Internal Architecture of the Common Habitat

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Abstract— **The core stage liquid oxygen tank of the Space Launch System can be manufactured as a habitat instead of as a propellant tank, with a common design such that it is equally suitable for use in 0g, 1/6g, 3/8g, 1g, or variable artificial gravity. It is capable of sustaining a crew size of eight for missions up to 1200 days in duration. This Common Habitat can be the central element of a human spaceflight architecture that encompasses the Moon, Mars, and other destinations within the inner solar system. Within this archtiecture, the Common Habitat is specifically used as the core habitation element within a Lunar Base Camp, Mars Base Camp, and the Deep Space Exploration Vehicle. The Common Habitat internal architecture applies a design philosophy to separate crew functions according to deck. The lower deck is reserved for private functions. It includes eight private crew quarters and four waste and hygiene clusters – each with a private waste management compartment, private full body hygiene compartment, and private foyer/clothes changing area. The mid deck is primarily allocated to mission-related functions. It includes an exercise facility, fabrication / maintenance / repair facility, physical science laboratory (physics, geology, and remote sensing: astronomy, heliophysics, planetary science, and Earth science), and life science laboratory (biology and human research). The mid deck also has four external hatches, clocked one every 90 degrees, centered on the vehicle vertical centerline. Each hatch has a 60-inch tall by 40-inch wide opening with the mid deck floor 16 inches below the bottom lip of the hatch opening. The upper deck also includes some mission functions, but is primarily allocated to social functions. It includes a large galley, wardroom with projector and display screen, plant growth chambers, bulk stowage, command and control station, medical facility, hygiene compartment, and vehicle subsystems.**

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1. INTRODUCTION

Common Habitat Overview

The Common Habitat is a conceptual long-duration habitat that is manufactured on the Space Launch System (SLS) production line, similar to how the Skylab Space Station was manufactured from a Saturn rocket upper stage. The Common Habitat uses the SLS core stage liquid oxygen tank as its primary structure, shown in Figure 1, outfitted in production as a habitat instead of as a rocket tank.

Figure 1. SLS LOX Tank

It is approximately 8.4 meters in diameter and 15 meters in length. Following a habitability trade study, a horizontal orientation was selected along with a crew size of eight. [1]

The Common Habitat is part of a conceptual study and is not currently part of any active NASA reference mission or human spaceflight program.

Common Habitat Architecture

The Common Habitat is intended to serve as the core element for long-duration human habitation in any in-space or surface environment. The goal is for identical Common Habitats to be used on the lunar surface, Mars surface, in microgravity, and in Earth trainers. Possible other applications include habitats on asteroids or small moons such as Phobos or Deimos, commercial low Earth orbit (LEO) space stations, Venus atmospheric skyships, or as habitat modules within rotating artificial gravity spacecraft.

Common Habitat Internal Architecture

The internal architecture of the Common Habitat must provide an acceptable crew living and working environment for eight crew members when used in the previously mentioned and varied gravity environments for crew stays as long as 1200 days.

Crew Restraints and Mobility Aids Deferred as Forward Work

In microgravity, foot rails and handrails, such as those aboard the International Space Station (ISS) shown in Figure 2, aid in crew mobility and can restrain a crew member at a worksite, but if the same habitat module were in a gravity environment, these mobility aids would become trip hazards.

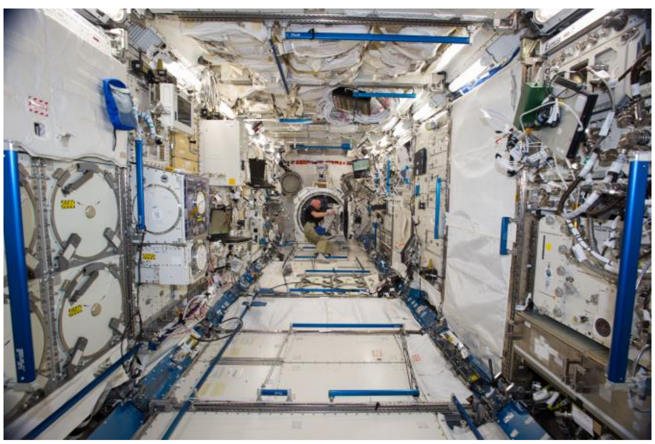

Figure 2. Foot Rails and Handrails Aboard the ISS

Additionally, handrails are sufficient in microgravity for translation in both vertical and horizontal directions. And cabin intersections for vertical passageways are open, with no barriers or other implements to separate vertical and horizontal travel. In a gravity environment the handrails are inadequate, and an open vertical passageway is a falling hazard.

Further, in microgravity a footrail or tether may be a reasonable accommodation for a crew member who will need to work at a specific location for hours at a time, day after day, such as at the glove box visible on the left side of the image in Figure 2. This may be unacceptable in a gravity environment, where the crew may wish to be able to sit down at a workstation, much as they might sit in a chair or on a stool in a terrestrial laboratory. In an artificial gravity spacecraft, that particular workstation may be in microgravity some days and in gravity other days. Thus, the foot rail or tether solution is inadequate for the Common Habitat.

Crew restraints and mobility aids have been identified as forward work. This paper will carry as an assumption that a system or system of systems can be designed for vertical and horizontal translation that (1) requires no manual reconfiguration to operate in microgravity or gravity environments; (2) enables crew translation whether suited, unsuited, hands-free, or carrying equipment; (3) supports horizontal and vertical translation of any cargo/equipment masses capable of being manifested within the habitat; and (4) presents no interference or safety hazards when not in use. Some initial progress has already been made through the work of interns, global crowdsourcing, and NASA internal challenges. This system will be published and incorporated once it reaches a higher level of maturity.

2. HATCH SIZING AND PLACEMENT

Hatch Size

A hatch is, of course, necessary to move between the Common Habitat and any docked vehicles or the exterior environment. It is critical to properly size the hatch as an undersized hatch is literally a choke point that can make it impossible to conduct necessary operations in the habitat. Hatch sizing was studied in 2007 during the Constellation Program. Human factors and habitability practitioners built an adjustable test rig, shown in Figure 3, to derive hatch size constraints.

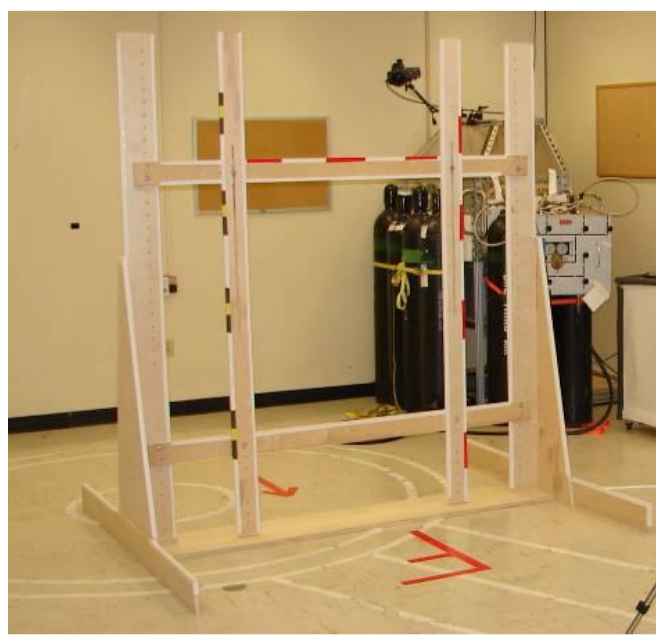

Figure 3. Hatch Sizing Test Rig

The test rig allowed for adjustment in both height and width for rectangular hatch openings and allowed for the insertion of several circular hatch profiles. This enabled the collection of hatch dimensions as suggested by Figure 4.

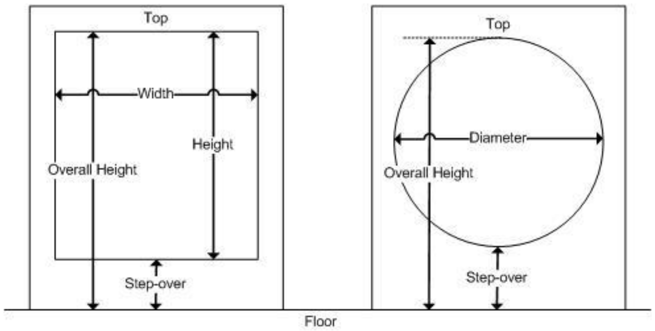

Figure 4. Hatch Sizing Critical Dimensions

Figure 5 shows a suited test subject crossing the hatch during a hatch size test. The rear-entry I-suit was used during this test, pressurized to a 4.3 psi pressure differential. Anthropometry specialists measured critical dimensions of the test subject and extrapolated the impacts of larger or smaller crew members. Based on the requirement to accommodate the entire anthropoetric range of crew members, the test team ultimately determined a necessary hatch size of sixty inches in height, forty inches in width, and a step-over height of sixteen inches.

Figure 5. Suited Test Subject Translating Across Hach

The identified hatch dimensions are interrelated – hatch height cannot be separated from width or from step-over height. Most crew members are significantly taller than the hatch height of sixty inches. They are able to fit through such a hatch through a combination of motions.

As can be seen in Figure 5, the crew member is stepping sideways through the hatch. The first motion is to step over the bottom lip of the hatch opening. This step-over height virtually adds to the total hatch height. If a suited crew member is shorter than the sum of hatch height and step-over height then stepping over the hatch threshold is sufficient to enable translation. But for taller crew members this is not enough. Taller crew members must also bend or stoop as they side step across the hatch, thereby lowering their height. This stooping action increases the forward to back length of the crew member, thus driving the necessary hatch width. Shorter crew members may have difficulty with the 16-inch step-over, but a deployable intermediate step on each side of the hatch can enable hatch crossings for the shortest crew..

It is necessary to size the hatch for a suited crew member because some vehicle contingencies can cause the habitat to lose pressure and force the crew to evacuate to a safe haven while preparing repair actions. The crew may then need to enter the damaged areas wearing spacesuits to conduct repairs.

Coincidentally, the dimensions of an ISS International Standard Payload Rack (ISPR) of 41.3 inches (width) x 33.8 inches (depth) x 79.3 inches (height) [2] indicate that ISPR payloads can fit through the 40-inch x 60-inch hatch. While presently none of the Common Habitat subsystems are packaged in ISS racks it is significant to note that ISS racks can be delivered through the Common Habitat's hatches.

Hatch Placement

The four hatches are placed on the habitat centerline as shown in Figure 6 to minimize structural mass penalties. They are clocked at 90 degree angles to each other, enabling docking on all sides of the habitat.

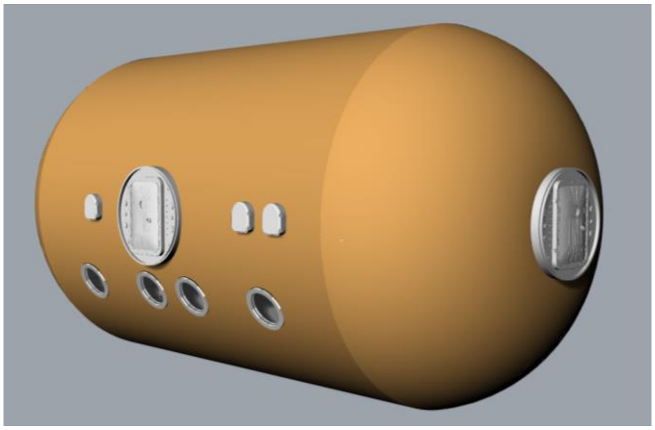

Figure 6. Common Habitat Hatch Placement

The 90-degree clocking of hatches also helps to minimize docking interfacernce. Even large spacecraft can dock at one hatch location without creating interferences with other spacecraft docking. The hatch placement also helps to create internal zones in the Common Habitat, defined by the hatches and internal translation corridors.

3. DECK SEPARATION AND PHILOSOPHY OF THE COMMON HABITAT

Deck Construction

The horizontal orientation of the Common Habitat and its 8.4-meter diameter constrain the habitat to a three-deck configuration. At one or two decks there is too much vertical height, resulting in massive quantities of volume inaccessible to the crew in a gravity environment. At four decks, deck height is insufficient for taller crew members and the top and bottom decks are very limited in usable volume due to the curvature of the floor (bottom deck) and ceiling (top deck). A division of three decks results in a configuration where all three decks can be outfitted for usable living and working spaces.

The mid deck is placed by centering the hatches on the vehicle centerline and based on the previously mentioned hatch study, the mid deck floor is sixteen inches below the hatch bottom opening. The deck has a floor to ceiling height of 2.25 meters (7.38 feet). The mid deck floor thickness is 15.24 centimeters (6 inches)

The upper deck height varies, with a maximum height of 2.85 meters (9.35 feet) along the centerline. Most habitable portions of the deck vary from this height to a minimum of 1.67 meters (5.48 feet), with only subsystems equipment in volumes with shorter heights. The upper deck floor thickness is 20.32 centimeters (8 inches).

The lower deck has a floor to ceiling height of 2 meters (6.56 feet). The lower deck floor thickness is 10.16 centimeters (4 inches).

The floor thicknesses allow for not only floor structure, but also for utilities routing and in some cases subsystem components to occupy the volumes between decks.

While the three-deck solution is viable, the curvature caused by the pressure vessel diameter and end domes does force architectural accommodation. The mid deck is the least impacted because the curvature is closer to a terrestrial vertical wall than either of the other two decks. On the upper deck, the wall curvature forces habitable areas inward, leaving the outer perimeter to floor-mounted subsystem components and stowage. On the lower deck, the wall curvature again forces habitable areas inward, in particular walking and standing areas, but does allow for upper body motion or elevated seating closer to the perimeter of the vehicle.

Separation of Functions

In addition to the physical deck constraints, it is highly beneficial to utilize the decks as a natural way to separate crew functions. There is psychological benefit in doing so in that the crew can associate each deck of the habitat with a specific forms of functionality, rather than having them all be mixed together. Additionally, in microgravity it can help to contain objects that have come unsecured and could otherwise travel through the habitat much more quickly.

Crew functions can be organized in multiple different manners. Living functions can be defined as the functions that must occur as a consequence of the crew being alive, irrespective of the mission of the spacecraft. Living functions include private habitation, hygiene, waste collection, meal preparation, meal consumption, group socialization and recreation, exercise, and medical operations. Working functions can be defined as those as that derive directly from the mission of the spacecraft. They include scientific research, robotics / teleoperations, EVA operations, spacecraft monitoring and commanding, mission planning, maintenance, and logistics operations. [3]

Functions can also be expressed in terms of private functions, mission functions, and social functions.

Private functions are those that the crew will perform alone and with as much isolation from other crew members as possible. Private functions include private habitation, hygiene, and waste collection.

Mission functions are those directly related to pursuit of mission objectives. They include exercise, medical operations, scientific research, robotics / teleoperations, EVA operations, spacecraft monitoring and commanding, mission planning, maintenance, and logistics operations.

Social functions involve more than one crew member and generally do not involve mission-related activity. These are meal preparation, meal consumption, and group socialization and recreation.

The Lower Deck is allocated exclusively to private functions, all of which are also living functions. The Mid Deck is allocated exclusively to mission functions, including a mixture of living and working functions. They are separated in that the working functions occupy the forward and middle of the deck and the living functions occupy the aft of the deck. The Upper Deck is primarily allocated to social functions but also includes several mission functions. Working functions occupy the aft and center starboard of the deck and living functions occupy the forward and center port of the deck.

Detail design of the Common Habitat interior is a work in progress and figures within this paper reflect the interior configuration at the time of image capture.

4. LOWER DECK ORGANIZATION

The Lower Deck, shown in Figure 7, is designed to provide the maximum privacy possible for the crew. Walls and doors are incorporated to create visual, auditory, and olfactory barriers. The functions on the Lower Deck are dissociated with those on the Mid Deck and Upper Deck to allow the crew to retreat from both group and mission demands and find personal alone time throuhgout the mission as needed.

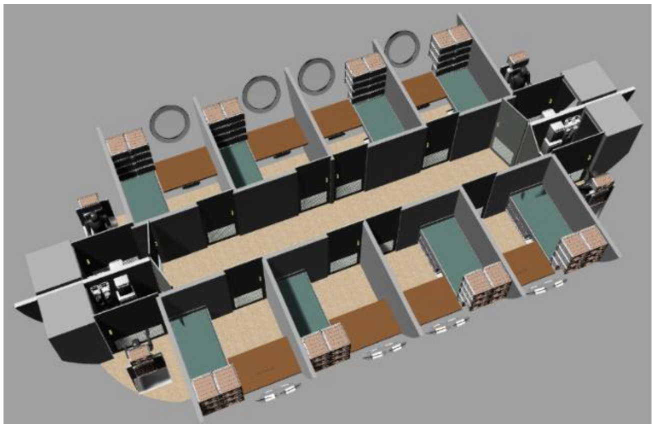

Figure 7. Lower Deck

Private Crew Quarters

Eight private crew quarters occupy the entire barrel section of the Lower Deck, showin in Figure 8. The crew quarters have the requirement to be identical in order to avoid any such differences becoming the source of any psychological stress for the crew. Each must have its own door and must also provide sufficeint volume for a crew member to lie down, use a personal workstation, change clothes, and strech. Each crew quarters contains a horizontal bunk, horizontal work surface, window, and 10.5 mid deck locker equivlaent (MDLE) stowage for clothing and other personal items.

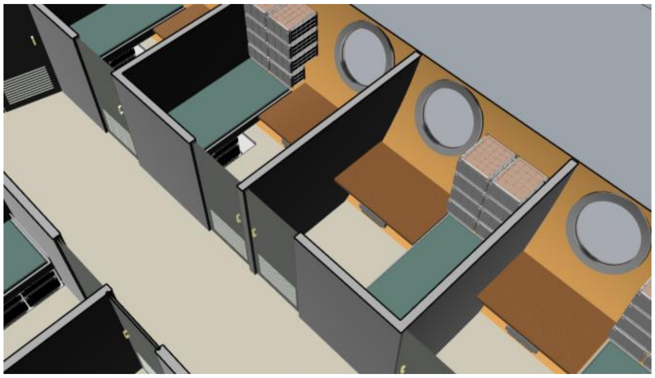

Figure 8. Private Crew Quarters

Waste and Hygiene Clustering

A key design goal for both waste management and hygiene is to minimize waiting in line. This is especially important at the beginning of each day when the crew has a limited time to move through all of the post-sleep tasks prior to the Daily Planning Conference with Mission Control.

Because the crew quarters consume the entire barrel section, both waste and hygeien are limited to the end dome sections. Separate waste management and hygiene compartments are provided based on crew comments that it is, "unacceptable to conduct hygiene-related tasks in the WCS (Waste Containment System) compartment." [4]

In order to complete the post-sleep task quickly, four units of both hygiene compartment and waste management compartments are provided, using both end domes, shown in Figure 9. Each dome contains two combo waste and hygiene compartments. Within each compartment is an outer chamber. It is a changing room and an entrance to both the waste management compartment and the hygiene compartment. The outer chamber includes stowage compartments and can support facial and hand hygiene. The hygiene compartment provides full body bathing. The waste management compartment includes a toilet and two stowage lockers that provide a total of 1 MDLE stowage for waste management supplies.

Figure 9. Waste and Hygiene Compartments

Water Tanks

The water tanks for the Common Habitat are located beneath the floor of the Lower Deck, occupying the volume between the floor and the pressure vessel. The three water tanks hold a total of 5598.67 kg of water, nearly 1485 gallons. [5] This water allocation is intented to enable a contingency mode in the event of failur of the closed loop system, allowing nominal water usage to continue for at least 30 days while the system is repaired.

Currently, only potable water tanks are modeled. Forward work is to include waste water tanks, potentially located both beneath the floor and in the domes behind the waste management compartments. Additionally, as a mass vs. risk trade, compartmentation of the potable water tanks may also be investigated.

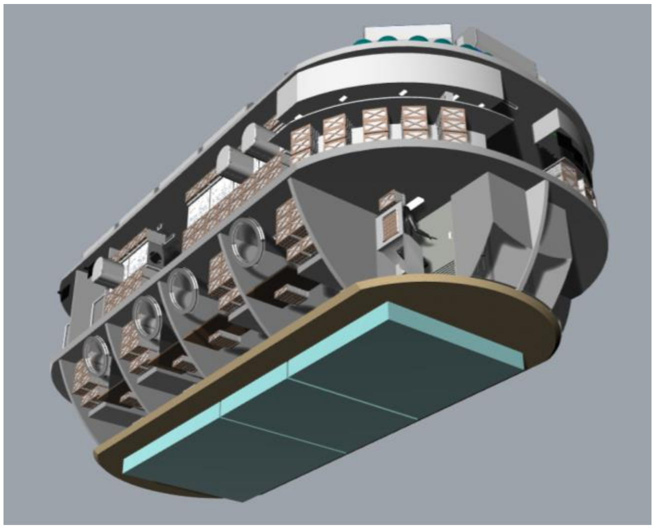

Figure 10. Water Tanks

5. MID DECK ORGANIZATION

The Mid Deck, shown in Figure 11, is the transfer point to any docked elements and it is where the crew spends the bulk of their work day.

Figure 11. Mid Deck

Exercise

As shown in Figure 12, the Common Habitat uses the ISS exercise devices due to the anticipated mission durations. The ISS has sustained crews for missons up to one year in duration. The Common Habitat is intended for missions more than three times as long.

Exercise devices currently in development for Orion and Gateway are based on mission durations in the vicinity of 20-30 days. There are no exercise devices in development that approach Common Habitat misson durations, leaving the ISS devices as the most advanced and most suitable options available. Additionally, due to the eight-person crew size, more devices are needed. Two Advanced Resistive Exercise Devices (AREDs), two Cycle Ergometers with Vibration Isolation System (CEVIS), and two second generation treadmills (T2) are included. Six MDLE stowage is provided for device accessories. Display screens are positioned in front of the aerobic devices for crew use while exercising. Lightweight partitions are used to isolate each exercise device to contain crew member sweat. The aerobic devices are on the port side of the deck and resistive devices are on the starboard side.

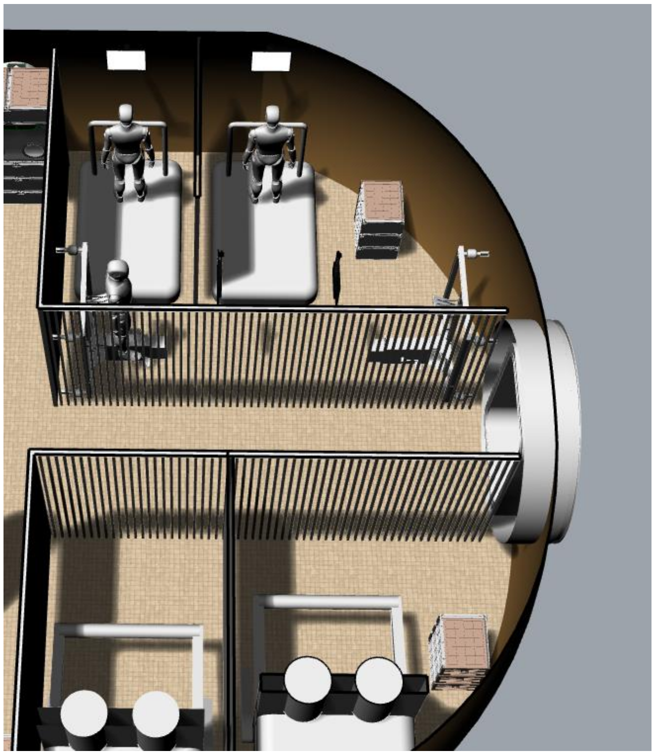

Figure 12. Exercise Devices

Life Science

The Life Science Laboratory is shown in Figure 13. This lab is devoted to space biology and human research. It contains a total of 47 MDLE, which are allocated to a mixture of science instruments, equipment stowage, powered cargo, and unpowered cargo. The lab also includes four gloveboxes, of which two are equipped with sample airlocks. These can expose the glovebox interior to the ambient local environment or can be used to transfer items from the glovebox to the exterior environment. The laboratory also contains a Minus Eighty-Degree Laboratory Freezer for ISS (MELFI).

The lab also includes a large instrument opportunity. The Common Habitat's diameter allows for at least one oversized science instrument in the Life Science Laboratory, with the only real constraint that it must fit through the 40-inch by 60-inch hatches. This capability is represented in the current baseline with a large centrifuge, sized to accommodate small animal payloads in the rotating section, allowing for fractional g and hyper-g studies.

Figure 13. Life Science Laboratory

Physical Science

Shown in Figure 14, the Physical Science Laboratory supports physics and geology research. It contains 65 MDLE and as with the Life Science Laboratory, these MDLE are allocated to science instruments, equipment stowage, powered cargo, and unpowered cargo. Included in the 65 MDLE are eight -185C freezers for cryogenic sample storage. Also similar to life scinece, the Physical Science Laboratory includes four gloveboxes, two of which have science airlocks. The Physical Science Laboratory provides additional horizontal work surface, a portion of which is devloted to a Remote Sensing Workstation that accesses extenral science instruemnts for astronomy, heliophysics, planetary science, and Earth science. Oversized equipment include two combustion chambers, two fluid dynamics chambers, and a gas chromatograph.

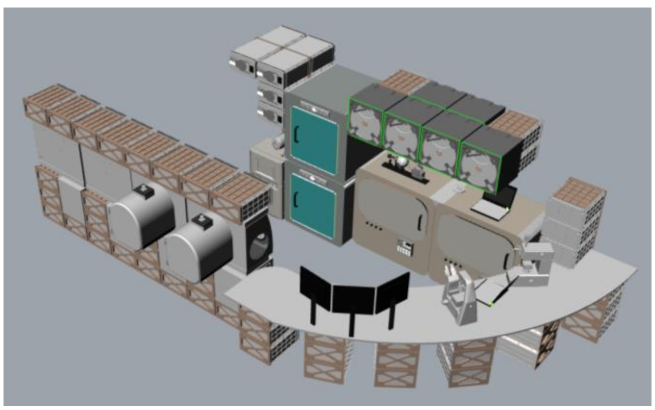

Figure 14. Physical Science Laboratory

Repair, Maintenance, and Fabrication

The Repair, Maintenance, and Fabrication (RMAF) Facility occupies the center of the Mid Deck and is shown in Figure 15. This does complicate its layout as it lies at the intersection of both horizontal and vertical translation paths. However, that also provides a direct access route for any equipment requiring RMAF services. It is currently organized into three distinct horizontal work surfaces and four gloveboxes, of which two have component air locks enabling direct access to the exterior environment. The component air locks enable repair of external equipment that should not be exposed to the cabin atmosphere. A bank of 3D printers is also contained within the RMAF Facility.

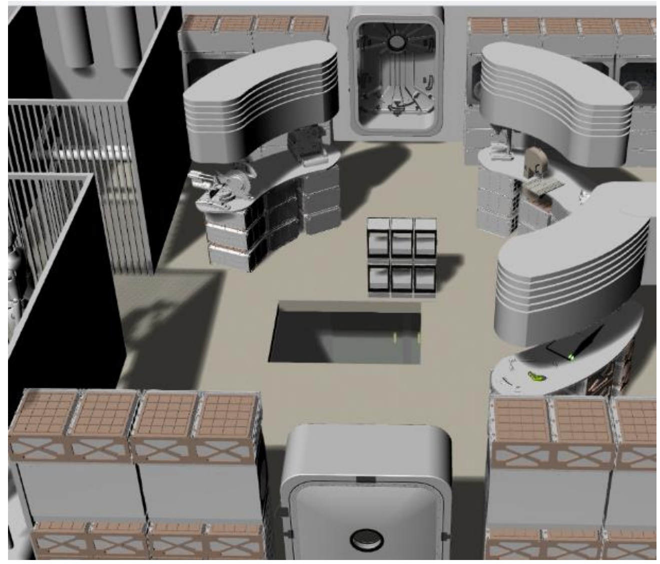

Figure 15. Repair, Maintenance, and Fabrication Facility

Significant forward work remains to design the specifics of this facility. It is intended to support additive manufacturing, includisve of PCB printing, plastic 3D printing, and metal 3D printing.

It will support non-additive manufactoring in the form of drilling, cutting, rolling, and bending. These processes will generate shavings or other particulates and an environmental control system will be needed to protect the crew from hazards associated with these byproducts.

The RMAF will also support soft goods and thermoplastics work, some of which will also require dedicted environmental control systems. Finally, software activity including software development, CAD modeling, simulation, and analysis can be conducted within the RMAF Facility.

6. UPPER DECK ORGANIZATION

The Upper Deck, shown in Figure 16, houses functions either of a social nature or mission-related functions that are best isolated from other mission functions.

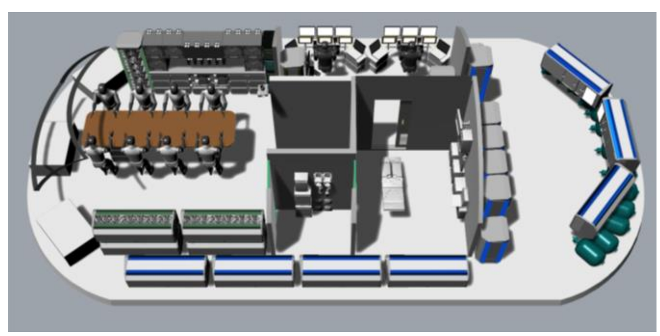

Figure 16. Upper Deck

Plant Growth

Five plant growth chambers, visibile in green in Figure 17, are located on the Upper Deck to grow fruits and vegetables to supplement the crew prepackaged food system. Each chamber is the size of the pallets initially proposed for Gateway subsystems, measuring 1.88 meters by 0.64 meters by 0.61 meters.

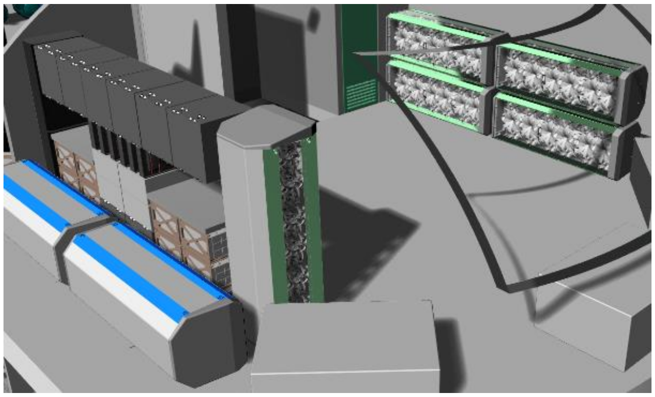

Figure 17. Plant Growth Chambers

Galley

The Galley, showin in Figure 18, is sized to provide rapid meal pepration for the eight person crew. It is intended to minimize wait times and enable all eight crew to prepare and eat meals together without one person's meal growing cold before the others have been prepared.

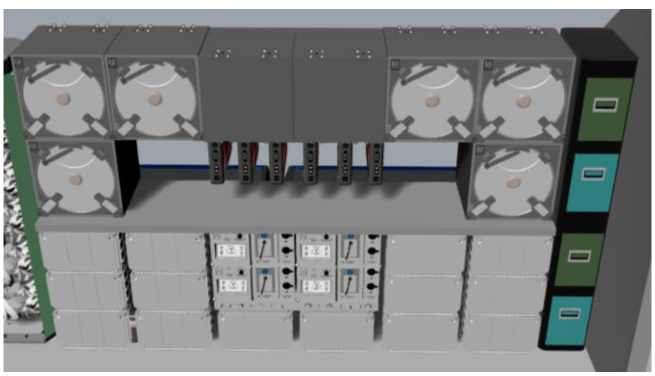

Figure 18. Galley

The Galley includes six modified food warmers that collectively can heat twenty-four thermostabilized or rehydrated packets in parallel and four water dispensers, each of which can dispense hot, ambient, or cold water. It includes a freezer volumeterically identical to the MELFI with six individual dewars. Its stowage capacity is fourteen MDLE and it includes two wet trash and two dry trash receptacles. A horizontal work surface with deployable leaves aids in organizing food during meal preparation.

Wardroom

The Wardroom table, shown in Figure 19, provides room for eight crew members to dine together during meal events and also provides sufficient volume to facilitate crew meetings. The table is mounted on eight mid deck lockers that provide stowage for dining, meeting, plant growth, and recreational equipment. The table and lockers can disassemble and stow against the wall, freeing up space for group recreation activities. A ceiling mounted projector can project videos on a panoramic screen mounted on the habitat pressure vessel hull for crew movie nights or other video entertainment.

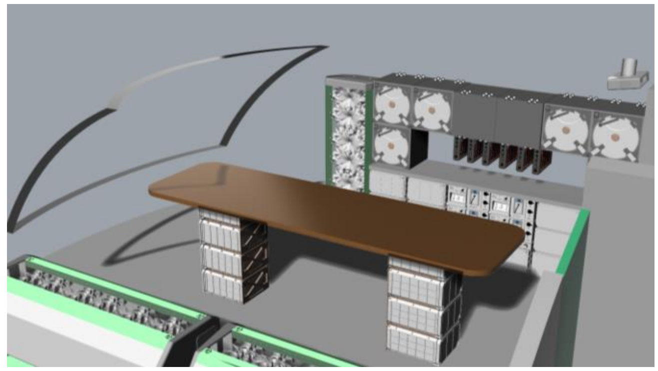

Figure 19. Wardroom Table and Projection System

Bulk Stowage

The Common Habitat has limited volume for bulk stowage on the Upper Deck. Three M3 stowge bags, shown in Figure 20, each of which holds 10 Cargo Transfer Bag Equivalent (CTBE) stowage, are accommodated on the floor, just beneath the projection screen. These bags represent an intermediate storaege system – items that have been retrieved from the Logistics Module, but are not yet daily use items. These bags will include food resupply, plant growth conusmables, replacement recreational items, medical resupply items, and subsystem spares. When these items run low in their nominal areas of use, the crew will resupply from these bags rather thn having to make trips down to the Logistics Modules. It is only when these bags run low that the crew will resupply the Upper Deck by bringing one or two fresh M3 bags up and consolidating the prior, nearly empty bags.

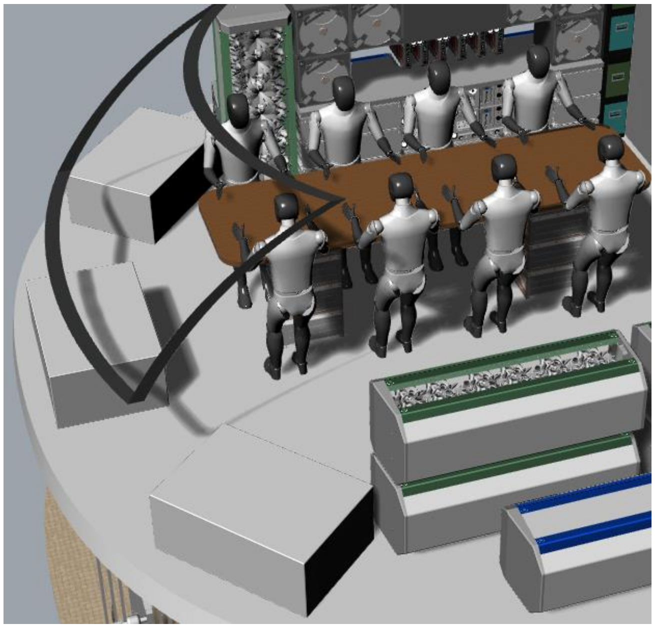

Figure 20. Bulk Stowage Containers

Command and Control Center

The Command and Control Center shown in Figure 21 gives the crew monitoring and command access to all of the spacecraft subsystems and telemetry. It also facilitates teleoperated command of other surface or space elements. It can also serve as a backup to the Remote Sensing Workstation to operate the observatories and other sensing platforms connected to the Common Habitat's surface or in-space configuration, enabling the crew to conduct astronomy, heliophysics, Earth science, and planetary science investigations.

Figure 21. Command and Control Center

Power and avionics subsystems also allocate some equipment to the Command and Control Center. A power half-pallet, containing power management and distribtuion components, and an avionics pallet, containing most of the avionics subsystem component, are also located within the Command and Control Center.

Medical Facility

The Medical Facility in Figure 22 provides preventative and emergency medical care for the crew. The facility is designed to provide 360-degree caregiver accecss to the patient.

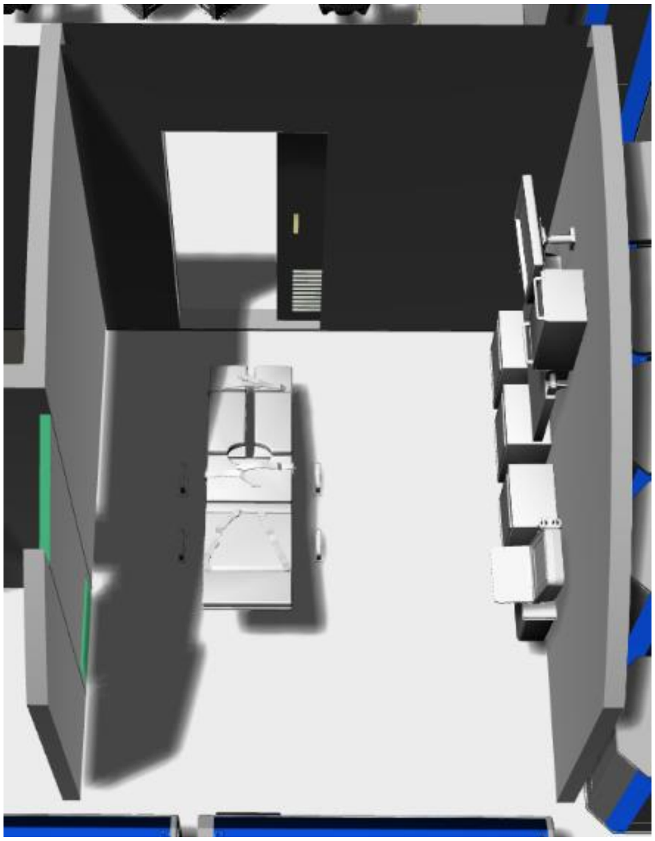

Figure 22. Medical Facility

The volume is more than sufficient to accommodate an outfitting of medical supplies greater than that allcoated to the International Space Station. Actual outfitting of this facility remains as forward work. The notional models represened in Figure 22 do suggest an important design consideration. The surgical bed is reconfigurable to support a variety of patient postures for different medical events. This will be carried forward as a design requirmeent. Additionally, there is a display screen on the wall, suggesting potential telemedicine capabilities. However, there is significant opportunity to improve cargeiver access to medical equipment while providing patient treatment. A complete redesign of the facility is planned.

Hygiene

A unique feature in the Common Habitat layout places a Hygiene Compartment next to the Medical Facility. While it is also used in support of the Galley and Wardroom and is accessed via a forward entrance, the compartment, shown in Figure 23, also opens directly to the aft into the interior of the Medical Facility. This can support hygiene for both the cargeiver and patient prior to initiating medical care.

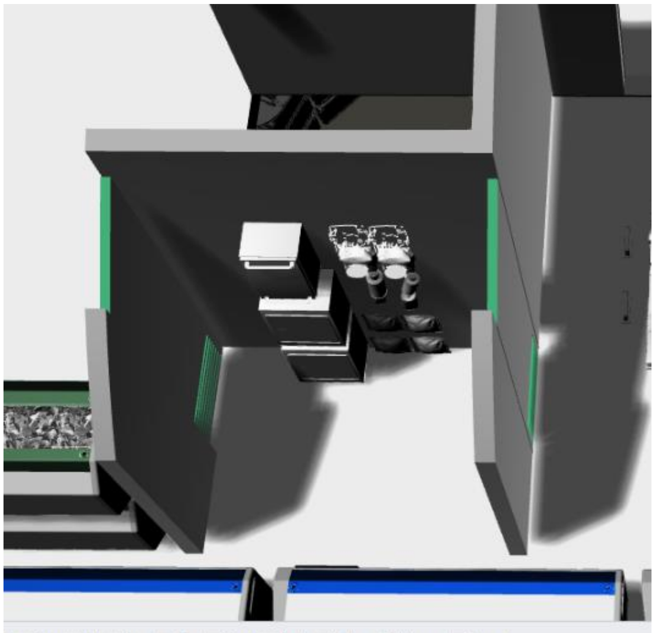

Figure 23. Hygiene Compartment

Subsystems

The aft dome of the Upper Deck, shown in Figure 24, is allocated to habitat subsystems, primarily environmental control and life support (ECLSS).

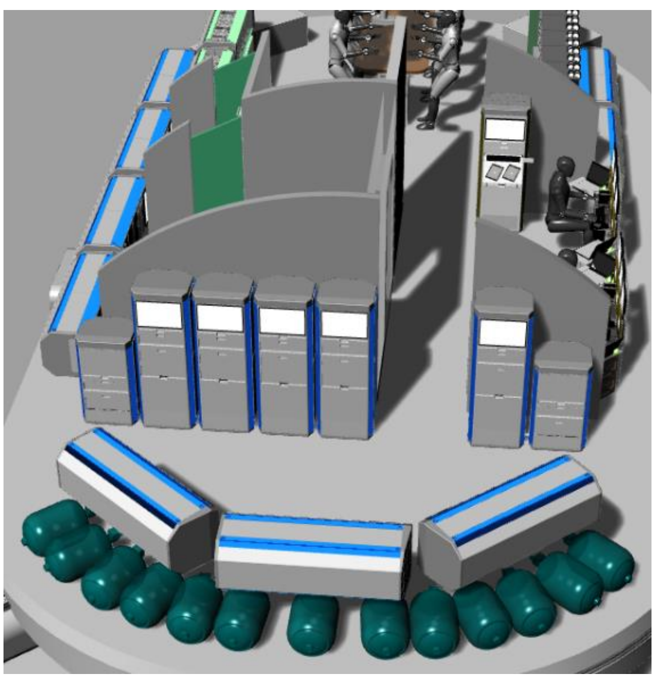

Figure 24. Subsystems

The subsystem pallets used in this model are similar to those initially proposed for the Gateway spacecraft. Eight full size and two half size ECLSS pallets are located in the aft dome, with another six ECLSS pallets line the starboard and port sides of the Upper Deck. Retired NASA engineer Mark Jernigan had stated prior to his retirement that thirteen pallets are needed for a redudnant, closed loop life support system. The additional two pallets support plant growth and particulate/debris control in the Mid Deck gloveboxes and the Fabrication, Maintenance, and Repair Facility.

As previously mentioned, avioncis and power pallets are visible in the Command and Control Center in Figure 21. There are no pallets for the thermal control subsystem. It is assumed that thermal pumps, reservoirs, and other components are embedded in the volume between decks.

Additionally, nitrogen and oxygen are contained in thirteen Nitrogen/Oxygen Recharge System (NORS) tanks.

7. CONCLUSIONS / RECOMMENDATIONS

Summary

The interior architecture of the Common Habitat will allow eight crew to live and work effectively for very long duration missions in multiple destinations in Earth orbit and beyond. This represents the verison of the Common Habitat to be carried forward in studies to define its use on the lunar surface, Mars surface, in microgravity applications, and in other uses throughout the inner solar system.

Forward Work

Forward work involves adding additional design detail to virtually every aspect of the Common Habitat. Each of the crew stations and work areas require refinement. A gravity-independent restaints and mobility aids system is in work and will be incorporated when suffiicently mature. A trade of window locations and nubmers will be conducted. The water tanks will be expanded to include both potable water and waste water, sizing and adding waste water tanks to support water recovery. A utilities network will be created, connecting subsystems to components throughout the habitat and to the docking ports. Vehicle subsystems will be analyzed at a higher level of fidelity and the impact of gravity on fluid flows will be considered. Finally, a bottoms-up mass estimate will be conducted with optimization trades as needed to keep the Common Habitat mass less than or equal to a target allocation of 90,000 kg.

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