Arusha Rover Deployable Medical Workstation

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Abstract - *The NSBE Arusha rover concept offers a means of human transport and habitation during long-term exploration missions on the moon. This conceptual rover calls for the availability of medical supplies and equipment for crew members in order to aid in mission success. This paper addresses the need for a dedicated medical work station aboard the Arusha rover. The project team investigated multiple options for implementing a feasible deployable station to address both the medical and workstation layout needs of the rover and crew. Based on layout specifications and medical workstation requirements, the team has proposed a deployable workstation concept that can be accommodated within the volumetric constraints of the Arusha rover spacecraft.*

Keywords: Arusha, rover, lunar, deployable medical workstation, stowage, surgical table, surgical light.

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

Project Arusha is a research initiative of the Space Special Interest Group of the National Society of Black Engineers (NSBE Space). Arusha, Kiswahili for “He makes fly (into the skies)”, is a conceptual design for a 48-person lunar facility, intended as an international government/commercial venture to be deployed in the timeframe after the NASA Exploration initiatives. Its purpose is to accelerate the commercial use of the Moon, in line with the provisions of the National Aeronautics and Space Act. [3]

Based on a Moonbase Arusha configuration that included six pressurized rovers capable of supporting short range crew and cargo transfers within the base and longer range excursions thousands of kilometers away from the base, previous research by NSBE Space determined a need for optimal cabin layout usage. The rover will be capable of transporting and accommodating a maximum crew and passenger size of twelve for short range transfer missions less than twelve hours in duration and a crew and passenger size of up to six for long-range excursions of up to thirty days away from the base. [7]

1.2 Arusha Rover Medical Considerations

Medical concerns have been present since the earliest days of space flight. During the relatively short Gemini and Apollo space flights, crews were susceptible to various medical conditions, including loss of red blood cell mass, cardiovascular deconditioning, loss of calcium and muscle nitrogen, and sleep interference. [1] In preparation for missions beyond Low Earth Orbit, NASA has developed a medical conditions list, based on the lunar sortie and lunar outpost mission profiles of the Constellation Program. [9] NASA flight medicine groups continue to develop additional modeling capabilities for other deep space missions to predict medical needs.

This historic flight data and ongoing NASA research makes it clear that due to the length of proposed Arusha rover excursions there is a need for an onboard medical capability. Crew members could be up to fifteen days away from the Arusha outpost in the event of a medical emergency requiring mission abort and could be up to thirty days away from the Arusha outpost in the event of less severe medical conditions. NASA-STD-3001 specifies levels of medical care based on mission scenario. The standard does not explicitly define levels of care for sorties away from planetary outposts and the Arusha rover excursion seems to fall between the descriptions of Level of Care Three and Level of Care Four. [8] Because some of the conditions for Level of Care Four are met, notably, "Return to Earth is not readily available and takes days, not hours, for more serious illnesses/injuries," [8] a Level of Care Four will be assumed for the rover. This is equivalent medical capability to the International Space Station, which also carries of Level of Care Four medical requirement.

An earlier investigation of the Rover layout established the inner dimensions, as well as the three separate sections of the cabin [5]. An examination of that layout decision determined the aft section of the cabin as the most suitable location to house the medical workstation. Subsequently, the allotted space in the cabin layout design did not accommodate a fixed medical workstation, resulting in the need to explore alternative means of access to medical resources. It was determined that a deployable medical workstation was the best option within the designated area. This paper discusses the project team's efforts to investigate the most plausible design options for the deployable medical workstation within the volumetric confines of the Rover.

2 Arusha Medical Workstation Overview

2.1 Medical Workstation Requirements

A dedicated medical workstation is essential to the success of lunar missions. The deployable medical workstation will serve as the central medical resource location for Rover both short-range and long-range excursions, and also while stationary at the Moonbase site. In order to address and meet the medical needs of the mission crew, the deployable medical workstation must meet the following requirements:

- Shall support telemedicine
- Shall sustain any injured/ill crewmember up to 30 days prior to transfer to a base medical facility
- Shall provide medical care and patient restraint while rover is in motion
- Medical equipment/supplies shall stow in the rover's aft port stowage bay
- Medical workstation shall stow when not in use
- Shall stow along the spacecraft port wall, in an area roughly 40 cm length, minimizing penetration to interior
- Shall provide ISS-equivalent medical care
- Shall supply 500 lux lighting to any point of injury
- Shall deploy to include a surgical table 190 cm in length
- Surgical table shall support the weight of a 300lb person, in both seated and prone position when deployed
- Deployed medical workstation shall not cross vehicle centerline (caregiver can, but not workstation)
- Deployed medical workstation shall not block access to medical stowage

These requirements will allow crew medical needs to be met, while also ensuring minimal interference with routine mission operations.

2.2 Project Objectives

The goal of the project team was to more fully investigate and define a concept for a deployable medical workstation. In doing so, the project objectives were defined, and included the creation of a CAD model of the Arusha rover and Deployable Medical Workstation (DMW) – including a surgical table, surgical lights, and stowage lockers; the research and documentation of existing conditions and medical care treatments of the International Space Station (ISS); the estimation of stowage volume; and the brainstorming of concepts and deployment mechanisms for a surgical table and surgical lights. The team also included recommendations for project next steps.

2.3 Cabin Baseline Design

2.3.1 Interior Layout

The Rover cabin has a proposed cylindrical shape, measuring approximately 9.8 feet (~3m) in diameter and 27.4 feet (~8.35m) in length. The interior is separated into three designated sections: forward, middle, and aft as shown in Figure 1. The forward section is intended for use as Rover driver seating and crew mission workstations, along with an elevated conference table that is able to descend for crew use. The middle section offers both additional storage and a sanitation section, including a hygiene station and a waste containment station. It also offers space for crew exercise in the hallway of this section. The aft section is proposed to accommodate spacesuit ports, a maintenance area, the deployable medical workstation stowage space, and 6 stowable crew sleeping bunks. Along with these three sections of the interior cabin, there is an overhead pressurized logistics module used for additional storage beyond the interior cabin that is located directly above the middle section.

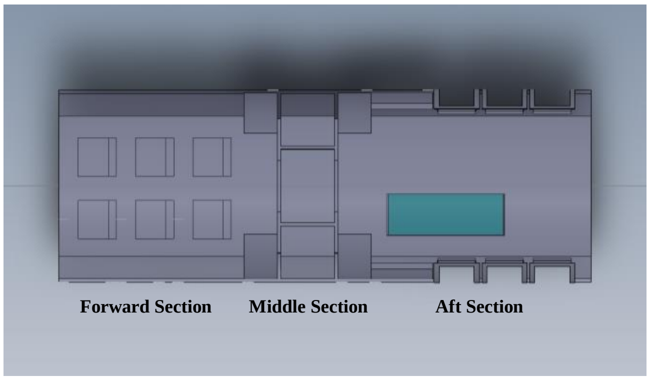

Figure 1. Cabin Interior Layout

2.3.2 Volumetric Envelope Availability for Medical Workstation

Though the medical workstation shares a general space with other Rover workstations and storage requirements, it does contain allotted locker storage space equivalent to seven space shuttle mid-deck lockers (seven MDLE) on the port side of the vessel for the storage of medical supplies, as well as space between the stowage lockers and port suit ports for the deployed workstation components. When the crew sleeping bunks are stowed, the deployed workstation, with surgical table is able to fit within the port side of the aft section volumetric area, stretching roughly from the aft port stowage lockers to the end of the second suit port. An image of the proposed space is illustrated in Figure 2.

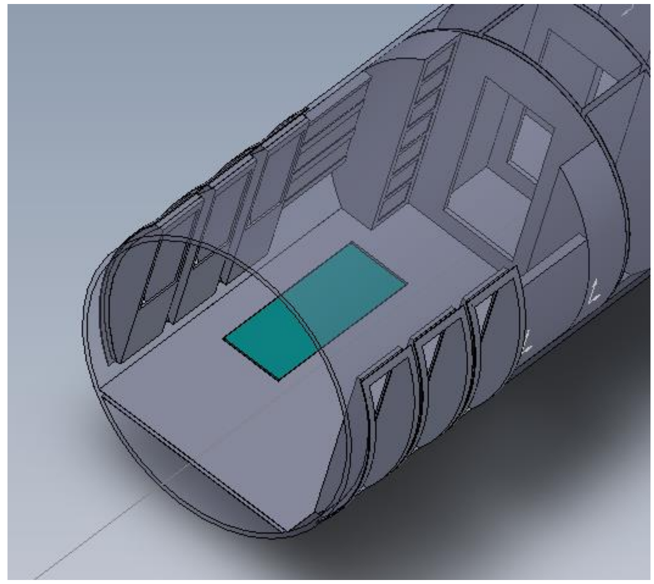

Figure 2. Medical Workstation Area

3 Stowage Volume Allocation

The medical workstation stowage area is derived from the stowage configuration used by the NASA Deep Space Habitat (DSH) project, which applied medical Level of Care Four to a medical workstation intended for use in a Near Earth Asteroid mission. This approach used ISS medical packs, but allocated the stowage of most medical supplies and equipment to full height and half height space shuttle mid deck locker trays. [6]

In the case of the DSH, the medical workstation was designed in the context of a five-meter diameter vertically oriented pressure vessel, while the Arusha rover is a three-meter diameter horizontally oriented pressure vessel. Consequently, the layouts of the two workstations are significantly different, but they carry the same stowage accommodation.

Table 1 shows the designation of Arusha medical stowage trays. The Physician Equipment and Ultrasound trays are full height trays; all others are half height. [6] This results in a seven MDLE allocation, completely filling the aft port stowage bay.

Table 1. Stowed Medical Equipment and Supplies

Medical Equipment/Hardware	Functional Description
Convenience Medication Tray	Over the counter medication (i.e. allergy medication, cough drops, Tylenol, pain medicine
Emergency Medical Treatment Tray	Emergency medical treatment
IV Supply Tray	Intravenous therapy
Medical Diagnostic Tray	Tools for disease diagnosis (i.e. electrodes, magnifying glass, blood pressure monitor)
Medical Supply Tray A	Commonly used medical aids (i.e. alcohol pads, BZK wipes, chemical resistant bag)
Medical Supply Tray B	Commonly used medical aids (i.e. cotton balls, eye pads, syringe)
Minor Treatment Tray	Medication for non life threatening injuries (i.e. Catheter, ace bandages, finger splint)
Oral Medication Tray	Pharmaceuticals (i.e. Celebrex, Zofran, Ambien)
Topical and Injectable Tray	Creams and ointments
Electronics Tray	Laptop, tablet, cameras, cabling, data storage
Physician Equipment Tray	Surgical equipment
Ultrasound Tray	Used to identify medical conditions using ultrasonography

Table 2 lists additional medical workstation equipment that is not stowed in the locker trays. This includes deployable work surfaces and a small number of equipment items, all of which are stowed between the aft port stowage bay and the port suit ports, with the exception of the surgical table which is stowed beneath the floor. These items are deployed by the caregiver when needed.

Table 2. Deployable Medical Equipment

Medical Equipment/Hardware	Functional Description
Automated External Defibrillator	Automatic device that detects and corrects cardiac rhythmic irregularities
Electrocardiogram (ECG)	Records electrical activity of the heart
Medical Refrigerator	Stores small temperature-controlled samples
Workstation Desk	Horizontal work surface to accommodate built-in computer and medical supplies in use
Surgical Table	Storable table to restrain patient conduct medical operations

4 Surgical Table Concept

The Rover team identified a commercially available surgical tables determined that the reconfigurable Steris 5085 General Surgical Table is suitable as an initial concept (with some modification) to provide patient restraint functionality for the Arusha rover. The Steris vendor website offers the following claims regarding the surgical table's capabilities. [10]

- Accommodates virtually all patients with generous weight and height ranges, as in Figure 3.
- Provides unrestricted perennial access with removable leg section, as exemplified in Figure 4.
- Optional Featherweight Leg Section complies with the Association of periOperative Registered Nurses (AORN) Safe Handling principles.
- Enhances lateral procedures with a powered, radiolucent kidney elevator
- Provides outstanding access for C-arm, permitting clear high-quality images crucial to minimally invasive surgery, cardiothoracic, orthopedic and neurosurgical procedures.
- Facilitates quick and safe patient positioning with an easy-to-use, easy-to-read hand control.
- Contours to virtually all patient postures with four section tabletop, as shown in Figure 5.
- Compensates for uneven OR floors with self-leveling floor locks.

- Prevents sectional and table collisions with the Auto Limit Sensor.

Figure 3. Surgical Table Accommodation Example [10]

Figure 4. Surgical Table Removable Leg Section [10]

Figure 5. Surgical Table Posture Adjustment [10]

5 Surgical Table Cabin Placement Review

A review of surgical table placement options within the Rover cabin was also conducted to help determine the most feasible choice for accessibility and use. A permanently fixed surgical table was immediately ruled out due to the small confines of the vehicle. Thus, the table must be capable of stowing when not in use. The pros and cons of four table placement possibilities are highlighted, taking into account the available space and medical stowage configuration.

5.1 Murphy Bed

The strengths of the Murphy bed option are two-fold. The Murphy bed has stowing flexibility that allows for other uses of the floor space it may occupy and it is also easily accessible by a user.

A weakness of this option is that the Murphy bed stowage requirement demands use of valuable rover height and depth space. There is also lack of wall space within the Rover to accommodate the raised bed, and it limits, or even eliminates, possible storage beneath the deployed table. The Murphy bed is therefore eliminated from consideration because it cannot fit within the rover.

5.2 Folding Bed/Workstation Desk Stowage

The concept of a Murphy bed could be extended further with a surgical table that can fold over one or more times before folding to stow against a wall. It is already assumed that the workstation desk will fold to stow in this manner, so perhaps the surgical table can fold up into the same volume. The advantages of the folding bed and workstation desk are that it saves volume elsewhere in the vehicle and it potentially offers a compact solution. This option also ensures close proximity to medical supply stowage.

A disadvantage of the folding option is that there may not be sufficient volume between the aft port stowage lockers and the port suit ports to stow both the surgical table and the medical desk, particularly given the additional medical equipment listed in Table 2 that must also share this volume. Thus this remains a potentially viable, but not preferred, solution.

5.3 Ceiling Descent

Instead folding to stow, the surgical table may simply descend from the ceiling. This may provide stowage flexibility that allows open space in the cabin for alternate uses. This option also permits easy access to the surgical table.

The negatives involved with ceiling descent option include possible stowage impediment, due to the curved nature of the Rover ceiling, interference with the crew sleeping bunks that also descend from the ceiling, and decreased overhead space inside the aft section of the cabin. The Steris surgical table would also require relatively complex interfaces to deploy from the ceiling and retain its capabilities for reconfiguration. Significant cabin reconfiguration would be required to accommodate ceiling storage of the surgical table, making this also a less than desirable solution.

5.4 Floor Ascent

The surgical table might deploy from the opposite direction, stowing under the floor and ascending upward into position. This eliminates the burden of attempting to stow the surgical table on either the port wall or the ceiling, where the volume may simply be unavailable to accommodate the table.

Benefits of a floor ascent include retention of a high degree of commonality with the Steris surgical table. The mounting platform of the Steris would need to be replaced with a deployment mechanism, but much of the table itself would remain functional as is.

A disadvantage is that it does require that the deployment mechanism be capable of compacting for stowage into a very small volume. There may also be some interference with utility runs or other subsystems that would otherwise be stowed beneath the floor. And there must be a floor covering of sufficient strength to prevent crew members or objects from falling into the surgical table's stowage volume when the table is raised into position. Floor ascent is the recommended solution for the Arusha rover surgical table.

6 Surgical Table Lift Mechanism

A mechanism of some kind is necessary to enable the surgical table to traverse between its stowed and operational positions. While a manual solution may be possible, the project team opted to focus on preliminary assessments of powered systems. In a medical emergency, it is preferable for the caregiver to simply push a button and have the surgical table deploy itself than have to spend time implementing a deployment procedure with manual steps. Down selection of a specific mechanism is beyond the scope of this initial study, but some pros and cons have been identified for additional work in future studies. Hydraulic, pneumatic, and motorized geared systems are assessed. Table 3 lists the pros and cons of a hydraulic lift system, Table 4 describes the pros and cons of pneumatic lift system, and Table 5 details the pros and cons of a motorized gear based lift system.

Table 3. Pros and Cons of Hydraulic Lift System

Hydraulic System	
Pros	Cons
Smooth, better controlled operation	Risk of fluid leaks into the cabin
Greater force available for moving large load	

Table 4. Pros and Cons of Pneumatic Lift System

Pneumatic System	
Pros	Cons
Clean system -- no risk of contamination to the environment	Offers less overall supplied force; less efficient than hydraulic systems
Simpler, less expensive hardware to design and maintain	
	Prone to jerky movement

Table 5. Pros and Cons of Motorized Gear Based Lift System

Motorized Gear Based System	
Pros	Cons
Direct gear system provides controlled timing and deployment	Requires maintenance and lubrication
High efficiency in converting rotary motion into linear motion	

7 Surgical Lighting

Cabin lighting will be insufficient to provide the higher lighting levels required for medical care, necessitating steerable surgical lighting that can direct task lighting onto treatment surfaces. Medical operations may require illumination levels up to 500 lux at the treatment surface depending on the specific medical operation. [2] The light must stow out of the way when not in use, but for medical care it must be maneuverable to project light onto various parts of the patient's body, while yet retaining stability during Rover movement.

Figures 6 and 7 illustrate wall mount and ceiling mount configurations of the Centurion surgical light [4], a COTS device that provides characteristics representative of those needed for Arusha rover surgical lighting. This light, or one with similar performance, would be appropriate for inclusion in the Arusha medical workstation. When not in use it would need to stow along the curvature of the pressure vessel, above the stowed workstation desk but not so far into the ceiling as to interfere with stowed sleep stations.

Figure 2. Centurion Surgical Light with Wall Mount

Figure 3. Centurion Surgical Light with Ceiling Mount

Some of the more important capabilities of the Centurion light are listed below: [4]

- 15" diameter reflector with 4,000 ft candles (43,000 lux) of output at 1 meter
- Pre-focused 6" (150mm) spot, at 1 meter distance
- Color temperature rated at 4,000º Kelvin
- Standard removable, sterilizable handle
- Color correcting, heat-absorbing glass cylinder

It should be noted that the Centurion light is designed for terrestrial hospital applications. Thus, the COTS mounting configurations supplied with the light are unlikely to meet the stability requirements for a lunar rover. It is possible that proper analogues may exist among ambulances or oceangoing vessels. Alternately, a custom mounting may need to be designed.

8 Conclusion

Rover excursions away from the immediate vicinity of the Arusha Moonbase will require sufficient medical supplies and a dedicated medical workstation that is easily accessible to crew members. However, due to the limited volume of the rover this workstation must deploy, including a work surface that deploys from the port wall and a surgical table that deploys from beneath the cabin floor. High power surgical task lights are also required to provide sufficient lighting during medical procedures. Initial investigation has concluded that there is sufficient volume within the Arusha rover to accommodate such a workstation. Information and knowledge acquired during this workstation design effort has resulted in suggestions for next steps to be explored.

- Complete recommendation of a surgical table lift mechanism.
- Develop a mechanism for providing visual privacy for crew members undergoing medical treatment.
- Complete detailed design for the Deployable Medical Workstation, including CAD, mass models, and power profiles.
- Develop a medium fidelity prototype of the Deployable Medical Workstation, including deployable workstation desk, floor ascending surgical table with lift mechanism, surgical lights, aft port stowage lockers, patient privacy curtains, and complete outfitting off all medical equipment and supplies.

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