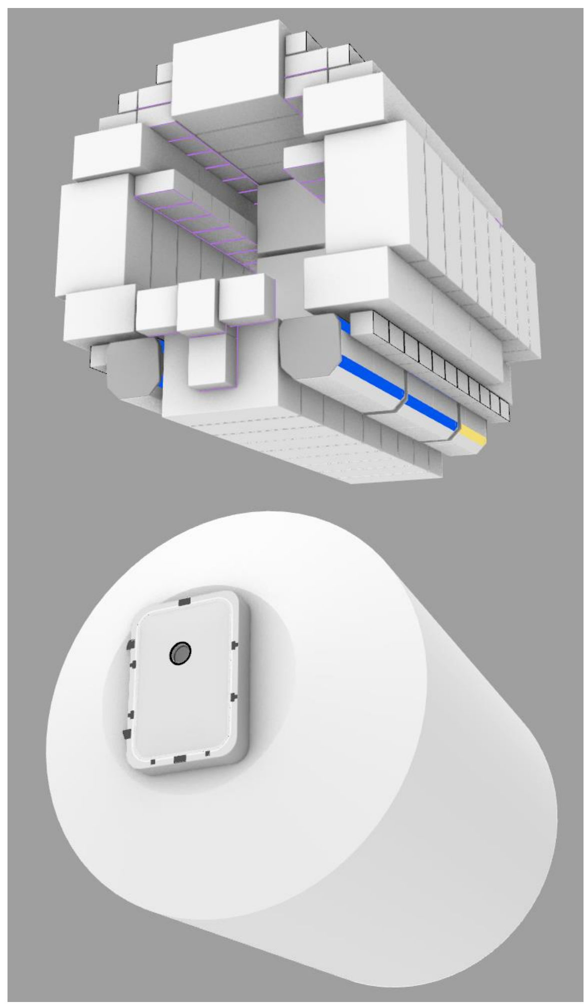

Figure 5. Logistics Module

It is worth noting that the subsystems configuration of the logistics module enables some “lifeboat” capability. In the event of a serious vehicle emergency, the crew can retreat to the logistics module and use it as a shelter until repairs are completed. However, the current configuration of the logistics module does not include water tanks. If needed as a lifeboat, Contingency Water Containers (CWC) such as those used on ISS could be filled via docking port utilities connections. Future design iterations can trade this approach against integrated water tanks.

Trash Management

Trash management remains forward work. One option advocated in some circles is to contain all trash and waste within pressurized volumes. This approach gives the highest consideration to the surface issue of planetary protection and in-space issue of orbital debris generation. Another preference is to eject trash and waste periodically. From a propulsion perspective, this reduces the load on an in-space propulsion system. It also eliminates concerns of odor management. At the current state of Common Habitat development this issue is not addressed, other than to baseline that the Common Habitat itself will not store trash and waste. Whether it is moved to a docked element or ejected remains for a future design maturation task. Either long-term trash storage or trash ejection will be accomplished via the logistics module. Local trash storage will be needed within individual workspaces and this has only been notionally represented in the Galley. The addition of fixed or deployable trash receptacles will have a volume impact that will be assessed in a future design maturation cycle after a down-selection of a single Common Habitat variant to further develop.

5. STOWAGE SUMMARY

Estimated Stowage Requirements for 1200 Days

The stowage requirements for a 1200-day mission, shown in table 1, are estimated based on a mixture of parametric formulas and interpolations from prior NASA studies including habitats, landers, and rovers. Additionally, the Common Habitat developed maintenance and science estimates driven by the maximum volume accommodations of the respective workstations across the four variants, resulting in higher stowage volumes than in other NASA studies. These values are used instead of interpolations to reflect Common Habitat design philosophies of maximizing science utilization and spacecraft survivability. Consequently, the stowage estimates for the Common Habitat variants will not be an exact match for corresponding estimates in any specific NASA Design Reference Mission (DRM). Instead, the stowage quantities for any conceivable future DRM will likely be able to be accommodated within a Common Habitat.

Table 1. Estimated Stowage Requirements for 1200 Days

	Mass (kg)		CTBE	
	4 Crew Baseline	8 Crew Baseline	4 Crew Baseline	8 Crew Baseline
Food	10,278.40	20,556.80	273.75	547.50
Wipes and Gloves	993.60	1,987.19	111.25	222.25
Health Care Consumables	546.13	1,092.27	61.25	122.25
Trash Bags	149.32	298.64	17.75	35.50
Waste Collection - Fecal Canisters	1,142.90	2,285.80	127.75	255.50
Waste Collection - Urine Prefilter	198.92	397.84	23.75	47.50
Operational Supplies	139.20	278.39	12.75	25.25
Recreation & Personal Stowage	278.39	556.78	25.25	50.25
Hygiene Kits	185.59	371.17	21.25	42.25
Clothing	873.05	1,746.10	19.00	37.75
Towels	537.13	1,074.27	60.25	120.25
Fecal/Urine Collection Bags	27.84	55.68	3.50	7.00
LiOH Canisters	292.31	584.62	11.25	22.50
EVA Maximum Absorbency Garments (MAGs)	130.56	130.56	22.00	22.00
Total Spares	5,145.01	5,145.01	192.25	192.25
Maintenance	1,600.00	1,600.00	60.00	60.00
Utilization Allocation	1,973.33	3,546.67	74.00	133.00
Total Stowage	24,491.68	41,707.79	1,117.00	1,943.00

Comparison Summary

As indicated in the stowage implementation section, the different layouts resulting from the variations in crew size and orientation has led to different stowage quantities, both with respect to domain-specific stowage and bulk stowage. In some cases, commonality was noted, such as in the cases of the wardroom table and medical stowage. In other cases, a functionality such as a Hygiene Compartment has a defined stowage that is consistent across variants, but the number of compartments changes based on crew size. And in still other cases, such as science and maintenance, the design is different across each variant, resulting in unique stowage allocations for each variant. Table 2 provides a summary of stowage volumes available across the four habitat concepts, expressed in units of CTBE. Where a functional area contains subdivisions that may vary, those subdivisions are right justified, while the stowage for each area is centered. See the Galley stowage as an example. Table 3 summarizes the ECLSS fluids stowage.

Table 2. Common Habitat Stowage Allocation in CTBE

	Four-Crew Horizontal	Four-Crew Vertical	Eight-Crew Horizontal	Eight-Crew Vertical
Galley	20	60	62	72
Wardroom Table	8	8	8	8
Meal Preparation Area	6	6	12	12
Freezers	6	6	12	12
Bulk Food Stowage	0	40	30	40
Crew Quarters	66	42	84	84
Exercise	3	3	6	6
Hygiene	9	6	15	12
WMC	2	2	4	4
Medical	8	8	8	8
Life Science	37	32	53	68
Lockers	31	26	47	56
Freezers	6	6	6	12
Physical Science	37	28	65	56
Maintenance	46	45	58	48
Command	4	4	8	8
Bulk Stowage	100	50	0	50
Total Stowage	332	280	363	416

Table 3. ECLSS Fluids Stowage

Variant	Tank Water Volume, m³	Tank Water Mass, kg	NORS Tanks
Four-Crew Horizontal	4.23	4221.37	13*
Four-Crew Vertical	6.93	6913.27	10
Eight-Crew Horizontal	5.62	5598.67	13*
Eight-Crew Vertical	7.42	7393.27	10

* Volume is available to increase to 14 NORS tanks.

Logistics Module Implications

It is generally assumed that the Common Habitat will have to operate with a docked logistics module to provide additional stowage that is not contained within the habitat. However, the Common Habitat can potentially operate without a logistics module for shorter duration missions. Table 4 indicates the maximum duration in days that each Common Habitat can be inhabited using only its internal stowage capacity. It is worth noting that these habitation durations should not be considered a mission duration. The mission begins the moment the crew launches from Earth and does not end until they have safely landed on Earth. The crew will spend time in various habitable environments, both before reaching a Common Habitat and after departing it (e.g. Orion, Gateway, HLS, etc.). In some cases – such as a Mars mission, they may spend time in two different Common Habitats (transit hab and surface hab). This table only refers to the portion of the mission spent living and working inside a given Common Habitat.

Table 4. Maximum Habitation Duration for Each Common Habitat Without a Logistics Module Present

	# Days
4-Crew Horizontal	206
4-Crew Vertical	153
8-Crew Horizontal	101
8-Crew Vertical	138

It may initially seem counter-intuitive that the eight-crew variants require a logistics module sooner than the four-crew variants, given that they are larger elements. However, the Common Habitats all have non-consumables allocations for science and maintenance capabilities. These are a higher percentage of the internal stowage volume in the eight-crew variants, leaving proportionally less volume available for consumables. And due to the increased crew size, more consumables are needed in the eight-crew variants.

Various NASA concept studies and Design Reference Missions (DRMs) have assumed widely varying durations for long-duration human activity in Cislunar space, the lunar surface, Mars transit, and the surface of Mars. The Common Habitat does not need to be redesigned for each duration, though the stowage quantities will change, thus impacting the logistics module requirement. Table 5 expands on this, listing the number of logistics modules required for various habitation durations. Fractional values indicate the percentage of a logistics module needed for a given duration.

Table 5. Number of Logistics Modules Required as a Function of Habitation Duration for Each Common Habitat

	Number of Logistics Modules Required			
Habitation Duration (Days)	4-Crew Horizontal	4-Crew Vertical	8-Crew Horizontal	8-Crew Vertical
30	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000
120	0.000	0.000	0.034	0.000
150	0.000	0.000	0.091	0.022
180	0.000	0.029	0.148	0.079
210	0.003	0.059	0.204	0.134
365	0.165	0.221	0.494	0.425
500	0.306	0.362	0.748	0.679
700	0.515	0.571	1.124	1.055
800	0.619	0.676	1.312	1.242
1200	1.037	1.093	2.063	1.993

A couple of these may serve as examples. Consider the Four-Crew Horizontal at 210 days, the Eight-Crew Vertical at 800 days, and the Eight-Crew Horizontal at 1200 days. Clearly there are no such things as 0.003, 1.242, or 2.063 logistics modules. They instead indicate scenarios where the stowage allocations on both the Common Habitat and in the latter two cases also its logistics module(s) are full but there is additional stowage that has no place for it to be stowed: 2.25, 185.25, and 48.25 CTBE respectively.

In the 0.003 logistics module case, it would be prudent to consider finding a location in the Common Habitat for the additional 2.25 CTBs. There are places where this could be accomplished with negligible habitable impact and that small a quantity of stowage will be consumed relatively quickly, returning the stack to a nominal configuration very early in the mission.

The 1.242 logistics module case is a different story. It is unlikely that an additional 185.25 CTBE can be stuffed into the Common Habitat/Logistics module stack without creating noticeable habitability problems. This is reminiscent of stowage conditions that have long plagued ISS where stowage has spilled out of its intended locations and blocked hatches, translation paths, and other areas because there is more stowage on the station than it has allocated space. All efforts should be expended to avoid such a scenario. Because the logistics module is at this point merely a paper concept, a future logistics module design phase should consider alternate dimensions for the element, either growing it such that a single module accommodates the additional 185.25 CTBs (951.25 total CTBE) or shrinking it to make two logistics modules accommodate 951.25 CTBE.

Finally, the 2.063 logistics module case suggests a need for a design trade. It might be possible to accommodate 48.25 CTBE across the eight-crew vertical habitat and two logistics modules. This would require a Virtual Reality habitability evaluation to test placement of additional CTBE throughout the habitat and logistics modules. If this is feasible, then it is similar to the 0.003 logistics module case. If, however, it creates a degradation in habitability, then it may suggest the 1.242 logistics module case where a redesign of the logistics module dimensions is warranted.

Of course, the actual solution should not be a point design for any one mission. All of the fractional values should be considered. For this reason, a detailed assessment of the logistics module and its dimensions should wait until after a single Common Habitat variant has been selected and a design maturation cycle has been conducted on that habitat. Its internal stowage will change and there will be only one habitat to consider instead of four.

There are some general trends that can be considered immediately. The data does suggest that (whether or not such a scenario would be allowed) the four-crew horizontal (and possibly vertical) habitat may be able to perform some of the faster conjunction-class Mars transits without an attached logistics module, provided there is a logistics module awaiting it in Mars orbit to restock it for the return home. That may be considered too risky as logistics module docking in Mars orbit would then have potential loss of crew consequences, but it is worth noting that such a mission is physically possible. The return leg for such a transfer is certainly viable without a logistics module. However, for any longer Mars trajectory an attached logistics module of some kind is required, and all the other habitat variants will require one or two attached logistics modules for any conceivable Mars trajectory. Opposition-class surface habitats and limited duration lunar surface habitats (≤ 120 days) will not require logistics modules, but as the surface duration increases between 120 and 365 days each variant begins to require some kind of logistics module. For a traditional conjunction-class surface mission any variant will require one logistics module. A lunar surface habitat may begin to require a second logistics module as the surface duration reaches the two-year point, a duration not currently part of any NASA planning but could be a potentially useful duration to maximize the use of crew time on the Moon either as a testbed for conjunction-class Mars missions or to support lunar-specific science and utilization.

6. FORWARD WORK

Additional Assessments

The stowage assessment is the first of seven assessments to be performed for the four variants of the Common Habitat. The results of the seven assessments, taken collectively, will answer the questions of orientation and crew size for the multi-mission Common Habitat. The other six assessments are: functional analysis, crew time assessment, science productivity analysis, maintenance capacity analysis, contingency responsiveness analysis, and a habitability evaluation. The stowage assessment needed to occur first because it provides key input data to many of the other assessments.

Because there is a finite amount of stowage allocated to science in each variant, there are implications for the quantity and diversity of science that can be performed in each. This, along with other influencing factors, will be considered in the science productivity assessment.

The stowage capacity allocated to maintenance, fabrication, and repair will scope the quantity and dimensions of tools that can be provided within each Common Habitat. This may be shown to be a contributing factor in the types of activities that can be performed.

A variety of different spacecraft emergencies and other contingency scenarios will be assessed for each Common Habitat variant. Stowage locations and capacities may have an impact on the survivability of the habitat or crew under these scenarios.

While the overall stowage within the habitat variants do add to the total habitat mass with respect to radiation protection, stowage locations are not driven by radiation considerations. This was a consequence of the Common Habitat's stowage philosophy and runs counter to the traditional design mantra to surround the crew with stowage. No deep space habitat design to date which has followed the traditional mantra has been able to provide sufficient protection for the mission durations involved and it will be a noteworthy future data point to determine if the Common Habitat stowage philosophy has resulted in significantly greater or less radiation hazards than other deep space habitat concepts.

The habitability evaluation will consider the impact to habitability of various stowage tasks such as access to stowage, staging of stowage items, and resupply from logistics modules. It will also assess encroachment of stowage on various living and working functions.

With the data from these assessments, it will be possible to recommend a single variant of the Common Habitat to carry forward.

Common Habitat Design Maturity Cycle

Following selection of a single Common Habitat to move forward, its design will be matured, incorporating lessons learned from the down-select assessments. The design cycle will also increase the fidelity and performance of workstations and subsystems. During the cycle, mass estimates and an accompanying Master Equipment List will also be created. This exists in part, but at present a total mass for the Common Habitat is not known. This updated design will then be evaluated to assess the consequences of design changes and ensure that the changes resulted in net improvements to the spacecraft.

Logistics Module Design Maturity Cycle

The logistics module will be advanced from its current notional concept, based on implications from preceding Common Habitat analyses. It will also consider impacts to launch vehicles, use with an in-space transit stack, and incorporation into a surface architecture.

Launch Vehicle, Lander, Offloading, In-Space Element, and Surface Outpost Designs and/or Assessments

Presumably, the only two launch vehicles that can lift a Common Habitat into space are the SLS and Starship, though it may be worth a quick assessment to determine if any other commercial launch vehicles (CLVs) could launch a Common Habitat as a "hammerhead" payload. It will also be important to conduct a high-level assessment of how the Common Habitat can be integrated into SLS and Starship launch vehicles.

Space X has on many occasions declared that with in-space refueling, the Starship can land 100-ton class payloads on both the Moon and Mars. While mass estimates for the Common Habitat have not yet been completed, it is clear that even a fully outfitted Common Habitat is beneath this threshold. However, in order to not be solely dependent on Starship, work will also continue on the JUMP Lander (Joinable Undercarriage to Maximize Payload). [11] The JUMP lander is a conceptual, multi-element lunar lander whose individual elements can be launched by CLVs and integrated in Cislunar space to form a heavy cargo lunar lander capable of landing the Common Habitat on the Moon. Additionally, high-level assessments will be performed on the hypersonic inflatable aerodynamic decelerator (HIAD) and mid lift over drag (Mid L/D) Mars landers to identify options for each to accommodate a Common Habitat.

An offloading study will define options and operational concepts to unload the Common Habitat from the Starship, JUMP Lander, HIAD, and Mid L/D landers on the Moon and Mars, transport the habitat to a surface base camp location, and position the habitat in the proper location.

An in-space element study will consider the implications of the Common Habitat for Mars transit. This study will trade safe haven options and will examine power, thermal, and propulsion implications for attached elements. Historically, chemical propulsion, solar electric propulsion, nuclear electric propulsion, nuclear thermal propulsion, and hybrids of these have all been considered for Mars transit. This study will roughly size a reference option for each propulsion type and determine if any of them fall off the table due to the mass of the Common Habitat and its logistics modules.

A surface outpost design study will perform first order site planning for both Moon and Mars base camps. It will develop options to use the local terrain for radiation protection, identify options for the attachment of various pressurized elements to the habitat (rover, airlock, logistics modules) and for unpressurized connections of service elements (power, heat rejection, communications). Finally, it will identify non-attached elements of the base camp in the local area (e.g. launch and landing zones; samples, spares, and trash depots; high-use travel paths; unpressurized rovers and robots; etc.

An acquisition assessment will consider different acquisition and partnering strategies to identify options to develop the Common Habitat and associated infrastructure within the constraints of NASA's current funding levels and commitments to international and commercial partners.

Artemis Campaign Integration and Comparison

The previously mentioned assessments will be compared against corresponding assessments of Artemis Phase 2 Moon and Mars concepts. The hypothesis of this effort is that the Common Habitat can be developed within Agency constraints while providing significant improvements to human spaceflight.

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9. BIOGRAPHY

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