Designing for Virtual Windows in a Deep Space Habitat

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This paper discusses configurations and test analogs toward the design of a virtual window capability in a Deep Space Habitat. Long-duration space missions will require crews to remain in the confines of a spacecraft for extended periods of time, with possible harmful effects if a crewmember cannot cope with the small habitable volume. Virtual windows expand perceived volume using a minimal amount of image projection equipment and computing resources, and allow a limited immersion in remote environments. Uses for the virtual window include: live or augmented reality views of the external environment; flight deck, piloting, observation, or other participation in remote missions through live transmission of cameras mounted to remote vehicles; pre-recorded background views of nature areas, seasonal occurrences, or cultural events; and pre-recorded events such as birthdays, anniversaries, and other meaningful events prepared by ground support and families of the crewmembers.

Nomenclature

AES	=	NASA Advanced Exploration Systems
D-RATS	=	NASA Desert Research and Technology Studies field analog tests
DSH	=	Deep Space Habitat
ECLSS	=	Environmental Control and Life Support System
EML-2	=	Earth-Moon LaGrange Point 2
EVA	=	Extra-Vehicular Activity
HDU	=	Habitat Demonstration Unit
MMSEV	=	Multi-Mission Space Exploration Vehicle
NASA	=	National Aeronautics and Space Administration
NWSE	=	north, west, south, east
PEM	=	Pressurized Excursion Module
TRWS	=	Tele-Robotics Intravehicular Work Station

I. Introduction

THIS study on virtual windows came out of a need to provide for extended apparent volume for Deep Space Habitats (DSH) that will be occupied by crews on long-duration space missions. Habitat volumes tend to be minimal due to launch vehicle and mass budget constraints. Where crews will remain in isolation for extended periods of time in confined vehicle cabins, the need for external situational awareness, connection to proximity operations, and connection distant settings, including nature and cultural scenes call for a simulated projected means of artificially expanding the apparent volume of the habitat.

The study took place on NASA's Habitat Demonstration Unit Deep Space Habitat (HDU-DSH) prototype. 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

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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 Desert Research and Technology Studies (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 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. In 2012 the HDU project became the Advanced Exploration Systems (AES) Habitation Systems project continuing development of a Deep Space Habitat. For 2012 NASA built and tested the HDU-DSH habitat/laboratory (Figure 1) using the 2010-2011 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.

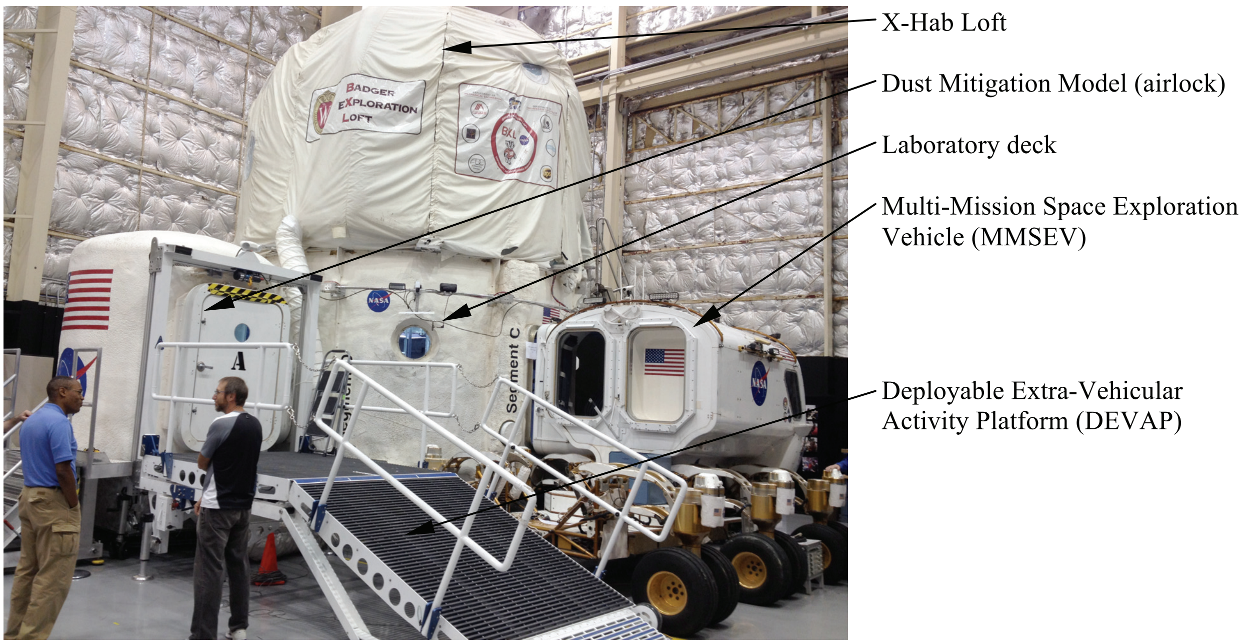

Figure 1: Habitat Demonstration Unit Deep Space Habitat (HDU-DSH)

II. Virtual Window Concept

For long-duration missions, crews will be confined in small volumes for months at a time without the ability to exit and refresh their minds with alternative environments and scenery. For transit vehicles, even if the crew went outside the vehicle for an Extra-Vehicular Activity (EVA) task, the only thing that would likely be visible would be black space, the exterior of the vehicle, and perhaps points or small disks that represent the sun, moon, Mars and a starry sky. In this study, we have looked at how an artificial extension of the volume could be accomplished by projecting external views in an immersed way, that can perhaps eventually approach the capability of a virtual reality “cave”.

In Earth buildings, windows provide occupants with the ability to extend their environment visually, even though the actual volume of the room may be quite small. Studies relating to how a person deals with stress in a confined volume by occasionally looking out a window were not performed by the authors, but are available in the literature (Oberg, Oberg 1986; Ulrich 1984). Small volumes can also be artificially extended using mirrors, which were not a part of this study, but may be worth future investigation.

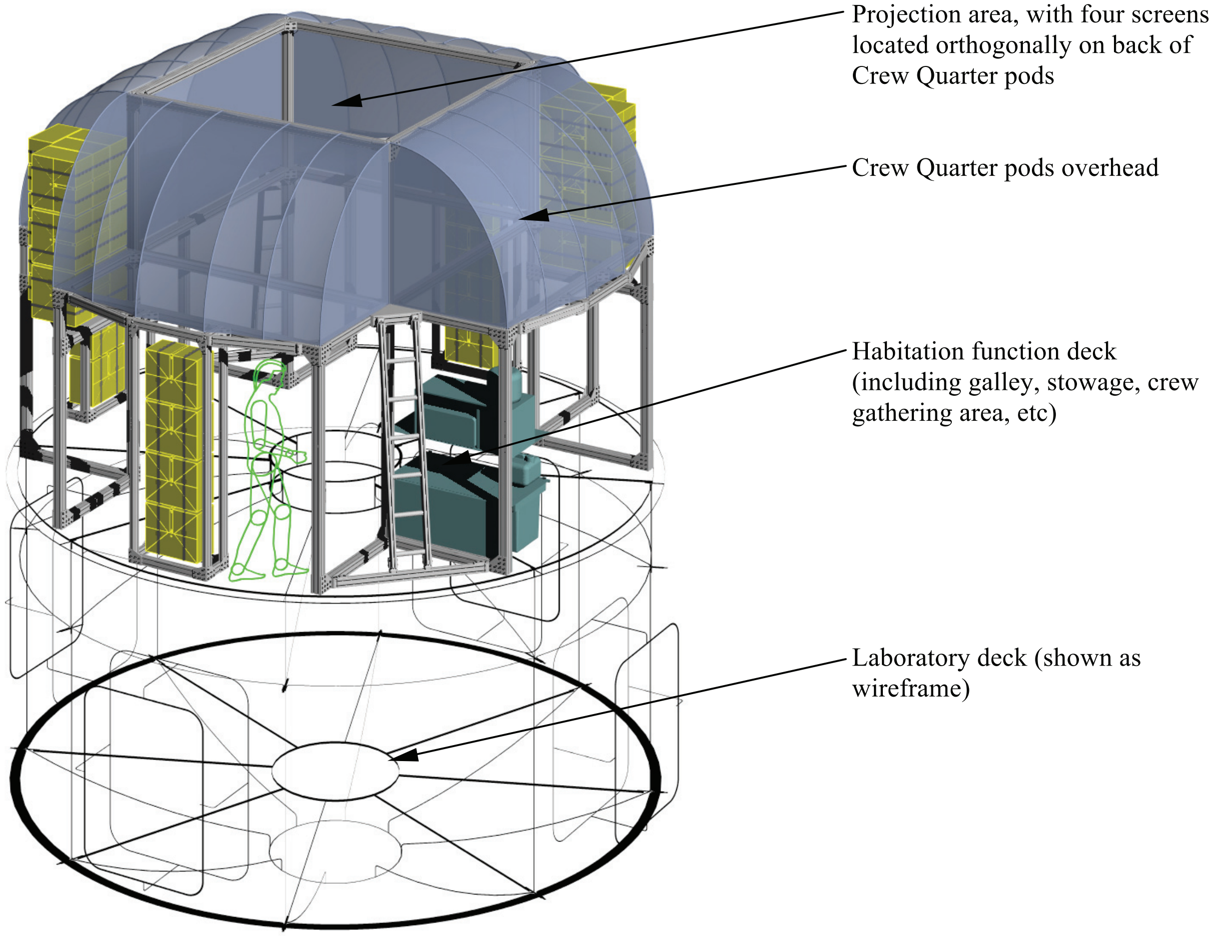

Figure 2: HDU-DSH X-Hab Loft configuration

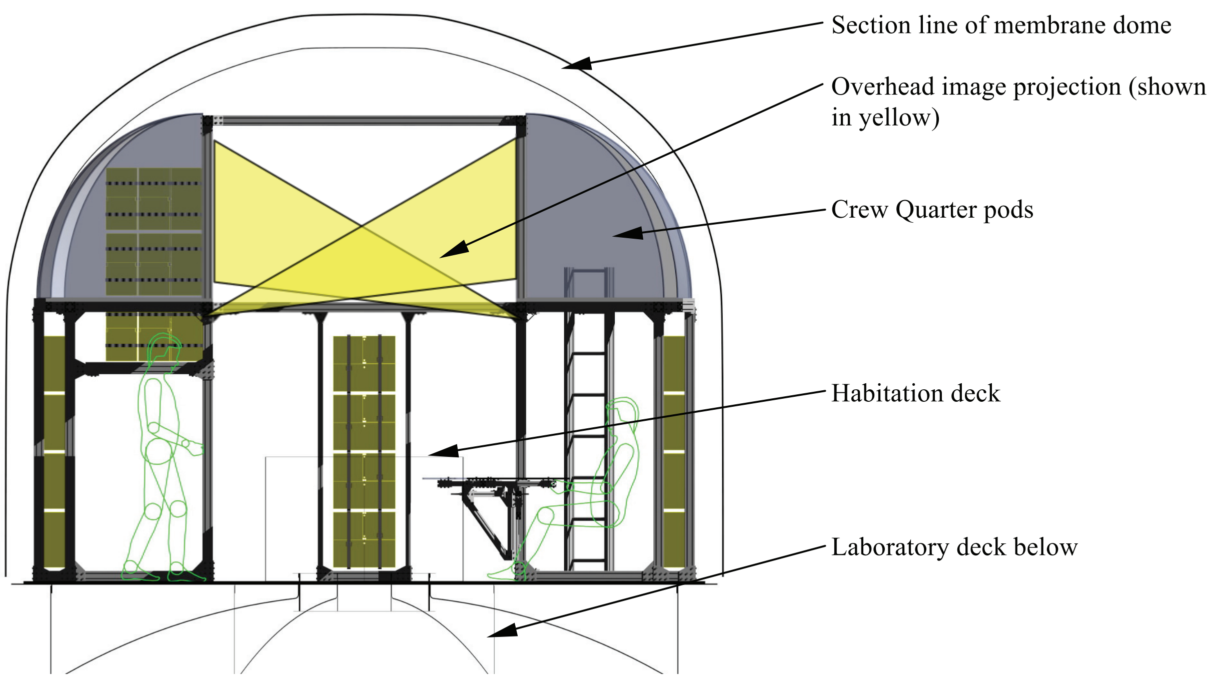

Figure 3: HDU-DSH projector screen CAD configuration

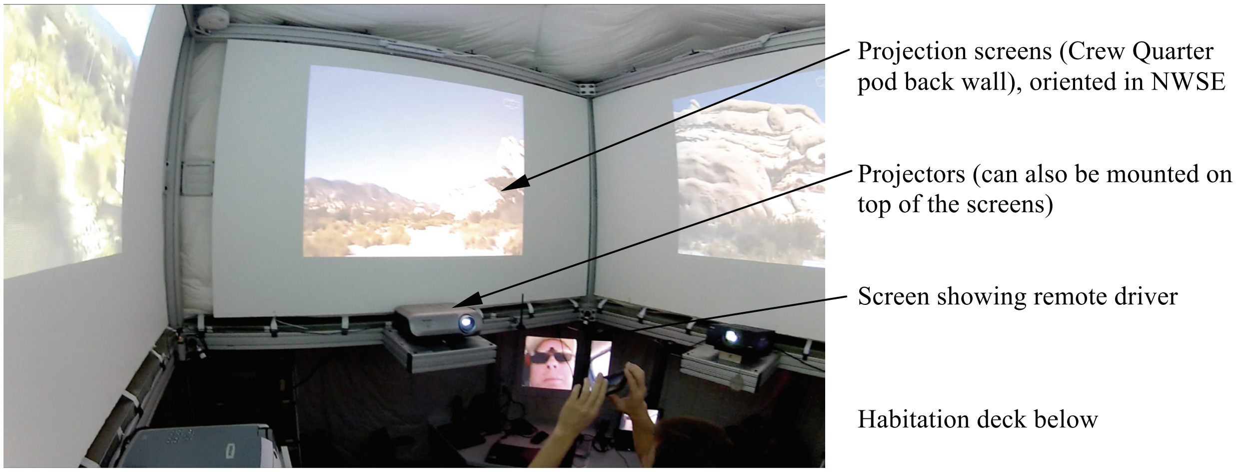

Figure 4: HDU-DSH projector screen in use

Consisting of projections or images on digital screens, Virtual Windows do not currently have the three-dimensionality of actual windows, but may eventually be configured to trick the eye and brain into inserting the person into the scene. Small spacecraft volumes can be artificially expanded to include the actual projected space outside, or pre-recorded environments. Virtual Windows can also include data and image manipulation in the form of augmented reality, or pre-recorded events and scenes from back home. Using a combination of live projected video streams, augmented reality, remote live video streams, and pre-recorded video, it will be possible to combine such functions as pilot cockpit, telerobotics workstation, and conference functions.

III. Virtual Window Technology Demonstrations

The HDU-DSH demonstration unit provided an opportunity to install and test simple virtual window hardware and configurations. The Virtual Window configuration consisted of four screens mounted to the back of the Crew Quarter pods on the second level, with four dedicated digital projectors (Figure 2). The projections were configured to be overhead above the habitation deck, such that day-to-day activities do not disrupt the projection, and images and video do not distract activities conducted below (Figure 3). Figure 4 shows three of the screens with video streams projected onto them.

The demonstrations in the HDU-DSH addressed five possible functions for the virtual window hardware: spacecraft situational awareness; remote vehicle piloting and control; remote mission participation; pre-recorded environments; and pre-recorded special occasions prepared by ground-based stakeholders (family, mission support, etc).


Figure 5: Simulated live view (four screens) from Earth-Moon LaGrange Point 2 (EML-2). These images have stars in them, and underscore the importance of selecting useful resolution projectors or screens.

A. Spacecraft Situational Awareness

The Virtual Window requires a minimal amount of added complexity (cameras and software) while providing a better structure without actual glass or composite windows that are vulnerable to damage. A mass reduction can also be expected by eliminating the glass and supporting structure. In addition, this system will also increase the usable interior volume by not requiring access to actual glass windows. This research does not advocate eliminating real windows entirely because in case of camera failure real windows can provide redundant visibility in critical events like rendezvous and docking. However, it is assumed that Virtual Windows may strengthen the case for real windows to be placed only where required for mission critical backup functionality, or where important depth cues (such as binocular parallax and motion parallax) are required but cannot be obtained from available virtual window technology, or where other heavy supporting structure is already present, such as in hatch doors.

This concept was tested during the 2012 HDU-DSH Mission Operations Test (MOT) with 4 external cameras that wirelessly connected to an application called Portable Virtual Porthole (PVP). The crewmembers would be able to see the camera views using the PVP App on their iPads. The display on the iPad would show the view from the camera that the iPad was pointed to, and allowed the crewmembers to pan their iPads and see the view of a near-continuous porthole around the habitat. The crewmembers were able to see the exterior views while they were anywhere in the DSH, thus providing situational awareness at all time.

In a long-term mission, Figure 5 simulates four orthogonal camera views that a crewmember might see using the PVP system, or as projected on the Virtual Window screens.

Using augmented reality, live views can be enhanced to provide information or tools for research. Figure 6 shows two views from a smartphone astronomy database app that overlays information and allows for hyperlink identification of stars and other heavenly bodies. Augmented reality enhanced live views can give crews a greater artificial situational awareness than just the raw video from cameras pointed outside. In addition, digitally enhanced live video feeds could transition into computer generated views to allow the crew to “fly ahead” if desired.

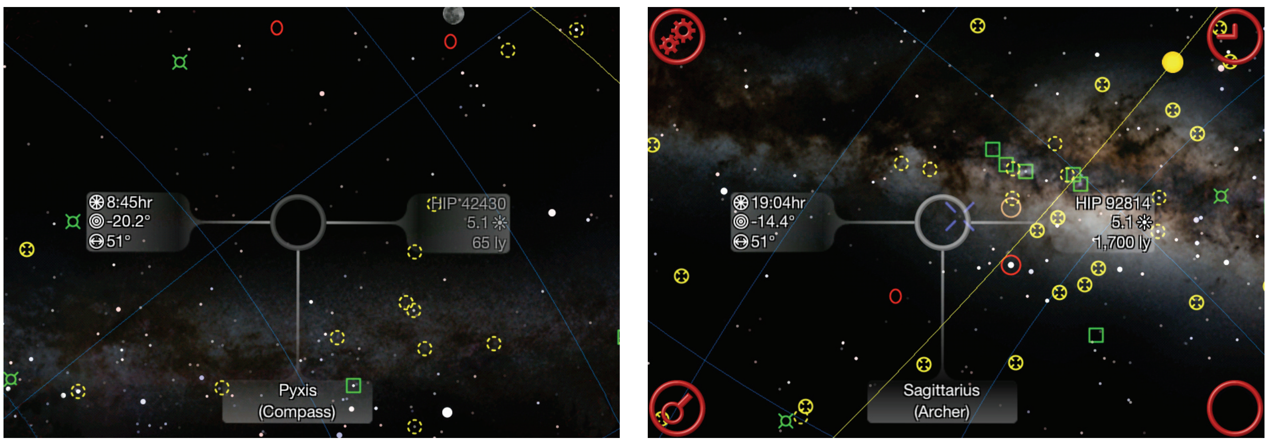

Figure 6: Augmented reality views of space environment, showing hyperlinks to astronomical data base (courtesy of GoSkyWatch app by GoSoftWorks)

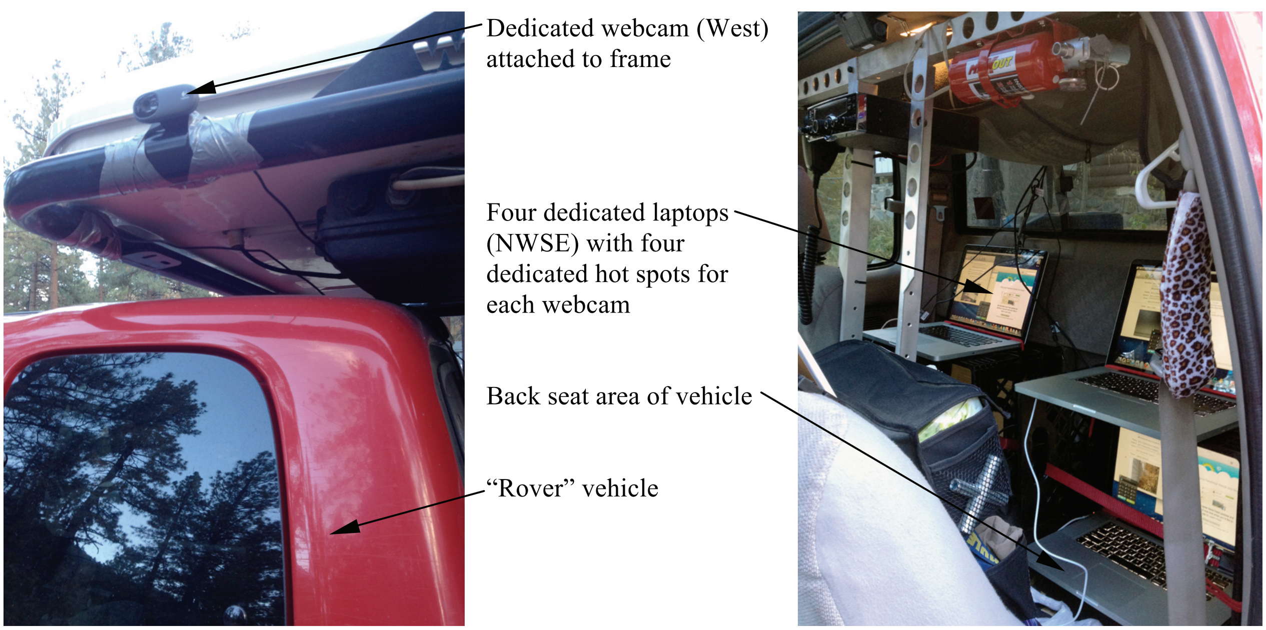

Figure 7: Simulated rover setup, exterior (left) and interior (right)

B. Remote Vehicle Piloting and Control

A Virtual Window function can also allow for piloting and control of remote vehicles, taking up the function of a telerobotics workstation. As part of the HDU-DSH Virtual Window demonstration, a simulated rover vehicle was outfitted with dedicated NWSE webcams fastened to the vehicle frame, which streamed video into four dedicated laptops and hot spot modems. Views from the simulated rover were transmitted over Skype teleconference system from the desert and mountains in California over the Internet to the HDU-DSH located in Houston, Texas.

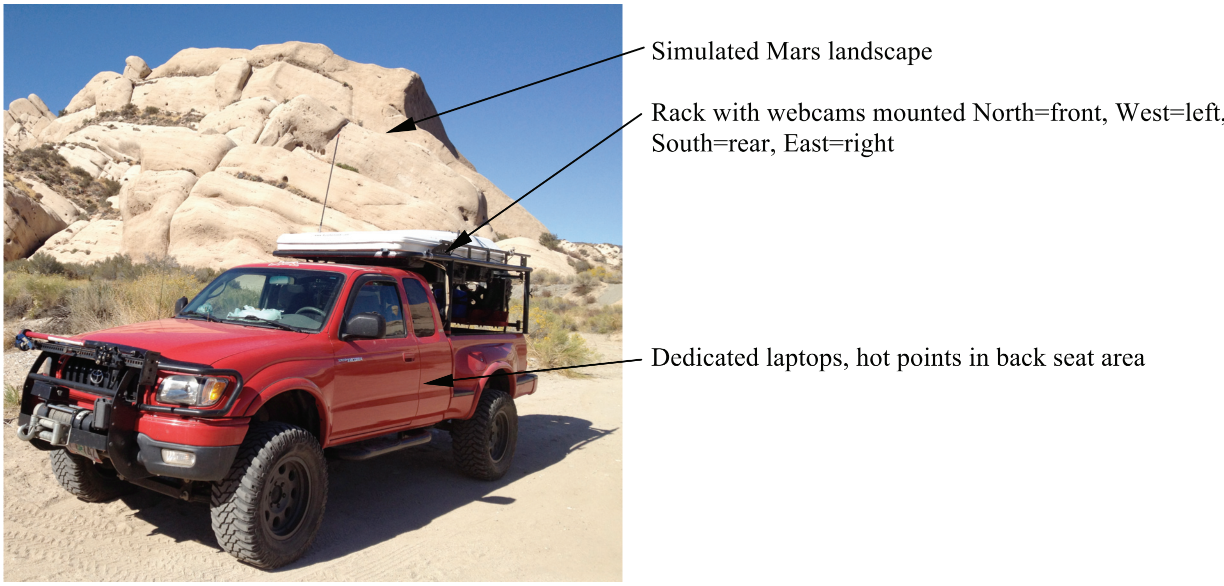

Figure 8: Simulated rover in Mars analogous landscape (Mormon Rocks, West Cajon Valley, California)

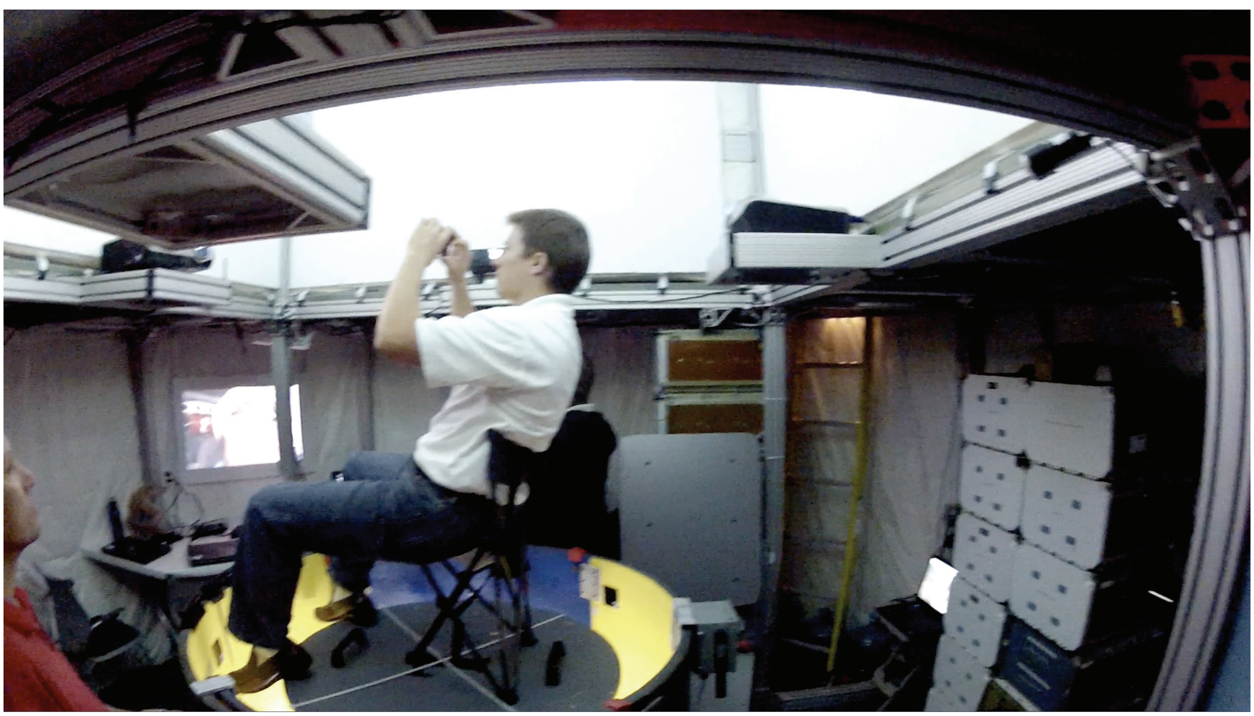

Figure 9: Live video streams from simulated rover projected into HDU-DSH

The simulated rover video setup is shown in Figure 7, with the four cameras mounted orthogonally from each other (left), and dedicated laptops installed in the back seat (right). Cameras were installed at orthogonal points and labeled North (aiming to front of vehicle), West (aiming left), South (rear), and East (right) on the vehicle (Figure

8). In several tests, the vehicle was driven by a remote operator through a simulated Mars landscape located at Mormon Rocks in West Cajon Valley, California. Crewmembers located inside the HDU-DSH at Houston, Texas simulated the driving of the vehicle (via verbal commands such as “turn right, go straight” etc) to demonstrate remote vehicle piloting. The crewmembers inside the HDU-DSH sat in a raised seating area enclosed by the projection screens to simulate immersed experience in the projected environment.

C. Remote Mission Participation

An experiment was performed in the DSH involving a vehicle in a remote part in the country that was instrumented with video cameras pointed in different directions, with the live video being displayed on screens inside the HDU-DSH, as described above. As the vehicle was being driven through a Mars-like terrain, the crewmembers in the DSH reported that they felt as if they were passengers in the vehicle. For this experiment, the screens were positioned in a similar orientation to the cameras mounted on the vehicle (forward, left side, right side and back views). Although the experiment was not comprehensive, the similarity between the camera and screen orientations was attributed to the inclusiveness that the crew experienced. Crewmembers interacted with the simulated rover’s driver, and the immersion experience allowed the HDU-DSH crewmember to participate in a simulated in-situ mission (Figure 9).

D. Pre-recorded Environments

A crewed test in the DSH utilized the projectors to display various seasonal earth scene videos to aid the crewmembers in the seasonal rhythms that are common to life on earth. The intent was to maintain the crewmembers perception of the passage of time as is experienced on earth. For the demonstration crew the nature scenes provided a relief from the artificial environment of the spacecraft, with tranquil surroundings that can reconnect the crewmembers to their memories of the outdoors.

As part of the Virtual Window demonstration, a special camera capable of recording four simultaneous video streams in NWSE directions was designed and built, that could be carried to a variety of natural, cultural, or other environments (Figure 10).

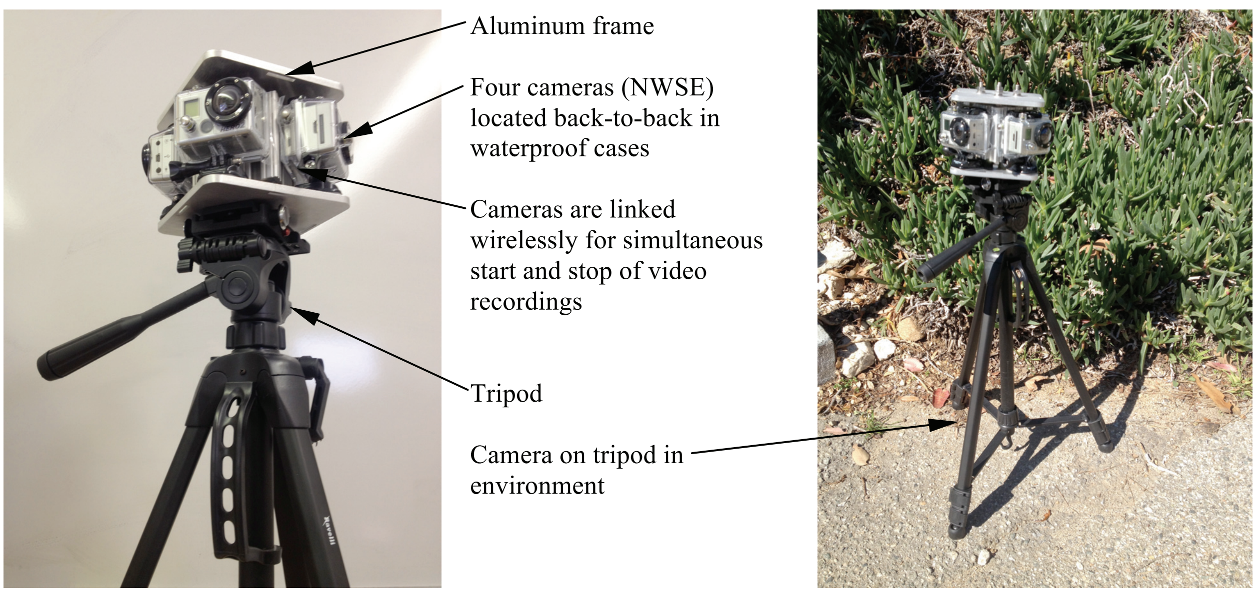

Figure 10: Camera for preparing pre-recorded nature scenes projected into HDU-DSH

Live video feeds of natural environments in various seasons can be pre-recorded, played, looped, or even uploaded later to provide a continuous artificially extended volume inside the habitat. Perceptionally, a continuous video of the scene at Lake Powell, Arizona shown in Figure 11 could artificially extend the perceived volume of a small habitat by many cubic miles, and provide much stress relief in confined quarters.

Figure 11: Four screen views of pre-recorded natural environment (Lake Powell, Arizona)

E. Pre-recorded Special Events

Similar to pre-recorded nature scenes, a Virtual Window capability will allow special occasions such as meetings, conferences, birthdays, anniversaries, and other events to be pre-recorded by ground-based stake-holders (families, ground support, etc) using the special camera, and uploaded to the habitat for crewmembers to enjoy on long-duration missions.

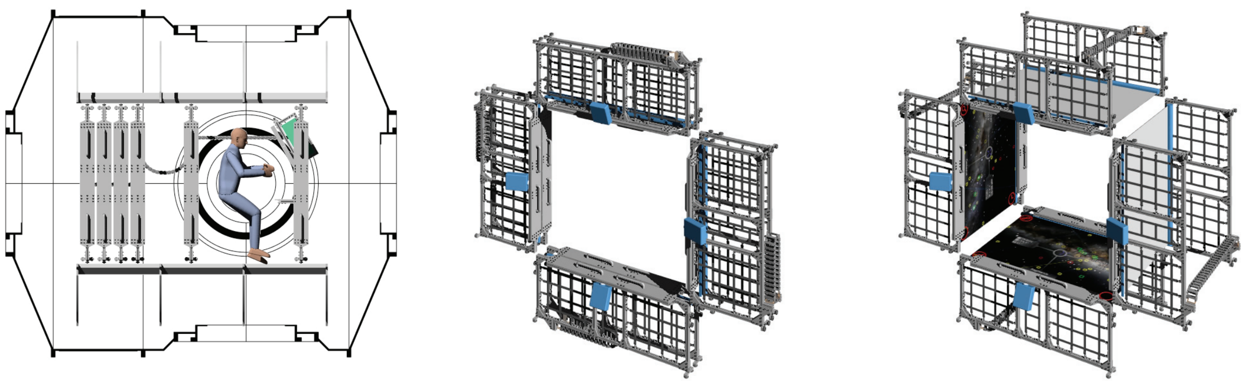

Figure 12: Random Access Frame (RAF) layout inside an ISS-based Node 1 module (left), with Virtual Window stowed (middle), and deployed (right)

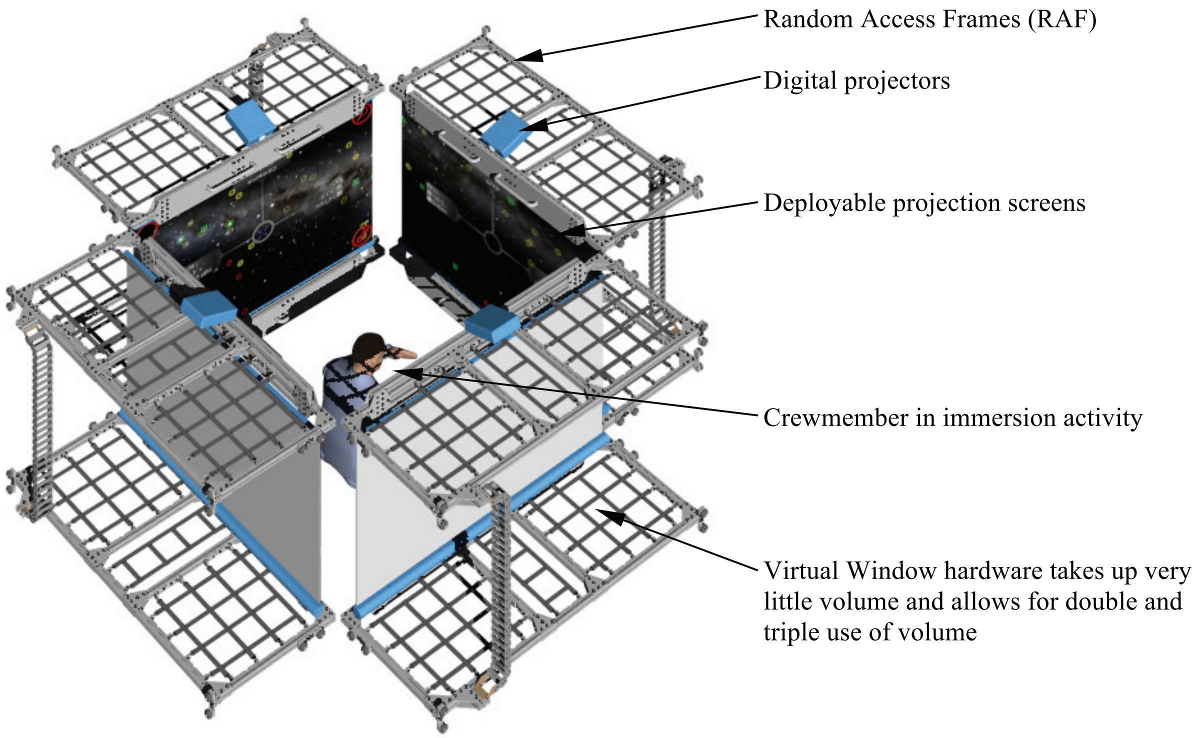

Figure 13: Lightweight projection screens used as a Virtual Window showing crew in immersion activity

IV. Current and Future Work

The Virtual Window research is currently being conducted in conjunction with NASA Flightdeck of the Future, and Tele-Robotics Intravehicular Work Station (TRWS) research, with the intention that a Virtual Window capability would also enhance telepresence capabilities and allow the crew to monitor and control different aspects of the habitat.

Future work includes devising lightweight projection systems for use in ISS-derived Cis-lunar spacecraft that can be deployed or stowed on demand. Figure 12 shows a cross-section of an ISS Node 1 (left), with Random Access Frames (RAF) providing mounting locations for hardware, stowage, and equipment. A Virtual Window setup would take up minimal volume stowed (Figure 12, middle), and allows for multi-use of volumes while deployed (Figure 12, right). Similar to the configuration tested and demonstrated in the HDU-DSH, a Virtual Window will perceptively extend the limited volume of a small Cis-lunar spacecraft or habitat (Figure 13).

V. Conclusion

The purpose of this study was to design and test a physical system that could be provide a basis and configuration for future study. The study was limited in that there was little or no budget available, and team members only included space architects, human factors engineers, and configuration specialists – no psychologists or human health experts were available during initial stages. While a Virtual Window capability does not literally expand or extend the volume of a habitat, several of the demonstration crew members expressed an impression that they were able to extend themselves into the projected environment. This was especially true in cases where the crewmember had some control over maneuvering the distant rover, even if it was just a vocal suggestion to "turn right" or "stop at this rock" given to the remote rover operator. Though a rigorous psychological analysis of how a variety of subjects might react to the system was not in the scope of this paper, there was enough of a hands-on study using physical prototypes to provide for a platform to move forward.

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References

Howe, A. S., Spexarth, G., Toups, L., Howard, R., Rudisill, M., & Dorsey, J. (2010). Constellation Architecture Team: Lunar Outpost Scenario 12.1 Habitation Concept. Proceedings of the Twelfth Biennial ASCE Aerospace Division International Conference on Engineering, Science, Construction, and Operations in Challenging Environments (Earth & Space 2010); Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.

Kennedy, K. J., Tri, T. O., Gill, T. R., & Howe, A. S. (2010). The Habitat Demonstration Unit Project Overview. Proceedings of the Twelfth Biennial ASCE Aerospace Division International Conference on Engineering, Science, Construction, and Operations in Challenging Environments (Earth & Space 2010); Honolulu, Hawaii, 14-17 March 2010. Reston, Virginia, USA: American Society of Civil Engineers.

JE Oberg; AR Oberg (1986). *Pioneering Space: Living on the Next Frontier* (p 58, 196). McGraw-Hill.

RS Ulrich (1984 April 27). View Through a Window May Influence Recovery From Surgery. *Science*, Vol 224, No 4647, p 420-421. American Association for the Advancement of Science.