Deployable Maintenance Workstation for the Project Arusha Long Range Pressurized Rover

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***Abstract** - Project Arusha is a conceptual design project of the National Society of Black Engineers (NSBE) intended to evaluate technical issues and potential solutions for a transition from small, limited duration lunar expeditions to a permanent and expanded lunar presence. Arusha involves a primary outpost located at the lunar south pole, but presumes man-tended and autonomous facilities are scattered across the lunar globe. Surface transportation, in the form of a long range pressurized rover, is used to access these facilities. The rover may be deployed for traverses up to 30 days in duration. Due to the duration and distances involved, it is necessary to carry an onboard maintenance capability. A maintenance philosophy is derived for the rover, taking into account necessary time for rescue or return. An assessment of potential failures that cause the vehicle to become uninhabitable before rescue or return could occur leads to a determination of critical maintenance functions and associated tools that must be carried onboard the vehicle. The vehicle is then assessed to determine constraints that limit the deployed and stowed volumes of a maintenance workstation. A conceptual design for the workstation is then described, including stowage volumes, deployable work surfaces, particulate containment, and operational constraints.*

Keywords: Lunar base, rover, in-flight maintenance, spares, contingency, exploration, human spaeflight, National Society of Black Engineers, NSBE, Arusha.

1 Introduction

The Space Special Interest Group of the National Society of Black Engineers conducts engineering projects to investigate technical challenges surrounding human and robotic space flight. Research conducted by Space SIG members and documented in this paper represents volunteer labor executed on behalf of NSBE, a 501(c)3 nonprofit organization headquartered in Alexandria, VA. NSBE coordinates the inputs of aerospace industry experts to propose innovative solutions to complex technical challenges facing the United States. Recommendations, results, and conclusions in this paper do not reflect NASA policy or programmatic decisions.

1.1 Project Arusha Overview

1.1.1 Arusha Concept

The name Arusha is Kiswahili for "he makes fly (into the skies). It is a conceptual design for a 48-person permanently occupied lunar base. The idea of Arusha is a design study to bridge the gap between Constellation-type small outposts and artist concepts of lunar colonies. (The Constellation program proposed a 4-person lunar outpost for 180-day missions.) Arusha is designed to be located at the South Pole and operate in a manner analogous to the McMurdo station in Antarctica. It serves as the primary lunar facility with other man-tended and unmanned facilities scattered across the near and far sides of the Moon. Several lunar studies have determined that lunar science goals can only be met by deploying facilities at multiple locations across the lunar surface, stretching literally from pole to pole including the equator [1], [3] Transportation between these facilities is by means of surface transportation.

1.1.2 South Polar Base Location - Shackleton Crater

The Arusha base is located on the rim of Shackleton crater, an impact crater at the south pole of the Moon. Data from the SELENE spacecraft indicates that the crater measures 21 km in diameter at the rim, 6.6 km in diameter at the floor, and has a depth of 4.2 km. [4] It lies entirely within the South Pole Aitken Basin, a giant impact crater measuring 2500 km in diameter and 12 km deep at its lowest point. [2] Mountain peaks along the rim of the crater have near continual sunlight while the interior is in permanent shadow. There was interest in this region during the NASA Constellation program due in part to possible evidence of hydrogen at or beneath the crater basin. The location also has strategic value due to its access to both the near and far sides of the Moon.

1.2 Arusha Long Range Rover

The Arusha long range rover is the primary means for transportation between lunar facilities. The pressurized rover nominally carries a 6-person crew, which it can sustain for a 30-day nominal mission duration. The rover is designed for global lunar coverage, capable of traversing the distance from South Pole to North Pole within a 14-day drive. Rover missions include servicing remote sites, transportation between sites, remote science, and teleoperations. [5]

The cabin physical structure measures 3 meters in diameter and 8.45 meters long. The cabin is divided into three main sections as shown in Figure 1: Forward Section, Hygiene Section, and Aft Section. [5]

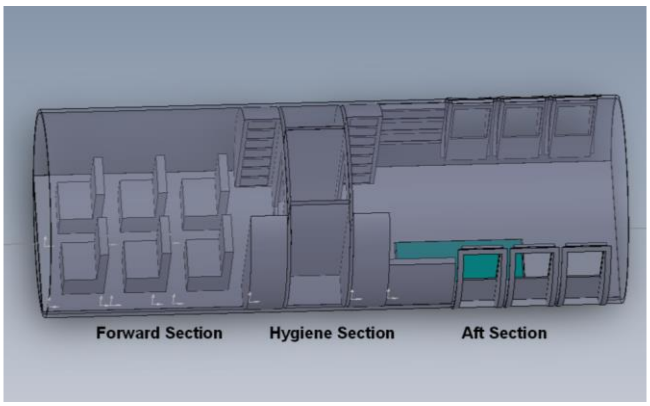

Figure 1. Arusha Rover Cabin

The forward section contains cabin seating for all six crew, including driving and operator workstations. A deployable meal and meeting table is stowed in the ceiling. A volume equivalent to 14 space shuttle mid-deck lockers is provided for stowage and galley equipment. [7]

The hygiene section contains two compartments and a central aisle way. The port compartment is a waste containment facility, with a toilet and sink similar to an aircraft lavatory. The starboard compartment is a full-body hygiene facility. The center aisle provides overhead access to the logistics module, a roof-mounted pressurized stowage volume. [7]

The aft section contains six suit ports for extra-vehicular activity (EVA) access and an aft-facing docking hatch. A deployable medical workstation is located on port and a deployable maintenance workstation on starboard. Six sleep bunks deploy downward from the ceiling. A second 14 mid-deck locker equivalent (MDLE) volume is divided equally between medical and maintenance stowage. [7]

2 Arusha Lunar Rover Maintenance Philosophy

2.1 Time Required for Rescue or Return

A key question in developing a maintenance philosophy is determining which failures require maintenance attention. If a failed item has no impact on the mission then there is no need to devote mission resources to its repair. Similarly, if a rescue crew can arrive to recover the crew and/or service the rover it is also not mandatory to carry repair equipment. Moreover, if the rover can simply return to base under its own power without injury to the crew there may be no need for repair. Onboard repair during a sortie is only required when these conditions cannot be met. A key driver for this is time. For instance, if a failure is causing a gradual degradation in vehicle life support, it will eventually become unable to sustain life. If the vehicle can return to base or receive a rescue/repair vehicle before life support has failed completely, then the rover does not need to carry equipment to conduct those repairs. If the degradation might happen faster than rescue or return could be achieved, then it will be necessary to carry such maintenance capability.

2.1.1 Mobile Rover Case

If the emergency has not resulted in the rover being disabled, it has the option of aborting the mission and returning to base. Because a rover could theoretically experience a problem in any location, the driving case is the furthest one-way distance the rover can traverse; a 15-day return. This sets an upper boundary for the time required for a rover to return in the event of a maintenance emergency that does not immobilize the vehicle.

2.1.2 Disabled Rover Case

If the rover is immobilized, a second rover may be dispatched from the Arusha base at the South Pole. As previously described, the worst case driving time to reach the disabled vehicle is 15-days. However, this is a minimum response time and some additional time must be included based on key assumptions.

The Arusha base may not be immediately aware that a rover has become disabled due to loss of communications. An incident may include as part of the problem a loss of communication capability. Alternately, an incident may occur during a previously planned loss of signal period, such as when driving in a canyon. It will be assumed that a worst case maximum of four hours will be required to verify a true emergency requiring dispatch.

It is unreasonable to assume that a rescue crew can be standing by in a rescue vehicle for an entire 30-day period when a rover is out. Also, it is unreasonable to assume that the same outfitting is appropriate for all response scenarios. Therefore, a rescue crew must be assembled and a rescue vehicle outfitted when an emergency occurs. It will be assumed that this can be accomplished within a 12-hour period.

However, before the outfitting can begin there may be a need for mission planning to determine the proper equipment needed to respond to the emergency and the appropriate skills mix for the response personnel. This planning may require up to 18 hours.

Taking these worst case times into consideration, it may take up to one day to dispatch a rescue vehicle in the event of an emergency.

Once a response vehicle has arrived on scene, there may also be some time required to safe the environment before gaining physical access to the rover or crew inside. This may involve clearing debris from around the rover in the event of a crash or collision. A maximum two day period is assumed as a worst case. This totals to a potential 18-day delay between a maintenance event and recovery via a rescue vehicle. As such, it is the driving case.

2.2 Critical Rover Capabilities

The 18-day response period enables the definition of critical rover capabilities. These include all vehicle functions that fall into the following categories:

- Those that when failed result in fatality or injury within 18 days or fewer
- Those that when failed prevent a rescue rover from locating the rover
- Those that when failed prevent rover from navigating back to base

These vehicle functions cannot wait for a rescue vehicle or for the rover to abort and return to base under its own power. The rover crew must be capable of repairing these functions in the field. Most subsystems have components that fall within this category. Assessment of these components has identified 53 potential types of critical failures as indicated in Table 1.

It should be noted that this is not a probability-based assessment. Clearly some of these 53 critical failures may be "more likely" to occur than others. However, the Arusha Moonbase is a permanently occupied facility. The rovers could therefore be in routine use for a 30-year period or greater. The vast majority of excursions may involve none of these failures, but it was not deemed credible to rank these failures in an order of likelihood and then only provide maintenance capabilities for those with the highest probability of occurrence. Because of the consequence of any of them occurring, the decision was made to attempt to design a maintenance capability with sufficient robustness to address all of them.

Table 1. Arusha Rover Critical Failures

1. Actuator FOD
2. Actuator overpressure
3. Actuator underpressure
4. Adhesive failure
5. Bad wireless connection
6. Belt break
7. Broken cables
8. Broken electrical connection
9. Broken physical structure
10. Bulb burnout
11. Bulb shatter
12. C&W software failure
13. Connector overtorque
14. Connector pin/connection failure
15. Connector under torque
16. Consumable depletion
17. Cracked housing
18. Cracked screen
19. Debris clog
20. Debris impact damage
21. Debris in motor
22. Diaphragm damage (digital)
23. Electrical lead failure
24. Electrical short
25. Fabric erosion
26. Fabric tear
27. Failed electrical connection
28. Fin breakage / bending/ding
29. Fluid line rupture
30. Fuse blown
31. Kinked line
32. Material abrasion / erosion
33. Material corrosion
34. Material delamination
35. Material stretching
36. Motor failure
37. Physical obstruction
38. Potting failure
39. Power surge
40. Pressure bladder puncture, tear, or rip
41. Spring too weak or too stiff
42. Structural bending
43. Structural buckling
44. Structural burst
45. Structural crack/fracture
46. Structural deformation
47. Structural gouge
48. Structural membrane disjoin
49. Structural rupture / puncture
50. Structural seal failure
51. Structural shear
52. Surface chemical contamination
53. Wire detach, split, tear, rip, or break

3 Required Maintenance Functions and Tools

3.1 Arusha Rover Maintenance Functions

The Arusha rover must have the ability to repair any of the previously mentioned 53 critical failures in order to ensure safety of the crew. Doing so will imply a need for the Arusha rover maintenance workstation to be capable of the following 14 generic maintenance functions:

1. Soldering
2. Drilling
3. Metal cutting and bending
4. Metallurgical analysis
5. Bonding metal, composite, and other surfaces
6. Electronics analysis and repair

7. Computer inspection/testing and repair

8. CAD Modeling / Software Coding / Computer Analysis

9. Material Handling

10. Precision Maintenance

11. 3D Printing

12. Soft goods sewing, cutting, and patching

13. Dust/Particle/Fume Mitigation

14. Welding

An analysis was conducted to map the 14 maintenance functions to each of the 53 critical failures. The result of this analysis is a 53x14 matrix that identifies which maintenance functions are required to address each critical failure. It is impractical to represent a 53x14 matrix in this paper, but the important takeaway is that all 14 maintenance functions are required in order to provide the capability to repair all critical failures.

3.1.1 Areas of Commonality with Deep Space Habitat Maintenance Functions

The previously mentioned list of maintenance functions is a near match of the maintenance functions identified by NASA human factors and habitability teams for maintenance capability for a Deep Space Habitat. [8] The two differences are that the NASA team did not specifically identify welding as a required maintenance function and the NASA team held a specific EVA maintenance category.

The welding discrepancy is explained in that the Deep Space Habitat studied by NASA was constrained to be a zero-gravity vehicle only. By comparison, the Arusha rover is a moving vehicle in a local gravity field. Many of the drivers for the Arusha welding function are structural failures that could conceivably result from failures induced by repeated vehicle motion over rough terrain.

The EVA maintenance discrepancy is explained in that the Arusha rover team has the option to consider a suit failure to be a non-critical event. A nominal rover excursion includes six spacesuits – one for each crew member. In the event of a suit failure, that one crew member is assumed to have lost EVA capability for that 30-day excursion. The suit can be repaired upon return to the primary base. For the Deep Space Habitat, this was not an option – a suit failure would have to be repaired onboard the spacecraft.

With these two exceptions, the maintenance capability required for the Arusha rover is nearly the same as that required for a Deep Space Habitat. This suggests a convergence of maintenance capability that is required for any spacecraft that operates independent of support from other spacecraft and is beyond the range of an immediate mission abort capability.

3.2 Arusha Rover Required Maintenance Tools

Based on the identified maintenance functions and critical failures, a tools list of 140 items was developed using commercial off-the-shelf (COTS) tools as analogues. Maintenance workstation tools identified by the NASA habitat studies were used as a starting point. [6] These tools were then divided into three groups: those stowed within the seven mid-deck lockers in the rover aft section's starboard lockers, those that deploy along with the workstation in some capacity, and those that are permanently fixed in place. Coincidentally, the stowed tools measure approximately 6.9 MDLE, suggesting maintenance tools will fully consume the starboard stowage lockers in the aft section.

Several repositionable tools are stowed on the floor and on fixed shelving beneath the deployable maintenance table (between the stowage lockers and the suit ports). These items can be handled by a single crew member in lunar gravity and can be positioned on the deployable tables as needed. These tools include a drill press, multi-function sheet metal machine (finger brake, shear, and roller), worm gear tube benders, pipe bender, small sewing machine, face shield, and a high performance laptop computer. A set of hammers and mallets are stowed on the wall of the aft bulkhead starboard of the hatch, held in place with spring loaded clips.

Two tools are permanently fixed, located under the floor in the maintenance workstation – a milling machine and a 3D printer. In both cases, these tools are computer-driven, producing parts directly from CAD models without requiring user interaction while the parts are being fabricated. Access ports in the floor allow the operator to insert raw materials, remove completed parts, or remove the tool for servicing.

Several tools require compressed air. Terrestrially, this would be supplied by an air compressor. This capability will be built into the environmental control and life support system (ECLSS) and will only require gas lines from the ECLSS hardware to the maintenance workstation.

It should be noted that the welding function is not addressed within this paper. The scope of the paper is a deployable maintenance workstation located in the interior of the rover's pressure vessel. The Arusha team has made an assumption that all welding can be made an EVA (robotic or human) activity and that a welding station can be located on the exterior of the pressure vessel. This remains as forward work to be defined in a design study concerned with the vehicle exterior.

4 Deployed and Stowed Volumetric Envelopes

4.1 Stowed Volume Constraints

The starboard region of the cabin aft section between the suit ports and port stowage tower is available to house the stowed maintenance workstation. As shown in Figure 2, this region is approximately 40 centimeters in length.

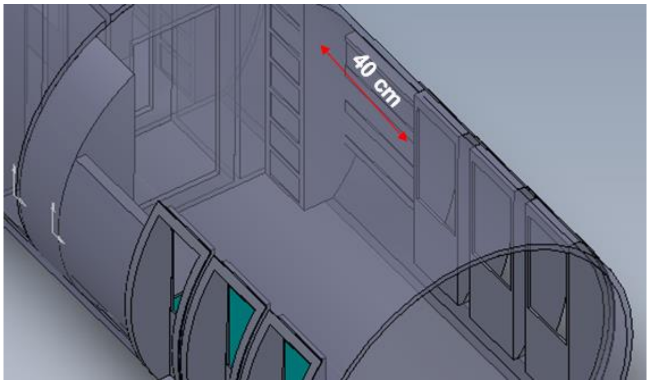

Figure 2. Length Available for Stowed Maintenance Workstation

When stowed, there is a limit as to how far the workstation can penetrate into the cabin interior. This is driven primarily by the crew starboard sleep bunks, which deploy immediately inboard of the maintenance workstation. As shown in Figure 3, there is a maximum available depth for the stowed workstation measuring from the side wall to the interior of approximately 74 centimeters.

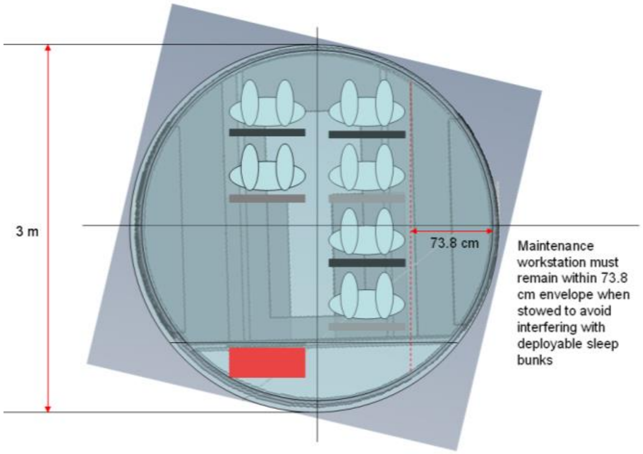

Figure 3. Crew Bunks Clearance for Stowed Maintenance Workstation

In addition to crew sleep, crew exercise and EVAs are scheduled activities that occur in the aft section. The stowed maintenance workstation may not create volumetric interference with either of those activities.

4.2 Deployed Volume Constraints

When the workstation is in use the allowable volume can extend as far inboard as the vehicle centerline, but may not penetrate beyond. As shown in Figure 4, this includes volume occupied by the deployed workstation, tools, any device(s) being maintained, and the operator(s).

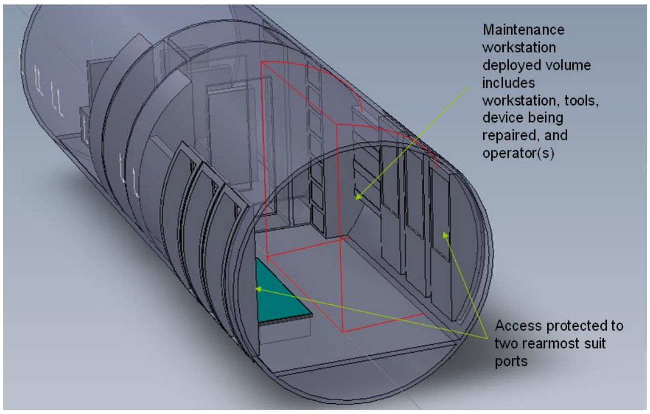

Figure 4. Deployed Workstation Volume Envelope

This volume leaves access available to the two aftmost suit ports to allow for 2-person EVAs during any maintenance activity. This access is depicted as viewed from above in Figure 5.

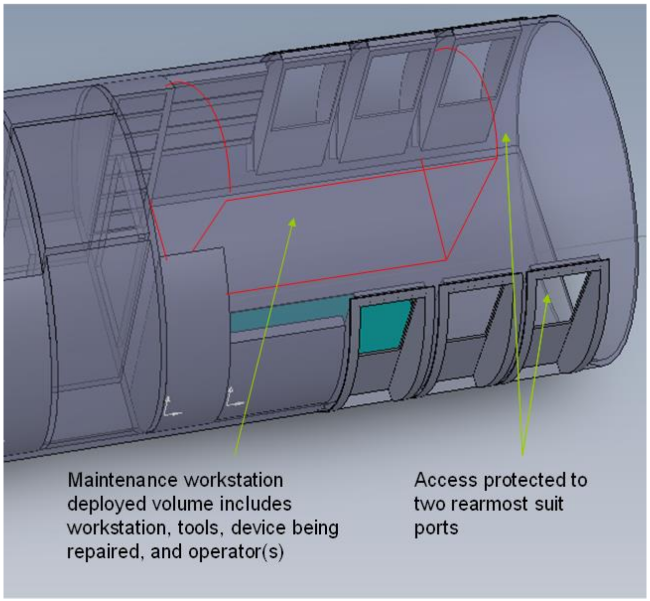

Figure 5. Protected Access to Two Suit Ports for EVA

As can be seen in Figures 3 and 4, access is also protected to the port (medical) and starboard (maintenance) stowage lockers and to the hygiene section. The medical workstation is not explicitly called in these figures, but is the port volume immediately across the centerline from the maintenance volume. This is also a protected volume, theoretically enabling medical and maintenance activities to occur in parallel. Usability testing in a full scale, medium fidelity mockup would be required to verify the ability to effectively perform both operations at the same time.

5 Arusha Maintenance Workstation Design

5.1 Stowage Access

Lockers will slide out towards the center of vehicle. Locker doors may be hinged, slide, or be soft fabric. Lockers may be full, half, double, or other height increments based on contents.

5.2 Work Surfaces

A deployable horizontal surface is roughly illustrated in Figure 6. This five-piece table deploys from the starboard wall between the stowage lockers and suit ports and folds down to a working height just below the suit port hatches. The largest segment is the primary working surface. The extensions beneath the suit port hatches provide work surfaces when the two suit ports enclosed in the maintenance work volume are used in conjunction with suit port transfer modules to pass hardware to or from the space environment. The two small extensions that protrude further into the vehicle provide convenient work volumes for deploying large tools.

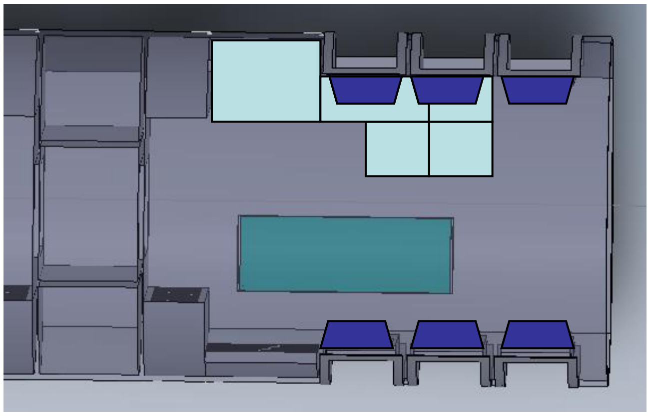

Figure 6. Overhead View of Horizontal Work Surfaces

Two small, vertical work surfaces can be deployed on the horizontal work surfaces as shown in Figures 7 and 8. These work surfaces can be positioned in any of several slots in the horizontal work surface, allowing the crew to partition the maintenance work area when necessary to organize repair tasks. Figure 8 also depicts removable legs that attach to the work surface when deployed in order to provide structural rigidity to allow operators to exert tool force against. The workstation is shown fully stowed in Figures 9 and 10.

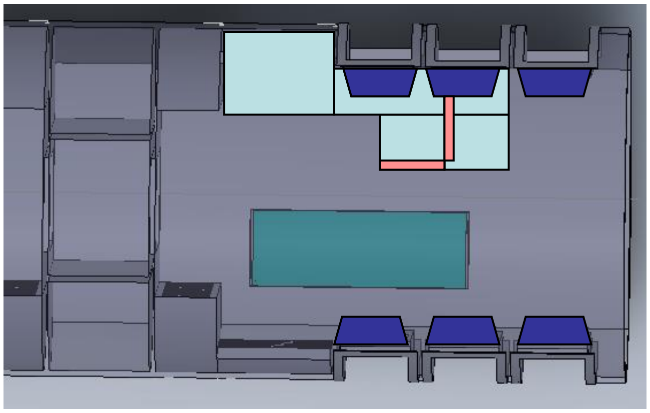

Figure 7. Overhead View of Vertical Work Surfaces

The configuration represented in Figure 7 might be used to mount an object being serviced on the large work surface between the suit ports and stowage locker. The smaller work area with the vertical work surfaces might be used as a place to stage tools and removed components, with the vertical work surfaces used as additional mounting spaces. The vertical surfaces are at 90 degrees partially to serve as a function of enclosing the staging work space, and also to place tools stowed on that surface within easier reach of the maintenance crew member.

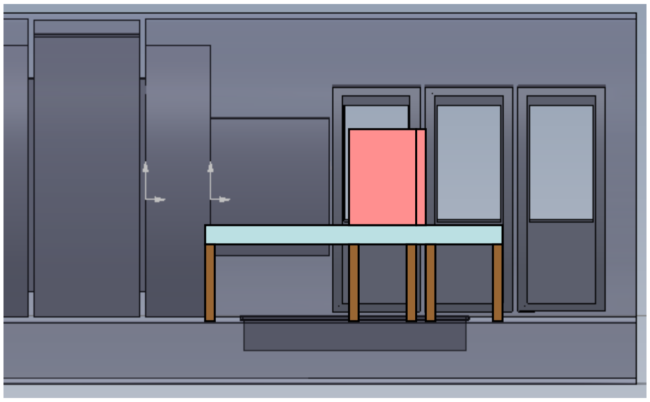

Figure 8. Side View of Vertical Work Surfaces

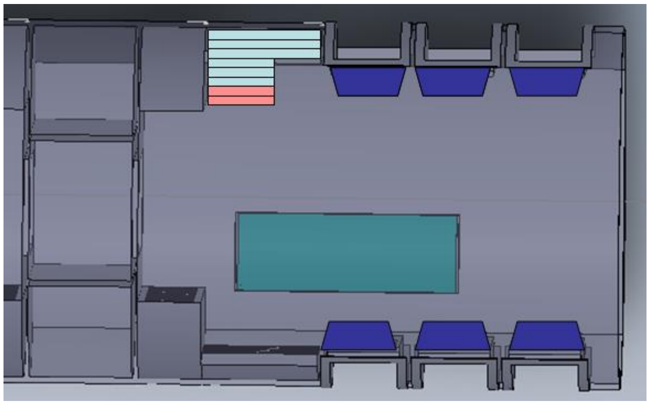

Figure 9. Overhead View of Stowed Workstation

Figure 9 is intended to illustrate that than when stowed, the workstation is essentially flush with the intrusion of the suit port hatches, essentially forming a clearance plane to allow the sleep stations to deploy when needed at night. This open volume is also available during the day for deployable crew exercise equipment. It can also be seen in Figure 10 that the stowed table is roughly even vertically with the bottom of the suit port hatches. This leaves the volume beneath the table free for additional tools stowage as described later in this paper.

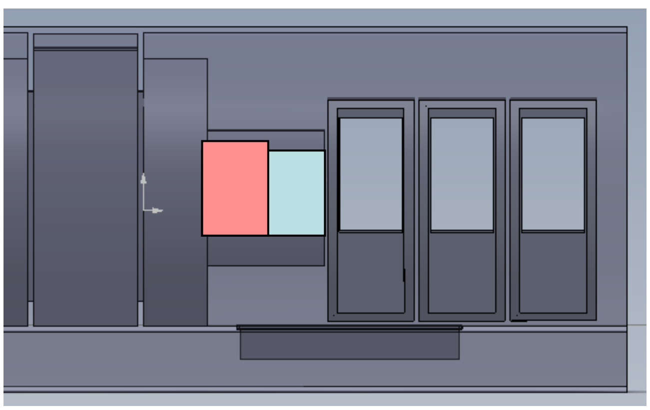

Figure 10. Side View of Stowed Workstation

The laptop can be mounted directly to the horizontal work surface, or attached to a bogen arm that can mount to either the horizontal or vertical work surfaces. Additional display devices (tablets, flat screens, etc.) can be deployed if needed for additional display capability.

5.3 Particle Containment

Several maintenance tools generate particulate debris or shavings during operation. Additionally, large equipment being serviced may also generate debris or emit gases or fluids. In order to prevent contamination of the rest of the spacecraft a deployable enclosure is set up when such tools or equipment are in use. This enclosure is a set of three transparent plastic vertical partitions, the rough contours of which are shown in Figure 11.

The long partition running the length of the vehicle longitudinal axis also has a flap that attaches horizontally to the rover ceiling, protecting the stowed sleep stations from debris. The aft partition in figure 11 is shown connected to the starboard rover wall between two suit ports. It is also possible to attach this partition to the aft bulkhead, on either the starboard or port side of the hatch, creating additional work volume options that may be used under certain operational conditions.

Because this fully encloses the maintenance workstation, it implies a requirement for the ECLSS system to have a separate supply and return lines for cabin air inside the maintenance volume. All three partitions have zippered doors to allow crew members to translate between the maintenance volume and the remainder of the vehicle.

There is sufficient flexibility in the plastic partitions that they can deform to accommodate crew members and equipment squeezing past tight locations. Examples include a crew member translating between the medical workstation and the hygiene section may cause the partition to deform inwards, while a maintenance crew member accessing stowage in the maintenance lockers may cause the partition to deform outwards.

For some maintenance tasks, crew members within the partition may need to wear protective equipment, possibly including portable breathing apparatus. This equipment is stowed with vehicle housekeeping equipment in another section of the rover.

Also, several sizes of reusable and disposable deployable glove boxes are stowed in under-floor compartments. These units may be used for tasks involving releases of toxic fluids or gases. When used in conjunction with the partitions, these glove boxes allow for multiple layers of containment to protect equipment, crew members, and the vehicle.

Following use, the partitions must be carefully cleaned to remove trapped debris before folding for stowage between the aft-most suit port and the aft bulkhead of the rover.

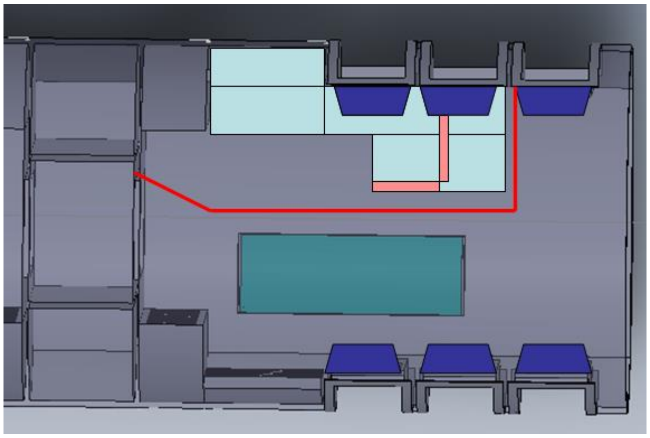

Figure 11. Outline of Deployable Partition Coverage Area

5.4 Operational Constraints

Due to the size of the Arusha rover, the maintenance workstation is nominally a one-person workstation. There is, however, room within the particle containment system for a second crew member to assist with maintenance activity. When the particle containment system is not deployed and the medical workstation is not in use there is easily room for three crew members to work within the volume, though this will cause one or more crew members to intrude upon the inactive medical workstation volume.

When both medical and maintenance are in concurrent use, it is recommended for either or both workstations to deploy their respective particle containment systems as the two are in extremely close proximity to one another. With both deployed it is particularly difficult, though presumably not impossible, to access the aft suit ports.

6 Potential Human in the Loop Testing

6.1 Medium-Fidelity Mockup Development

In 2009, the NSBE Houston Space Professionals Chapter utilized a Constellation lunar habitat mockup shell with similar dimensions to the Arusha rover to conduct a low-fidelity walk-through evaluation of the cabin layout. [9] This evaluation led to multiple refinements in the cabin interior design. [7] A medium fidelity mockup of the aft section of the rover could enable a series of human-in-the-loop tests that conduct maintenance activities to verify the operability of this design.

6.2 Potential Medium Fidelity Mockup Tasks

It is important for maintenance tasks evaluated in an Arusha medium fidelity mockup to have relevance to corresponding maintenance issues that may potentially be faced by present-day spacecraft. This will enable comparative assessments that help to verify the usefulness of this workstation configuration and the viability of a vehicle the size of the Arusha rover to support necessary maintenance activity. The International Space Station is the most relevant existing spacecraft so potential tasks will be those that could also be relevant to ISS. In theory, these same tasks could also be executed onboard ISS as DTOs, either using ISS's existing maintenance capability or a high fidelity representation of the Arusha rover inside ISS or an attached module, such as a Dragon or Cygnus cargo module. Coincidentally, the Cygnus shares a similar diameter to the Arusha rover and may be particularly well suited as a test module. [10]

(Granted, the ISS operates in a microgravity environment while Arusha is a lunar architecture, but because rover operations may require use of the maintenance workstation while the vehicle is not in a level orientation – such as a disabled vehicle on a slope with significant roll or pitch, similar tool and equipment restraints will be required for both the rover and a microgravity spacecraft.)

Generally speaking, there are two major classes of maintenance that are relevant for ISS-based DTOs. The first class involves maintenance that is not currently possible on ISS. This includes maintenance that involves small parts, non-captive parts, and systems with hazardous toxicity levels. Presumably these tasks would not be executed onboard ISS as a DTO in its existing maintenance capability, but could be executed aboard ISS as a DTO in a high fidelity rover maintenance workstation representation.

The second class is maintenance that is not required on ISS due to the availability of spares. ISS has the luxury of frequent resupply from logistics freighters and is in close proximity to Earth, enabling it to stockpile orbital replacement units (ORUs). It is possible to simply replace and discard a failed unit instead of restoring it to operating condition. Deep space missions may not have sufficient mass and volume allocations to carry enough spares for an equivalent ORU strategy. Two potential DTOs that fit these classifications may involve the Fluid Control Pump Assembly (FCPA) and Micro-meteoroid Object Damage (MMOD) Replacement Metal Housing Fabrication.

6.2.1 Fluid Control Pump Assembly (FCPA) Repair

The FCPA is part of the urine processing system within the ISS regenerative ECLSS system. This maintenance DTO will demonstrate repair of a FPCA solenoid. Some valve solenoids are currently irreparable on ISS because attempting to do so would create a release of urine and brine, which are classified by NASA as hazardous fluids. The repair also involves small, non-captive parts. The DTO will involve fabricating a new solenoid, removing the existing (failed) solenoid, installing the new solenoid, and cleaning then repairing the failed solenoid, thus making it an available flight spare. The DTO will not necessarily involve the actual ISS FCPA, but may instead use a high fidelity simulator, a spare unit, or a new FCPA intended for future incorporation into an exploration spacecraft. For purposes of the DTO, a non-hazardous urine and brine simulant may be used.

6.2.2 Micro-Meteoroid Object Damage (MMOD) Replacement Metal Housing Fabrication

Assorted internal and external housings or closeouts will exist on any future deep space vessel. Critical damage to such an object could experience damage from MMOD strikes, spacecraft collisions, or EVA or robotic manipulator mishaps. This maintenance DTO will use a series of notional metal housings and closeouts as proof of concept examples. The maintenance workstation will be used to fabricate replacements to these items using sheet metal and bar stock as source material. The DTO will also demonstrate crew autonomy by requiring crew use of the workstation to develop the fabrication and assembly process, including creation of fabrication drawings. Effectively, no ground support will be involved in the repair of the panels and closeouts.

7 Conclusions

The deployable maintenance workstation for the NSBE Project Arusha long range rover is required to meet repair capabilities very similar to those required for deep space exploration. The small diameter of the Arusha rover as compared to NASA Deep Space Habitat concepts suggest that the Arusha rover maintenance workstation may represent a minimum volume implementation of deep space maintenance capability. Possible follow-on activity to this paper includes the fabrication of medium fidelity mockups and human-in-the-loop testing to validate the design. Based on this testing, it may be beneficial to conduct actual on-orbit DTOs using the International Space Station as a testbed to prove maintenance concepts that may have application beyond the Arusha project to deep space exploration in general.

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