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Radial Internal Material Handling System (RIMS) for Circular Habitat Volumes

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A Radial Internal Material Handling System (RIMS) has been developed to service a circular floor area in variable gravity. On planetary surfaces, pressurized human habitable volumes will require a means to carry heavy equipment between various locations within the volume of the habitat, regardless of the partial gravity (Earth, moon, Mars, etc). On the NASA Habitat Demonstration Unit (HDU), a vertical cylindrical volume, it was determined that a variety of heavy items would need to be carried back and forth from deployed locations to the General Maintenance Work Station (GMWS) when in need of repair, and other equipment may need to be carried inside for repairs, such as rover parts and other external equipment. The vertical cylindrical volume of the HDU lent itself to a circular overhead track and hoist system that allows lifting of heavy objects from anywhere in the habitat to any other point in the habitat interior. In addition, the system is able to hand off lifted items to other material handling systems through the side hatches, such as through an airlock. This paper describes the RIMS system which is scalable for application in a variety of circular habitat volumes.

Nomenclature

AES	=	NASA Advanced Exploration Systems
D-RATS	=	NASA Desert Research and Technology Studies field analog tests
DSH	=	Deep Space Habitat
ECLSS	=	Environmental Control Life Support System
EVA	=	Extra-Vehicular Activity
GMWS	=	General Maintenance Work Station
HDU	=	Habitat Demonstration Unit
PEM	=	Pressurized Excursion Module
RIMS	=	Radial Internal Material Handling System

I. Introduction

The Radial Internal Material Handling System (RIMS) project was born out of a need to provide for lift and carry capacity within the circular volume of the Habitat Demonstration Unit (HDU) operational field habitat. The HDU project consisted of a multi-center team brought together in a rapid prototyping tiger-team approach to quickly build, test, and validate hardware and operations in analog environments (Kennedy, Tri, Gill, & Howe, 2010). The project integrated operational hardware and software to assess habitat and laboratory functions in an operational prototype unit. The HDU project began in 2009, resulting in an analog of a Pressurized Excursion Module (PEM) laboratory for simulating a lunar habitat for the 2010 NASA D-RATS field analog. The initial elements included a 5-meter diameter hard shell vertically oriented one-story cylindrical module with four side hatches as docking ports for support modules, analog rovers, spacecraft, and other mission elements (Howe, Spexarth, Toups, Howard, Rudisill, & Dorsey, 2010). With a portable base configuration compatible with multi-mission architecture, various teams from all over NASA brought their technologies into the HDU shell to participate in a functionally integrated

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environment. Extra-Vehicular Activity (EVA), power, communications, Environmental Control Life Support Systems (ECLSS), dust management, avionics, human factors, and many other teams contributed technologies that have been maturing in laboratories around NASA, but have heretofore not had a common portable platform that would allow them to come together in an integrated manner. For 2011 NASA built and tested a Habitat Demonstration Unit Deep Space Habitat (HDU-DSH) habitat/laboratory (Figure 1), using the 2010 configuration and technologies as a foundation, that was utilized to advance NASA's understanding of alternative mission architectures, requirements definition and validation, and operations concepts definition and validation. The HDU project has since become the Advanced Exploration Systems (AES) Habitation Systems project.

Figure 1: Habitat Demonstration Unit, 2011 D-RATS configuration (left), section (right)

Within the 2010 HDU-PEM configuration, the General Maintenance Work Station (GMWS) was tested with repair operations for suit maintenance and rover mechanical components. The GMWS was equipped with an overhead hoist located directly over the work surface, but items needing to be transfered to and from the work surface had to be hand-carried. The importance of in-field maintenance operations and the difficulty of hand-carrying heavy equipment stressed the need to develop a material handling system for the habitat. Even though the DSH 2011 configuration was intended to test a deep space habitat in a zero-g environment, the need for a material handling system in the 1-g earth analog provided an opportunity to design a system that could eventually be applied to planetary surface habitats, including the moon and Mars. In this paper the material handling obstacles and unique solutions provided by the RIMS are discussed.

II. RIMS Description

The RIMS consists of two concentric circular tracks connected by a radial beam. On the beam is a trolley where a removable hoist connects. The hoist used is an off the shelf, removable hoist. The trolley travels radially on the beam while the beam itself can be rotated around the two circular tracks, allowing the trolley to reach virtually any point within the habitat. A CAD model of the system, including stowage system, is shown in Figure 2, and Figure 3 shows the RIMS in its final configuration in the habitat.

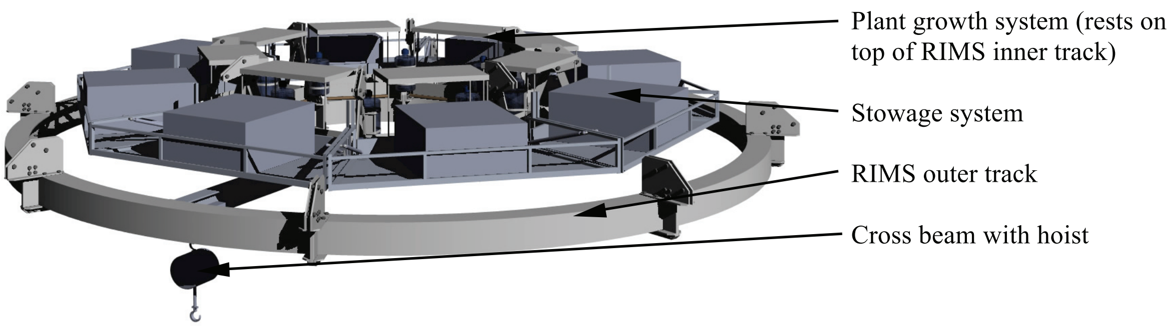

Figure 2: HDU Radial Internal Material System (RIMS) and stowage system final CAD design

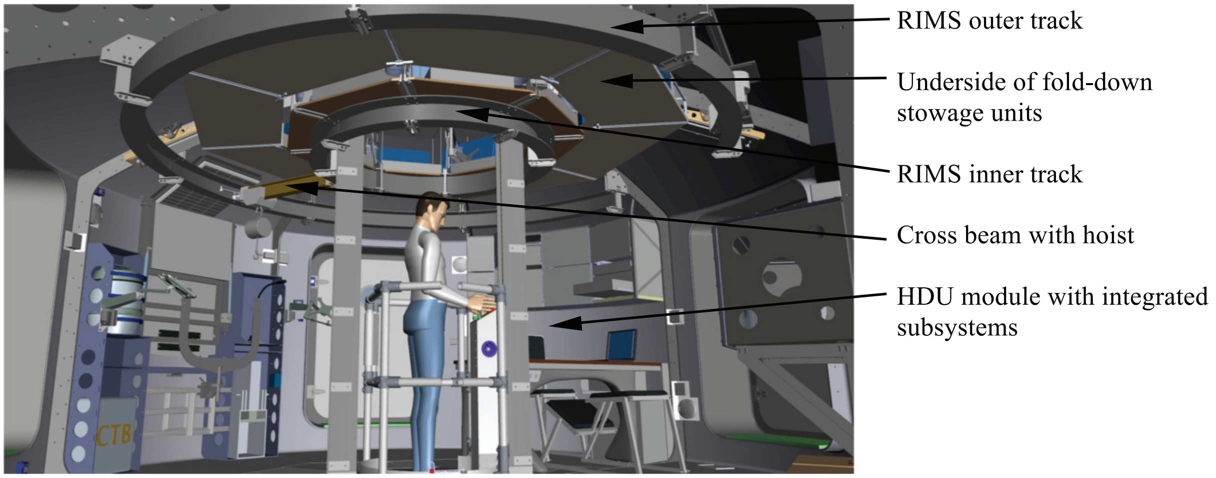

Figure 3: HDU RIMS and stowage system installed on ceiling of habitat

The RIMS system was created specifically for the circular geometry of the habitat. The circular geometry of RIMS warrants smooth, continuous movement from any part of the habitat while avoiding the "no-fly zones" in the middle and in areas where people are working. The cross beam functions in the same way a bridge crane covers a rectangular floor area, allowing lifting of any load on the floor to any other location. The circular tracks allow the cross beam motion to be continuous around the perimiter of the cylindrical volume.

As a supplemental material storage space, a series of overhead bins were created to stow extra cargo. These bins were uniquely shaped for the geometry of the habitat and sit between each of the ribs of the habitat structure. They are between the two tracks of the RIMS and are up and out of the way until needed as shown in Figure 4.

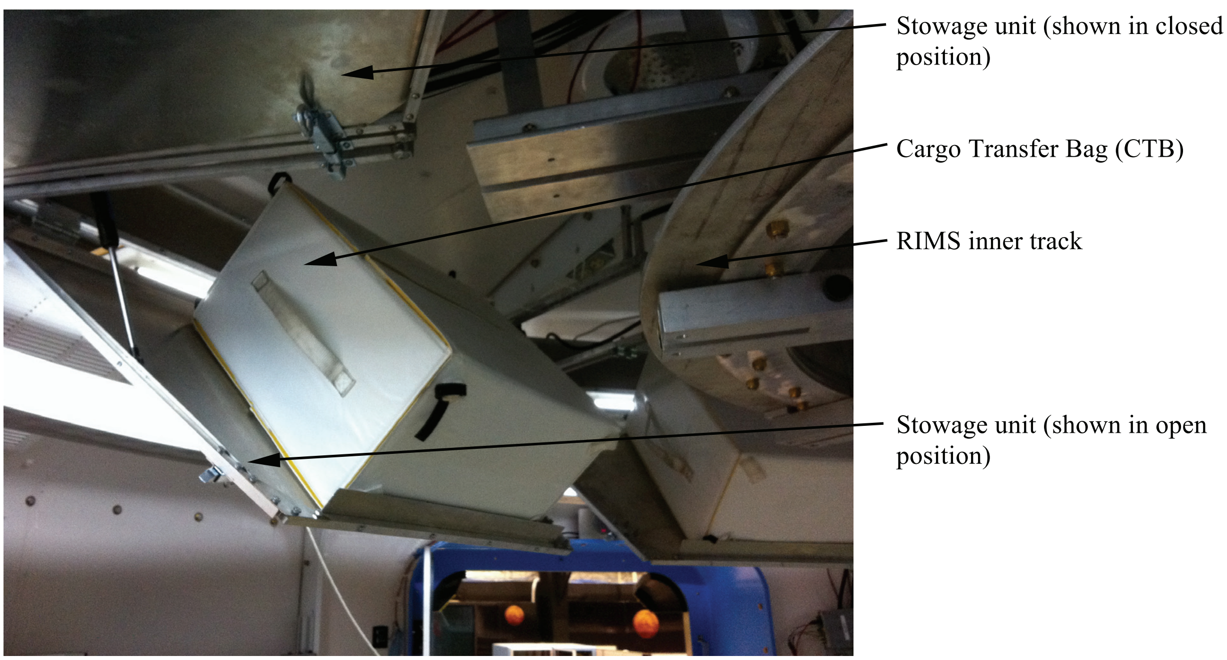

Figure 4: Stowage system with Cargo Transfer Bag (CTB)

A special roller system was designed for the radial I-beam to interface with the circular track. The roller sytem consists of a set of castors for the beam to roll along the track and arms with additional rollers to constrain the twisting of the I-beam (Figure 5). Spring-loaded end carriages make up for any slight inconsistencies in the width between inner and outer tracks, and keep the motion of the cross beam smooth and continuous.

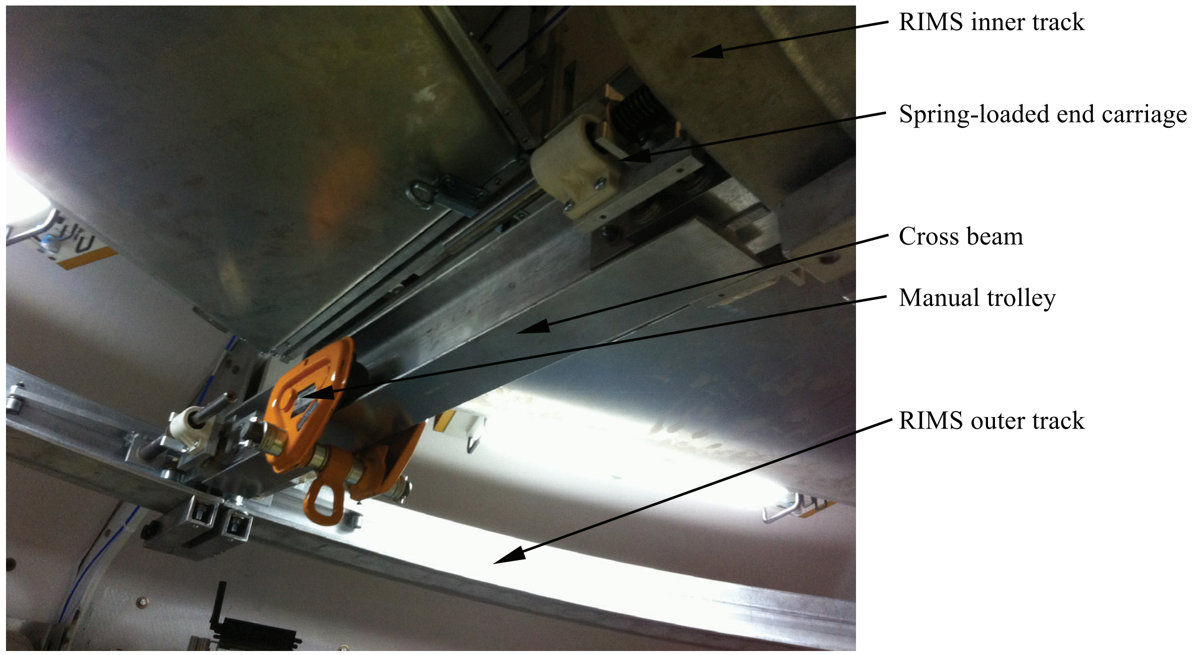

Figure 5: Sliding cross beam and trolley

III. Material Handling Operations

In a planetary surface outpost, such as those planned for the moon or Mars, multiple pressurized volumes brought up in several launch manifests will be docked together to create the target volume (Figure 6). For long-duration missions it will be necessary to repair and perform maintenance on various equipment at the outpost. In the DSH, a General Maintenance Work Station (GMWS) has been designed and tested for this purpose. The RIMS system was designed to help carry equipment from not only other locations in the circular volume of the single volume, but also to pass payloads between volumes.

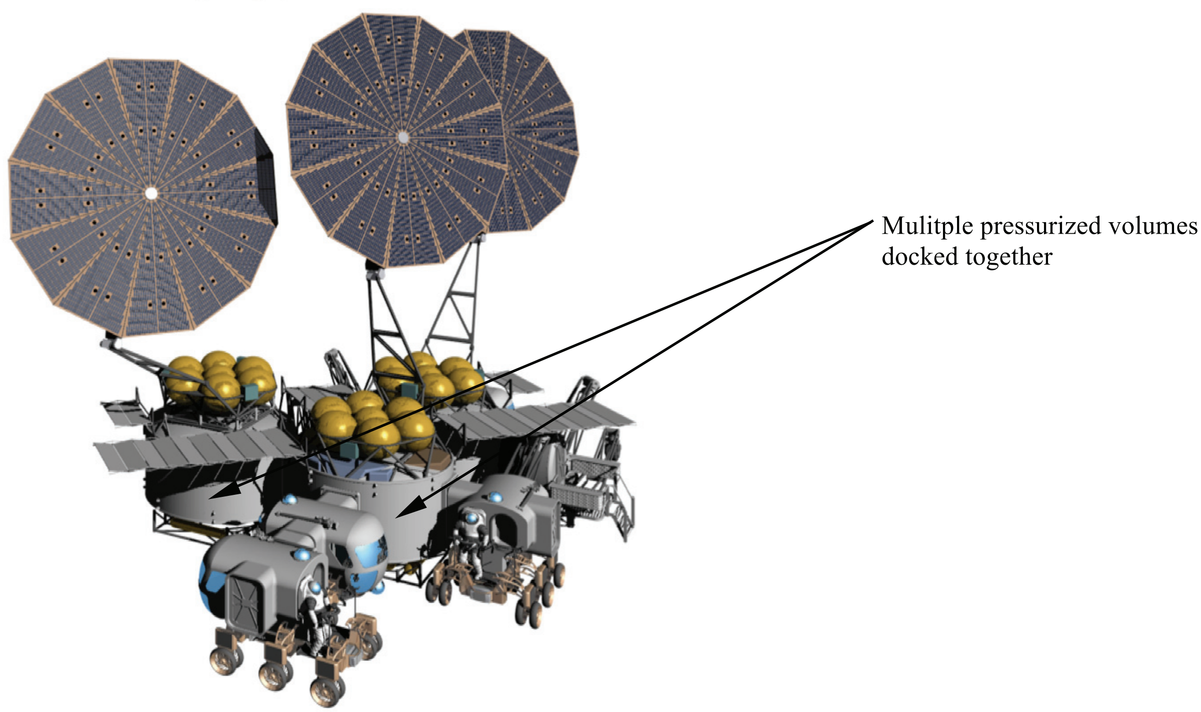

Figure 6: Lunar outpost scenario with docked pressurized volumes

The RIMS incorporates two methods of use to safely transport items 1) in the habitat and 2) from/to the main chain of the habitat to/from the suitlock, dust mitigation, and other volumes. Figure 7 depicts the floor plan of the habitat with destination areas indicated. The RIMS is currently set up on Level 1, where the cargo lift in the center will allow equipment to be passed between decks.

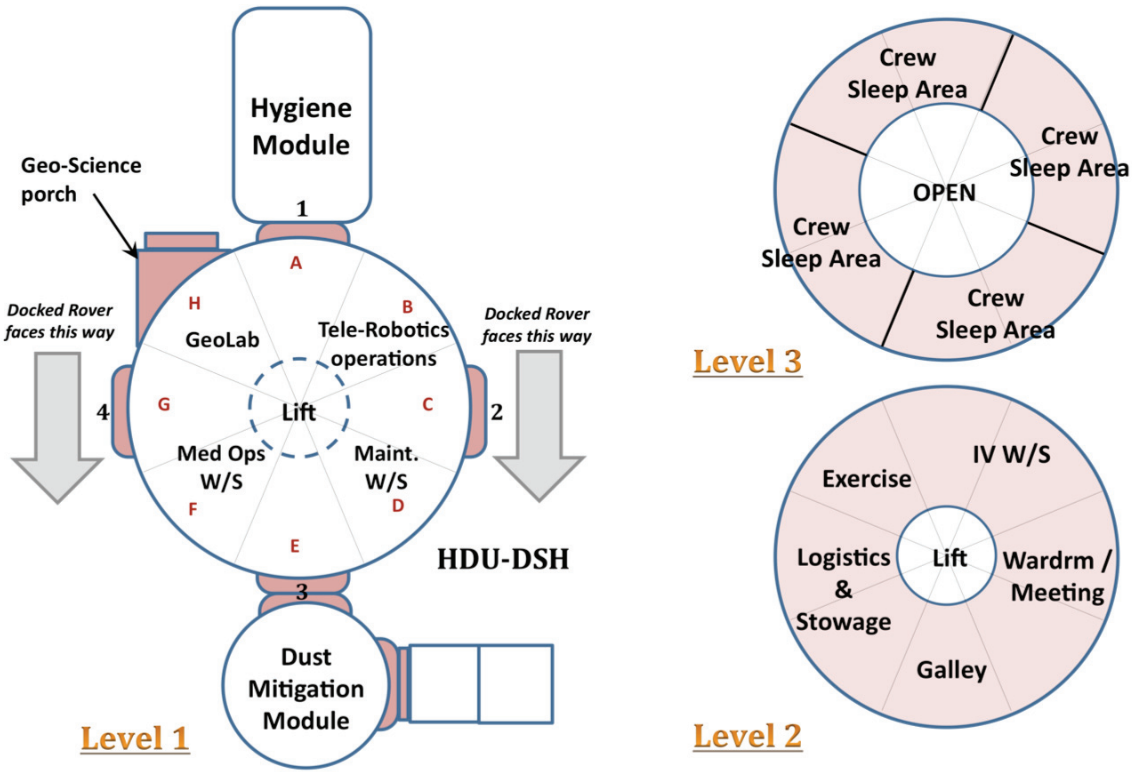

Figure 7: HDU-DSH floor plan showing layout of workstations

The GMWS, shown on Level 1 in Figure 7 as "Maint. W/S", contains work surfaces, tools, diagnostic equipment, and digital manuals for the repair of various equipment in the habitat or outpost. Other workstations in the DSH include Med Ops medical operations, Geolab science workstation and glovebox, TeleRobotics Work Station (TRWS), Hygiene stations, and other workstations not shown. Avionics and ECLSS equipment are located under the deck, which is removable and will allow for un-plugging and transport of that equipment for maintenance and repair at the GMWS.

For operations within the habitat only, the user must first attach the hand-operated hoist to the trolley on RIMS. Next, the object to be moved is securely attached to the hoist. Then, the user will use the hoist to lift the object and move item to desired location in habitat. Finally the object is detached from the hoist and the trolley and the hoist is stored away.

The user may also carefully push the payload to/from directly underneath the RIMS coverage area onto the lift in the center of the habitat, to the avionics bays, or to other areas of the habitat while the hoist is being raised or lowered. This will likely require more than one user to carry out; however, it increases the mobility of the system.

To transport from/to inside the habitat to/from the suitlock and other volumes, the RIMS must pass off the object to a winch located in the suitlock or passed off to another RIMS system in the neighboring volume. the RIMS in the habitat is designed with a stop on the radial I-beam for the hoist to rest against. Figure 5 shows the block clamp stop that allows for side loading. The hoist rests against the stop while the springs compress fully.

The RIMS was designed to interface with a recommended system in the suitlock because the suitlock and the RIMS were under construction at the same time. Figure 8 shows a floor plan of the suitlock docked to the DSH volume. To interface the two systems, a load can be brought into the suitlock via EVA crane and lifted using the suitlock winch (Figure 9, Figure 10). A user will hook both chains to the payload, and ease the chain of one while cranking in the chain of the other (Figure 11, Figure 12). Once the payload is directly under the other hoist, the user can disconnect the other chain and proceed to place the payload where they wish (Figure 13, Figure 15).

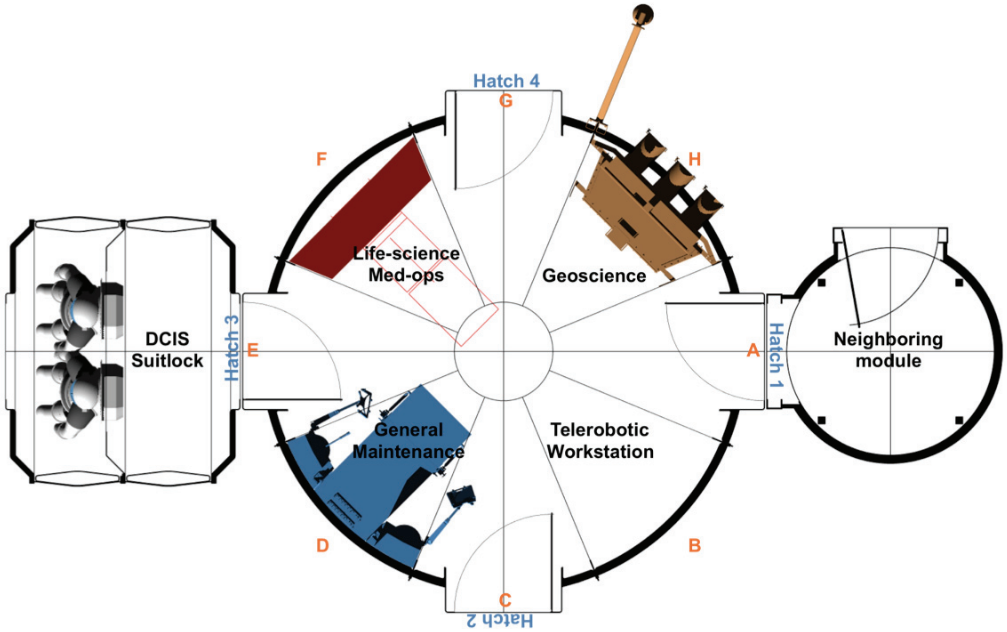

Figure 8: Floor plan showing suitlock docked to the cylindrical laboratory module volume

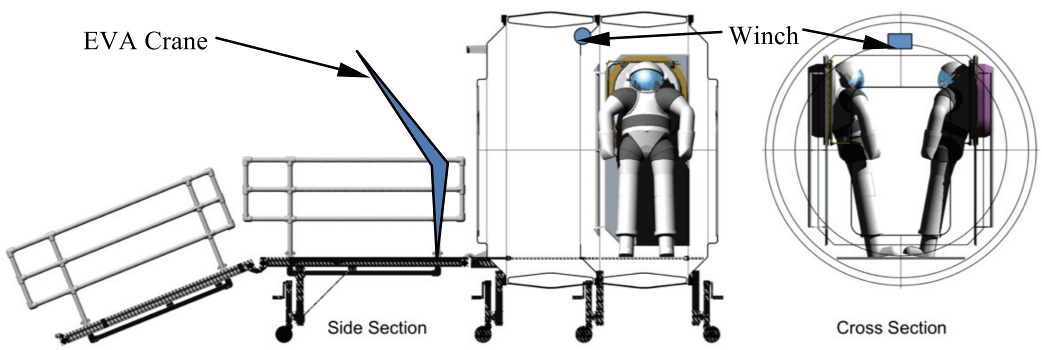

Figure 9: Section of suitlock showing winch and EVA crane locations

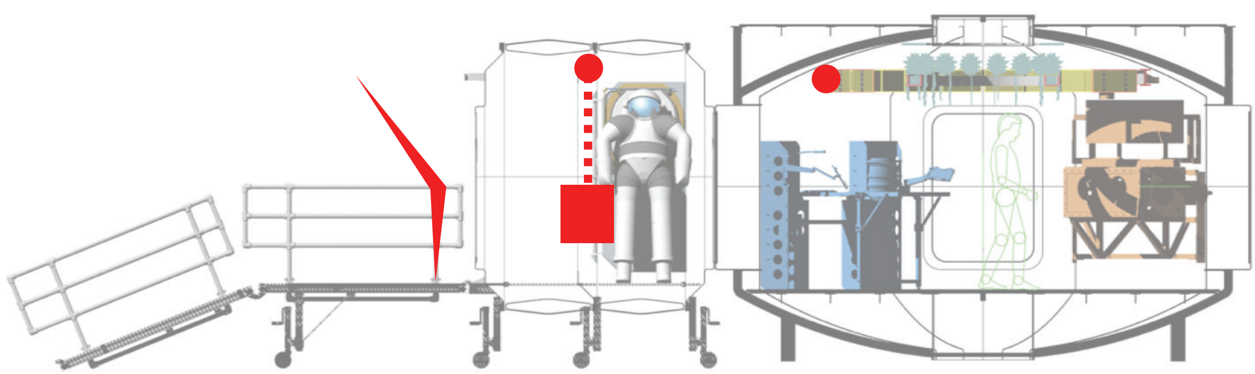

Figure 10: Passing from suitlock to module STEP 1: load hangs on suitlock winch (EVA crane also shown)

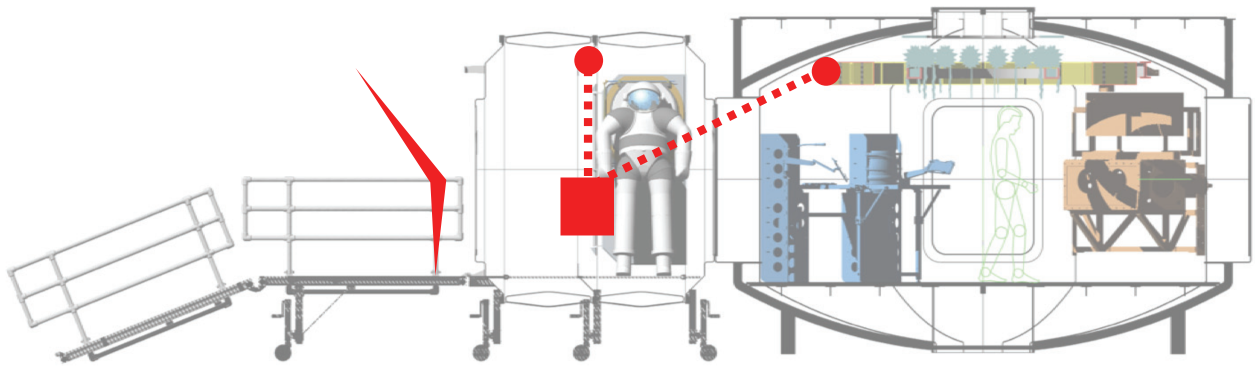

Figure 11: Passing from suitlock to module STEP 2: connect RIMS chain to load

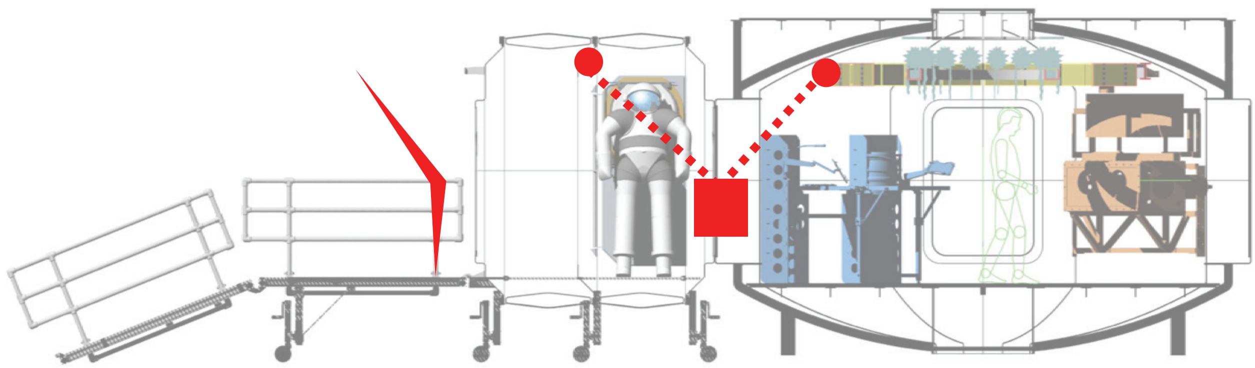

Figure 12: Passing from suitlock to module STEP 3: slack winch cable while tightening RIMS chain

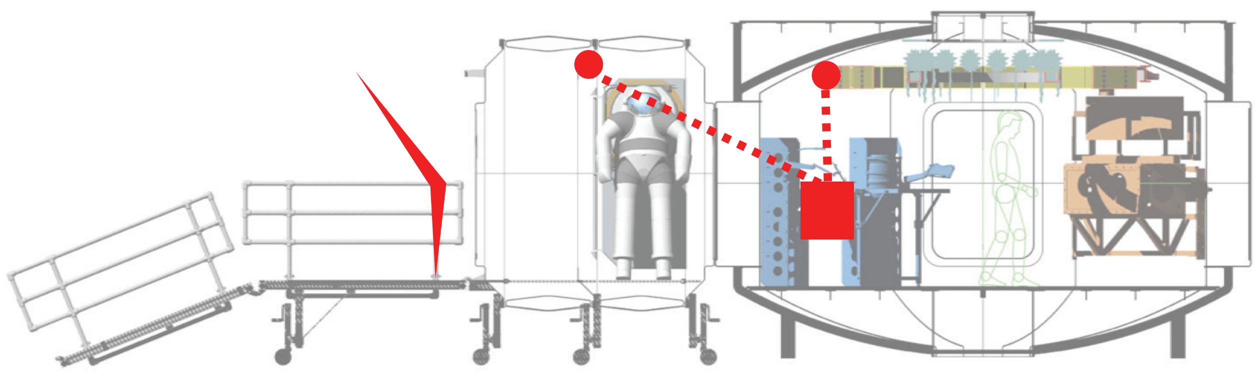

Figure 13: Passing from suitlock to module STEP 4: disconnect winch cable

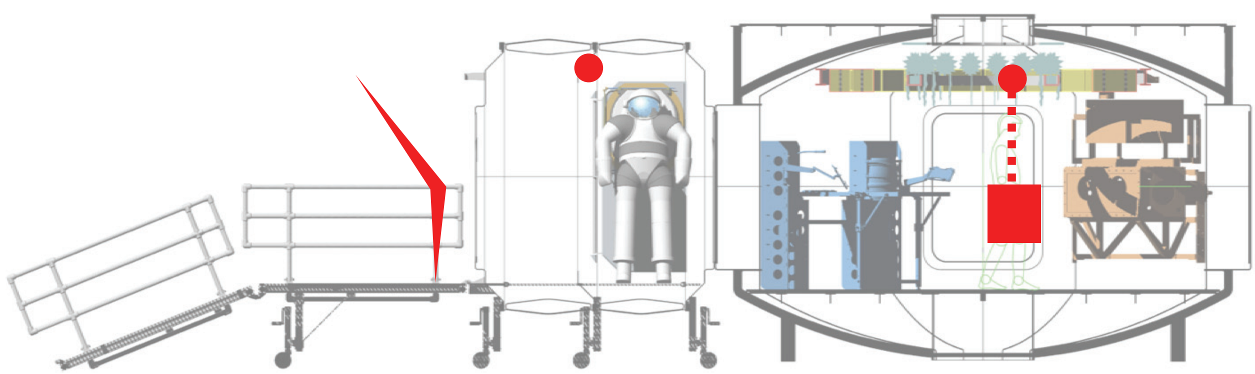

Figure 14: Passing from suitlock to module STEP 5: move load to wherever needed in habitat volume

In a similar way, loads can be passed between two RIMS systems where two modules are docked together, to allow any cargo load to be moved from any location in the outpost to any other location. It should be noted that the user will require additional ties/chains or other restraints of their choice to attach the object to the RIMS hoist. The RIMS was not designed with a specific type of tie-in in mind in order to accommodate more types of objects. Figure 15 shows the Level 1 laboratory deck that the RIMS operational envelope covers, and Figure 16 shows the RIMS in its operational environment.

Because the RIMS is installed in a very tight space, it was assumed during design that the user(s) should communicate with others in the Habitat before and during the transport of objects, alleviating the need for an alarm. Future work could include development of a visual or audible alert system to indicate that the RIMS is in use as an extra safety precaution.

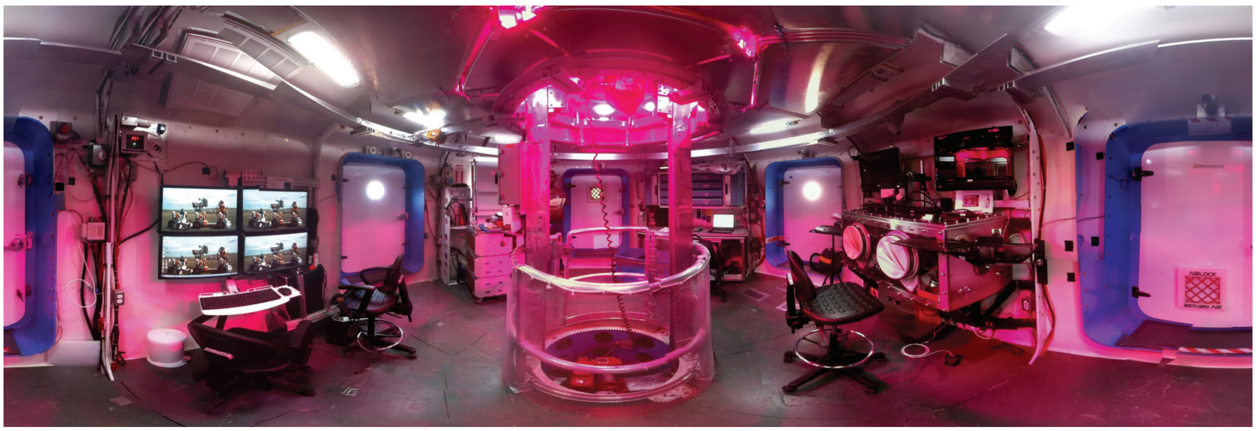

Figure 15: 360 degree view of HDU-DSH laboratory deck, with RIMS installed in ceiling

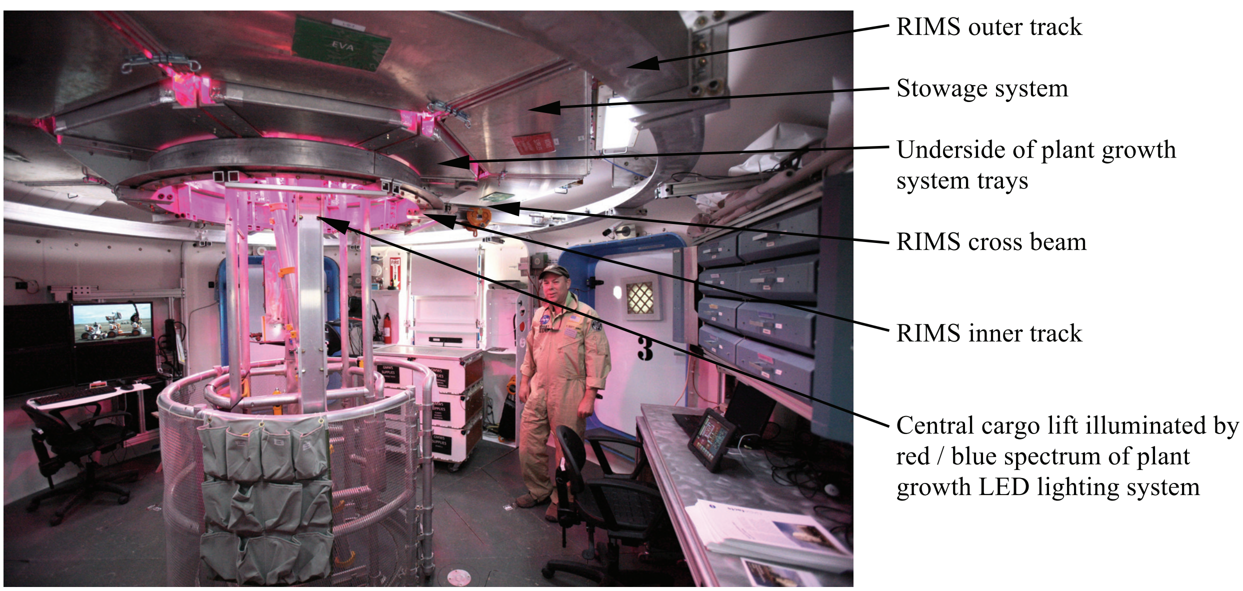

Figure 16: Deep Space Habitat (DSH) interior with RIMS in place on ceiling (photo: James W. Young)

IV. Future Work

Among the future work do be done on the RIMS is determining scalability, both for the volume which the RIMS will cover, and for the mass of objects it will carry. Several improvements and assessments will be made along these efforts.

In terms of volume scaling, the scalable parameters are the radius of the track, the length and cross-section of the radial beam, and features of the roller assembly. Scaling up may cause increased torqueing on the roller assembly. If a different I-beam cross section is chosen, a different trolley will be needed. Scaling down may eliminate the need for a radial beam, however it is not possible to curve the track to very tight radii.

In terms of load scaling, the scalable parameters are the cross-section of the track and beam, features of the roller assembly, and the hoist. Again, scaling up will increase torque on parts of the system. For future work, a study could be conducted showing minimal and maximal radii for the system, and sizes track, cross beam, and hoist for a variety of configurations. It is assumed that tracks and cross beams could be designed as truss structures for very large diameters, similar to the way large bridge cranes operate in rectangular volumes.

The current RIMS system is all manual, with no electric motors, winches or drives. Further work may include capacity for remote control winches and drives, with the ability to move the trolley to any required location using remote commands. The RIMS material handling system will eventually be one component in a fully automated material handling chain, to support habitat maintenance and repair when crew members are not present.

Keeping the above parameters in mind, as well as others, the RIMS will be assessed in its scalability. It is believed that the RIMS will be scalable to other cylindrical volumes and a useful tool for material handling within them.

The RIMS system was designed with the assumption that the habitat would be equipped with a self-leveling base that overcomes unevenness in the terrain upon which it is placed. The current HDU-DSH was equipped with manual leveling devices to keep the habitat level in the desert environment. The RIMS system would not work as well in a tilted habitat, since part of the time the load will be free rolling down hill, and part of the time pulled uphill by the user.

V. Conclusion

The RIMS system has borne the problem of transporting large and/or heavy items in order to maintain the nominal functions of the HDU-DSH. It consists of two concentric circular tracks with a radial beam spanning them, a trolley that moves radially on the beam, and rollers on the ends of the beam that allow the beam to rotate around the habitat on the tracks. The RIMS was designed to interface with other material handling solutions outside habitat during normal operations and can service virtually every part of the habitat. It is a unique solution, but is likely scalable to other cylindrical volume material handling needs. Since the 2011 D-RATS activities provided for tests and demonstrations for a Deep Space Habitat in a zero-g environment, the RIMS system was not included in the primary tests at D-RATS during simulated missions, but was used successfully for maintenance purposes by ground crew.

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