

An Alternate Configuration of the Multi-Mission Space Exploration Vehicle

Robert L. Howard, Jr., Ph.D.

Habitability and Human Factors Branch
NASA Johnson Space Center
Houston, TX, USA
robert.l.howard@nasa.gov

Abstract - The NASA Multi-Mission Space Exploration Vehicle (MMSEV) Team has developed an alternate configuration of the vehicle that can be used as a lunar lander. The MMSEV was originally conceived of during the Constellation program as the successor to the Apollo lunar rover as a pressurized rover for two-person, multi-day excursions on the lunar surface. Following the cancellation of the Constellation program, the MMSEV has been reconfigured to serve as a free-flying scout vehicle for exploration of a Near Earth Asteroid and is also being assessed for use as a Habitable Airlock in a Cislunar microgravity spacecraft. The Alternate MMSEV (AMMSEV) variant of the MMSEV would serve as the transport vehicle for a four-person lunar crew, providing descent from an orbiting spacecraft or space station and ascent back to the spaceborne asset. This paper will provide a high level overview of the MMSEV and preliminary results from human-in-the-loop testing.

Keywords: Constellation, lunar rover, lunar lander, MMSEV, AMMSEV, LER, SPR, Small Pressurized Rover, Lunar Electric Rover, human-in-the-loop testing.

1 Introduction

1.1 MMSEV Overview

The Multi-Mission Space Exploration Vehicle (MMSEV) was originally proposed under the now-defunct Constellation Program as a lunar surface rover capability. During the lunar program, most analysis regarding surface rovers considered them in the context of supporting exploration of lunar geologic features. Evolving from previous Apollo-like unpressurized rovers, the MMSEV (at the time named the Lunar Electric Rover – LER) demonstrated increased lunar geology effectiveness, primarily through prototype testing at NASA's annual Desert RATS analog mission simulations. The medium fidelity LERs, shown in figure 1, demonstrated an ability to provide mobile habitation for two crew members for up to 14 days [1], [4], in most mission concepts operating from a fixed lunar surface base, though it was also capable of supporting short duration missions from a crew lander in scenarios with no fixed surface assets.



Figure 1. Two LERs During Desert Testing

Desert testing demonstrated the ability of two rovers to operate both independently of each other [1] and in parallel with one another, and even to dock with each other during excursions, shown below in figure 2. A 2009 mission simulation of emergency scenarios demonstrated the ability of one rover to locate a disabled rover, retrieve the crew, and sustain a four-person crew during a 24-hour return to base. [4]



Figure 2. Two LER Cabins Docked During Desert Testing

One of the key advantages of the LER is its suit ports, two hatches on the rear of the rover that allow crew

members to mount their spacesuits on the exterior of the vehicle and use hatches on the rear wall to enter and exit their spacesuits. This promised to reduce the overhead associated with EVAs because a time-consuming airlock depressurization and repressurization could be eliminated, the mass of an airlock could be eliminated, and concerns of tracking lunar dust in to the cabin were eliminated. Figure 3 shows a graphical illustration of the suit port and figure 3 shows a crew member entering the suit port on the 2nd generation vehicle.

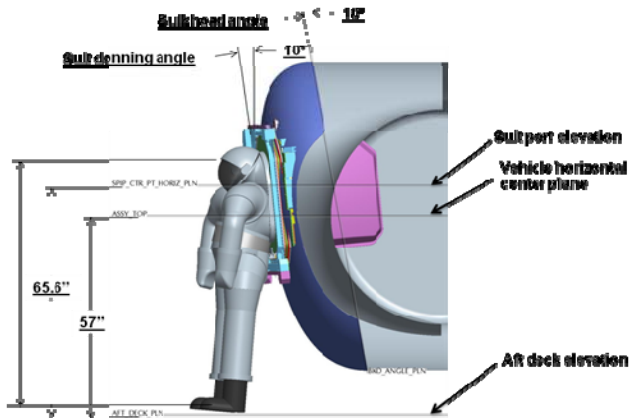


Figure 3. MMSEV Suit Port Configuration



Figure 3. Crew Member Entering Suit Port

Following the cancellation of the Constellation Program, the LER was re-designated the MMSEV and redesigned to support proposed missions to send humans to a distant asteroid. [3] The wheels of the LER were replaced by a propulsion sled, turning the scout rover into a scout spacecraft.

The actual mission is not significantly different from its lunar surface role. In the distant asteroid mission, the MMSEV would be based at a Deep Space Habitat (DSH) that serves as the transit vehicle from Earth as well as the crew's primary base of operations, much like a lunar outpost. Once the DSH arrives in the vicinity of an

asteroid, the MMSEV with a crew of 2-3 would depart the DSH and translate over to the asteroid to perform geologic exploration while flying at low altitude over the asteroid surface [3], as shown by the computer image in figure 4.



Figure 4. Computer Graphic of MMSEV Over an Asteroid

The project team made the conscious decision when redesigning the MMSEV to maintain commonality with a lunar surface mission, with the intent that the same spacecraft design would support both destinations. Thus, as the design matured team members kept informal constraints for both environments in mind. The MMSEV retained much of the field of view available to the LER, as shown by the 2nd generation MMSEV cabin in figure 5.



Figure 5. MMSEV Cockpit

The third incarnation of the MMSEV, following a decline in Agency interest for a distant asteroid mission, is that of a Habitable Airlock (HAL). As the asteroid mission began to not offer the cost savings it was originally assumed to provide over a lunar mission, NASA began to investigate more local destinations, with a focus on Earth-Moon Lagrange points. The idea of a Cislunar spacecraft emerged, which would essentially be a small space station

positioned at the Earth-Moon L2 point, perhaps using an Orion Multi-Purpose Crew Vehicle (MPCV) docked to a node module derived from the International Space Station's Node 1. The MMSEV team felt that this concept might not offer adequate crew habitation options and also noted that EVAs were assumed to require depressurization of the node, which would complicate design of subsystems and science equipment not intended to experience vacuum.

Consequently, the MMSEV team proposed the idea of the HAL, which retained the habitation capability of the LER and MMSEV, offering the capability to provide crew quarters for two astronauts aboard the Cislunar spacecraft. Both the LER and MMSEV had a contingency EVA capability where the vehicle could be depressurized to allow suited crew members to ingress via the side hatches in the event of a suit port malfunction or crew member injury that precluded use of the suit ports. In the HAL, this was upgraded to a nominal capability.



Figure 6. Crew Habitation in MMSEV

2 An Alternate MMSEV

2.1 AMMSEV Mission: Lunar Lander Cabin

One of the notionally proposed extensibility missions for a Cislunar spacecraft is a lunar surface expedition. This would be a much smaller scope mission than the Constellation lunar architectures. Most notably, there would not necessarily be a fixed outpost. While there was never any formal Agency commitment to adopt a lunar surface mission, the MMSEV team began to look at options for the vehicle to be used in such an architecture.

A revival of the LER mission was obvious – two LERs deployed via unmanned landers to the surface could provide sufficient crew habitation for short duration missions. However, the project team also began to investigate the crew lander and concluded that the MMSEV cabin could be adapted for use as a lunar lander crew cabin.

This lander would be what was termed a “down and out” lander during the Constellation program, in other words a lunar lander that serves as a taxi only. The crew enters the lander, descends to the lunar surface, but must exit immediately upon landing. Unique among the SEV variants, there is no capability for habitation in this variant of the spacecraft. Several other key changes were also made to this variant of the vehicle.

2.2 Side hatch extensions

The side hatch extensions were originally intended to allow the lunar rover to dock with a surface outpost or with another rover, as shown in figure 7. Because the lander mission assumed the rover would be mounted on a propulsion stage, it was likely to be inaccessible to another pressurized element, thus eliminating this potential need for side hatch extensions. Consequently, several possibilities emerged.



Figure 7. Two Rovers Preparing to Dock with a Surface Habitat

One option is to completely eliminate the side hatch extensions and go with a cylindrical pressure vessel with no side protrusions. In the case of an aluminum pressure vessel this is expected to result in slightly lower fabrication costs as it would delete the processes involved in manufacturing side hatch extensions and mating them to the hull. However, in the case of a composite spacecraft this is expected to result in higher fabrication costs as it would require a separate mold. (For a composite spacecraft the left and right halves are formed as a single piece and then joined together.) In both cases, elimination of both ports would reduce the structural mass of the vehicle.

Similarly, a single side hatch extension could be retained while the other is eliminated. This would provide of course half of the mass savings but in the case of the composite spacecraft would only require construction of one additional mold instead of two.

Finally, both side hatch extensions can be retained. This is of course the highest mass option, but results in no changes to the structural manufacturing process. The same primary structure is manufactured whether the intended vehicle is a planetary rover, microgravity scout, or planetary lander cabin.

The physical configuration tested in the NASA Neutral Buoyancy Laboratory retained both side hatch extensions. This, of course, introduces the question as to the purpose of these ports. One option is to retain both as crew translation hatches, perhaps one as a docking port to a transfer vehicle (e.g. Orion or a node of some kind) and the other as a surface egress hatch. Alternately, one or both side hatch extensions may be used for some other purpose.

An attractive option that emerged during FY13 test preparation concerned the use of one or both side hatch extensions for ECLSS hardware and umbilical stowage. It should be remembered that the prior variants of the SEV were intended for two-person shirt-sleeve operations – with the exception of the Habitable Airlock. Placing four suited crew in the vehicle was assumed to require a relocation of life support hardware and there had never been provision to stow four suit umbilicals in the vehicle. The side hatch extension volumes were attractive locations to place this hardware out of the way of the crew. It was beyond the scope of FY13 testing to reach a final decision on side hatch extensions and testing explored volumetric impacts of both uses.

2.3 Cabin Dome

If the side ports no longer contain hatches, the question is how does the crew ingress and egress the vehicle? In the normal spacecraft configuration, the forward section terminates in a domed structure with cockpit windows, as shown in the second generation beta prototype structural shell in figure 8.



Figure 8. Cockpit Windows of Cabin 2B

Normally, this is the front of the vehicle. But in the AAMSEV configuration it becomes the back of the lander cabin. The structural mass of these eight windows is far

too great to allocate to a planetary lander where every ounce of mass has implications for the propulsion subsystem that has to not only land it, but launch it back into orbit.

For the AAMSEV configuration, the forward cockpit is removed from the vehicle. It is replaced with a dome structure containing a hatch, shown in figure 9 in place on a low fidelity AAMSEV mockup used in underwater testing at NASA's Neutral Buoyancy Laboratory, simulating both 1/6 gravity and zero gravity conditions. This dome transforms the lander configuration such that the end of the vehicle that was the front in the in-space and planetary rover configurations is now the aft end of the vehicle for the lander configuration. The hatch is the same size as the side hatches, with the implication for manufacturing that the side hatch assembly is installed on this aft dome instead of on the side ports.



Figure 9. Low fidelity aft dome being fitted to underwater test mockup

2.4 Display and Control Window Unit

2.4.1 Concept

Essentially, by turning the MMSEV into an AMMSEV, several key changes have been made. The side ports are no longer for docking and hold ECLSS equipment and suit umbilicals instead of hatches. The forward cockpit is now an aft docking hatch. So how does the crew fly the vehicle? What was the aft of the planetary and in-space vehicles (now the front of the AMMSEV) is an angled bulkhead that contains two suit ports. The team hoped to minimize any structural changes to this bulkhead so it could remain as common as possible with the planetary and microgravity variants of the vehicle. But as the new front of the vehicle, it is the location from which the crew will fly the lander.

An important consideration is downward visibility. Figure 10 shows a typical descent profile flown by a lunar lander. The red arrow indicates both the direction of forward motion and the approximate direction of rocket exhaust from the main propulsion system. This results in the cockpit windows facing up into space for most of the descent. A notional field of view is represented by the yellow angle emerging from the DCWU, in this case a notional 38° range. Unless the downward viewing angle is great enough, the crew will never see the actual landing site. Note that the figure shows a case where even though the field of view is angled downward, the overall viewing angle is insufficient to ever see the landing site unless the lander adds a forward translation at hover, which would require significant extra propellant. To be an effective lander, the AMMSEV would require a greater field of view than this.

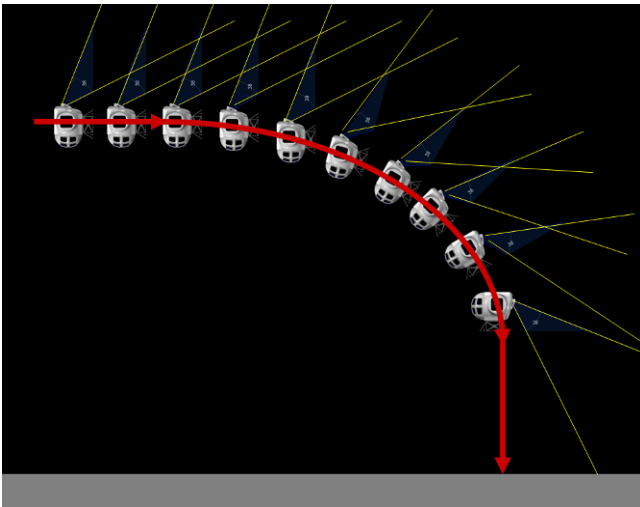


Figure 10. Typical Lander Flight Profile

To enable landing operations using the suit port bulkhead as a cockpit, the Habitability Design Center developed the Display and Control Window Unit (DCWU), with two variants developed for testing. Each DCWU mounts directly in the existing suit port, minus the suit port hatches. In theory, suit port hatches could be attached to a lander post-use, enabling reuse of a lander cabin for some other purpose, but FY13 activity did not investigate this possibility.

The two configurations, denoted as blue and red, are shown in figure 11. [2] The names blue and red were used to simplify reference for astronaut test subjects who evaluated the configurations in an underwater test. The blue and red labeling can be seen in figure 11. In an operational spacecraft, both DCWUs would be of identical configuration. The underwater mockup was instead outfitted with one of each configuration to obtain crew assessment and feedback to support a future down select decision.

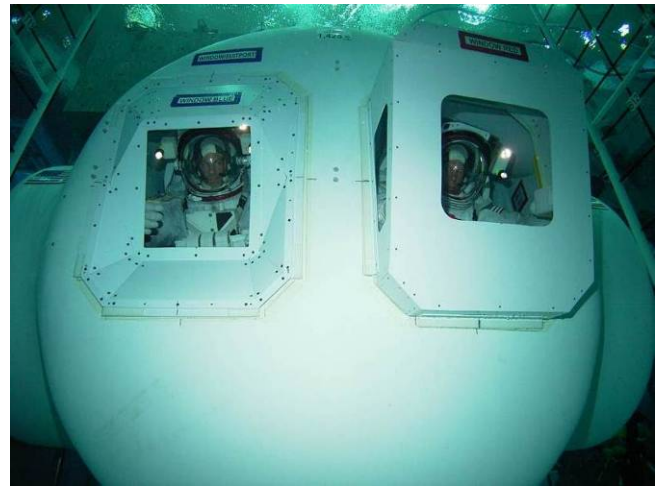


Figure 11. Display and Control Window Units (Blue – left and Red – right)

2.4.2 Blue Configuration

The blue configuration was designed with the primary objective to minimize mass growth. Shown in figure 12, it provides a single center window for pilot visibility. The window is angled 20 degrees [2] relative to the suit port bulkhead (which is already angled approximately 10 degrees), producing a 30 degree downward angle. This is intended to increase downward visibility. Because the window is not at the same angle as the bulkhead, the DCWU frame surrounding the window has a complex blending, mocked up with triangular shapes riveted together, to transform the angle from the window to the suit port interface plate, which is the set of flat ridges at the perimeter of the DCWU that connect with a suit port.

The DCWU also includes a single 15-inch display monitor, surrounded by Orion-derived edge keys for interface with the flight computer. [2] The display is mounted immediately beneath the window and the pitch angle of the monitor can be adjusted by the user. The DCWU includes a translational hand controller (THC) on the left side of the DCWU structure, positioned about halfway up the window. A rotational hand controller (RHC) is on the right side of the DCWU, mounted just below and to the right of the computer display.



Figure 12. Blue Configuration of the DCWU

test and several crew chose to relocate it midway up the left side of the center panel, much like the THC location on the blue window. This does, however, interfere with side visibility through the left window.



Figure 13. Red Configuration of the DCWU

2.4.3 Red Configuration

The DCWU red configuration, shown in figure 13, is a more aggressive design to maximize field of view, giving pilot visibility the highest priority as a design driver. Another diving concern was to maximize the interior cabin volume available to the crew. The MMSEV was originally designed for two unsuited crew to live in the vehicle for up to 14 days. By comparison, the AMMSEV is intended for four suited crew to fly in the vehicle, albeit for a very short period of time. The resulting DCWU is a bump out protrusion, effectively extending the cockpit volume beyond the suit port bulkhead.

The red DCWU maintains the same center window as the blue DCWU, but it achieves a 24 degree downward angle by adding trapezoidal side frames to pitch the entire pane 14 degrees downward beyond the existing 10 degree pitch of the suit port bulkhead. This creates an opportunity to add small windows to the side frames. The same monitor with edge keys used in the blue window is also used for the red. The monitor is similarly positioned adjacent to the bottom of the center window and is user adjustable in pitch. The RHC is located to the right of the monitor, positioned on the lower frame of the DCWU. The TCH is roughly parallel to it on the left side of the monitor. However, the low fidelity THC was repositionable in this

2.5 Interior Architecture

Several changes are made to the interior architecture of the AAMSEV to account for its lander mission. The interior side benches, cockpit seats, waste containment system, curtains, suit port hatches, and overhead closeouts are all removed from the interior. The floor and under-floor stowage are also deleted from this version of the vehicle, leaving only the sub floor, as shown in figure 14.



Figure 14. Mockup AAMSEV with Sub Floor

ECLSS hardware is moved from the cockpit and overhead closeouts (with the exception of ECLSS ducting that remains in place) to the side hatch extensions, a volume that also shares space with the suit umbilicals. The mockup ECLSS ducting in the FY13 assessment did experience contact with the shuttle spacesuits used in the evaluation [2] suggesting that there may be a need to reshape or move them to better get them out of the crew's way.

The crew is arranged inside the AMMSEV in a standing position, set up in a "T" formation as shown in figure 15. Two pilots are at the DCWUs and the other two crew members are in a single file line centered and behind the pilots, essentially occupying the "aisle" section of the vehicle. In this location the aft two crew members are able to stand vertically on the sub floor. The two pilots, however, are not able to stand upright, but are instead in a hybrid leaning/crouching position, resting their bodies partially against the side walls and partially against the suit port bulkhead, bracing their feet against the floor. Testing revealed a need to improve this posture and further design iteration was intended to explore shuttle and station era crew restraints and mobility aids for solutions.

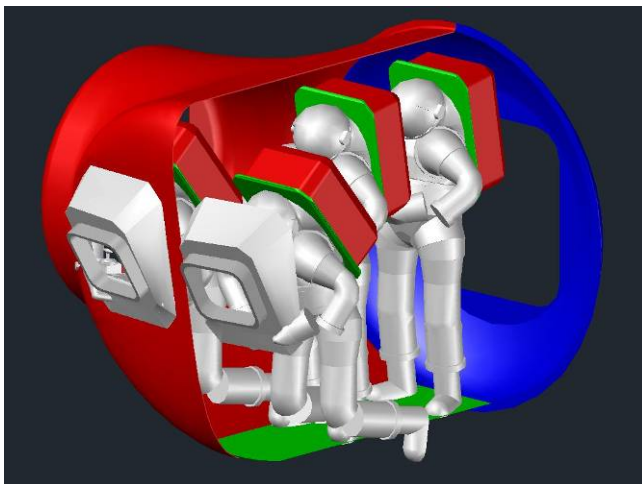


Figure 15. Crew positioning inside the AMMSEV

An interior view of the resulting DCWU configuration is shown in figure 16. Note that in this image the cockpit reflects a state of mid-reconfiguration between the AMMSEV and alternate MMSEV configurations – the RHC and THC are not installed on the DCWUs and the benches from the MMSEV configuration have not been removed. However, the figure 11oes provide a good view of how the DCWUs are integrated into the suit ports.



Figure 16. Integration of Red and Blue DCWUs into the AMMSEV Suit Ports

It can be observed in the test photo in figure 17 that the crew member at the red window (left) does not protrude as far into the cabin as the crew member at the blue window (right). This demonstrates the ability of the Red DCWU to provide a few more inches of room for the crew to maneuver than the Blue DCWU. This may be of importance to crew member number four (the rearmost crew member in figure 15), who will have the responsibility of opening and closing the cabin hatch. This action will require that the crew member be able to turn 180 degrees in either direction and manipulate a 1 m² hatch, which may be either hinged or removable.

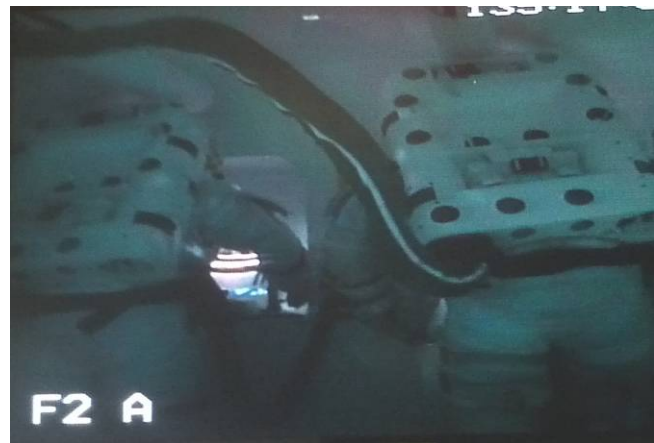


Figure 17. Crew Members at the Red and Blue DCWUs During 1/6 Gravity Testing in the Neutral Buoyancy Laboratory

3 AMMSEV Field of View Testing

3.1 Test Description

A primary objective of FY13 AMMSEV testing was to obtain field of view data as observed by space suited

crew members positioned in the AMMSEV with a body posture consistent with lunar (1/6) gravity. [2] Using NASA's NBL enabled this to be accomplished. The low fidelity AMMSEV mockup was submerged at the bottom of the NBL and crew members were placed in space shuttle / space station era spacesuits, which were then outfitted with weights to approximate 1/6 gravity.

A test rig was designed and fabricated by the Habitability Design Center to measure the field of view obtained by the crew. Shown in figure 18, the rig was a large grid measured in one foot increments that surrounded the AMMSEV cockpit, measuring 15 feet tall, 10 feet wide, and 5 feet deep. [2] By reading off coordinates on the grid, the crew members were able to indicate the maximum limits of their visibility.



Figure 18. Field of View Measurement Device

3.2 Field of View Results

3.2.1 DCWU Blue Configuration

The horizontal field of view from the blue window ranged from 61° - 141° , with 0° as the reference angle off the left shoulder of the test subject. The vertical field of view ranged from 7° - 93° , with 0° as the reference angle horizontal from the eye point. [2] This range is illustrated graphically in figure 19.

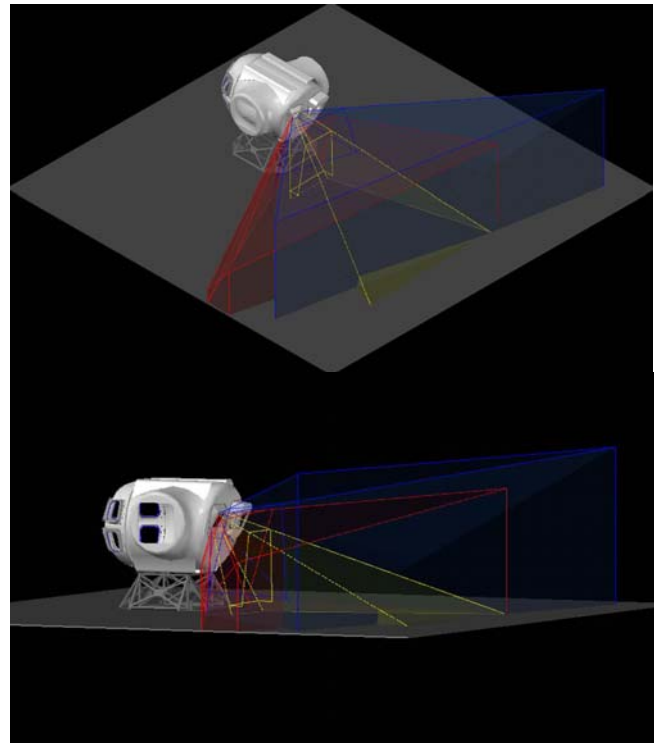


Figure 19. Blue DCWU Horizontal and Vertical Field of View

3.2.2 DCWU Red Configuration

As might be expected given its greater number of windows, the Red DCWU provided a horizontal field of view of 21° - 167° and its vertical field of view was 0° - 90° . Field of view is graphically depicted in figure 20. Test data suggested that crews prefer the greater horizontal field of view of the Red DCWU [2], which offered 66 additional degrees of horizontal view, which would be beneficial when using local terrain to assist in navigation. It would probably prove beneficial to slightly modify the Red DCWU to provide the same 20° slope found on the Blue unit. This will likely increase the downward viewing angle by several degrees.

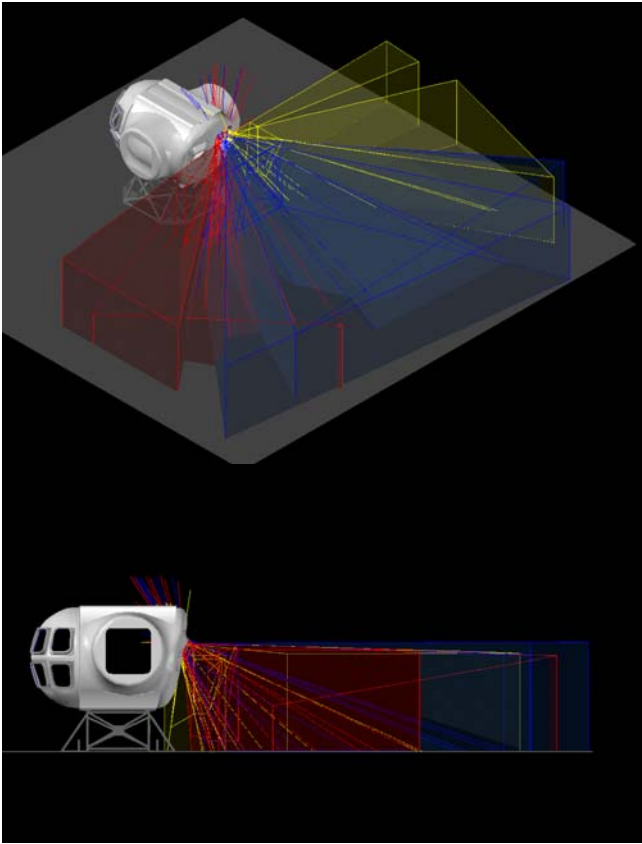


Figure 20. Red DCWU Horizontal and Vertical Field of View

4 Conclusions

The MMSEV is perhaps one of the most versatile spacecraft ever conceived by NASA. Originally intended as a lunar rover, it has demonstrated an ability to reinvent itself as a free-flying microgravity scout, an airlock, and most recently as a lunar lander, aided by the development of the DCWU augmentation to the vehicle's suit ports. With an amazing field of view capability, further testing may reveal the AMMSEV planetary lander vehicle to offer human factors performance during the piloting phase superior to that achieved by the Apollo lunar lander or possibly even the Constellation Altair lunar lander. Paired up with its other three alternate configurations, the AMMSEV illustrates how a single vehicle development effort can meet the needs of many seemingly disparate components of a human space exploration architecture.

Acknowledgment

The author would like to express thanks and appreciation to all persons who have supported development activity for the various incarnations of the Flexible Roving Exploration Device, Small Pressurized Rover, Lunar Electric Rover, Multi-Mission Space Exploration Vehicle, Habitable Airlock, and Alternate Multi-Mission Space Exploration Vehicle. In particular,

the author expresses thanks and appreciation to members of the Habitability Design Center and Usability Testing and Analysis Facility, as well as to Rhode Island School of Design interns who also supported the project.

References

- [1] Harry Litaker and Robert Howard, *Human Factors Assessment of a Dual Rover Field Study*, NASA Habitability and Human Factors Branch, Unpublished Document, January 2011.
- [2] Harry Litaker, Nathan Moore, Robert Howard, Andrew Abercromby, Steven Chappell, *Test of a Theoretical Model of Static and Dynamic Field-of-View (FOV) using NASA's Neutral Buoyance Laboratory (NBL)*, Unpublished NASA Technical Publication, October 2013.
- [3] Harry Litaker, Robert Howard, Maijinn Chen, Bryan Cloyd, *Human Factors Assessment for the Space Exploration Vehicle (SEV) GEN 2A Habitable Volume Three Day Study – Research and Technology Studies (RATS) Phase 2*, Unpublished Document, November 2012.
- [4] Harry Litaker, Shelby Thompson, Robert Howard, Rich Szabo, Carl Conlee, Stephen Green, Evan Twyford, *A Human Factors Assessment of the Lunar Electric Rover (LER) During a 14-Day Desert Trial*, NASA Habitability and Human Factors Branch, Unpublished Document, February 2010.