Arusha Pressurized Rover Lighting

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Abstract - *Project Arusha is a research initiative to develop a moonbase configuration including pressurized rovers and other surface systems. This paper covers lighting concepts for the pressurized rovers. Spacecraft lighting is much more involved than simply providing light bulbs and on/off switches. Arusha pressurized rover internal lighting will provide positive reinforcement to crew member circadian rhythms. Additionally, internal lighting will provide main cabin visibility within each of six vehicle lighting zones, display and control panel lighting, task lighting, vehicle configuration status, and alert condition notification. External lighting is necessary on the lunar surface for purposes of both illumination and communication. Lighting systems such as headlights and spotlights will assist rover crew members with visibility of the lunar surface, in support of driving and teleoperation tasks. Signal and alert lights will provide situational awareness to other rovers, personnel performing extra-vehicular activity, base personnel, or others in nearby habitats or lander spacecraft.*

Keywords: Constellation, Arusha, lighting, rover, Moon, lunar.

1 Introduction

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.

This paper assumes a Moonbase Arusha configuration including six pressurized rovers capable of supporting short range crew and cargo transfers within the base and longer range excursions ranging several hundred kilometers away from the base. This concept is a large pressurized rover, capable of functioning independent of other elements during its excursions away from the base. The paper assumes shirt sleeve transfer between the rover and other Arusha elements such as the surface habitats, other pressurized rovers, and crew lander vehicles.

2 Lighting Effects

2.1 Circadian Rhythm

Because lighting can play a role in the human circadian rhythm it is important to provide a lighting system that can be beneficial to the crew members' sleep patterns. All living organisms (including animals, plants, and even fungi and bacteria) exhibit a roughly 24-hour cycle in their biochemical, physiological, and/or behavioral processes. This is referred to as the circadian rhythm [1].

The circadian rhythm is linked to the planet's light-dark cycle. The body "resets" itself daily to the 24-hour cycle of the Earth's rotation due to lighting received from the Sun. However, artificial lighting of sufficient intensity can disrupt this pattern. Studies have shown that humans can be reconditioned to slightly longer or shorter light-dark cycles, such as the 24.65-hour day-night cycle on Mars [2]. However, the Moon has a 28-day cycle and humans cannot be reconditioned to this cycle. In this case, solar lighting could be disruptive to the natural human circadian rhythm. Interior vehicle lighting can also be disruptive or assistive, depending upon how employed.

A Rockefeller University study suggests that disruption of circadian rhythms can disturb the body and brain, increasing a tendency towards impulsive behavior, weight gain, and reduce problem solving ability [3]. Sleep shift workers experience circadian disruptions and have a higher incidence of fatigue, work-related accidents, and single-vehicle car crashes (on the drive home after work) [4].

Clearly in human spaceflight this could produce disastrous consequences for the crew. Thus, it is important for the lighting system in the Arusha rover to assist in the maintenance of a nominal 24-hour circadian rhythm.

Recent research suggests that morning blue lighting exposure may be more effective than other forms of visible light in improving alertness during shift work and resolving circadian disruptions in astronauts during spaceflight [5]. In the study, blue lights were employed in the post-sleep phase, suggesting a need for morning blue lighting onboard the Arusha rover.

3 Lighting Hardware

3.1 Hardware Options

3.1.1 General Luminaire Assembly

The nominal internal lighting source for the International Space Station (ISS) is the General Luminaire Assembly (GLA). The GLAs provide general illumination for the interior of the pressurized elements and passageways as needed for ISS operations. The GLAs are mounted on the footbridges, standoffs, or rackbay areas within each module. These serve as general lighting, providing illumination for ISS modules and translation paths [6]. Figure 1 represents a typical GLA.

Figure 1. Typical GLA.

Each GLA provides a lighting intensity up to 108 Lux, with a 30 W input power [7]. There are four GLAs in the ISS US Airlock, twelve in the US Lab Module, 8 in Node 1, and 8 in Node 2 [7]. The GLAs are not software controlled, but have manual switches [7]. Each GLA has Lamp Power Buttons (2 buttons - “ON” and “OFF”), a rotating Light Output Knob, a Fault Detection Isolator (FDI) & Light Emitting Diode (LED), and tether handles. Only a crude software control is possible by turning on/off the associated upstream power source (which may or may not also be powering other devices). The GLA hardware consists of the Lamp Housing Assembly (LHA) and the Baseplate Ballast Assembly (BBA). The LHA is a removable triple-contained fluorescent lamp enclosure. The lamp utilizes 5mg of mercury mixed with 16mg of indium amalgam. The BBA contains the main card, auxiliary card, and operating controls. The main card consists of the main power converter, housekeeping power converter, and fault detection isolation circuitry. The main power converter converts 120 V dc to 30 kHz ac for lamp power. The housekeeping power converter converts 120 Vdc to low voltage dc for dimming control, filament power and FDI power. The FDI circuitry detects an open circuit across the lamp indicating lamp failure and illuminates the LED when the lamp has failed.

This design has experienced a failure rate of more than three times that expected on the ISS. This failure rate jeopardizes the ability to provide spares for the life of the program.

3.1.2 Solid State Lighting (SSL)

Recent work has been conducted to evaluate the use of solid state lighting as an alternative to the GLA. Solid state lighting uses arrays of LEDs as opposed to fluorescent lights. LEDs are small, solid state electronic devices that emit visible light proportional to electric current flowing through them [8]. NASA research has shown that LED systems weigh less, have a longer mean time between failures, have a higher output per watt, do not contain shatterable materials (e.g., glass) or hazardous substances, run on lower voltage, and have the potential to produce different color lights [9].

A NASA ground-based study compared SSL performance against GLAs in the International Space Station Laboratory Module, using the high fidelity US Laboratory mockup at Johnson Space Center’s Space Station Mockup Test Facility [8]. The module was divided in half, with SSL installed on one side and GLA on the other (see Figures 2 and 3).

Figure 2. Workstation on SSL side of Lab Module mockup.

Figure 3. Workstation on GLA side of Lab Module mockup.

This study used astronauts as test subjects and concluded that SSL is a suitable replacement for GLA. The test determined that neither lighting system produced significant glare, but that higher light intensity than could be provided by GLAs would be beneficial. (SSL is capable of higher light intensities.) [8]

A Station Development Test Objective (SDTO) is currently onboard the International Space Station to compare the performance of SSL against that of GLA. Like the ground-based study, a SSL module (SSLM) identical in fit and form to the GLA is installed on the station [10]. The experiment will involve a ten-minute crew evaluation of the quality of SSLM light output, usefulness of the dimmer feature, and ease of installation and removal [10].

The NASA Constellation program has baselined the use of solid state lighting aboard its spacecraft. Similarly, Arusha will use LEDs for interior and exterior lights.

4 Vehicle Lighting

4.1 Internal Lights

Lighting within the rover interior will consist of a combination of main cabin lights, display panel lights, and task lights.

4.1.1 Main Cabin Lights

Cabin lights are divided into six zones, which can be controlled collectively or individually:

- Zone 1: Forward Section
- Zone 2: Waste and hygiene section corridor
- Zone 3: Body Hygiene Station
- Zone 4: Waste Containment Station
- Zone 5: Suit Maintenance Work Area
- Zone 6: Airlock.

Within each zone, the cabin lights can be brightened or dimmed to provide lighting levels up to 350 lux of general lighting and as low as 2 lux (in conjunction with the use of window shades), thus meeting NASA Human-Systems Integration Requirements (HSIR) requirements [11]. Cabin lights can be controlled from any rover computer network interface, allowing interior light levels to be adjusted by a single crewmember.

4.1.2 Display and Control Panel Lighting

Vehicle displays and controls must be operable regardless of level of cabin or task lighting. Display monitors will not require additional lighting beyond the display illumination, but additional lighting will be required for control buttons, switches, levers, etc. not located near a display. A combination of illuminated controls, illuminated labels, and adjacent lighting will be used to illuminate displays and controls. Light levels can be adjusted at each panel.

4.1.3 Task Lighting

Each workstation in the forward section will include a manually controlled, adjustable task light and a removable flashlight. The same will be located in the Body Hygiene Station and the Waste Containment Station, though these will be waterproof. Two repositionable task lights and two flashlights will be stored in the Suit Maintenance Work Area. A high intensity (500 lux) task light will be stored with the medical equipment. The task lights, in conjunction with the main cabin lights, will enable the rover to meet NASA HSIR standards for task lighting as reflected in Table 1.

Table 1. Minimum Lighting Level by Task [11].

Task	Minimum Illumination (lux)	Measurement Location
Intravenous treatment	500	On the needle
Reading	350	On the page to be read
Handwriting/tabulating – ink on white paper	320	On the paper
Fine maintenance and repair work		On the affected component surface
Food preparation	300	On food preparation surfaces
Dining	250	On intended dining surfaces
Grooming		On the face located 50 cm. above center of mirror
First aid		On the wound
Exercise		On the exercise equipment
Video conferencing		On the face(s)
Gross maintenance & housekeeping		On surfaces involved
Mechanical assembly		On the components involved
Manual controls	200	On the visible control surfaces
Panel – dark legend on light background		On the panel surface
Waste management	150	On the seat of the waste collection system
Translation	110	At all visible surfaces within the habitable volume
Panel – light legend on dark background	50	On the panel surface
Emergency equipment shutdown	30	On controls
Night lighting	20	On protruding surfaces
Emergency egress	10	On protruding surfaces

4.1.4 Signal Lighting

Signal lights are mounted within the rover pressurized sections to visually indicate vehicle configuration. Conditions such as "vehicle docked," "drivetrain active," and "airlock hatch open" can be indicated via colored LED indicators throughout the cabin, allowing the crew to be aware of certain critical states without having to monitor a display panel.

4.1.5 Alarm Lighting

The rover onboard Caution and Warning System will use a similar alarm nomenclature as that used aboard the International Space Station, consisting of caution, warning, alert, and emergency, with the last three triggering audible enunciator tones. Typically, cautions are less critical and can be handled by the vehicle's automated diagnostic systems, Moonbase Arusha mission control, or Earth mission control, often without rover crew intervention. The other alarm conditions are more serious and require immediate rover crew attention.

Alarm lighting (Table 2) is required in addition to Caution and Warning System displays and enunciator tones because crew members may not always be facing a display and noise conditions may potentially drown out alert tones, such as during certain Extra-Vehicular Activity (EVA) suit servicing operations or noisy payload equipment operation. Colored main cabin lights will activate based on vehicle Caution and Warning System alarm conditions.

Table 2. Arusha Rover Internal Alarm Lighting.

Alarm Condition	Internal Alarm Lighting	Audio Enunciation
Caution	None	Single computer "ding" tone
Warning	Yellow steady lighting	Repeating "whoop, whoop"
Alert	Red steady lighting	Repeating siren
Emergency	Red flashing lighting	Klaxon

4.2 External Lights

Exterior lighting will consist of a combination of headlights, spotlights, signal lights, and alert lights. High intensity LEDs will be used for all external lights.

4.2.1 Headlights

Fixed headlights attached to the vehicle front and aft will facilitate driving visibility. These lights will be controllable from all driving workstations as well as via remote commanding from EVA crew members or other Moonbase Arusha elements and can be dimmed to facilitate various illumination levels.

4.2.2 Spotlights

Directed spotlights will be used to augment driving visibility or support EVA or remote manipulator tasks. Turreted spotlights will be located at the vehicle front, aft, and on manipulator arms. These lights will be controllable from all driving workstations and EVA support workstations. Similar to the headlights, they can also be commanded by authorized external elements.

4.2.3 Signal Lights

Signal lights are mounted on the rover pressurized exterior to visually indicate vehicle configuration. Conditions such as "vehicle docked," "forward drive," "reverse," "left/right turn," "drivetrain active," "manipulators active," and "airlock hatch open" can be indicated via colored LED lights, allowing EVA crew, other rovers, or the Moonbase to be aware of certain critical states without having to monitor a display panel.

4.2.4 Alert Lights

Nominally, the rover communications system will broadcast verbal Caution and Warning System alerts to EVA crews over the crew radios. However, additional alarm lighting is required because some contingency scenarios could involve failure of the rover communications systems, preventing data transfer between the rover and an EVA crew member or other Arusha elements. Colored spotlights and signal lights (Table 3) will activate based on vehicle Caution and Warning System alarm conditions.

Table 3. Arusha Rover External Alarm Lighting.

Alarm Condition	External Alarm Lighting
Caution	None
Warning	Yellow revolving spotlights Steady yellow chaser lights
Alert	Red revolving spotlights Steady red chaser lights
Emergency	Red rapid blinking spotlights Flashing red chaser lights

5 Forward Work and Conclusions

Future work will include mass, power, thermal, and volume sizing of the solid state lighting assemblies for Arusha interior and exterior lighting subsystems. Additional literature review will be needed to identify existing space qualified systems. Of particular interest will be solid state lighting systems developed over the next several years for the Lunar Electric Rover project, most of which will be directly applicable to Arusha rover lighting subsystems. Mockup testing is also desirable to validate required lighting levels and to test the benefits of the various color schemes suggested in this paper. Additional human factors and psychology research will also help to identify benefits from varied internal lighting beyond the previously mentioned circadian rhythm benefits.

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