Vertical Translation System for the Common Habitat Architecture

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The Common Habitat is a large, long-duration habitat that uses an SLS core stage Liquid Oxygen (LOX) tank as its primary structure. Measuring 8.4 meters in diameter and 15 meters in length, it is manufactured as a habitat and launched as such into space. 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. The Common Habitat Vertical Translation System provides a means for transporting crew and cargo between decks in a Common Habitat spacecraft in gravity levels varying from 0g to 1g. A crowdsourcing campaign was conducted through the GrabCAD platform to initially solicit ideas for restraints and mobility aids, including vertical translation. Four of the five top responses repeated ideas that would be incorporated into features of the Vertical Translation System. The first was a safety barrier (to prevent falls into the opening between decks) that could collapse to form a floor surface covering the opening when not in use. The second idea was a folding ladder that could be stowed in the ceiling when not in use. The third idea was an elevator platform that could traverse the ladder. Several key driving requirements were established for the Vertical Translation System: it may not penetrate into or through the lower deck; it must work on the Earth, Moon, Mars, and in microgravity; it must be easy to operate; it must enable translation of any item that can fit through the Common Habitat's 40" x 60" hatches, inclusive of suited and unsuited crew with any degree of incapacitation and any equipment or cargo item; and it must include three component systems – deploying floor / safety barriers, a deployable ladder, and an elevator platform. Additional requirements were established for each of the component systems. The safety barriers must form a roughly 40-inch tall, complete wall enclosure on all four sides when deployed; it must include an easy to open gate that allows access to/from the ladder when deployed; and when retracted, the safety barrier must form a smooth, load-bearing floor that can be walked on, and wheeled objects can be rolled across in gravity, without being a trip hazard. The deployable ladder must be composed of multiple ladders that work together; it must stow in the ceiling when not in use; and it must not penetrate into the 40" x 60" vertical passage corridor. The elevator platform must work with the deployable ladder system; it must be able to bridge any gap in ladders between decks; it must stop at each deck flush with the deck surface; it must be capable of transporting an incapacitated crew member as a single rescuer operation; it must be capable of transporting a full-size subsystems pallet; it must function as an elevator for a crew member carrying large objects; it must have safety functions to prevent falls from the platform, or crew/cargo collisions with edges of hatch openings, or entanglement with ladder rungs/structure; it must stow when not in use; and it must autonomously both connect itself to the ladder and deploy itself to any deck where needed when called (e.g., a crew member on any deck can call for the platform and it must connect itself to the ladders without assistance and translate to the requestor's deck). These requirements were developed into a system concept with the assistance of a NASA Pathways Intern who also added the requirement to size the design based

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on the use of commercial components, using existing motors and other mechanisms to ensure that the resulting system could be inexpensively produced. The Floor and Safety Barrier consists of four panels, two roughly 40 inches long and two roughly 60 inches long that can fold into the floor on top of each other when not in use. The uppermost panel is load bearing and acts as the floor surface. When deployed, they connect with each other to form a rigid barrier surrounding the vertical passageway. One of the panels contains a hinged gate that can be opened when deployed to allow for access to/from the passageway. The Deploying Ladder consists of two ladder segments, one mounted on the ceiling of the lower deck and the other mounted on the ceiling of the mid deck. A rotating mechanism is mounted on the ladder to allow it to rotate into a horizontal position against the ceiling for stowage, or down to a vertical position for use. A second rotating mechanism is built into the ladder, allowing the rungs to rotate. A toothed surface intended to work with the elevator platform covers the front of the ladder rails and the top and bottom of the rails are designed to be flush when aligned with another ladder segment. The elevator platform is essentially a motorized, self-propelled deck. It has a mechanism that holds it in contact with the ladder rails and drives itself against the toothed surface. This mechanism allows the elevator platform to ascend or descend the ladder. In order to stow the platform when not in use, a set of short ladder rails (without rungs) are mounted to the ceiling of the mid deck. When the mid deck ladder is stowed, it is flush with these rails and the platform can drive itself onto those short rails for stowage. An additional mechanism on the platform can pitch its deck surface 90 degrees, such that when the ladder is to be stowed, the platform can fold up against the ceiling. As a consequence of the ladder and elevator platform design, the opening between decks in the Common Habitat was enlarged to ensure that the elevator platform can accept a payload up to 40”x60” in dimension.

I. Introduction

The Common Habitat is a large, long-duration habitat that uses the SLS core stage LOX tank as its primary pressure vessel, shown in Figure 1. [1] Like Skylab, it is manufactured as a habitat and launched as such into space. Unlike Skylab, it features one design capable of being used in multiple environments.

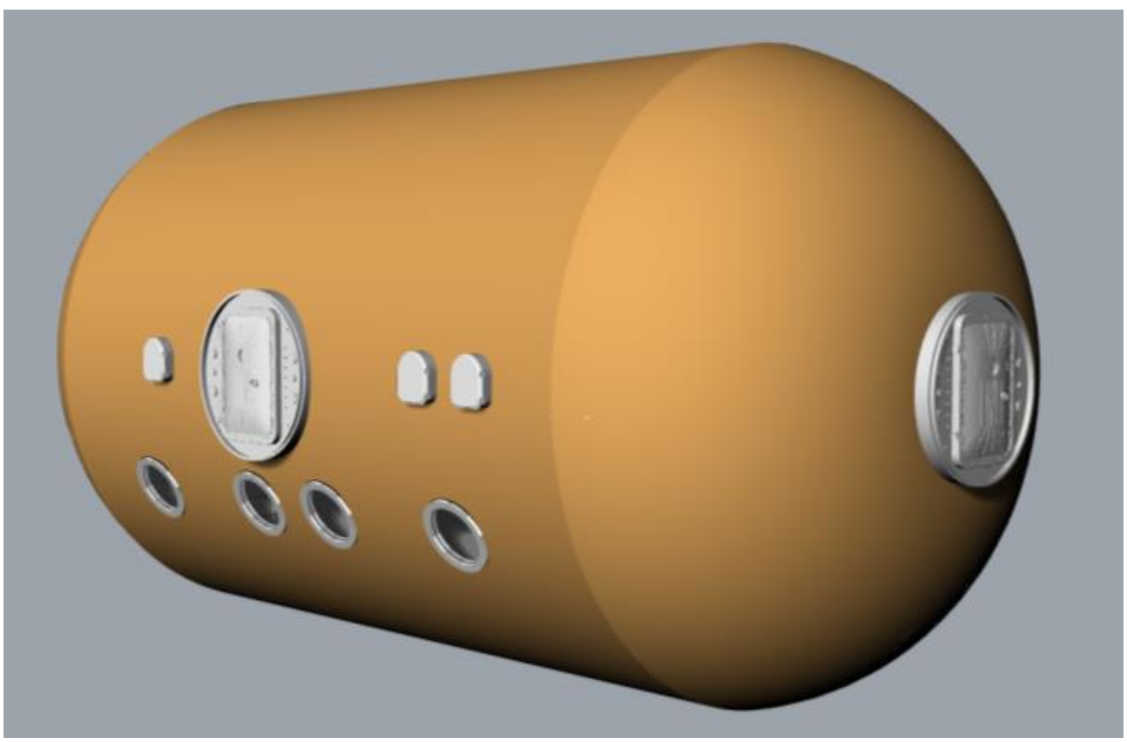

Fig. 1 SLS LOX Tank as the Common Habitat

It is intended for use on the Moon as part of a permanently occupied Moon base, shown in Figure 2, on Mars as part of a Mars outpost that will be occupied for hundreds of days at a time, and in deep space as part of the Deep Space Exploration Vehicle, shown in Figure 3 where it will support missions up to 1200 days in duration. [2] [3]

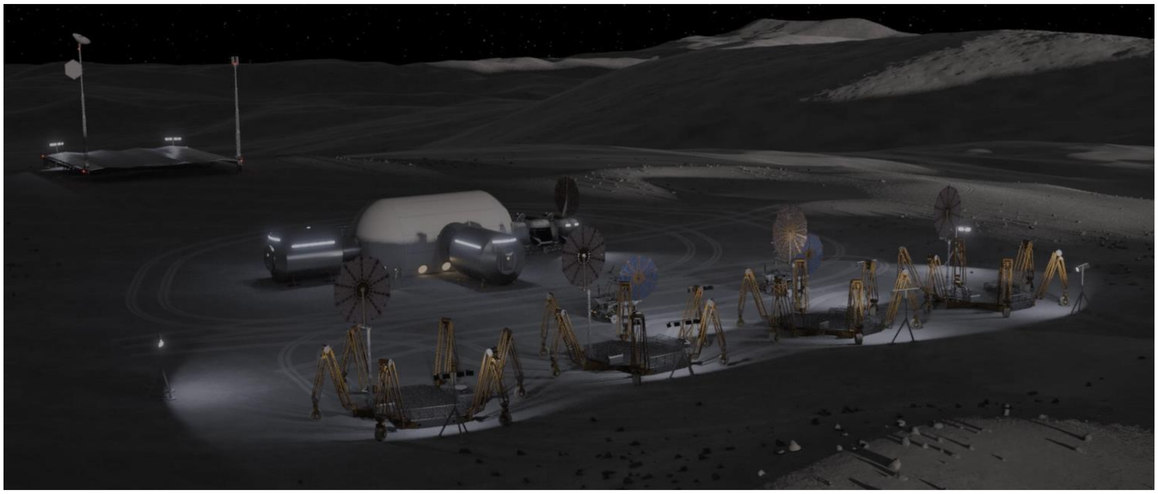

Fig. 2 Lunar Surface Base

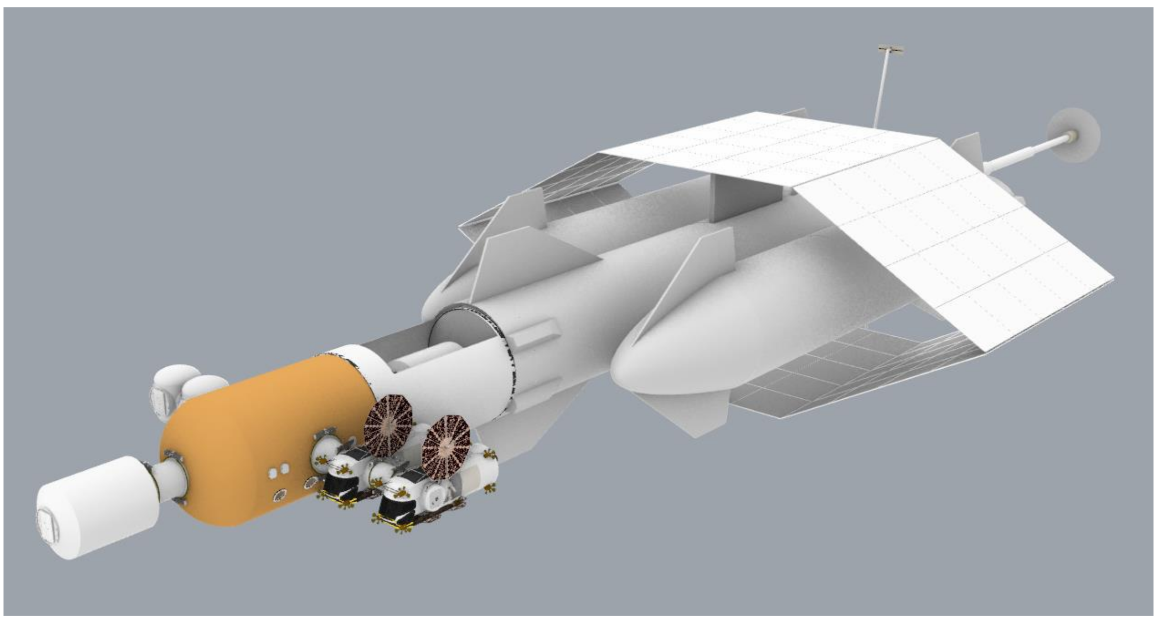

Fig. 3 Deep Space Exploration Vehicle

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.

A trade study assessed different options for how the LOX tank could be configured as a habitat, trading both vertical and horizontal orientation and four or eight crew. The trade study selected the eight-crew, horizontal variant for further development. [4]

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.

Measuring 8.4 meters in diameter and 15 meters in length, the habitat has three decks – an upper deck, mid deck, and a lower deck, shown in Figure 4, Figure 5, and Figure 6. This requires some capability to move crew and a variety of items between decks in any gravity environment. [5]

The upper deck, shown in Figure 4, is a social and operations deck. The galley and wardroom area dominate the forward section of the deck The Command-and-Control Center, Medical Care Facility (MCF), and a Hygiene Compartment occupy the center of the deck. Life support subsystems occupy the aft of the deck.

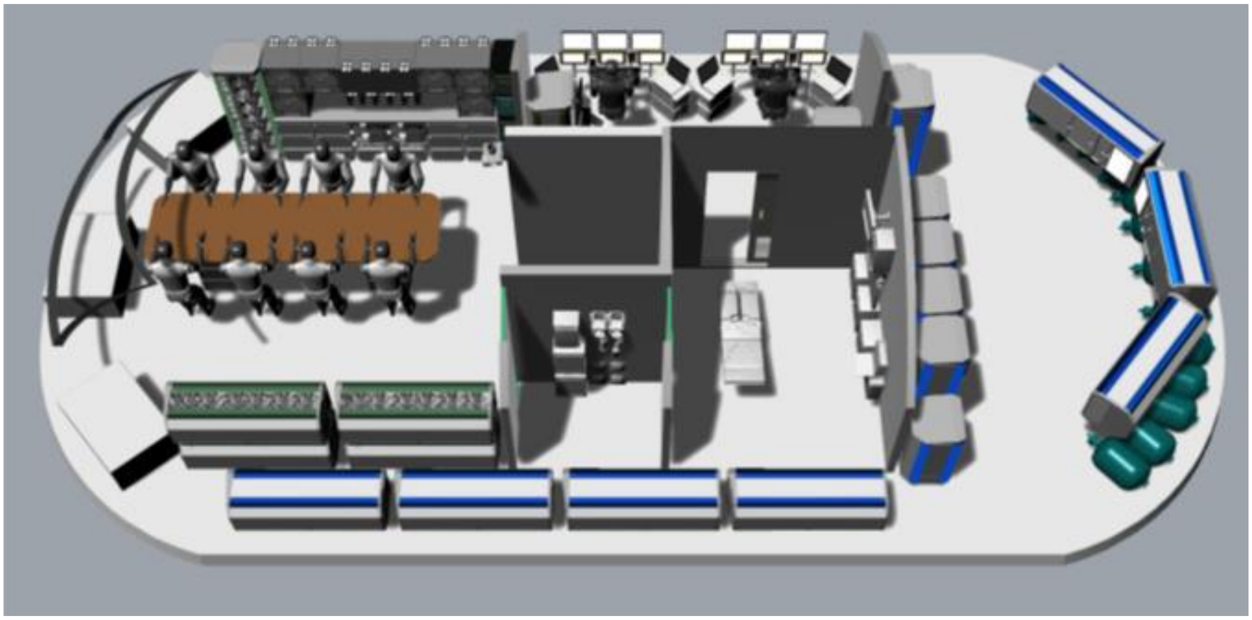

Fig. 4 Common Habitat Upper Deck

The mid deck, shown in Figure 5, is the primary deck for crew work activity. The deck contains a life science laboratory with biology and human research payloads, a physical science laboratory with geology, physics, and remote sensing / teleoperations payloads, the Repair, Maintenance, and Fabrication facility, and the crew exercise facility. The habitat's four docking ports are also located on the mid deck.

Fig. 5 Common Habitat Mid Deck

The lower deck, shown in Figure 6, is dedicated to private functions. Eight identical crew quarters, hygiene facilities, and waste management facilities are located on the lower deck. A vertical translation corridor runs through the center of all three decks.

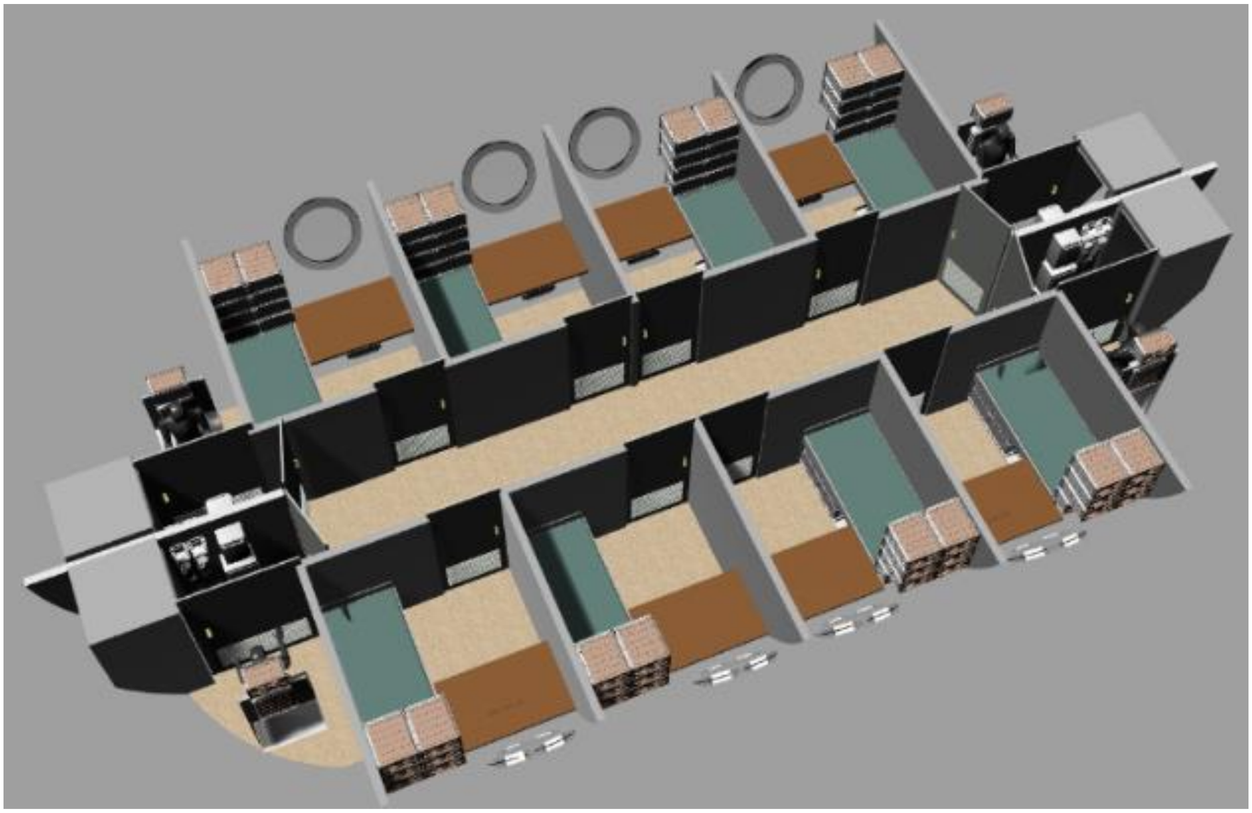

Fig. 6 Common Habitat Lower Deck

This paper describes a system that provides this capability, enabling crew and equipment traverse between these habitat decks in 0g, 1/6g, 3/8g, and 1g. Several ideas submitted in a 2020 GrabCAD crowdsourcing challenge [6] were used as points of inspiration. In particular, the ideas of a folding ladder that stows in the ceiling when not in use; collapsing guardrails that serve as a floor to cover the vertical passageway when not in use but become a fall-protection barricade when in use; and a motorized platform that can climb the ladder when deployed – capable of transporting cargo or incapacitated crew. These ideas – the result of over a hundred total entries from 35 countries across 6 continents – were combined into a single solution, the Vertical Translation System (VTS).

II. Vertical Translation System Overview

A. Vertical Translation System Ground Rules and Design Constraints

As the Common Habitat Architecture is not a program, there are no requirements in the classic systems engineering sense. However, just shy of two dozen ground rules and design constraints were applied to shape the design of the VTS.

Overarching Ground Rules and Design Constraints:

1. The Habitat has one 40” x 60” vertical translation corridor
2. The upper deck has a floor thickness of 20.32 centimeters (8 inches).
3. The mid deck has a floor thickness of 15.24 centimeters (6 inches).
4. The Vertical Translation System may not penetrate into or through the lower deck.
5. The Vertical Translation System must work on Earth, on the Moon, on Mars, and in microgravity.
6. The Vertical Translation System must be easy to operate.
7. The Vertical Translation System includes three component systems: Deploying Floor / Safety Barriers, Folding Ladder, and Elevator Platform.

Component-specific Ground Rules and Design Constraints:

Deploying Floor / Safety Barriers

1. Safety barriers form a 42-inch tall, complete wall enclosure on all four sides when deployed.
2. Easy to open gate allows access to/from ladder when deployed.
3. When retracted, safety barriers form a smooth, load-bearing floor that can be walked on, and wheeled objects can roll across – it must not be a trip hazard.

Folding Ladder

1. Ladder stows in ceiling when not in use.
2. Ladder does not protrude above ceiling or below floor (no penetration into opening between decks – there must be multiple ladders that work together).
3. Ladder does not obstruct 40" x 60" vertical passage corridor.

Elevator Platform

1. Must work with Folding Ladder system.
2. Must be able to bridge gap in ladders between decks.
3. Platform must stop at each given deck flush with deck surface.
4. Must be capable of transporting an incapacitated crew member as a single rescuer operation.
5. Must be capable of transporting a full-size subsystems pallet.
6. Must function as elevator for crew member carrying large objects.
7. Must have safety function to prevent falls from platform, or collision with edges of hatch openings, or entanglement with ladder rungs/structure.
8. Must stow when not in use.
9. Must autonomously connect itself to ladder and deploy to deck where needed when called (a crew member on any deck can call for the platform and it must connect itself to the ladders without assistance and translate to the requestor).

B. Leading Crowdsourcing Concepts

The deploying floor/safety barrier was inspired in part by a GrabCAD submission from the United States, the Multipurpose Peg and Rail System, [7] which introduced swing gates, shown in Figure 7. In this case, the gates serve to provide fall protection when the ladder is not in use, and as a landing platform for crew ascending or descending from above. The idea that the vertical translation path becomes a floor when not in use was particularly inviting as it increases the flexibility of the workspace available to the Repair, Manufacturing, and Fabrication facility on the mid deck of the Common Habitat.

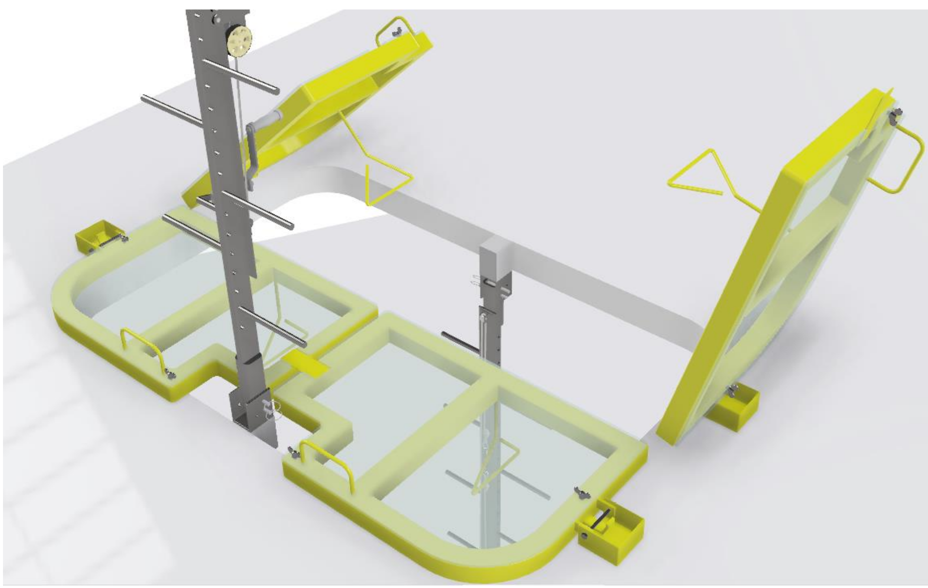

Fig. 7 Swing Gates for Fall Protection

The folding ladder was inspired in part by two different GrabCAD submissions, the Daedalus Project [8] from a five-nation team including Mexico, Argentina, Chile, the United States, and India; and the Restraint Chair and Folding

Ladder [9] from Japan. The Daedalus Project included the Helix Lift, shown in Figure 8, a non-deployable 500mm x 500mm elevator platform intended for use between two decks.

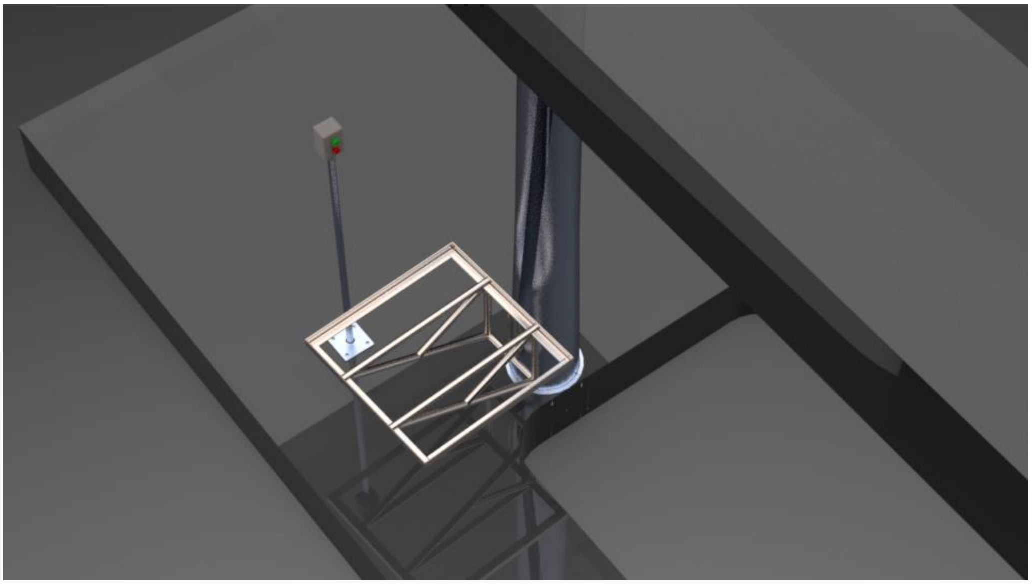

Fig. 8 Helix Lift

The Restraint Chair and Folding Ladder submission included, as the submission name suggests, a folding ladder. Shown in Figure 9, Figure 10, Figure 11, and Figure 12, this ladder featured several innovations. The ladder could assume four different configurations: Fully Open, as shown in Figure 9, allows the ladder to be used in any gravity condition. Fully Closed, shown in Figure 10, shows the rungs flattened to form a surface. The ladder covers the hatch opening thereby providing fall protection. Open Hatch, shown in Figure 11, slides the ladder along a track to open the hatch for translation in microgravity or for any large item transfer where the ladder might be in the way. Half Ladder, shown in Figure 12, is intended to support ladder use in 1/6 and 3/8 gravity where upper body strength is likely sufficient to enable translation without needing the lower portion of the ladder for the legs. Half Ladder is intended to keep the deck floor clear.

Fig. 9 Folding Ladder, Fully Open Configuration

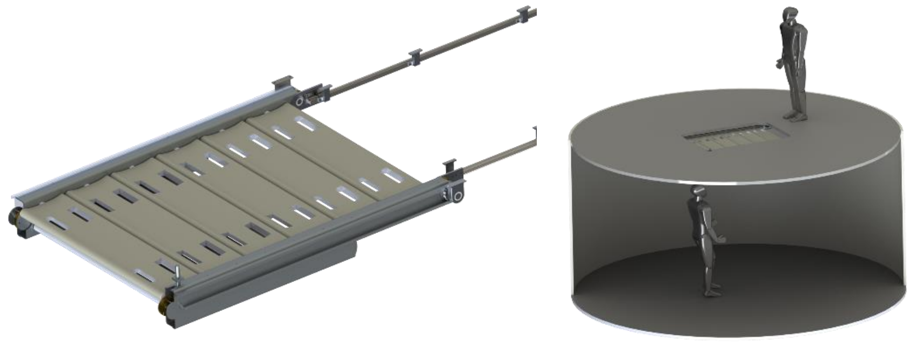

Fig. 10 Folding Ladder, Fully Closed Configuration

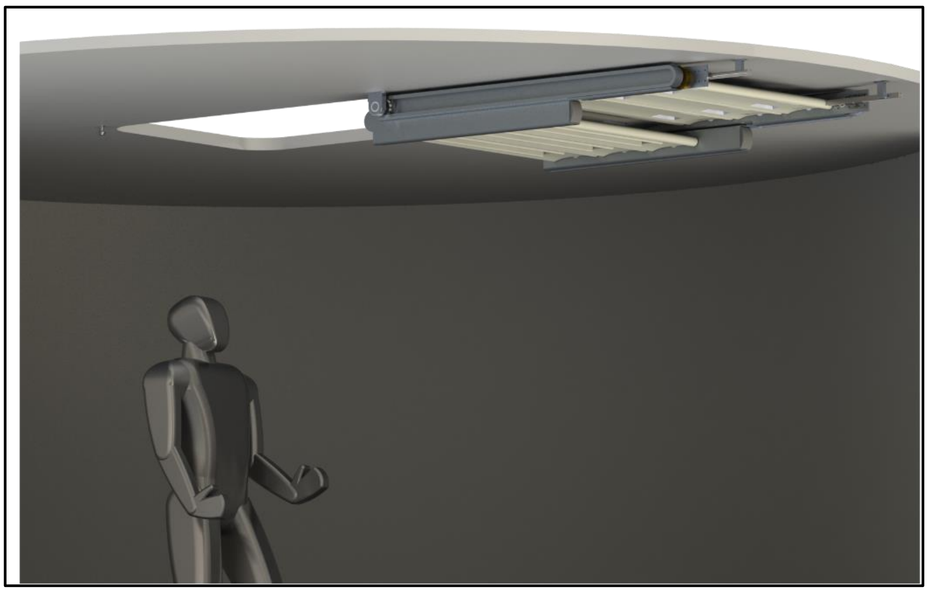

Fig. 11 Folding Ladder, Open Hatch Configuration

Fig. 12 Folding Ladder, Half Ladder Configuration

The elevator platform was inspired in part by two GrabCAD submissions, the previously mentioned Multipurpose Peg and Rail System [7] and the Integrated Slot and Cleat Ram System [10] from the United States. The Multipurpose Peg and Rail System included a monorail system, shown in Figure 13, that included a small cart attached to a cable and drive system. The monorail could be used as an elevator platform, or with the ladder reconfigured to a horizontal position it could provide limited lateral transportation.

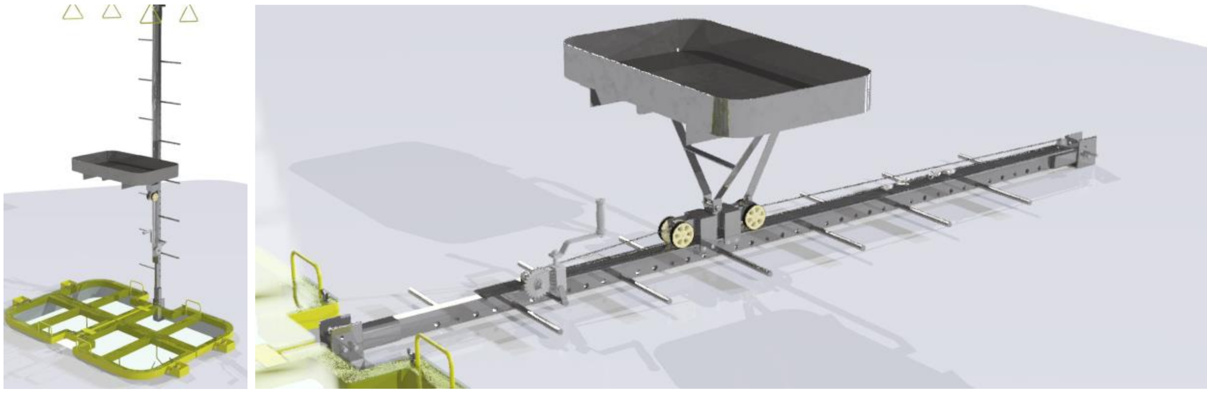

Fig. 13 Monorail System

The Integrated Slot and Cleat Ram System included a powered elevator car, shown in Figure 14. The elevator system is intended to allow for the transport of heavier loads than can be hand carried under gravity. It attaches to the ladder and engages teeth integral to the ladder rails. A cage nominally surrounds the ladder to provide additional protection, especially to prevent collisions between persons traveling horizontally on one deck and persons traveling vertically between decks.

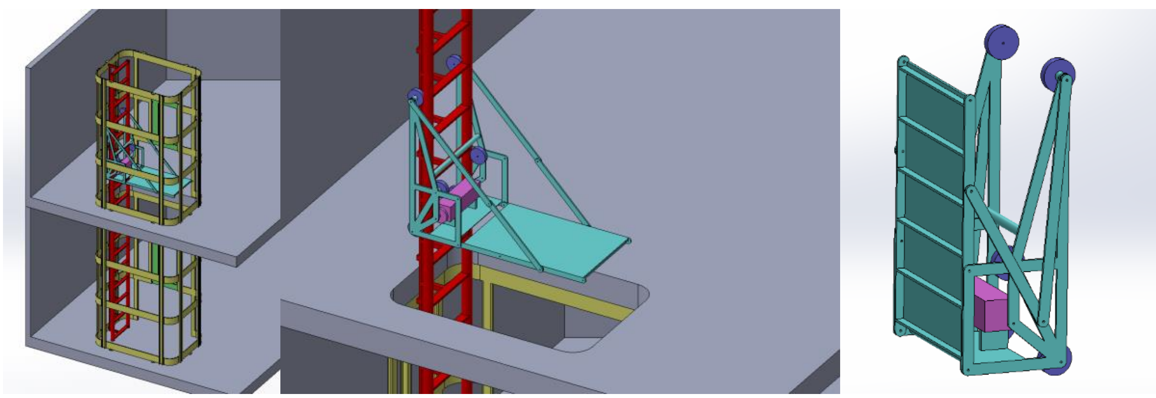

Fig. 14 Powered Elevator Car

C. Vertical Translation System Design Philosophy

The VTS considered the inspirations form the GrabCAD competition along with the ground rules and design constraints. Additionally, the VTS was sized based on the use of commercial off the shelf (COTS) components. Specific motors and mechanisms were identified and incorporated into the design. This was done for two reasons. First, it ensured that the design could be implemented without requiring mechanisms to be invented to fit within unnecessarily small volumes. Second, it was intended to result in a design that could be prototyped with limited funding.

III. Vertical Translation System Deploying Floor and Safety Barrier

The Deploying Floor and Safety Barrier is an innovative feature to minimize volume while maintaining crew safety. When the VTS is not in use, that section of the deck is not obstructed by the VTS. The vertical passageway is closed, literally becoming part of the floor and can be used as needed for other purposes. When the VTS is deployed, the section of floor covering the vertical passageway deploys, becoming a safety barrier on all four sides, with a gate that can open to allow crew and/or equipment to enter and exit the passageway. Figure 15 shows the floor (left) and safety barrier (right).

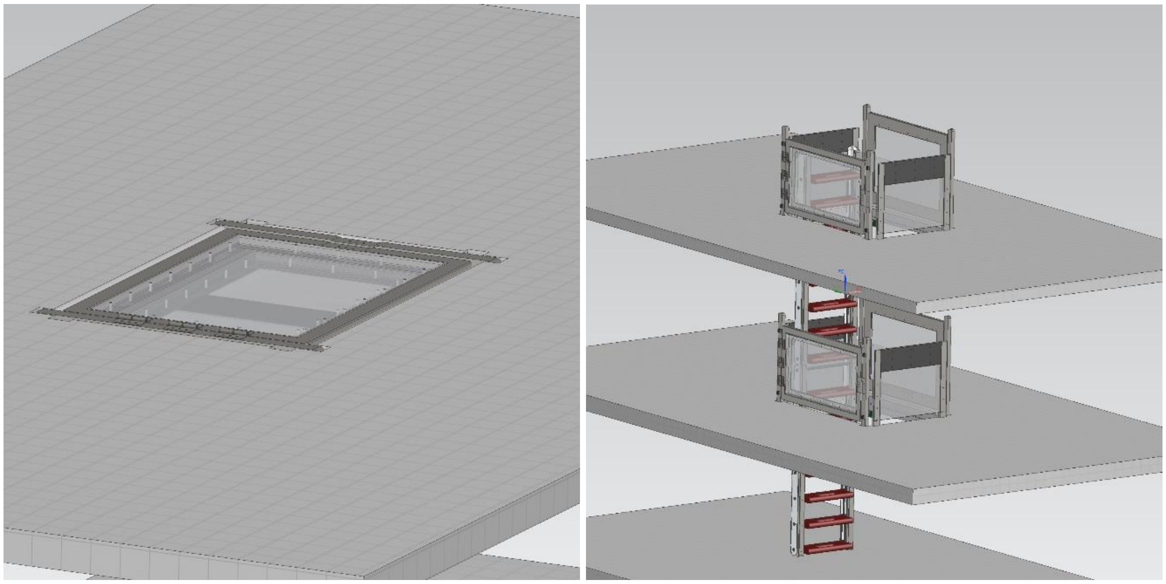

Fig. 15 Conversion from Floor to Safety Barrier

The floor is intended to be flush with the deck, allowing rolling objects to translate across the surface. The section of floor that covers the vertical passageway is one of the four safety barriers and is a hard surface. This sets the safety barrier as slightly greater than 40 inches tall. This implies that given the 40 x 60-inch vertical passageway, the floor section is roughly 60 inches wide and 40 inches tall when deployed as a barrier. Technically, this barrier is by definition somewhat larger in both dimensions, as it needs to fully cover the vertical passageway and mechanisms for the barrier on the opposite side of the passageway, but defining these dimensions requires a higher fidelity design of the system than has been completed at this point.

The material for the other three barriers is an open trade. All barriers could be hard surfaces, but it is not absolutely necessary that they all be. The two 40-inch-wide barriers can potentially be fabric. The second 60-inch-wide barrier could either be an all-hard surface or a hybrid, such as a composite or metal frame with fabric material stretched across.

It is worth noting that on the upper deck, the Vertical Translation System exits in at least two, and possibly, three, directions. It exits directly into the MCF and will exit into either the wardroom, the Command-and-Control Center, or both. This will result in either two or three gates in the upper deck Deploying Floor and Safety Barrier. For purposes of commonality, the same configuration will likely be used on the mid deck.

IV. Vertical Translation System Deploying Ladder

The Deploying Ladder serves the purpose of acting as a ladder for nominal crew transit and additionally serves as the track for a self-propelled elevator. It must also stow itself out of the way when not in use. As shown in Figure 16, the ladder features step-like rungs, with a portion of the center removed to provide an easy hand hold for ascending or descending crew members. These large rungs are intended to make it easier for the crew to use their feet when traversing the ladder, both in gravity and reduced gravity scenarios. While it is difficult to detect in the fidelity of the CAD model, the darker gray on the edge of the ladder rails facing the user indicates a toothed surface. This is similar to the teeth in the ladder proposed by the Integrated Slot and Cleat Ram System [10] but is based on commercial linear gear rack drive manufactured by the German company LEANTECHNIK. [11] These gear rack drives come in various sizes with lift capacities ranging from 2-25 kN (450-5620 lbs), [11] indicating a performance more than sufficient for use in the VTS.

It is expected that the elevator platform would make physical contact with the ladder rungs, preventing the platform from being able to traverse along the ladder. Consequently, the ladder rungs can rotate like those of the Restraint Chair and Folding Ladder [9] but for a different purpose. Here, there is no attempt to form a floor-like surface with the ladder rungs, only to get them out of the way so the elevator platform can traverse the ladder. Figure 17 shows the gearing system that enables the rungs to rotate into position for either elevator or ladder operations as well as an example of the rungs in the rotated position necessary for elevator operations.

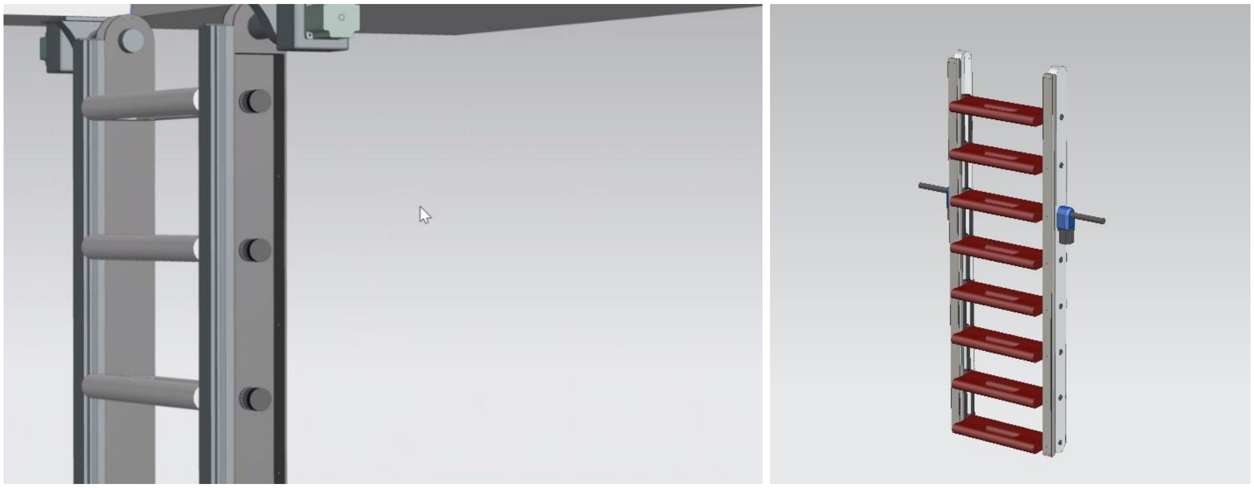

Fig. 16 Ladder with Elevator Track Teething

Fig. 17 Ladder Rung Rotation

Figure 17 also indicates a change that occurred during the course of VTS development. Both the left and right images suggest a rotation axis for the ladder. However, the left image shows the rotation axis at the top of the ladder and the right image shows it at the third rung from the top. (The same is visible in Figure 16.) Initially, the center of rotation coincided with the top of the ladder to comply with Folding Ladder Ground Rules and Design Constraints #2: Ladder does not protrude above ceiling or below floor (no penetration into opening between decks – there must be multiple ladders that work together).

Several complexities were uncovered when attempting to develop the system under this constraint, most significantly how to ingress and egress the VTS on the top deck. It was clear that two folding ladders – one on the mid deck ceiling and one on the lower deck ceiling enabled transit between those decks, but accessing the upper deck was challenging.

An alternative to adding a third ladder on the upper deck ceiling (which would have interfered with the wardroom projector location and would have been a complex installation on the arched ceiling) was to shift the ladder up, such that the top two rungs protrude into the deck above. This placed the center of rotation on the third rung as shown in the right images of Figure 16 and Figure 17. The right image of Figure 15 and Figure 18 show how the two ladders align to form a single vertical passage linking the three decks. Figure 18 in particular has direct view that shows where the two ladders meet.

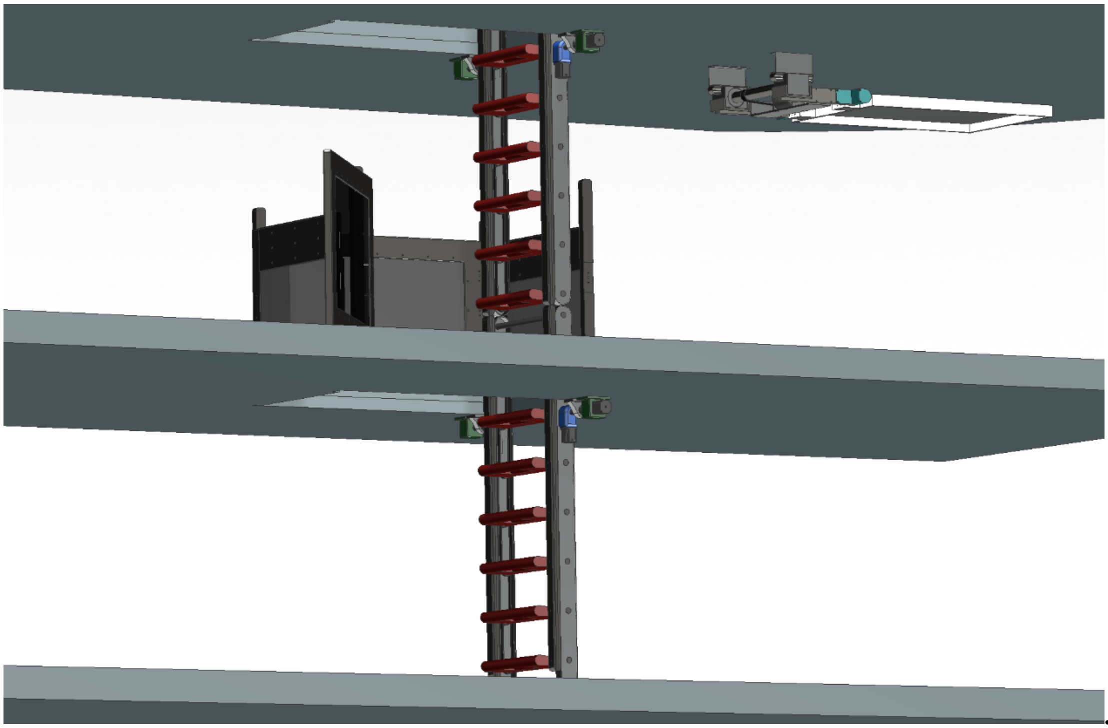

Fig. 18 Mid Deck and Lower Deck Folding Ladders Deployed

It is worth noting that when the ladder is stowed it does block the translation path. However, there are no known use cases that call for the Folding Ladder to be stowed and the Deploying Floor and Safety Barrier to be in barrier configuration. Figure 19 shows the mid deck ladder deployed while the lower deck ladder is stowed. In such a case, the Deploying Floor and Safety Barrier on the upper deck is raised to form the safety barrier, while the one on the mid deck is lowered, forming a floor surface. The mid deck ladder is available for use as either a ladder or elevator lift.

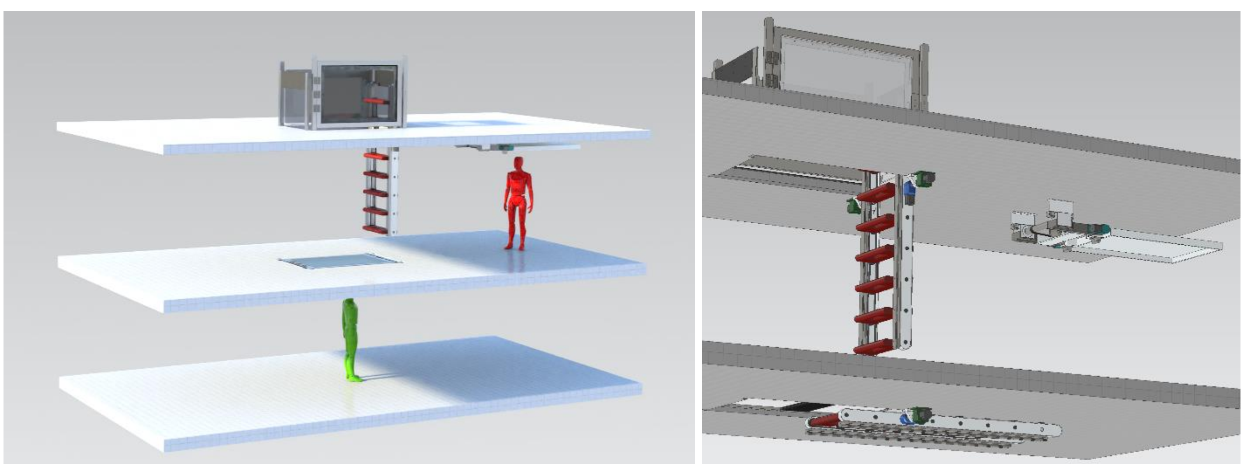

Fig. 19 Mid Deck Ladder Deployed while Lower Deck Ladder Stowed

V. Vertical Translation System Elevator Platform

The elevator platform is a self-propelled system, sized to enable transport of any equipment that can fit through the 40-inch by 60-inch hatch openings in the Common Habitat. It can also transport multiple crew at a time, or crew with cargo. It is also capable of moving itself onto and off of the VTS ladder rails. Figure 20 shows a view of the elevator platform.

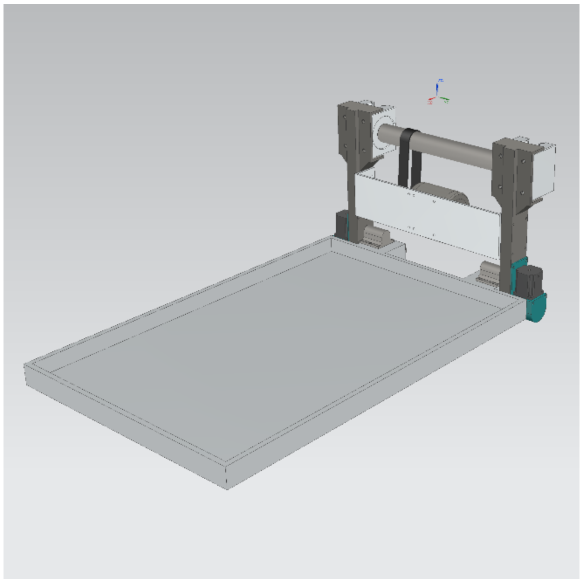

Fig. 20 Elevator Platform

The mobility aspects of the Elevator Platform, including both its vertical translation and its ability to stow, involve multiple motors and mechanisms. These are housed in the back of the platform as shown in Figure 21. These mechanisms control the platform's translation along the teeth of the ladder rails and enable the platform itself to pitch 90 degrees down. The current iteration of the platform assumes it does not carry onboard batteries but instead receives power from the habitat through the ladder rails. However, the space in Figure 21 surrounding the motor has been identified as a candidate location for batteries. It is likely that a future iteration will incorporate rechargeable batteries in this location, with the platform recharging in its storage location between uses. Figure 22 shows the Elevator Platform positioned on the ladder , with the ladder rungs rotated to a vertical position to allow the motor assembly proper clearance.

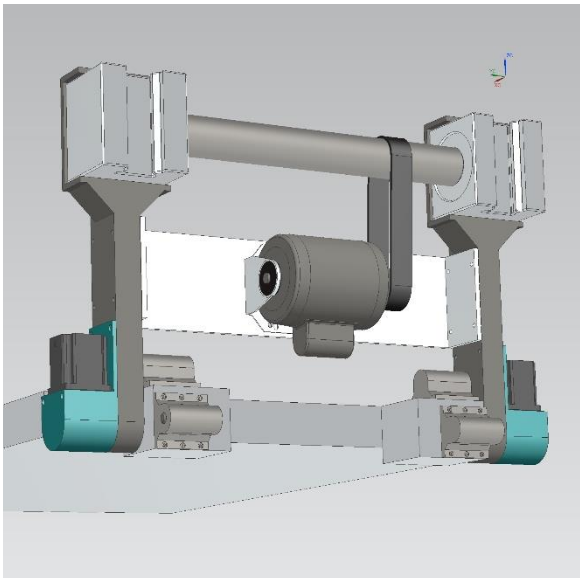

Fig. 21 Elevator Platform Motor Assembly

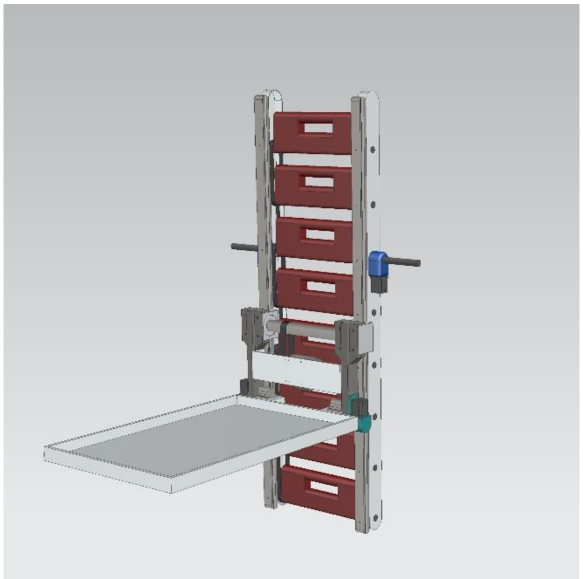

Fig. 22 Ladder with Elevator Platform, Rungs Rotated to Vertical Position

Figure 23 shows the Elevator Platform in use, in this case transporting a crew member. It is obvious from the picture that the ladder cannot be used while the platform is attached to it. So, there must be a means to move the Elevator Platform on and off of the ladder.

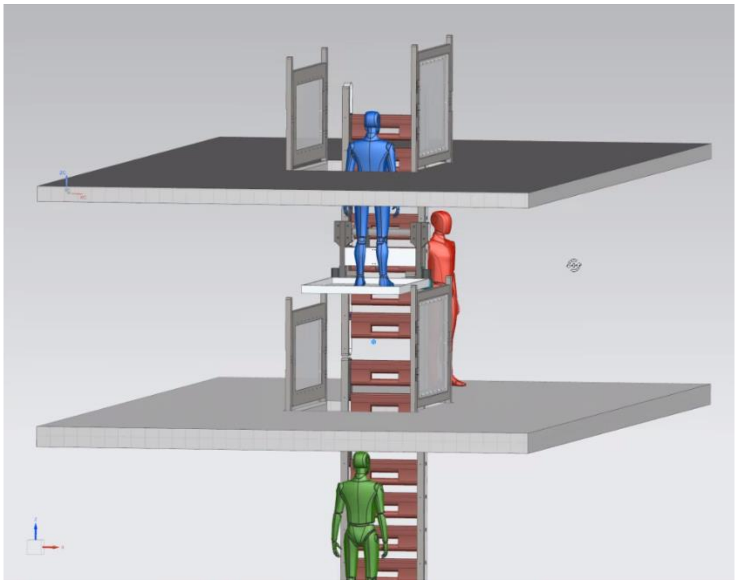

Fig. 23 Elevator Platform Used for Crew Vertical Translation

To this end, a storage location is provided for the Elevator Platform on the ceiling of the mid deck. The Elevator Platform is shown in this storage location in Figures 18 and 19, but how does it get there? In order to stow the Elevator Platform, it must first be moved to the top of the mid deck ladder. The platform must then pitch downward 90 degrees, such that the platform surface is parallel to the ladder. The ladder is then stowed against the mid deck ceiling, as shown in Figure 24. Note that this places the bottom of the ladder flush with a set of short rails that are permanently attached to the ceiling. The Elevator Platform will then translate along the ladder and onto the short rails, reaching its stowed position, shown in Figure 25. With the Elevator Platform no longer on the ladder, it can be deployed for ladder operations, shown in Figure 26.

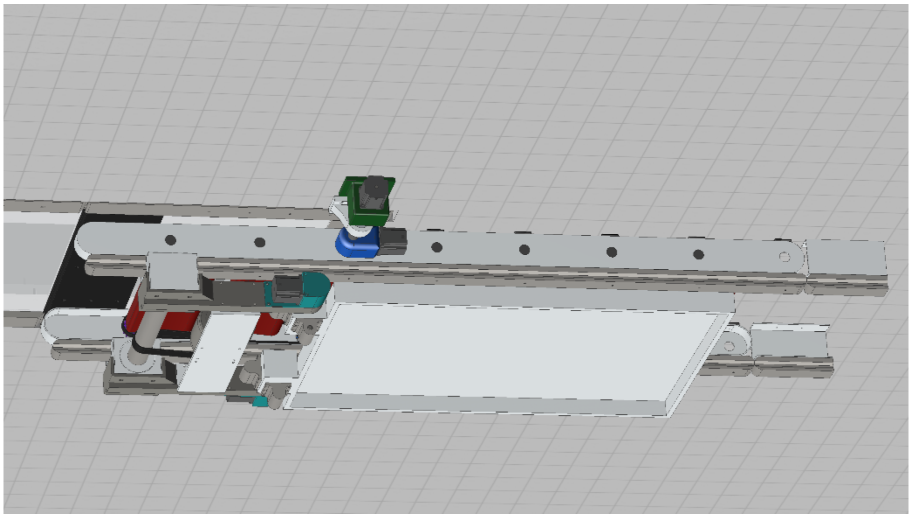

Fig. 24 Elevator Platform on Stowed Ladder

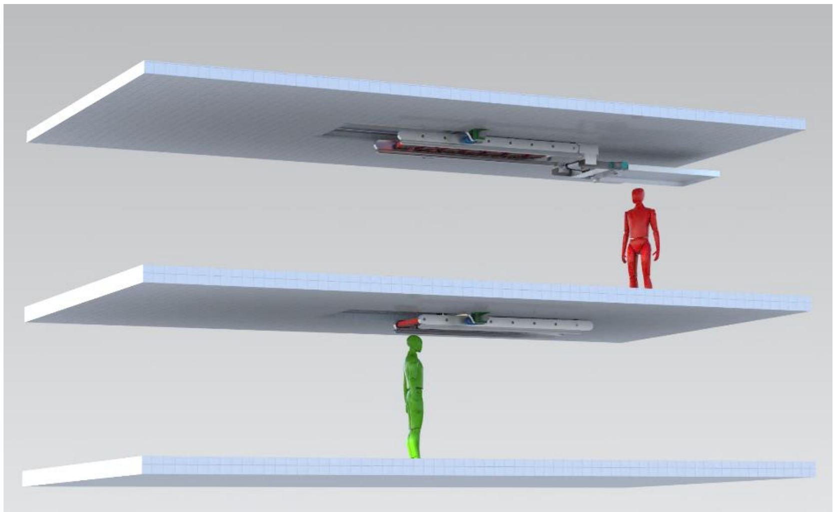

Fig. 25 Elevator Platform in Stowed Configuration

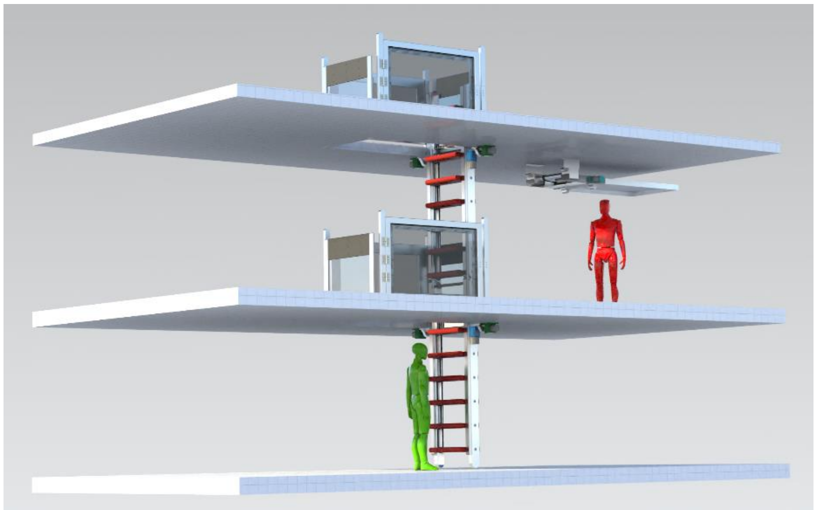

Fig. 26 Ladder Operations Independent of Elevator Platform

VI. Vertical Translation System Use Cases

A. Crew Deck Transfer

The primary use of the VTS involves unsuited crew members moving back and forth between decks. All crew begin and end their day on the lower deck but will spend the majority of their duty hours on the mid deck, with meals and some duty tasks on the upper deck. As a general rule, crew will use the deployed ladder configuration shown in Figure 26.

In microgravity, the ladder will only serve as a light guide to direct their motion, while in gravity they will directly climb the ladder. In lunar gravity this may only require the use of their upper body, while Mars is more likely to require the use of arms and legs. In Earth-based trainers, they will of course fully rely on both arms and legs for translation. If the crew are not encumbered with other items, this will be sufficient. However, if they are carrying bulky or heavy (if in gravity) items with them, they may not be able to take those with them on a ladder, causing them to deploy the Elevator Platform instead, using it as shown in Figure 23. These items should potentially be secured and moved with the elevator even in microgravity to avoid potential injuries due to the momentum of high mass items trapping/pinching a crew member carrying the item into the ceiling if the velocity vector of the item is not correctly aligned to transit through the opening

It should be noted that if suited crew are operating inside a depressurized Common Habitat, the VTS would still enable transfer between decks. The ladder would be sufficient for crew translation in microgravity. Depending on suit weight it may also be possible in lunar and perhaps Martian gravity. A 200-lb suit would weigh 75 pounds on Mars, so in such a case while climbing a ladder might be possible, some crew would definitely opt for using the Elevator Platform instead. And of course, in an Earth trainer the Elevator Platform would be used for any conceivable suit weight.

B. Large Cargo Item Deck Transfer

Periodically, large items will need to be moved between decks of the Common Habitat. During resupply operations, large stowage bags such as the M1, M2, and M3 stowage bags [12] will need to be moved from logistics modules to the upper and/or lower decks to transport bulk cargo to local stowage systems. Another example of this vertical translation is moving an environmental control and life support subsystem (ECLSS) pallet from the subsystems bay on the upper deck to the Repair, Manufacturing, and Fabrication (RMAF) facility on the mid deck for servicing.

In gravity, even in lunar 1/6g, the Elevator Platform will be needed. Using the ECLSS case, for instance, this use case illustrates the advantage of having a VTS opening on the upper deck towards the Command-and-Control Center. Figure 4 shows this is the shortest path to the subsystems bay. Once the crew has moved the ECLSS pallet to the VTS, they will secure it to the Elevator Platform. In the case of an ECLSS pallet, there may be sufficient room on the pallet for a crew member to ride with it, but larger items may have to be transported by themselves. In either event, the elevator will descend to the mid deck, where waiting crew will remove the pallet from the Elevator Platform and move it into a designated servicing area.

In microgravity, it would not be necessary to use the Elevator Platform. The crew can simply float the ECLSS pallet down the corridor, into the vertical translation space, and into the RMAF facility. In the case of a large item with loose or flexible components, the Elevator Platform might still be used in microgravity in order to constrain the various pieces.

C. Incapacitated or Injured Crew Member Transfer

Crew injuries can occur anywhere in the Common Habitat, during EVA activity, or in other vehicles. Injured crew will need to reach the Common Habitat MCF for treatment. In the case of crew members who are injured outside of the Common Habitat, the point of entry is always the mid deck, whether it is an EVA or a docking vehicle. A crew member who is ambulatory may be able to reach and use the deployable ladder with no further assistance.

If they are non-ambulatory, they will need to be transported. The MCF's surgical stretcher-chair is mobile within a given deck and (pending forward work) will retain that mobility in microgravity. The VTS can be commanded to autonomously summon the Elevator Platform to the needed deck. Pending autonomous mobility capability in the surgical stretcher-chair, this could be to the deck of the injured crew member. Otherwise, it would be to the upper deck where the chair would be loaded onboard, as shown in Figure 27. It would then be sent to the deck where the injured crew member is located. Once it reaches that deck, the chair would be moved (manually or autonomously) to the crew member. Caregivers will place the injured crew member on the surgical stretcher-chair, move it back to the VTS, place it on the Elevator Platform, and send it back up to the MCF.

The current iteration of the surgical stretcher-chair is too large for both the injured crew member and a caregiver to ride on the Elevator Platform together, so at least one caregiver will either already be present in the MCF or will traverse the VTS ahead of the injured crew member.

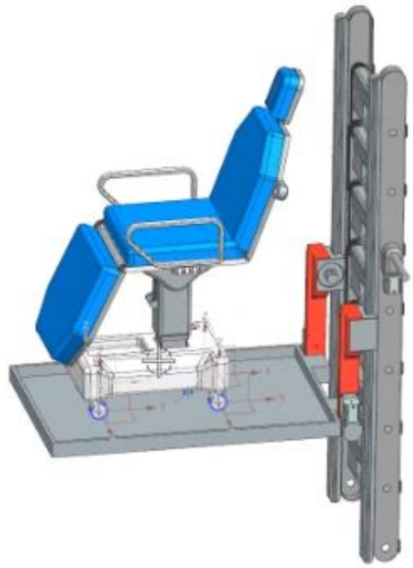

Fig. 27 Surgical Stretcher-Chair on the Elevator Platform

VII. Conclusions / Forward Work

The VTS is a flexible capability that allows the crew of the Common Habitat to traverse its decks in any gravity environment, inclusive of Earth trainers, the lunar surface, Mars surface, and in microgravity. It, along with the parallel development efforts Gecko Mobility Aids and Multi-Gravity Crew Seat (to be featured in future papers), provide a system of restraints and mobility aids needed for the crew to operate across the range of gravity environments in the Common Habitat Architecture. Several areas of forward work are needed to continue to mature the VTS.

The Common Habitat CAD model does not yet include the VTS. The VTS and Common Habitat CAD models were created in two different CAD systems (NX and Rhino respectively) and the VTS models will need to be converted into formats readable by Rhino. They can then be incorporated into the Common Habitat CAD model.

Analysis is needed to determine whether a need exists for the rotating rungs. As presently designed, the rungs are too large to allow the elevator platform to translate unless the rungs rotate out of the way. If this interference can be removed from the design, the mass and complexity of the rotating rung system can also be eliminated.

Some minor design work is needed with respect to the interface between the folding ladders mounted on the ceilings of the mid deck and lower deck. When the two ladders deploy, they must line up such that the toothed tracks on the two ladders are close enough that the elevator platform can traverse from one ladder to the other. This was considered during the current design, but additional work will continue to be needed as the fidelity of this architecture is increased.

The way the elevator platform’s motor provides torque to the gear boxes should be changed to remove the belt and replace it with a more robust mechanical means of connecting the motor to the gear boxes.

The ladder step heights are not ideal. A study is needed to determine the best step locations (specifically on the mid deck where the two ladders meet). Currently on the mid deck, either the first step onto the top ladder (visible in Figure 19) is unreasonably high or there is a low top step on the bottom ladder.

Additional work is needed to identify appropriate safety features related to the elevator platform. When carrying equipment or crew it must prevent anything from sticking outside the envelope of the vertical translation path. Otherwise, injury or damage could result when the cart is transported between decks. This could involve additional restraints, such as attachable guards) or a physical barrier matching the profile of the vertical translation path. Any of a number of design solutions could prevent any accidental contact with ladder rungs or habitat structures during elevator platform traverses.

Refinement of both the VTS and the Surgical Stretcher-Chair is needed to support injured crew member transport across decks. While the commercial stretcher-chair is sufficient to illustrate the concept, it is not sufficiently reconfigurable to support all relevant body postures during vertical translation across decks. Of particular concern are spine injuries or broken limbs that would restrict the patient to non-seated postures.

Currently, the Common Habitat has only one vertical translation path. It would be beneficial to perform a traffic flow analysis to determine whether the habitat would be better served by adding a second or third path. It is not clear that there is sufficient volume to accommodate more than one VTS, so this analysis should also include the architectural impact of adding additional paths.

Mass and power estimates for the resulting VTS will need to be completed and added to the overall Common Habitat mass and power estimation.

VIII. References

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