Configuration and Projected Capabilities of the Common Habitat Medical Care Facility

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The Common Habitat is a large, long-duration habitat being explored as part of a conceptual study (not an active NASA program) that uses an SLS core stage Liquid Oxygen (LOX) tank as its primary structure. It is intended for use on the Moon as part of a permanently occupied outpost, on Mars as part of an outpost that will be occupied for hundreds of days at a time, and in deep space as part of the Deep Space Exploration Vehicle where it will support crewed missions up to 1200 days in duration. A study of internal orientation and crew size resulted in a Common Habitat configuration sized for a crew of eight with a three-deck horizontal orientation. Additional work outside the scope of this paper is developing a vertical translation system, a crew mobility aids system based on wearable gecko-derived grippers, and a crew seating/restraint system. These systems are all intended for use in conjunction with the Medical Care Facility, which is needed to maintain crew well-being during these missions, where distance from Earth precludes the possibility of evacuation to Earth. This paper describes recent improvements in the Common Habitat Medical Care Facility and associated benefits for crew survivability in long duration missions beyond Earth orbit. These improvements were made with the assistance of a NASA Pathways intern whose experience includes a tour of duty in Afghanistan as an Army combat medic with the 691st GHOST-T, attached to the 1st and 7th US Special Forces Groups as part of Operation Freedom's Sentinel, where he helped provide far-forward surgical capabilities in austere combat environments. The initial baseline Medical Care Facility was developed working in conjunction with University of Houston Space Architecture graduate students. The facility was placed on the upper deck of the Common Habitat in a location that provided privacy, operational volume, and was close to the vertical translation pathway. The notional outfitting repurposed component CAD models from unrelated studies and notionally indicated a level of care roughly equivalent to that aboard the International Space Station. The CAD modeling provided notional stowage volumes, a deployable surface, some fixed equipment, an ultrasound, and a potentially reconfigurable treatment table. While this facility is clearly a competent arrangement, it was desired to leverage available expertise and upgrade the station given the vast distances from Earth to be experienced by the Common Habitat. Key capabilities applied to the upgrade included to provide NASA's Medical Level of Care V, offer enhanced telemedicine capabilities, provide patient physical accommodation, provide caregiver access to the patient from all sides, include sliding pocket doors for access to hygiene and to the Vertical Translation System, and to add any additional capability possible for the best achievable medical care. The first step in the facility upgrade was to quantify the current medical inventory on the International Space Station and ensure that sufficient stowage volume was present for this purpose. To that end, the ISS medical kits were reviewed, and eight full size mid deck lockers were placed in the facility. A number of additional devices were also added, based on the co-author's combat medic experience. Also, two fixed shelves and one horizontal work surface were added to the Medical Care Facility, with the shelves providing storage space for the additional devices and the work surface providing a location for the caregiver to work or stage equipment. Four display monitors were added to the wall above the horizontal work surface, supporting data display, telemedicine, conferencing, or

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other needs. The existing treatment table was replaced with a mobile surgical stretcher-chair. Two additional doors were added to the Medical Care Facility. One leads directly to the hygiene compartment, allowing it to support medical operations in addition to providing galley/wardroom support. The other door leads directly into the Vertical Translation System. The wall adjacent to the subsystems bay was moved, adding additional volume to the Medical Care Facility. This improved caregiver access to the patient and allowed for a larger number of caregivers to be present. It also provided options for relocation of support equipment relative to the patient as needed. In the upgraded Medical Care Facility, the Surgical Stretcher-Chair and the Vertical Translation System can work together to provide incapacitated crew member transport from a site of injury on any deck of the Common Habitat to the Medical Care Facility. It can also support patient treatment in a variety of positions including a variety of sitting postures and a supine posture at a variety of pitch angles. The facility can also support caregiver office work for review of examination results, private consultation, inventory and maintenance, and a variety of other purposes. A forward activity will be to conduct evaluations of the Medical Care Facility with different medical scenarios. Additionally, ambient and task lighting selections remain as forward work. The eight middeck lockers can be augmented to use as portable equipment carts, similar to a manner in which maintenance facility stowage was used as portable carts during the NASA Desert Research and Technology Studies in the Constellation Program. Trash accommodation will also need forward work to assess, including provision for wet trash, dry trash, and biological waste. It will be important to assess a redesign of the surgical stretcher-chair. The commercial version used in the upgrade can only enable vertical translation in the seated configuration, causing the patient to bend both hips and knees. A possible redesign of the chair will allow for vertical translation without` necessitating any bending at the hip or knees. Also, the commercial version is wheeled, making it mobile in gravity but unanchored in microgravity. Work will be needed to adapt the chair for gravity-independent performance. The hygiene compartment can be redesigned to serve both as a medical scrub facility and for galley hand washing. Pending sufficient volume, it may also be possible to place sanitation equipment in this location to clean medical tools. Finally, most space architectures have never allowed for more than one incapacitated crew member, but several scenarios could potentially injure two or more crew in the same incident. This facility could be assessed to determine its present ability to address two or more injured crew in parallel and determine the potential upper limit for number of treatable crew in a multi-crew injury scenario, or to treat polytrauma of a single patient.

I. Introduction

The Common Habitat is the conceptual central element of a human spaceflight architecture signified by a long-duration habitat designed to be equally suitable for human use in different gravity environments: 0g, 1/6g, 3/8g, 1g, and artificial gravity. [1] The Common Habitat is not part of the current NASA reference architectures for exploration of the Moon and Mars. It is instead an ongoing study of potential options that – should viability be demonstrated – could potentially be applied to human exploration programs. It shares a similar design approach to Skylab in that it uses the SLS Core Stage Liquid Oxygen (LOX) tank as the primary structure and pressure vessel. The hope is that Common Habitat studies will identify systems, architectures, and elements with potential to significantly advance NASA human space exploration if merged with NASA plans.

An entire architecture has been created around the Common Habitat, enabling human exploration of much of the inner solar system. Extensive commonality is applied to other elements in the architecture, which are used to constitute Moon and Mars surface bases [2] and a Deep Space Exploration Vehicle (DSEV). [3] Earth orbiting propellant depots are also used to enable the architecture.

The Common Habitat Medical Care Facility (MCF) is primarily responsible for providing medical care for the crew. This is inclusive of nominal preventative care as well as treatment of injuries, illnesses, or chronic conditions. The facility also supports human medical research. The laboratory equipment of science facilities within the Common Habitat may also be used to support medical activity.

Common Habitat work is a primarily unfunded effort limited to civil servant spare time and intern support. When the lead author gained access to an intern (the second author of this paper) with Army combat medic experience it was an opportunity to explore the medical care facility in greater detail. Brady completed Army Combat Medic School and attended the Army Trauma Training Center at the University of Miami Miller School of Medicine/Ryder Trauma Center. As an Army Combat Medic, he served our country as part of Operation Freedom's Sentinel, where he was deployed to Afghanistan with the 691st GHOST-T under the Special Operations Task Force. Attached to both 7th and 1st US Special Forces Groups, he provided far-forward surgical capabilities in austere combat environments.

Often, discussion of medical capability in exploration spacecraft is focused heavily on the contents of a crew health system (e.g., medicines, medical instruments, and data access/management) with limited discussion of how the resulting medical care systems are arranged within the habitat's layout. While this paper focuses specifically on the Common Habitat, the distinctives of this medical care facility may help stimulate discussion in other exploration habitat architectures.

As seen in Common Habitat layout images to date, such as in Figure 1, no restraints or mobility aids are shown. Because the Common Habitat will operate in microgravity, lunar gravity, Martian gravity, and terrestrial gravity, traditional spaceflight crew restraints and mobility aids such as handrails and foot restraints will not work. Neither will traditional terrestrial implements such as stairs and chairs. A common solution for crew restraints and mobility aids that will work in all gravity environments is developing under separate research efforts and fall outside of the scope of this paper.

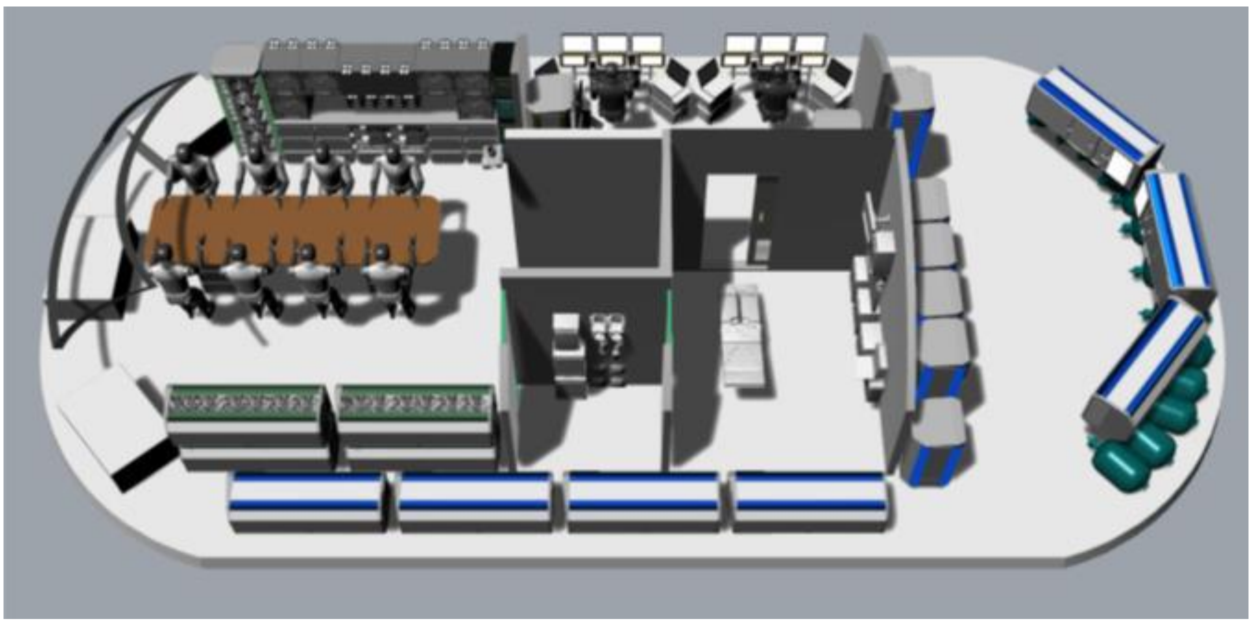

Fig. 1 Common Habitat Upper Deck

II. Medical Operational Concepts

A crew member can potentially be injured anywhere within the Common Habitat, or even while on an extravehicular activity (EVA) or while in another spacecraft element. Any such crew member will be transported to the Medical Care Facility for treatment. Depending on the nature of the medical event, the crew member in question may be able to translate to the MCF under his or her own power or may suffer from some degree of incapacitation and need assistance from one or more other crew members and/or MCF systems.

Within the MCF, a patient may be examined or treated in any of multiple postures. For some examinations a patient may be standing, either in open space, or against a specified wall. In other cases, the patient may be seated, with possible elevation of legs or reclining of the back. In still other cases, the patient may be fully prone, lying on the back, stomach, or either side. One or more crew acting as caregivers may be present to provide medical treatment. The current configuration of the MCF does not include robotic systems for providing care, but that could be considered in future design iterations.

The MCF also supports medical office work in addition to patient treatment. This may include research activity, review of patient records, report writing, training and continuing education, and private medical audio and video conversations. It may be noted that private medical conversations include ship-to-ship, ship-to-surface (e.g., Moon, Mars), ship-to-ground (e.g., Earth), and intercom to individual crew quarters.

It is likely that the Common Habitat crew includes at least two trained physicians fully capable of utilizing the medical equipment in the MCF. The remaining crew will possibly have training equivalent or superior to that of paramedics. Due to the distances from Earth and inability to evacuate crew, the provision of medical care must be an imbedded crew capability regardless of which crew member is the one needing treatment.

III. Baseline Medical Care Facility

A. Rationale for a Dedicated Medical Care Facility

One option that has been employed in other exploration architectures is to utilize the crew quarters for medical care. However, as the number of crew increases this approach becomes less practical as it would be necessary to relocate the medical inventory to the quarters whenever medical care is desired. It would additionally impose temporary stowage and utilities impacts on every crew quarters, which would be a substantial volume increase for an eight-person crew. Further, it imposes a burden on the crew to configure a medical care capability while the crew member in need of treatment waits, something that may be impractical in the event of a medical emergency.

Another option is to merely provide stowage for medical supplies with no specified location for medical treatment. However, given that the medical system will utilize some level of utilities – power, data, fluids – there will be a finite number of locations capable of supporting medical care. Any of these will need to be suitably scarred to receive medical equipment and reconfigure for patient treatment; like the crew quarters option, the patient is forced to wait while the crew sets up a medical care capability.

A third option is to merge medical care with life sciences. This approach was employed in the Deep Space Habitat analog habitat tested by NASA just after the cancellation of the Constellation program. However, during the 2012 Mission Operations Test, the crew noted that the presence of life science equipment cluttered the medical area. In general, switching between science and medical activity could delay the initiation of medical care.

The solution implemented in the Common Habitat is a dedicated medical facility. The amount of medical equipment is best managed with a dedicated location that is immediately accessible to the caregiver. Additionally, lighting, privacy, sanitation, and utilities interfaces can be configured as needed for medical care without imposing otherwise unneeded impacts throughout other sections of the habitat.

B. Rationale for Location Within the Common Habitat

Separation of functions was a key driver for placement of the Medical Care Facility. A foremost consideration was visual and auditory separation from utilization activities. It is expected there will be ongoing audio and video downlinks associated with science and maintenance activity. Many activities in these sections of the habitat will involve collaboration with multiple investigators across the Earth. These video downlinks must not include accidental views of medical care in progress or transmit associated sounds. Isolating medical care from these activities will eliminate the need to pause utilization activity while medical care is provided.

Separation from particulates and fumes was also a consideration. While the science and maintenance facilities employ glove boxes and other systems to capture generated particulates and fumes, it was deemed beneficial to add an additional layer of protection by placing the Medical Care Facility behind closed doors on a separate deck. This multi-layered defense is intended to ensure that crew medical care is never adversely impacted by utilization activity.

Medical care is also separated from, but in proximity to, mission operations. This optimizes communication between mission commanders, caregivers, and Earth or other spacecraft during real-time mission planning that impacts or is impacted by active medical care. Finally, medical care is located in proximity to environmental control and life support subsystem (ECLSS) hardware, simplifying access to oxygen, water, or other fluids as well as simplifying air control.

These considerations led to placement of the MCF on the upper deck of the Common Habitat, roughly towards the aft of the port barrel section.

C. Privacy Considerations

Visual, audio, olfactory, and data privacy are often sacrificed in human spaceflight crews due to limited spacecraft volume, but the Common Habitat attempts to enable these forms of privacy to better respect the psychological needs of the crew. The opacity of the floor, walls, and doors provides visual privacy for the MCF, isolating its activity from other areas of the habitat. Acoustic insulation adds a layer of audio privacy as well. Olfactory privacy isolates any smells associated with the MCF from the remainder of the spacecraft. Because of its proximity to the ECLSS, the MCF has a dedicated air supply and return loop that bypasses the rest of the vehicle. Data privacy is maintained within the vehicle's onboard networks and data encryption.

D. Initial Notional Outfitting

The initial Medical Care Facility, shown in Figure 2, was developed during a trade study of crew size and habitat orientation. [4] The layout and outfitting were identical in the four- and eight-person horizontal habitats. The outfitting was also identical for the four- and eight-person vertical habitats, though the layouts of those two variants were both unique. The notional layout shows a surgical bed that implies some degree of reconfiguration to support a variety of medical scenarios. This replaces the thirty-year-old ISS Crew Medical Restraint System. [5] A single display monitor is mounted to the wall, as is one laptop computer. A number of notional boxes representing stowage and waste containers are also mounted to the wall.

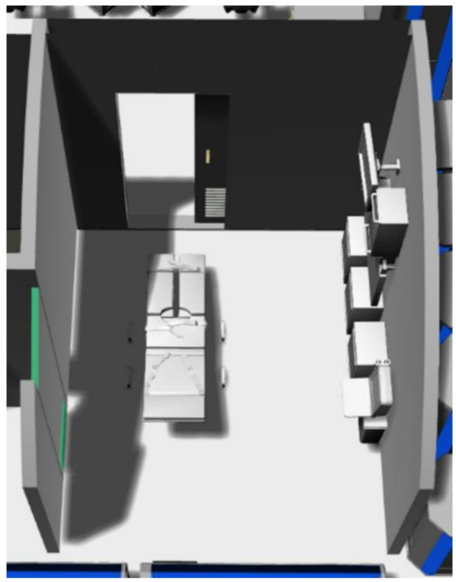

Fig. 2 Baseline Common Habitat Medical Care Facility

IV. Key Capabilities

While not true requirements in a systems engineering framework, several key capabilities were established to move the MCF beyond a notional representation and to provide enough fidelity to support future assessments of the viability of the Common Habitat architecture:

A. Medical Level of Care V

Due to the Common Habitat mission, the MCF must fully meet Medical Level of Care V standards identified in NASA-STD-3001. [6] However, it should consider this standard to be the lower limit of acceptability and should strive for the greatest possible medical care as there is no possibility of crew evacuation or alternate medical care.

It is not entirely clear what equipment is associated with Level of Care V, but Revision B of NASA-STD-3001 explicitly specifies the following capabilities for this level of care: Space Motion Sickness, Basic Life Support, First Aid, Private Audio, Anaphylaxis Response, Clinical Diagnostics, Ambulatory Care, Private Video, Private Telemedicine, Limited Advanced Life Support, Trauma Care, Limited Dental Care, Medical Imaging, Sustainable Advanced Life Support, Limited Surgical, Dental Care, Autonomous Advanced Life Support and Ambulatory Care, and Basic Surgical Care. Additional interpretation of NASA-STD-3001 Levels of Care was provided in a NASA Technical Memorandum. [7]

It is worth noting that after this work was completed, NASA removed levels of care from its standards. On April 8, 2022, NASA-STD-3001 Volume 2 was updated with Revision C, which deleted the Level of Care standards. [8] The current NASA approach is based on a probabilistic risk assessment using tools maintained by the NASA Human Research Program, notably the Integrated Medical Model. [9] NASA is currently developing a new tool, Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT), [10] but as of the time of the MCF design activity, Revision B of NASA-STD-3001 was in effect and was the key driver of minimum medical capabilities.

B. Enhanced Telemedicine

The facility must enable telemedicine – both real-time (when the Common Habitat is close to Earth) and delayed (when the Common Habitat is too far away for real-time communication). Telemedicine is taken to include audio, video, and data sharing between the MCF and other entities, which does include the ground but might also include another spacecraft. It is worth noting that the Common Habitat architecture includes four Common Habitats – one as part of the Lunar Base Camp, one as part of the Mars Base Camp, and one each as part of two Deep Space Exploration Vehicles. At least two of these habitats are crewed at any given time, and three are crewed for significant periods of time, opening the door to collaboration between medical crews on different vehicles. Future research could identify a wide variety of use cases to share and utilize medical data in the course of patient treatment.

C. Provide patient physical accommodation

The facility must physically accommodate the patient. The exact same system must work on Earth, the Moon, Mars, and in microgravity. This implies physical accommodation for a variety of medical scenarios and will inherently support multiple body positions, types of injuries, and anthropometric ranges.

D. Provide caregiver access to patient from all sides

Caregivers must be able to access the patient from all sides. This implies that the caregiver have sufficient access to treat concurrent injuries in multiple parts of the body (e.g., a scenario with head, foot, and arm injuries).

E. Include sliding pocket doors for access to the Hygiene Compartment and to the Vertical Translation System

Despite being a large pressure vessel, the numerous functions within the Common Habitat result in volumetric limitations. There is insufficient room in the upper deck for hinged doors, leading to sliding pocket doors as a solution. The hygiene compartment plays a key role in medical care and there must be direct physical access between it and the MCF. Similarly, patient transport from other decks imposes a need for direct access from the Vertical Translation System to the MCF. Figure 3 shows access to the hygiene compartment and to the Vertical Translation System. While these two doors are necessary, the MCF is not limited to only those two should there be value in other translation paths, such as the third exit shown in the figure.

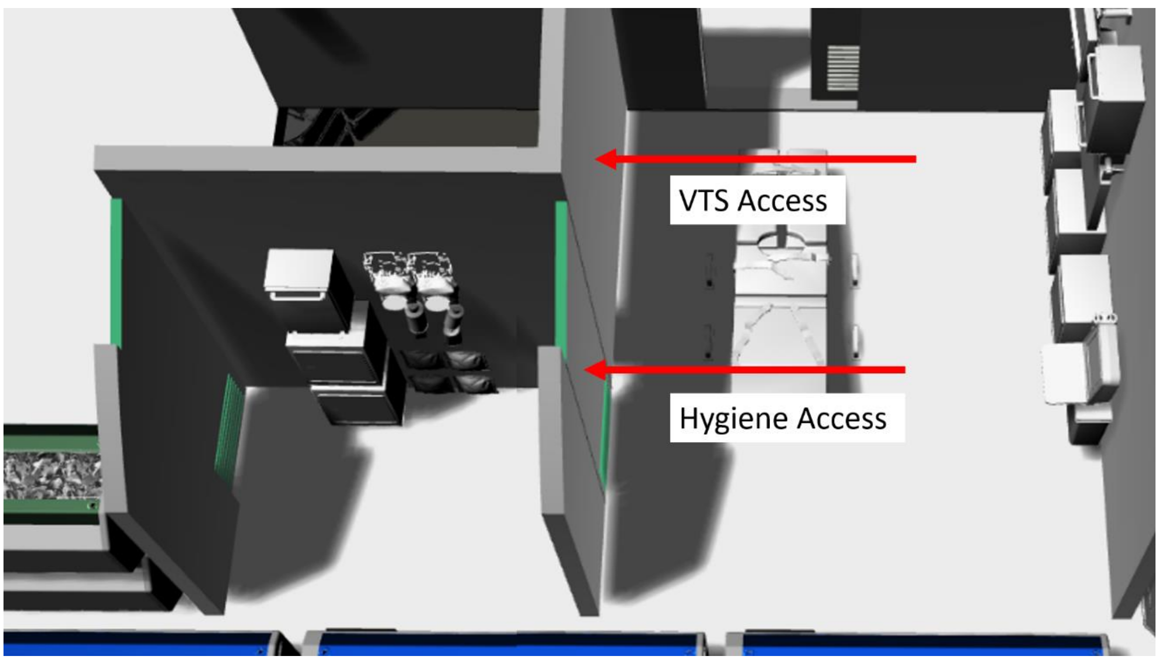

Fig. 3 Access to the Hygiene Compartment and the Vertical Translation System

F. Medical Privacy

Medical care must be isolated from other parts of the habitat to ensure medical privacy. As an example, cameras transmitting activity in other parts of the habitat (e.g., telemaintenance activity in progress or a science laboratory experiment) should not have accidental views of patients undergoing treatment.

G. Add Additional Capability for Best Possible Medical Care

Beyond the above directives, the Common Habitat is a long-duration spacecraft intended for human use throughout the inner solar system. Any medical scenarios are wholly dependent upon the habitat's resources to ensure crew survivability. Therefore, subject to the volumetric limitations of the Common Habitat and other existing functions, the directive is to increase medical performance where possible.

V. Updated Medical Care Facility Content and Layout

The update to the MCF began with an examination of the ISS medical inventory. The co-authors considered the description of Level of Care V and the intern co-author was instructed to use his medical experience to add what he thought might be missing from the ISS inventory to make up the difference. (An Integrated Medical Model run would have been ideal at this point, but as an unfunded exercise it was not possible, with the experience of an Army combat medic standing in its place.) Documentation of anticipated exploration medical conditions [11] was also used to help frame an understanding of medical needs. Conditions that would call for evacuation / return to Earth on ISS must instead be treated in place on the Common Habitat. And the missions beyond low Earth orbit may also lead to possible injuries that are not concerns on ISS. Medical scenarios used to help down-select the eight-crew horizontal variant of the Common Habitat were also considered, [12] along with consideration of the range of missions and possible destinations in the Common Habitat architecture.

A. Additional Medical Devices

Based on the co-author's experience as an Army combat medic, several additional or replacement devices were added to the MCF beyond the ISS medical inventory. In some cases, these were devices not currently part of the ISS medical inventory while in other cases these were devices the co-author preferred based on his field experience. Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

A surgical stretcher-chair was selected to update the surgical bed shown in the baseline configuration. Inspired by a commercial device, it combines the functions of transport device, procedure chair, and stretcher in one device. Like the notional baseline concept, it reconfigures to support different medical procedures. An additional feature is that it can be transported throughout the Common Habitat to provide on-site first aid or transport an incapacitated crew member to the Medical Care Facility. A CAD model of the surgical stretcher-chair is shown in Figure 4. Figure 5 shows the surgical stretcher-chair being transported between decks on the Vertical Translation System.

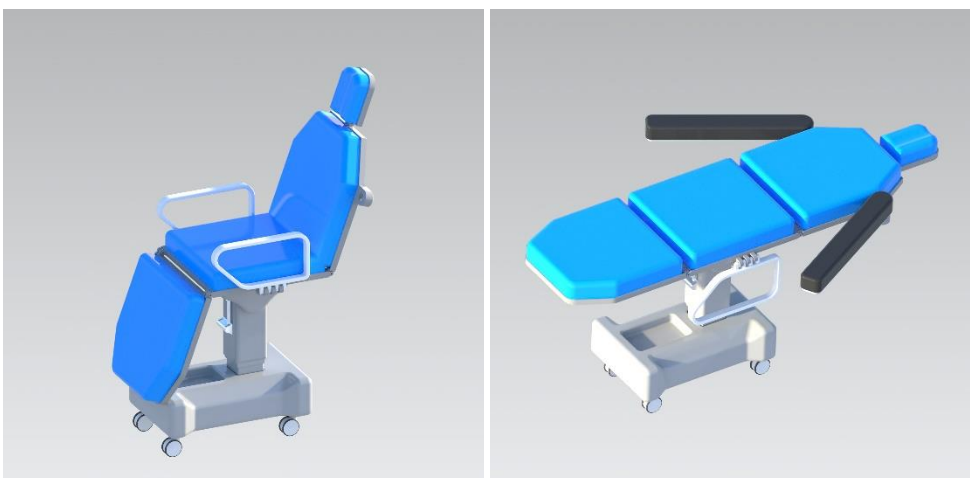

Fig. 4 Surgical Stretcher-Chair

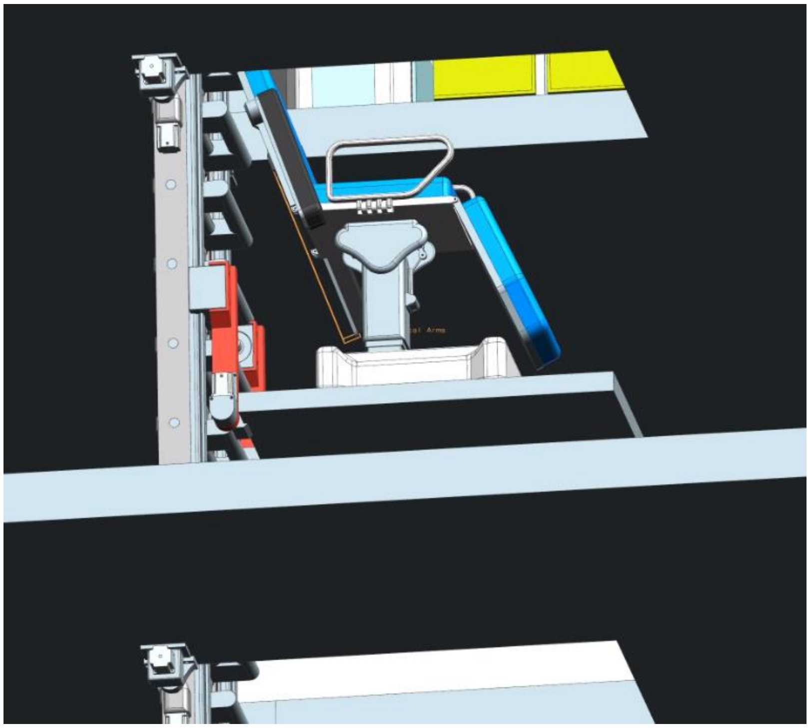

Fig. 5 Surgical Stretcher-Chair on the Vertical Translation System

A monitor/defibrillator device, shown in Figure 6, was recommended based on the co-authors Army experience. This unit measures and monitors patient vitals in addition to providing external and internal defibrillation capabilities. Monitoring vitals is a crucial capability needed to provide patient care for both injury and illness. A device is needed that provides this capability in a compact and lightweight form factor that was designed for field/military and aero medicine.

Fig. 6 Monitor / Defibrillator Device

The ultrasound is well known in human spaceflight as an important diagnostic tool. While ultrasounds continue to change in performance and form factor, the co-author recommended one, shown in Figure 7, based on his experience he thought was appropriate for conducting ultrasonic internal imaging for a variety of illness and injury profiles in a deep space mission.

Fig. 7 Ultrasound

The co-author recommended an X-Ray Machine as a new spacecraft device for internal imaging to complement the ultrasound. The field version selected, shown in Figure 8, can readily be hand operated or mounted to instrument arms for use in the MCF.

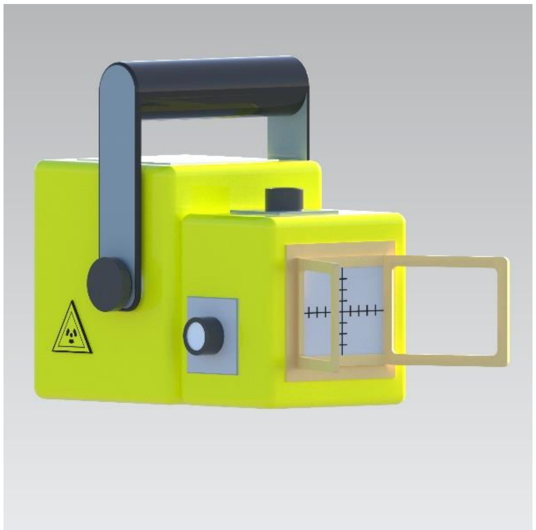

Fig. 8 X-Ray Machine

A handheld blood analyzer, shown in Figure 9, was recommended for crew member blood testing. This provides additional important diagnostic capability, such as conducting a basic metabolic panel.

Fig. 9 Handheld Blood Analyzer

A suction machine, shown in Figure 10, was added to the MCF capabilities. It provides caregivers surgical, pharyngeal, tracheal, and intermittent suction capabilities. It also includes altitude compensation abilities which may be helpful given that the Common Habitat architecture is expected to involve crew habitation at different cabin pressures.

Fig. 10 Suction Machine

A ventilator, shown in Figure 11, was added to the MCF for use in medical conditions where the patient is unable to breathe or is not getting sufficient oxygen into the blood. The field version used by the co-author provides 10-hours of continuous ventilation (per charge) in a compact and lightweight form factor. A flight version could run directly off of spacecraft vehicle power and not need any interruption in ventilation.

Fig. 11 Ventilator

B. Work surface

A desk-like work surface was added to the MCF, shown in Figure 12. This provides a workstation for the caregiver to perform medical data entry and review of patient records. It can also be used as a location for private medical conferences. The work surface also can host temporarily deployed items during crew medical care.

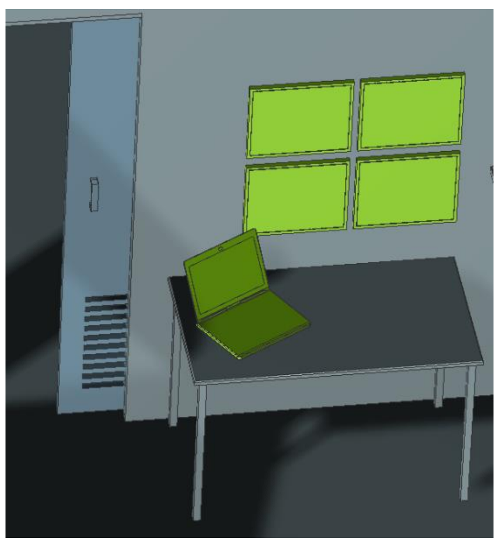

Fig. 12 MCF Work Surface

C. Stowage

A combination of stowage systems replaces the notional boxes shown in the baseline MCF. When serving in the Army, the co-author made extensive use of the Medic and Trauma Sheet Bag, a CAD model of which is shown in Figure 13. These flexible, fabric stowage systems can fold for stowage and can be attached to wall surfaces. They contain multiple zippered compartments that can be reconfigured for different medical procedures as needed.

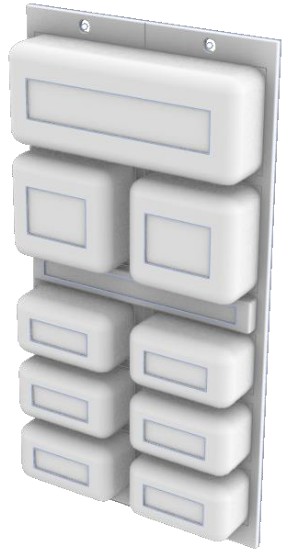

Fig. 13 Medic and Trauma Sheet Bag

Two shelves are located in the MCF to house the previously mentioned medical devices. Shown in Figure 14, the shelves notionally include some system to anchor the devices when in microgravity. Shelves are intentionally selected, given their open surfaces (as opposed to enclosed cabinets), in order to enable ease of retrieval of these devices by medical caregivers.

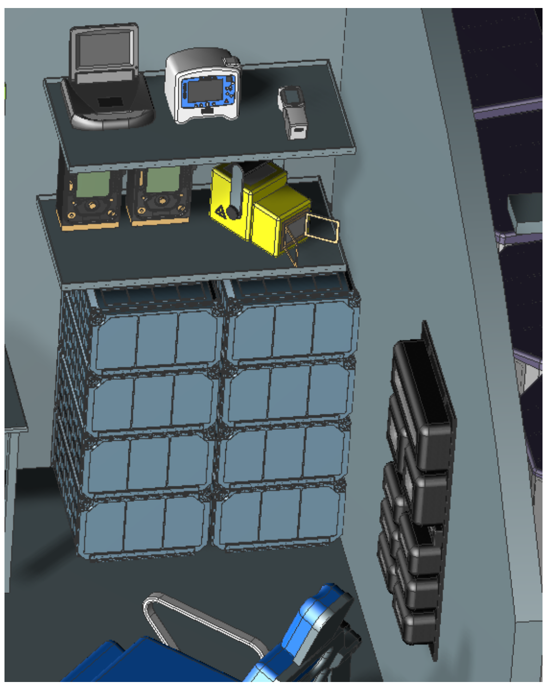

Fig. 14 MCF Stowage Systems

Eight middeck lockers in two stacks provide enclosed stowage beneath the shelves, also shown in Figure 14. It is conceivable, but not currently modeled either way, that the lower two or three lockers in each stack could be repositionable units, allowing the caregivers to deploy this stowage in the most accessible manner during patient treatment. The upper surface of the top locker would additionally provide a temporary storage location or work surface. It is readily obvious how such a solution is implementable in a gravity environment. Middeck lockers were used as repositionable work surfaces in prior NASA analog testing. Most notably the Habitat Demonstration Unit used several repositionable lockers on wheeled platforms in field testing from 2010-2012, as shown in Figure 15. In microgravity, this may still be possible, but relies on solutions from the previously mentioned restraint and mobility aid concepts being researched separately that are outside the scope of this paper.

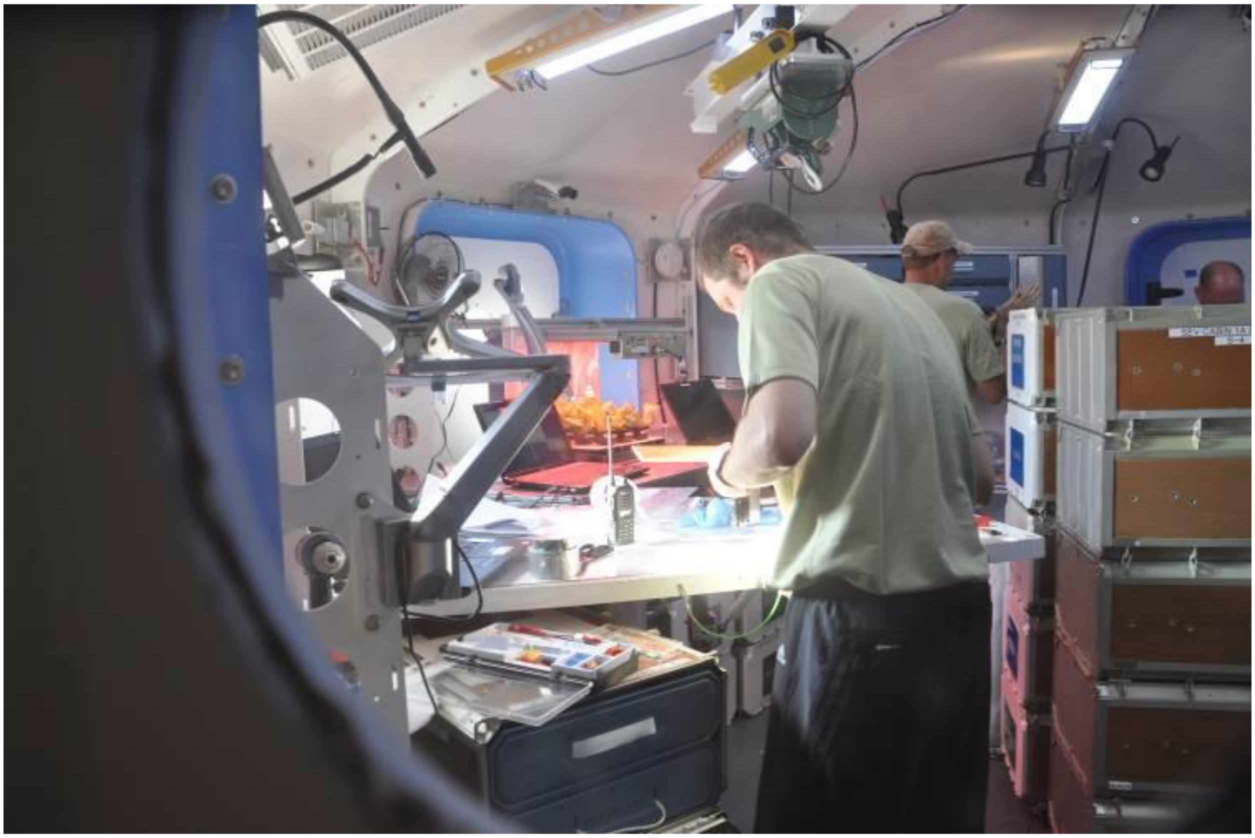

Fig. 15 Wheeled Middeck Lockers in Habitat Demonstration Unit During 2010 Test

D. Audiovisual and Information Technology

Medical information systems are notionally featured in the updated MCF. A dedicated medical laptop is included for data management and interface with wired or wireless medical equipment. If necessary, this can be supplemented with additional computing devices including tablets and peripherals and additional data storage devices. Four display screens are mounted on the wall above the work surface. Video and data output can be routed to these displays where they can be easily seen by a caregiver. While not specifically indicated in the updated CAD models, cameras are also incorporated to support telemedicine activity. While real time interaction is not possible at distances beyond the Earth-Moon system, Earth-based medical support can still provide remote assessments of patient examinations.

E. Caregiver Access

The MCF provides sufficient volume that a caregiver can have 360-degree access to the patient. This can be accomplished in either of two ways. There is sufficient room for a caregiver to walk around all sides of the patient. Also, because the stretcher-chair is mobile, it can rotate 360 degrees, allowing the patient to be moved as needed by the caregiver. There is also room to allow for more than one caregiver. While some scenarios may split the crew to such a degree that only one caregiver is available, it is expected that there will nominally be at least one assistant. Figure 16 shows three caregivers gathered around a patient. The MCF is large enough that, in theory, all seven remaining crew could gather around one patient, but this would likely be too many personnel to provide useful care.

F. Doors

The original two doors providing access to the hygiene compartment and access to the corridor leading to the control center are both retained. However, a third door is added, providing direct access to the Vertical Translation System. Without this door, access to the MCF from other decks is awkward, necessitating exit from the lower decks into the galley/wardroom area and then turning the corner to either access from the corridor or the hygiene compartment.

G. Facility configuration and imagery

In order to accommodate the increased functionality of the MCF, the dimensions of the facility were extended. Taking into consideration caregiver access to the patient, variable number of caregivers, increased number of medical devices, access to medical equipment and displays, still-in-development restraints and mobility aids, and operation in multiple gravity environments, the baseline MCF was deemed too small. The increase in volume was achieved by taking space from the subsystems bay in the aft end of the upper deck. This caused some repositioning of ECLSS pallets but there was sufficient volume in the subsystems bay to enable this growth in medical care volume. The resulting MCF is shown in context with the rest of the upper deck in Figure 16.

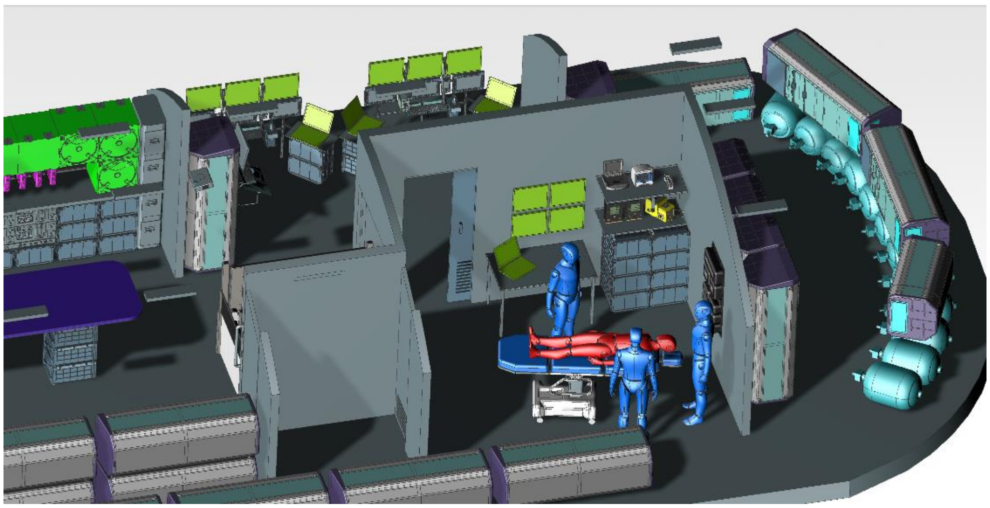

Fig. 16 Updated Common Habitat Medical Care Facility

VI. Conclusions and Forward Work

No longer a notional image with cartoon-level fidelity, the MCF now has sufficient design detail to initiate assessments of the Common Habitat medical capability. However, some design details remain as forward work.

As previously mentioned, restraints and mobility aids are being pursued under separate research. Crew seating options are not yet available for public release, but as that work advances it will need to be incorporated into the MCF, with possible implications for facility layout.

Ambient and task lighting are not yet depicted in the MCF. A unique consideration is that lighting systems will need to address the repositionable nature of the surgical stretcher-chair and ensure that adequate lighting can be brought to bear in any location where it might be positioned for patient treatment.

The example surgical stretcher-chair selected by the co-author is an initial placeholder, but additional design work is needed to modify this stretcher-chair for Common Habitat use. The commercial example has no microgravity capabilities. It can incorporate some of the restraints and mobility aids research and extensions of those concepts can enable the stretcher-chair to remain mobile in microgravity. This mobility may also be motorized and automated, enabling the chair to respond to commands to position itself as needed. Additionally, it may be useful to add portable equipment mounting points and temporary stowage locations on the stretcher-chair. The patient articulation will also need to be modified. Additional patient articulation may improve patient accommodation for medical care, and it is also desirable to accommodate a fully reclined patient while on the Vertical Translation System.

Other systems, including the shelving, work surface, and stowage lockers will also need to address the multi-gravity aspects of the Common Habitat architecture. These are aspects of the restraints and mobility aids research in progress that will be directly relevant once made available, but there may also be some additional mechanisms needed to address changes in gravity.

The telemedicine capability of the MCF needs better definition. As first pass, camera locations need to be identified, including both permanent locations and mounting opportunities for repositionable cameras. Opportunities for the use of Virtual Reality, sensor fusion, and teleoperation should also be explored.

One aspect not clearly addressed in the updated MCF is trash accommodation. The notional trash container in the baseline configuration was not clearly marked and was easy to miss. While technically, trash could be contained in one of the middeck lockers, this is not the intended approach and is not being considered as a viable option. Additionally, multiple categories of trash have been identified for the Common Habitat Architecture. [2] Of these, Biological and Medical (BAM) as well as Packaging and Miscellaneous (PAM) are likely to need receptacles in the MCF. BAM may be further subdivided into recoverable and non-recoverable, with separate receptacles for each along with a PAM receptacle. These receptacles will likely be located near one of the doors, potentially adjacent to or under the work surface table.

While not explicitly shown as such in any of the CAD models, it is intended that the hygiene compartment on the upper deck is a dual-use medical scrub and galley handwash facility. It is intended that this compartment provide hygiene necessary for food preparation. It is also intended that this compartment provide hygiene necessary for medical care. It is also desirable that if space is available this hygiene compartment might also house sanitation equipment for medical tools. Specific design of this hygiene compartment is forward work, and the resulting design will indicate the need for any changes or upgrades to the MCF.

Evaluation of the MCF will be helpful to aid in further refinement. An assessment with the IMM or IMPACT, if available, would be especially useful. General feedback from the NASA Human Research Program’s Exploration Medical Capability element will also identify areas for improvement. Tabletop or Virtual Reality walkthrough evaluations using known medical scenarios can further help guide future direction.

Finally, an effort is currently underway to estimate the total mass and power usage of the Common Habitat. A 90-ton control mass is currently being used in architectural estimates, but a bottoms-up estimate is needed. MCF estimated data will need to be compiled to feed into this work.

VII. References

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