Low Fidelity Mockup of NSBE Arusha Pressurized Rover

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Abstract – *The Arusha pressurized rover is a large pressurized rover intended as part of the Project Arusha Moonbase, a conceptual design project of the National Society of Black Engineers. A low fidelity temporary mockup of the Arusha pressurized rover was constructed at NASA Johnson Space Center with volunteer labor using excess and loaned materials from NASA Constellation lunar lander, rover, and habitat mockups. Roughly equal in fidelity to early NASA Crew Exploration Vehicle (CEV) and Lunar Surface Access Module (LSAM) mockups, this mockup was used to conduct an assessment of the Arusha cabin layout and enabled a recommendation for refinements to the interior design of the vehicle. Significant redesign is recommended for the rover galley, suit stowage, hygiene, and maintenance facilities. The mockup activity also resulted in a recommendation to replace the airlock entirely with suitports.*

Keywords: NSBE, Moon, outpost, base, Constellation, human factors, habitation, habitability, human-centered design, Arusha, tourism, colonization, exploration, rover.

1 Introduction

1.1 Project Arusha

Project Arusha is a conceptual design effort of the Space Special Interest Group of the National Society of Black Engineers (NSBE). Arusha is a lunar outpost concept that could be emplaced on the Moon after NASA's return to the Moon with its Constellation program. Once the Constellation program has developed techniques and operational experience for living and working on the Moon, it will be possible for commercial utilization of the Moon to begin, by means of an infrastructure such as Arusha.

Arusha is envisioned to be a multinational, joint government-commercial outpost with a nominal population of 48 persons. The Arusha Moonbase includes a centralized habitation facility, launch and landing facilities, and various remote facilities.

Moonbase Arusha is intended to conduct government-sponsored scientific and engineering research, incubate lunar-based businesses, and host tourism expeditions. Moonbase Arusha will combine these government, industry, and civilian space activities under a central complex. Its purpose is to accelerate the commercial use of the Moon, in line with the provisions of the National Aeronautics and Space Act.

The size of this outpost is significant and is what enables Arusha to be a transformational space program that can add extensive value to humankind. Moonbase Arusha will transform the Moon from a disk in the sky to a place where humans live, work, and play. The impact of Arusha will alter the human psyche and help to create a mindset that adds the Moon as part of the abode of mankind.

1.2 Arusha Rover

Moonbase Arusha will include a motor pool of six pressurized rovers. These vehicles will provide long and short-range pressurized transportation for the 48 occupants of the Moonbase. Rover missions include both local transportation between the lunar base and lunar landers as well as surface expeditions away from the base focused around scientific research or commercial industry activities.

The rover will be capable of transporting and accommodating a maximum crew/passenger size of twelve for short range transfer missions and a crew/passenger size of four to six for long-range expeditions of up to one month away from the base.

The habitable section of the rover is a cylindrical aluminum pressure vessel, with inner dimensions of roughly 8.35 meters in length and 3.0 meters in diameter, with a total pressurized volume of approximately 55 m^3.

1.3 Rover Mockup Objectives

The NSBE Houston Space Chapter constructed a low fidelity mockup of the Arusha pressurized rover crew cabin and conducted an initial habitability evaluation. Prior to the construction of the mockup, the only non-text representations of the Arusha rover were "not to scale" floorplan drawings [1, 2]. The mockup provided the first opportunity to view the rover in an approximately accurate scale. Specific mockup objectives were:

- Represent the Arusha rover layout in full scale
- Modify the rover layout as necessary to fit within the available volume
- Test the human factors viability of the Expedition Configuration

2 Mockup Concept

Only one configuration of the Arusha rover was mocked up, the Expedition Configuration [1]. This configuration is nominally used by a crew of six for missions away from the base for durations of up to one month [1]. The Passenger Configuration and Cargo Configuration [1] were not mocked up. Due to limitations that will be discussed later in this paper, the mockup was a very low fidelity volumetric construction using facilities and resources borrowed from NASA's Habitability Design Center (HDC) and Systems Architecture and Integration Office.

Johnson Space Center's Building 220 was gracious to allow NSBE facility access and use of the shell of the Core Habitat (one of several lunar habitat concepts under NASA study) as the pressure structure. The Core Habitat has the same dimensions as the Arusha rover habitable section, making it compatible. To the extent possible within these limitations, the interior architecture of the Arusha rover was visually represented in a manner that allowed NSBE volunteers to interact with the rover and assess its design.

3 Core Habitat Mockup Description

Shown in Figure 1, the Core Habitat Mockup is a low fidelity representation of the structural shell of a conceptual pressure vessel associated with several lunar design scenarios under consideration for NASA's human return to the Moon. The Core Habitat features three docking ports to connect it with other modules, one at each end and one in the center.

Figure 1. Core Habitat Mockup.

In the NASA Lunar Surface Systems (LSS) Scenario 12.0 three variants of the Core Habitat are outfitted as shown in Figure 2. The lower-most figure represents the Pressurized Excursion Module [3] and is the approximate configuration that the Core Habitat Mockup will eventually be outfitted to represent.

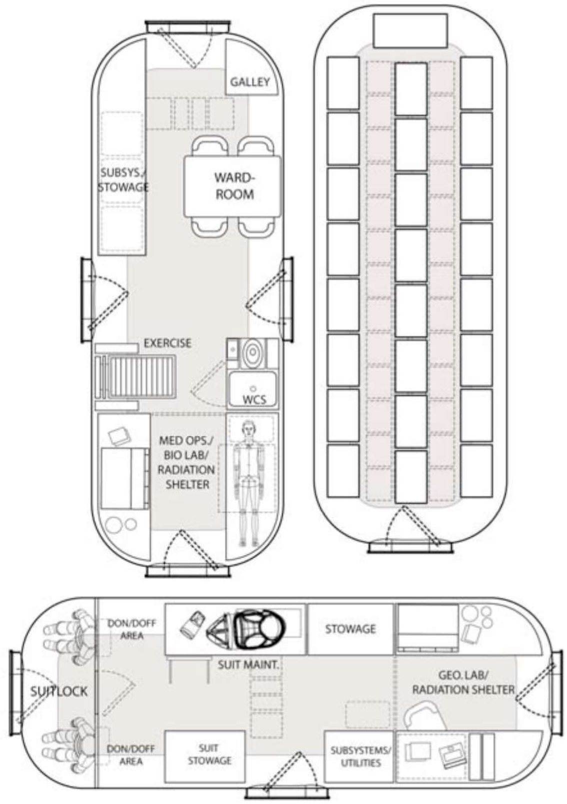

Figure 2. Core Habitats in LSS Scenario 12.0 Outpost.

At the point in time of NSBE's utilization of the Core Habitat Mockup, it had not yet been outfitted with this layout. A Lunar Wet Bath [4] study of potential waste containment system configurations had just been completed, leaving the mockup as shown in Figure 3. This made the structure an ideal candidate for temporary use by NSBE to construct an Arusha rover mockup interior inside the unit.

Figure 3. Lunar Wet Bath inside Core Habitat Mockup.

4 Mockup Build Process

As was mentioned previously, the majority of the mockup components were reused Foamcore items from prior NASA Constellation spacecraft mockups. Most interior components were non-load bearing Foamcore and wood, in most cases excess borrowed from the Habitability Design Center's stock of "retired" mockups. Select components – chairs and toilet – were load bearing items. The maintenance table and deployable crew dining/meeting table had very limited load bearing capability. Other items were standard office items (e.g., chairs) or purchased from local stores, and a few items were constructed specifically for the Arusha mockup.

Components included used and scrap mockup items from various iterations of the Orion Crew Exploration Vehicle [5], Lunar Surface Access Module (predecessor to Altair) [6], Habitank Ascent Module from Lunar Lander Preparatory Study (predecessor to Altair) [7], Altair Lunar Lander [8], Vertical and Horizontal Habitats from Lunar Habitats Mockup Project (predecessor to LSS) [9], Lunar Electric Rover [10], and Lunar Wet Bath [4].

The need to reuse existing Foamcore items did place some limits on the mockup construction and presented a challenge to NSBE volunteers to construct items that accurately represented the intended workstation. In some cases, the components did require some level of modification. And in others cases, this did cause minor deviations from the intended Arusha rover layout because volunteers were forced to work within available size and shapes constraints and forced to innovate when positioning/securing components at orientations they were not originally designed to support.

The level of fidelity imposed by the use of existing components may have had some level of negative impact to evaluators' ability to make assessments of the true size, shape, and usefulness of rover workstations, but this did not appear to be a serious problem. Figure 4 shows an example. In order to construct a maintenance table, NSBE volunteers cut in half a mockup box that had volumetrically represented a spacecraft subsystem. In order to raise the resulting table to the proper height, foam from an Orion cockpit mockup was used for legs. However, these "legs" were far more intrusive than anything intended in the Arusha mockup concept and caused an immediately obvious loss of fidelity beneath the maintenance table. However, the table was still usable for its representative task, as is shown in the figure by the placement of a mockup spacesuit torso on the table, as if for servicing purposes. Much of the volume beneath the table would have been used for stowage, so the loss of fidelity had only minimal impact on the mockup of the maintenance facility.

Figure 4. Creation of maintenance table configuration.

Other components were assembled with similar minor losses in fidelity. The Robotic Manipulator Workstation, shown in Figure 5, used sink mockups from the Wet Bath [4] project to form the workstation desk surface. This workstation includes a display monitor, data entry keyboard, and two hand controllers to actuate manipulators or other robotic systems exterior to the rover, or even to control remote robotic assets. This was easily equal to the level of fidelity in the Arusha rover layout, though clearly not flight-like with respect to exact volumetric representation. As one limitation, there were gaps between each workstation surface in the mockup, where the vehicle is intended to have one continuous surface. However, this did not impact the NSBE team's ability to assess the habitability of the forward section of the rover. In general, despite these and other fidelity issues the mockup successfully provided a valid representation of the vehicle.

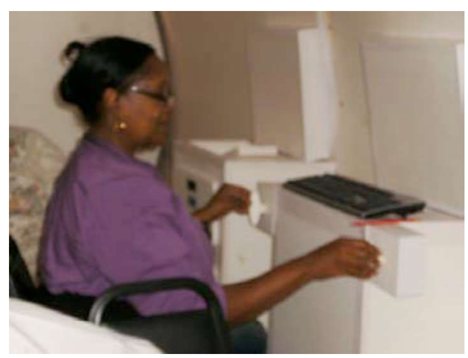

Figure 5. Mockup of Robotic Manipulator Workstation (Note hand controllers for robotic system manipulation).

A significant loss of fidelity was encountered with the airlock, as shown in Figure 6. There was not sufficient material to build a complete airlock mockup. Additionally, the image of the airlock in the cabin layout drawing [1] was clearly not to scale and the airlock as envisioned does not fit in the dimensions of the Core Habitat. The airlock was envisioned as a horizontal cylinder mounted inside the rover, which is also a horizontal cylinder, but of larger diameter. The six spacesuits are intended to be stored outside the airlock, in the aft cabin on either side of the airlock. This did not fit as originally intended. In order to fit both the airlock and the spacesuits, the airlock had to be reshaped into a rectangular structure, only slightly greater than forty inches in width.

Figure 6. Interior and exterior airlock views.

5 Mockup Limitations

As a volunteer activity, the Arusha project is by definition encumbered with certain inherent limitations. In particular, the low fidelity nature of the mockup along with time and personnel constraints naturally imposes limitations on the mockup, which must be properly understood.

5.1 Concept Fidelity Limitations

The original floor plan layout of the cabin was developed without the availability of volunteers trained in computer-aided design (CAD) or CAD software, resulting in a not-to-scale layout as the starting point for the vehicle concept. Additionally, vehicle systems equipment has not yet been designed, sized, or located within the rover. Thus, the mockup build was an approximation of an approximation.

5.2 Time and Personnel Constraints

NSBE is a nonprofit volunteer society. As such, manpower available for this project consisted of available NSBE members, whose day jobs consist of a variety of NASA and contractor full time duties. Work had to be scheduled after normal work hours on weekdays and on weekends.

5.3 Facility Constraints

While the Core Habitat has not been outfitted in its intended configuration, it is not a dormant facility. The NSBE mockup activity had to be scheduled during a brief lull in Building 220 activity. The Habitability Design Center was scheduled to conduct Lunar Wet Bath evaluations on Friday, August 14, 2009, and Monday, August 17, 2009. Facility and personnel schedule conflicts left only the weekend of August 14-16 available to conduct Arusha mockup activity inside the Core Habitat, with the restriction that no work in the mockup facility could begin before 5pm August 14 and the Core Habitat had to be restored to the Lunar Wet Bath configuration before going home on Sunday, August 16. The Habitability Design Center Lab was made available to the NSBE team for pre-work after hours the week of August 10-14.

Over the space of fifty-seven man hours spread across eight volunteers and four workdays, the NSBE Project Arusha rover moved from a two-dimensional concept on paper to a full scale three-dimensional physical representation and returned back to paper. Had this been a NASA project using civil service and contractor labor, HDC labor rates would have resulted in a labor cost of approximately $4,250 to construct the mockup.

6 Lessons Learned

NSBE applied the Habitability Cooper-Harper [11] rating tool to the Arusha design, with an overall Habitability Cooper-Harper Score of 3.07, suggesting overall vehicle acceptability. Derived from the Cooper-Harper rating system, the Habitability Cooper-Harper is a ten point scale intended to assess the livability of a particular spacecraft concept [11]. Ratings of 1-3 indicate a generally acceptable design, 4-6 suggests minor to moderate deficiencies requiring improvement, 7-9 indicates major deficiencies requiring improvement, and 10 indicates the most severe deficiency, such that the relevant operation(s) cannot be performed.

The deployable table in the forward section appeared to work especially well, shown in Figure 7. Though the deployment mechanism was not simulated in the mockup, it appeared there was sufficient overhead volume to store the table when not in use. The cabin width was adequate to allow for all six crew members to sit comfortably around the table when deployed for crew meetings or meals, even with sufficient room for someone to walk behind a seated crew member.

Figure 7. Stowable table, deployed.

NSBE mockup team members anecdotally observed that seeing the mockup in three dimensions greatly increased their understanding of the vehicle. This confirmed the viewpoint that a full scale mock-up is the best way to present a design concept whenever possible. It removes some of the human ergonomic guess work. The mockup was described by team members as bringing the design to life. It enabled the team to not only visualize how the rover would actually appear, but also allowed the team to experience positives and negatives that cannot be discovered from a 2D drawing. The mockup revealed several design changes that will be considered for future development of the Arusha rover.

Windows were only notionally represented in the mockup, but it was clear that ceiling and side viewing ports would add to the vehicle's habitability.

The crew sleeping arrangements shown in Figure 8 were workable, but less than ideal. The mockups of the bunks were awkward and may have been sized larger than necessary. Deployment and stowage was not functional in this mockup – NSBE team members held the bunks in place for analysis – yet it was clear that actual deployment and stowage in the flight design was still an open issue. It was not apparent to any team members how this could be efficiently accomplished. It was also obvious that the bunks as currently envisioned would provide very little crew privacy. It would be desirable to relocate the bunks away from the forward section entirely, but at present there is no other location in the vehicle capable of receiving them. The Arusha rover's sleep accommodations received a Habitability Cooper-Harper rating of 4, suggesting a desire for improvement. Work-life separation received a rating of 5 and personal space received a rating of 4, reinforcing this conclusion.

Figure 8. Deployed sleep bunks.

It is a concern that there is no dedicated medical station in this rover, particularly since the crew bunks must be stowed during nominal vehicle operations and cannot be left deployed for an injured crew member. While there are several locations within the vehicle that could support temporary emergency treatment, there is no place that would be suitable to allow a crew member to recover for greater than a few hours. Medical care received a Habitability Cooper-Harper rating of 6, indicating the seriousness of this omission.

While the rover contained significant stowage volumes, it appears that the total volume may be insufficient for a 30-day mission with six crew. A higher fidelity CAD model or mockup will be needed to fully evaluate all potential stowage bays, but it is likely that additional volume will be needed – either through an increase in pressure vessel size, a secondary stowage module physically attached to the pressure vessel, or an accompanying logistics rover following the crew rover. Stowage and trash management both received Habitability Cooper-Harper ratings of 4.

While maintenance access did receive a Habitability Cooper-Harper rating of 3, there is one issue surrounding its location. Its close proximity to the airlock caused problems because when the airlock hatch was opened, it intruded upon the working volume of the person using the maintenance station.

The entire airlock and extravehicular activity (EVA) system was also problematic, with clean-dirty separation receiving a Habitability-Cooper Harper rating of 6. This rating would have been higher had the mockup been at sufficient fidelity to test actual suited operations. By nature of the airlock system, EVA suits – with inevitable dust – are constantly moved in and out of the vehicle, making it impossible to control potentially hazardous lunar dust. There was sufficient volume to stow all six spacesuits, but the two rear-most suits were difficult to access unless other suits were first moved out of the way. Additionally, the airlock was far too small. This is not by any means the first rover study to be impacted by insufficient airlock volume.

In 1966, Honeywell conducted the LUNEX II simulation, a mockup study of a pressurized lunar rover intended for a 14-21 day mission [12]. Their mockup incorporated a 1.86 cubic meter airlock, shown as compared with the Arusha rover airlock in Figure 9.

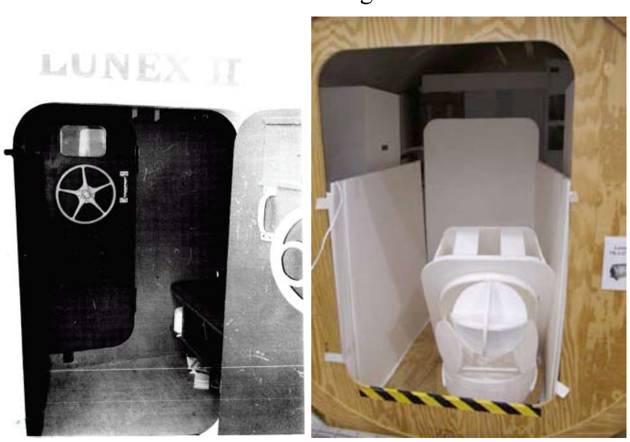

Figure 9. LUNEX II airlock (L), Arusha airlock (R).

From inspection, it is apparent that the LUNEX II airlock is somewhat wider than the Arusha airlock. (Note the benches visible in the LUNEX II airlock where there are straight walls in the Arusha airlock. During the LUNEX II evaluation, they simulated an injured crewmember scenario where one crewmember has to help an "injured crewmember" into the airlock. Operator 1 (the rescuer) fell while attempting to maneuver around his companion, wedging himself against the wall such that he was immobilized [12] – a condition that would have been fatal for both astronauts had it been a real situation.

There are not many viable solutions to the airlock problems both vehicles face. Of course, the LUNEX II task never proceeded to a vehicle development phase. However, in the case of Arusha, there may be two options. One is to expand the airlock to the full diameter of the rover, which has the negative impact of eliminating four suit stowage positions. The second option is to replace the airlock system with a suitport system, similar to that used by the NASA Lunar Electric Rover concept [10], in which the suitport is configured for entry/exit to/from a spacesuit that remains on the outside of the rover. The suitport would also reduce dust intrusion into the vehicle. In such a case an emergency inflatable airlock might also be carried internally or externally on the vehicle. A third option is to extend the length of the vehicle, to allow for additional airlock volume. Either the second or third option may also provide volume to relieve the medical station concerns and possibly allow for a relocation of the sleep stations.

7 Conclusions

This mockup exercise validated the approximate size and layout of the Arusha pressurized rover. Overall, the NSBE team concluded that the rover, as mocked up, provides a very sound concept, with of course, the exception of the EVA system, which requires resolution in future vehicle design iterations. The volume was noted to be limited, but manageable, given the training and motivation inherent to those who will become lunar astronauts. It was a generally sufficient work/living environment with a positive arrangement of equipment, furnishings, hygiene, and other living/working facilities. Following additional cabin design and layout activity, it would be beneficial to build a higher fidelity, permanent mockup structure to facilitate further human factors evaluations.

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