NASA-STD-3001 Technical Brief

Artemis Lighting Considerations Overview

OCHMO-TB-001
Rev B

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev D
[V2 3006] Human-Centered Task Analysis
[V2 3101] Iterative Developmental Testing
[V2 8051] Illumination Levels
[V2 8053] Emergency Lighting
[V2 8056] Lighting Controls
[V2 8057] Lighting Adjustability
[V2 8058] Glare Prevention
[V2 8059] Lighting Chromaticity
[V2 8060] Lighting Color Accuracy
[V2 8103] Environmental Lighting Attenuation
[V2 8104] Task-Specific Exterior Lighting for Operational Areas Partially or Fully Lit by Sunlight
[V2 8105] Navigation and Wayfaring (Exterior)
[V2 10150] Display Standards
[V2 10048] Visual Display Parameters
[V2 11018] Suited Field of Regard
[V2 11020] Suit Helmet Luminance Shielding

Executive Summary

NASA crewed spaceflight programs have had years of experience with the Space Shuttle and International Space Station (ISS) programs in performing exterior vehicle proximity activities such as crewed Extravehicular Activities (EVAs), robotics, docking, and inspections. These experiences have been operated in full sunlight every 45 minutes during each orbit in Low Earth Orbit (LEO). The lunar surface, especially at the South Pole, will have poor lighting conditions due to the day-night cycle lasting one Earth month (see photos below for comparison to Apollo conditions) and the extremely low angle of the sun relative to the South Pole surface. Exploration of exterior lighting systems need to plan for both perpetual darkness and perpetual harsh sunlight. This Artemis Lighting Considerations Overview Technical Brief is intended to provide guidance on development of an integrated lighting architecture plan that accommodates human and machine vision related EVA tasks. The lighting engineering process may involve trade-offs in meeting these needs within power constraints and physical restrictions on light sources and operator placement. Treatment of the solution as an integrated design project will provide for the development of all end-item components (suits, lunar terrain vehicle (LTV), Human Lander System (HLS), and Surface) needed to provide a productive lighting system that supports crew safety and performance of mission objectives.

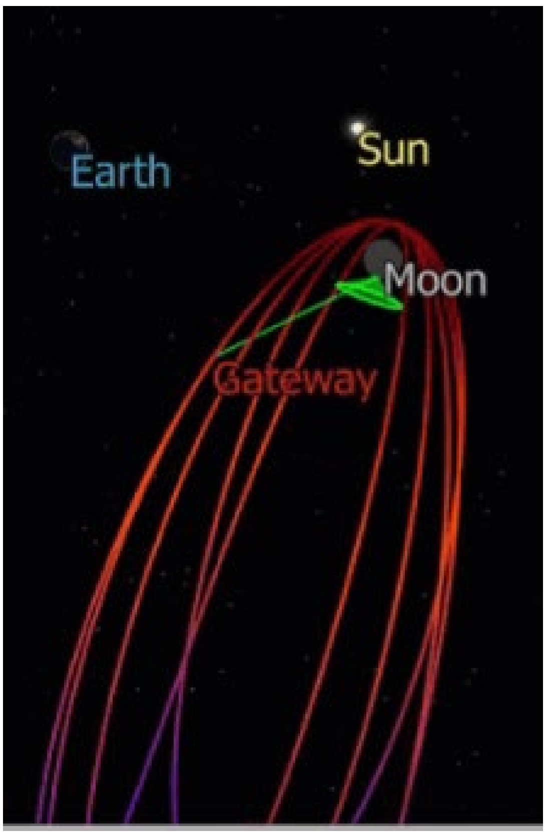
Example of lighting conditions on the lunar surface at the South Pole. *Generated by NASA JSC NASA Scientific Visualization Studio.*

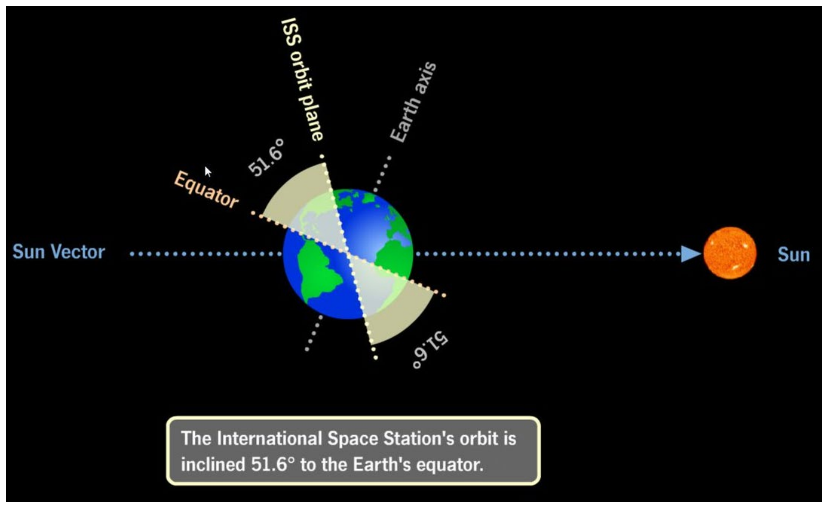
Background

Lighting System Development Beyond LEO

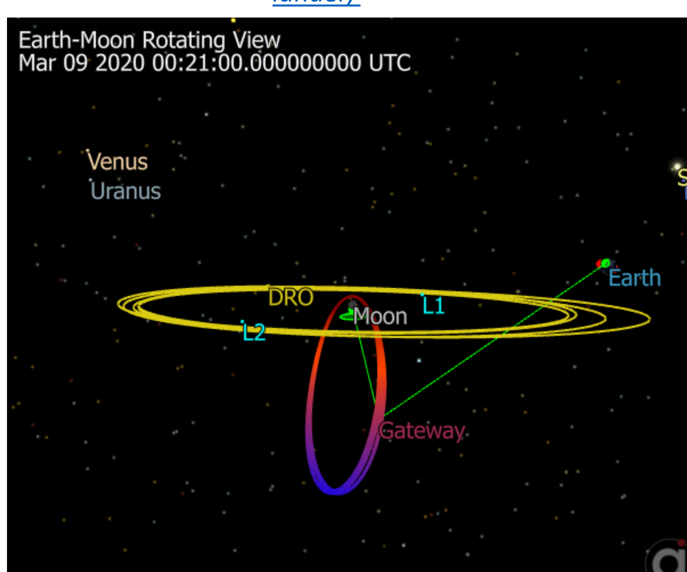
The ISS LEO orbit mainly consists of a repeating 90-minute day-night cycle. The time of year and solar beta angle (β-angle) affects the amount of solar lighting the ISS receives, with periods of constant sunlight occurring a few times per year. The ISS orbit has an inclination of 51.6° with respect to the Earth equator. This results in a β-angle that varies between ±75.1° over the course of a year. As the β-angle increases, the ISS is exposed to more sunlight per orbit

NASA's current planned 6-day lunar orbit of the Gateway vehicle will maintain the vehicle out of the Moon's shadow to create a continuous illumination from the sun.





a.i. solutions FreeFlyer orbit simulator: https://ai-solutions.com/newsroom/about-us/news-multimedia/lunar-lander/

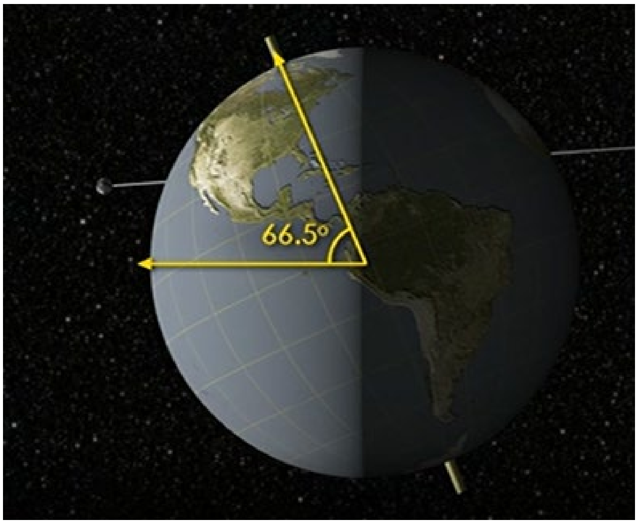


External lighting design for Gateway will differ from previous strategies used with the ISS. Continuous illumination from the sun and vehicle shadowing will need to be taken into account for docking, undocking, and EVA activities.

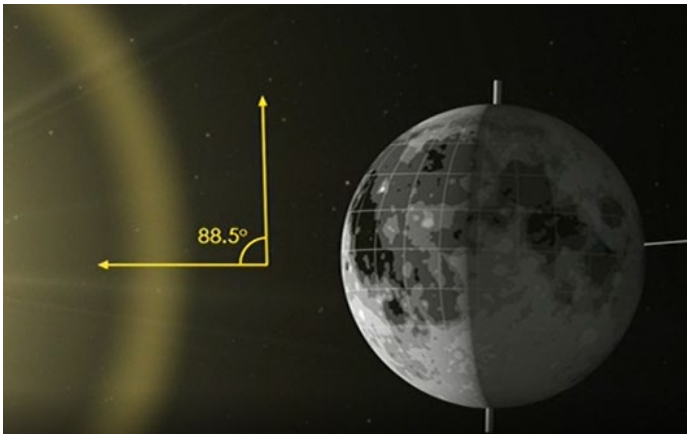
Reference Information

The Sun's Angle on the Lunar Surface

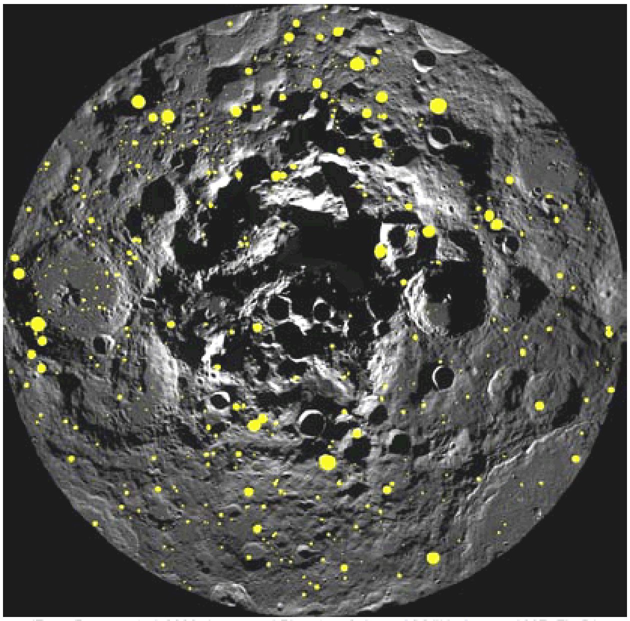
The Moon is nearly perpendicular to the direction of the sun's light, which can never reach the floors of some deep craters (known as permanently shadowed regions). At the Moon's poles, the sun is always near the horizon and the shadows are perpetually long, sweeping across the surface with the changing solar azimuth. As the Moon rotates on its axis, the sun skims the horizon, traveling a full 360° around the terrain. Mountains as far as 75 miles (120 kilometers) away cast shadows across the landscape.



Angle of the Earth to the sun's light



Angle of the Moon to the sun's light



(From Bussey *et al.* 2003, *Lunar and Planetary Science XXXIV*, abstract 1897, Fig.5.)

Craters at the lunar South Pole area containing permanent shadow

Craters and regolith formations at the lunar South Pole area showing complete darkness and long shadows. Generated by NASA JSC NASA Scientific Visualization Studio.

The sun incidence at the surface of the South Pole is 1.5°, which will generate constant sunlight with extremely long shadows and mission phases with complete darkness. Providing adequate lighting will be challenging due to the sun angle on the horizon and the resulting shadows.

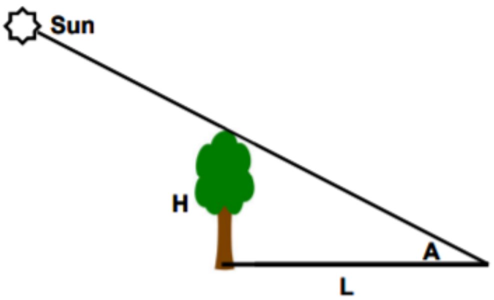
Source: Martel, L.M.V. The Moon's Dark, Icy Poles. Hawai'i Institute of Geophysics and Planetology.

Reference Information

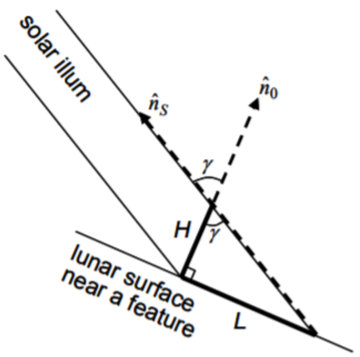
Determining Shadow Lengths

The length of shadows cast on the lunar surface by objects (i.e., crewmembers, lunar terrain vehicles (LTV), mountains, rim of a crater, etc.) can be calculated using mathematical equations.

Basic trigonometry concept for determination of shadow length



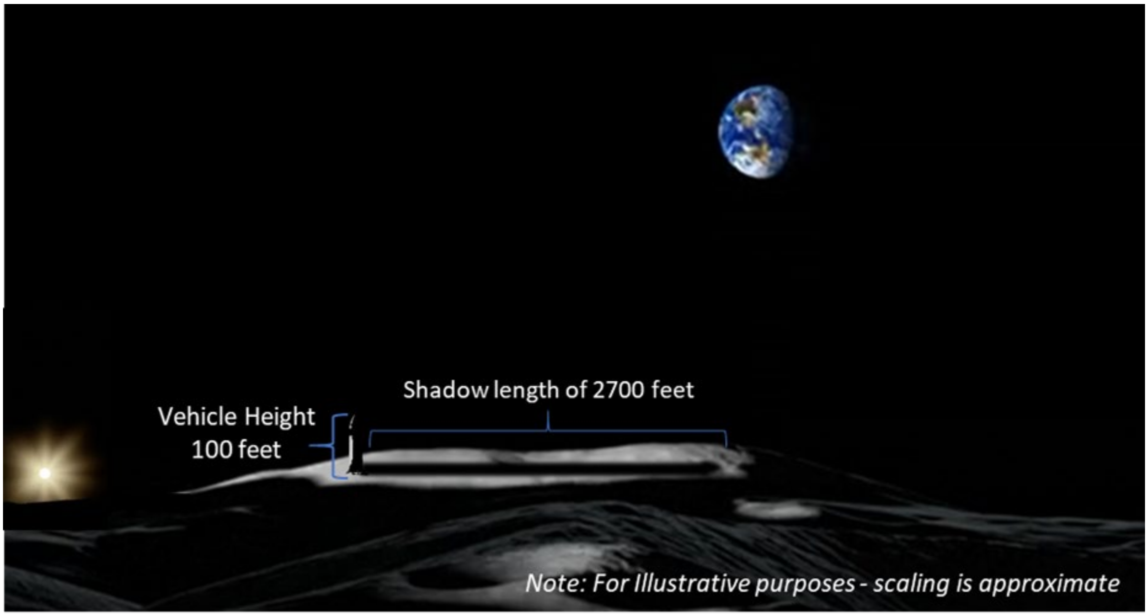
Plane of incidence of solar rays at the surface feature; *L* = Shadow Length; *H* = Object Height



Source: Venet, B.P. (2017). Determination of Lunar Feature Heights from Shadow Lengths

Example: Shadow Cast by a Lunar Lander

At an approximate 1.5-2 degree sun inclination angle, an object on the Moon's surface will have a shadow length that is approximately 27 times the height of the object (L = 27 x H).



Reference Information

Environmental Impacts on Lighting System Architecture

The following conditions will impact the lighting system architecture:

- The position of the sun and angle with respect to the worksite will impact both availability of natural light and visual hazards from the direction of shadows and extreme contrast. Areas with zero darkness will still be significantly affected by shadows. The position of the sun for a planned mission will drive architecture requirements to protect crew safety and ensure successful completion of mission tasks.
- Position of observer/camera and their field of view or line of site with respect to the sun.
- Reflectance of sunlight from nearby celestial bodies, such as the Earth to the Moon to Gateway, either contributing diffuse light to a task surface, or creating a potentially high contrast luminous backdrop within the observer's field of view.
- Surface topography, especially when the sun has low inclination angles with respect to the primary surface, creating visual challenges with long deep shadows with extreme contrast.
- Properties of natural surface materials, such as percent absorption and scattering (specular versus diffuse) and its impact on usable reflected light and unusable reflected glare.
- Timing and changes of natural lighting conditions as it relates to both the position of the celestial object (Moon/Earth) to the sun, the location of the task with respect to the celestial object (altitude), and the ordinal location of the task with respect to the celestial object (equator, poles, time of "day" and time of "year" [i.e., seasonal changes]).

Image captured during Apollo 17 surface mission

Example of lighting conditions on the Lunar surface

The relative uniformity of surface reflectance and color of lunar regolith obscure surface details when observed looking in the sun's direction or with the sun to one's back. When viewed at an oblique angle to the sun's rays, shadows cast by surface irregularities provide visual cues to objects' relative size and shape. For this reason, the lunar landing approaches by the Apollo landers were intended to be "cross-sun."

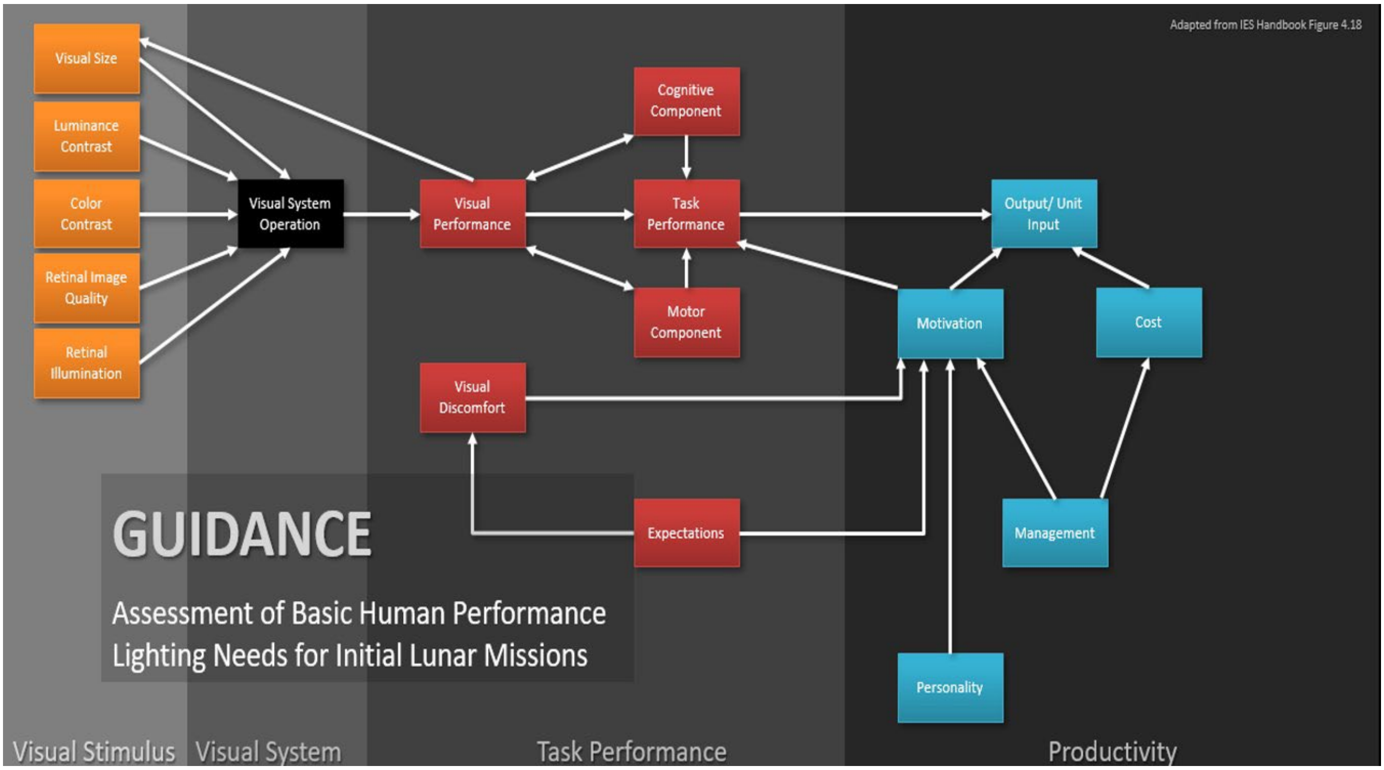
Design

Task Assessment

Exterior Light Specific Task Analysis

The Lighting Analysis will be scoped by the Task Analysis. To plan a lighting system, we need to know how it will be used. Proper planning of lighting systems is essential to determine:

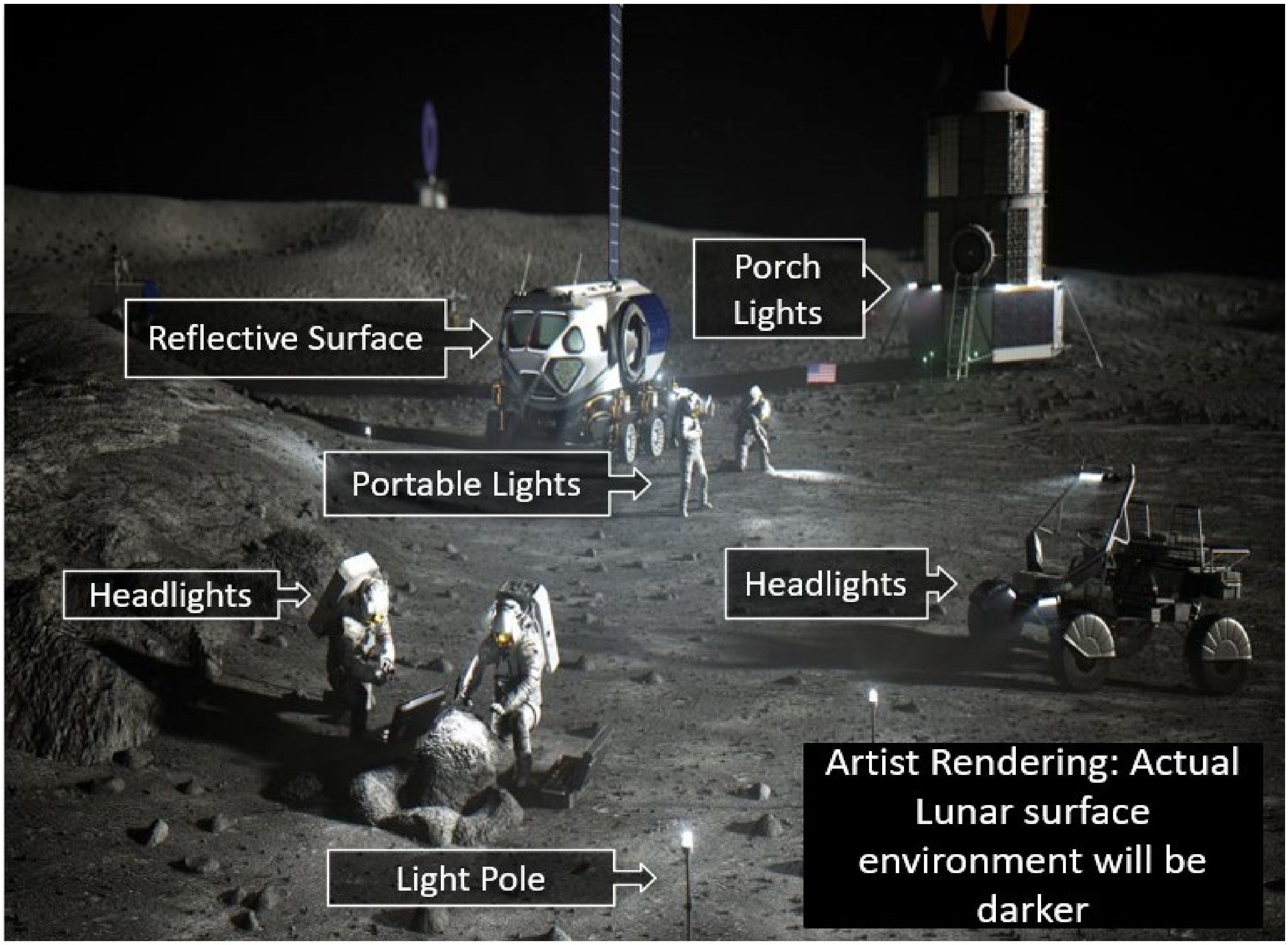
- Lighting types
- Beam type
- Determining the beam distribution per lamp
- Variability of beam distribution for multi-functional tasks in the same area
- Stationary (vehicle/rover mounted, suit mounted) vs. portable lighting (flashlight-type, lights on a stand)
- Night vision goggle technology
- Efficient power systems utilization
- Well thought-out control systems
- Development of redundancy and emergency designation of light sources
- Illumination level
- Lighting color
- Brightness needed



Design

Integrated Operational Environment

- The operational size will drive the number of stationary lamps required to maintain adequate illumination over the work area or to maintain a line of sight between translation points for safe navigation.
- A large surface that diffuses and transmits light could be put in the path of low-inclination lighting from the sun at the lunar South Pole to create a work zone with diffuse, high intensity, and quality spectrum lighting.
- Large vehicles can utilize the selection of diffuse white materials with the combination of permanent or portable lighting to create a diffuse indirect lighting effect for a soft diffuse work environment.
- Support vehicles can provide methods for the crew to craft a temporary “white room”, through use of structures, to allow the crew to utilize inter-reflected light, maximizing what can be accomplished with a limited set of portable lighting systems.
- Activities that are planned in close proximity to multiple vehicles that may be using light-colored surface materials versus activities that are largely planned in the open over dark lunar regolith require different lighting solutions due to the presence of beneficial inter-reflected light versus absorption and lack of beneficial inter-reflected light.

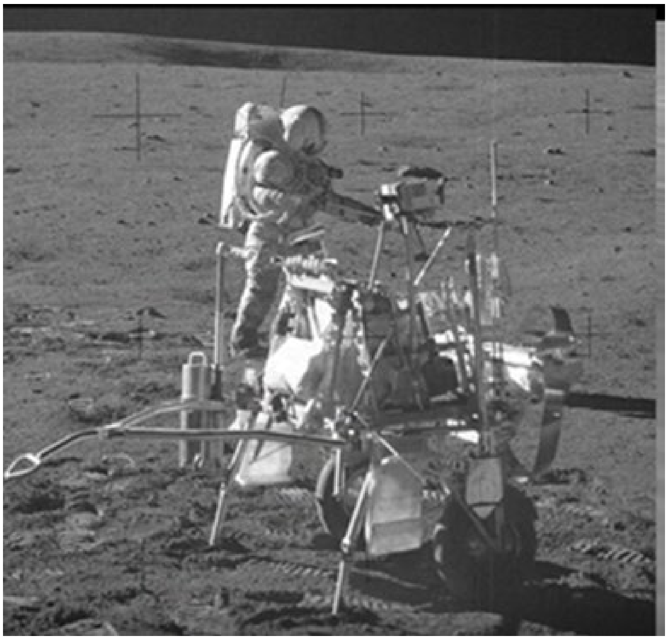


Design

Integrated Operational Environment

- Portable light poles could be equipped with popup fabric umbrella reflectors to provide the crew the option of having direct light or diffuse indirect light by redirection of a spot lamp into the reflector.
- Navigation and identification of a vehicle at a long distance can be enhanced by strategic selection of material reflectance types to enhance edge detection and visibility of important architectural surfaces at a distance. Additionally, illumination of these same surfaces can create luminous shapes that can be used for identification, even when sunlight is not available.
- The implementation of a lighting system is dependent on supporting power systems. Variable intensity, manual versus automatic, and considerations on dimming methods impact lamp and lamp-system design.
- Illuminance requirements must be determined in accordance with the anticipated operating luminance conditions. Factors affecting luminance include the reflective properties of the environment surface and surrounding features.
- The elevation of illumination (ground, head height, top of lander, etc.) impacts the ability of a lamp or set of lamps to redirect light to the area of interest and efficiency of that lamp to produce the correct illumination levels for the desired elevation.

Apollo 14 Modular Equipment Transporter (MET)



Apollo 17 Lunar Rover

An integrated system lighting architecture should utilize surrounding structures, surfaces, and materials. Creative thinking about how to harness, redirect, or soften the effects of direct sunlight on shadowed regions with use of architectures and materials is a strategic way to reduce extreme contrast and maximize the abilities of an artificial lighting system.

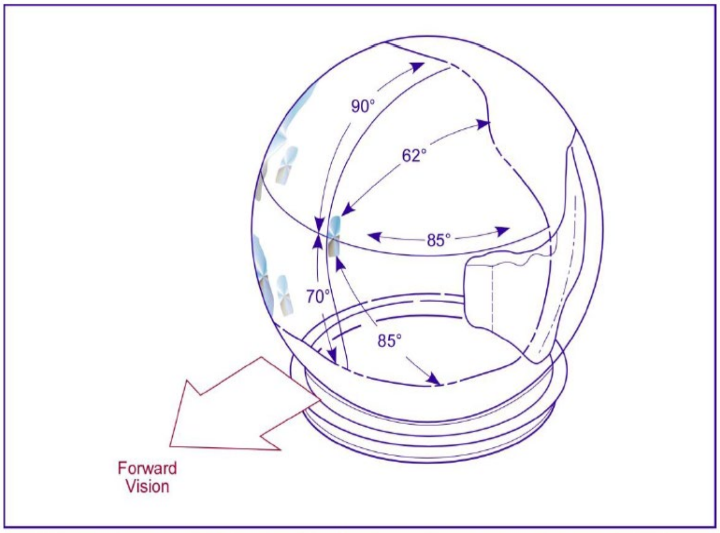
Design

EVA Suit Considerations

When the crew first lands on the Moon and begins exploration activities, the lights on their suit will be the only lighting system until they deploy temporary and permanent surface lighting support equipment. Suited lighting architecture will also be important during surface traversing and other task activities.

- The "First Lights" should be designed to support the tasks needed to prepare the crew's worksite until surface lamps and other lighting equipment are installed.
- The suit needs to provide worksite lighting intensity levels, without additional ambient lighting.
- After surface lamps are installed to provide general ambient lighting, the crew can conserve power by only using the suit lamps when needed.
- Helmet lighting design should prevent potential blinding and glare (including between suited crewmembers) during EVAs.
- Crew could be carrying hardware that obscures field of view or impacts light propagation.
- Helmet shapes contain elliptical geometry that could make it difficult to prevent light from making contact.
- The sun can be "blinding" when walking/driving towards it, making the use of visors a necessity.
- Walking down grade may have more challenges than walking upgrade.
- Surface topography and shadow contrast make it difficult to estimate slopes and judge distances.
- Visors may introduce distortions of shape or location or may reduce contrast or produce multiple images. Helmet visors also create additional shadowing and lighting angle considerations. Special treatments such as coatings or polarization may distort colors or reduce visibility of polarized sources (e.g., LCD displays).

Illustration of potential EVA suit lighting at the lunar South Pole. *Generated by NASA JSC NASA Scientific Visualization Studio.*



Example: xEMU helmet field of view

Design

EVA Suit Lighting Examples

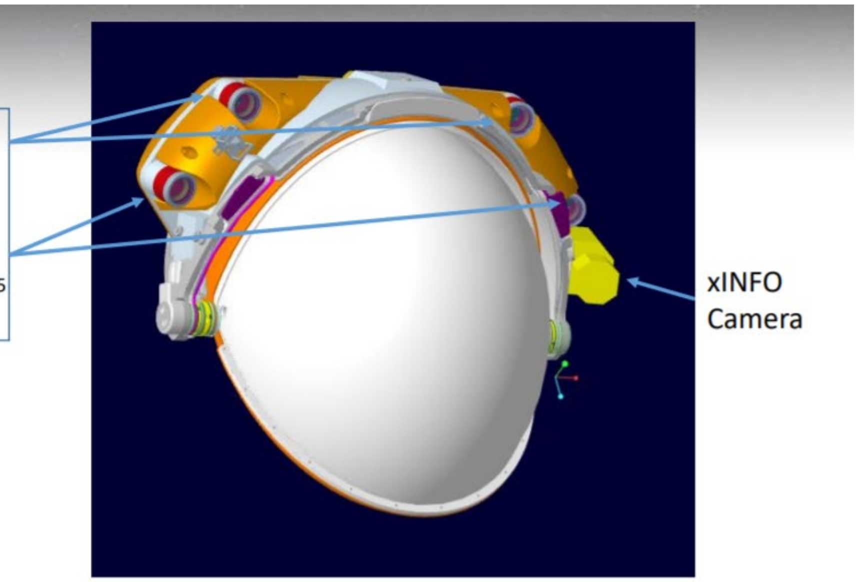
Other Considerations:

- Power required to provide adequate lighting
- Dissipating heat from lamps and electronics
- Preventing internal lamp light loss

Two types of light focus:

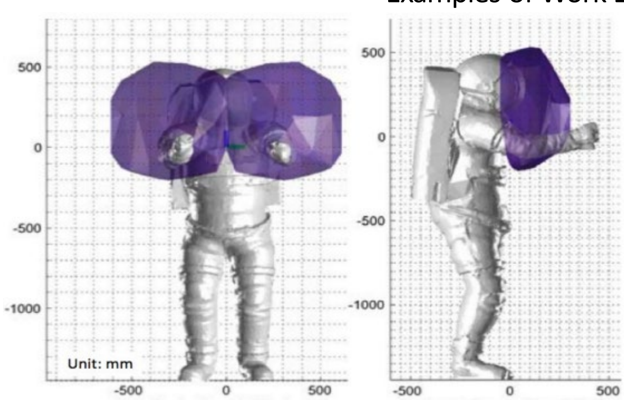
Translational: For traversing the lunar surface

Work: Focused on two-handed work envelope for task lighting



Visit the NASA Suit Up website to find current information on NASA xEMU suit technology and development. https://www.nasa.gov/suitup

Examples of Work Lighting – Light Distribution



Lighting Envelope

Working envelope of the hands/arms

Illumination envelope should match the working envelope of the hands/arms.

Design

Camera Lighting & Automation

Cameras play a dominant role in inspections, real-time decisions, and autonomous operations, requiring careful integration evaluations. Relying on basic system requirements of human performance, such as required lux levels for certain tasks, does not fully encompass the complexity of potentially increased visual needs due to the predominant appearance of the visual field of view (dark colored environment versus light colored).

Similarities and Differences Between Human and Camera-Based Visual Tasks

	Human Vision	Camera Vision
Safety	Inadequate illumination could result in a decision that indirectly or directly impacts the observer or the team's health.	Incorrect illumination could result in an incorrect indirect decision by the crew or ground that impacts safety of the crew and vehicle. If the input is to an autonomous system, a direct impact could result from poor illumination for an imager.
Timeliness	Inadequate illumination, lowers human visual acuity and contrast and could require the crew to spend more time to complete task, impacting mission timelines.	If a go/no-go requirement exists for a decision from an image, inadequate lighting could impact the mission timeline or the objective, due to lack of adequate feedback to proceed.
Accuracy	Inadequate illumination impacts judgement on shapes and locations of objects, especially if fine differences or fine manipulation is required.	The lighting conditions could reduce the contrast and quality of an image, limiting decisions that can be made from it.
Fatigue & Pain	Persistent operation under inadequate illumination requires a greater physical load, including eye strain, on the crew. Some lighting conditions can create immediate pain or damage the retina of the observer.	Cameras may not be able to feel pain, but sensors can be permanently damaged by a high intensity light source or a persistent high contrast object in the field of view.
Contrast	An adaptation time is required to transition from very dark to very bright environments. However, the human will adapt to the brightest environment, making it difficult to see objects that are more than 2 to 3 orders of magnitude less bright than the dominate surface.	Cameras, even ones with auto exposure capabilities, will have limited firmware options, especially if designed to withstand the orbital radiation environment. A camera's flexibility to respond to dynamic changes in contrast may be limited.
Color	Below 10 lux, human color vision begins to be compromised. The actual light spectrum of an artificial source can also impact human perception of color accuracy. The spectrum of a light source impacts human ability to discern fine differences in colored objects. A quality lamp spectrum should be selected to maximize human color vision for critical tasks.	Cameras with red-green-blue sensors for documenting the color of visible environments are benefited from quality light spectrum to maximize the purity of colored materials imaged. Light spectrum that is not broad across the range of visible wavelengths can yield images with low saturation of color.
Depth	Human perception of depth requires illumination that is consistent and uniform. Non-uniform illumination of surfaces creates trip hazards and impacts assessment of distance. Lack of illumination of distant objects impacts a sense of direction.	Depth perception comes from the use of more than one camera. Cameras that are paired to provide 3D imagery will require uniform illumination of their target within the contrast range of the imager.

Design

Testing & Verification Tools

Testing of lighting systems includes capture of lamp performance characteristics and evaluation of integrated lighting and hardware, such as lamp-sensor packages. The following list outlines important capabilities for a test and verification program responsible for optical performance requirements.

- Physical test facility should provide a large open room where all major surfaces are matte black, via paint or blackout cloth. Facilities with extremely tall ceilings may be able to avoid needing to have black ceilings. The intent is to mitigate surface reflectance in the room from impacting quality of lighting data captured by sensors.
- Light Source Beam distribution test is best performed with a type A or B goniometer, which automates the collection of lamp intensity data with respect to angle. Goniometer test systems can provide light distribution data in Illuminating Engineering Society (IES) beam distribution file format, which, in turn, can be used by computer-based simulation and visualization tools for proper representation of the lamp.
- Calibrated illuminance meters that have an operational range for all expected lighting test conditions. If validation activities include up to orbital light levels, ensure the meter will not be out of range for measurements of 130,000 lux.
- Calibrated luminance meters are necessary for measurement of lamp aperture and materials surface brightness. The ability to document surface brightness is important for mitigating eye hazards and addressing surface contrast.
- A calibrated spectral irradiance meter for spectral range of 350-780 nm is important for documenting lamp and integrated habitat compliance to spectrum-based requirements for chromaticity, color fidelity, and photobiological (eye hazards and circadian lighting) performance constraints. The added capability to measure 200-350 nm adds monitoring if ultraviolet light is included. The added capability of 780-1000 nm adds the capability to measure near-infrared (NIR) light, which represents wavelengths often used in line-of-site infrared transceivers.
- A calibrated hemispherical/spherical spectral reflectance meter is a valuable tool for integrated architecture design and validation. The tool can be used to document and optimize surface reflectance to maximize effectiveness of a lighting system and can be used in development of material properties for surface targets used by imagery components that provide input to autonomous systems.
- A flicker meter or an oscilloscope paired with a photo diode can be used to document the duty cycle and pulse modulation waveform for lamps that use pulse-width-modulation (PWM) for dimming. PWM light sources can create integration issues with cameras and transceivers if integrated constraints on flicker/sampling frequencies are not coordinated.

It is important to begin testing and verification of the lighting system early and repetitively to ensure an adequate lighting environment will be provided for the crew to safely and effectively perform mission operations.

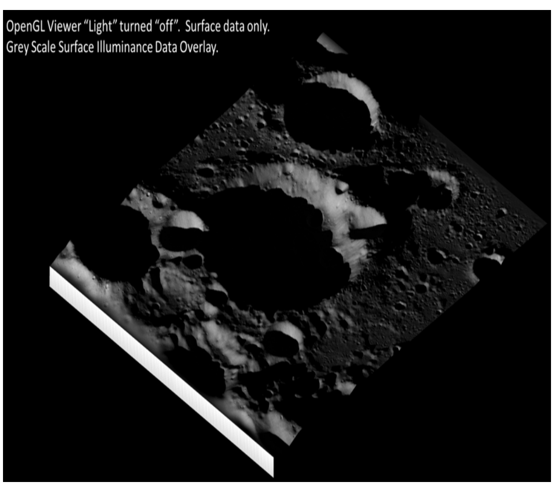
Design

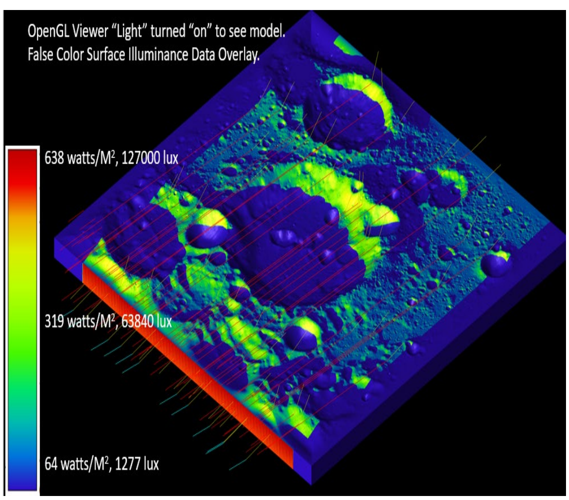
Testing & Verification Tools

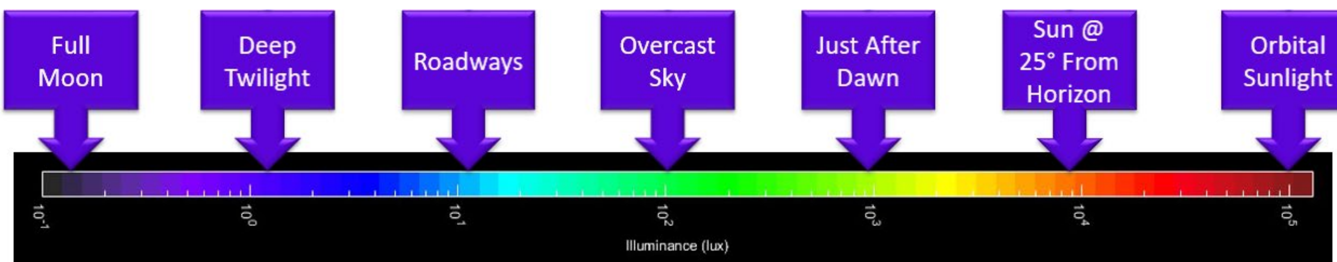
Computer lighting analysis software uses "ray-trace" technology. Ray-tracers can be "forwards" or "backwards" and utilize model input such as computer aided design (CAD), materials reflectance properties, lamp beam distribution data, and optical-refractive properties.

- Usage of optical modeling software as part of an "agile" design process enables development of lamp models for integrated lighting habitats. The same models can also be used to improve requirements in source control drawings when outsourcing lamp development projects.
- Usage of optical modeling for the lamp development stage can help a vendor optimize lamp optics to maximize usability of a lamp despite constraints on power. Some software models also allow for dynamic adjustment on lamp output in simulations based on LED thermal constraints.
- Usage of optical modeling for integrated lighting implementation solutions can help camera clients understand the luminance range and visibility of objects within the field of view of a camera, providing further feedback on lamp placement or redesign guidance for the lamp itself.
- Lighting simulations can be used as a tool to develop smart test procedures and pass/fail criteria for lamp and integrated environment testing.

The example below illustrates the use of a computer model to estimate the amount of 'naturally occurring' light in a specific environment to help design the appropriate lighting system.



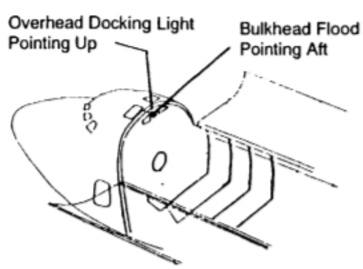


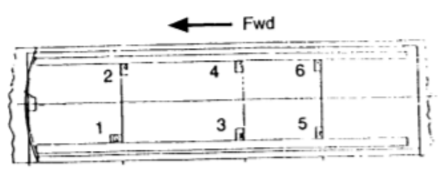


Design

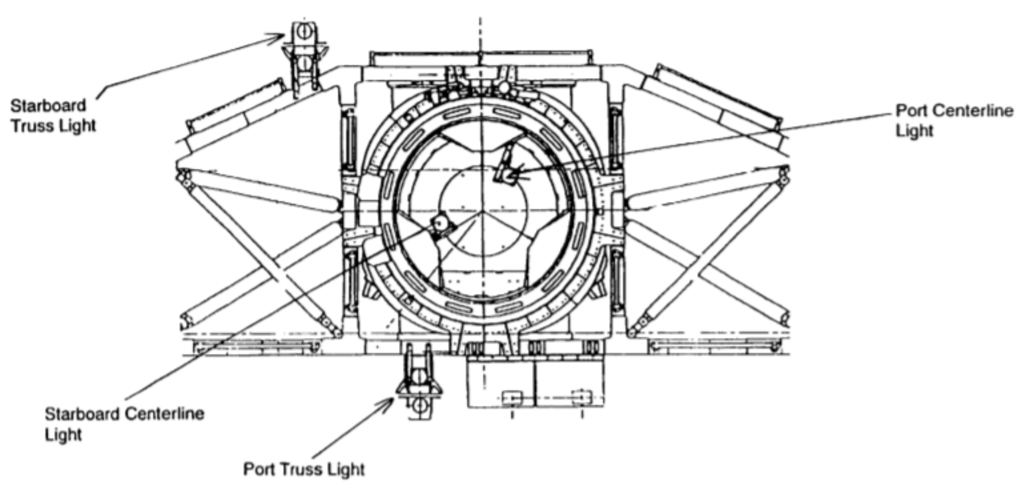
STS-71 Space Shuttle Docking System Testing

- At the Preliminary Design Review of the STS-71 Space Shuttle docking to the Russian Space Station Mir, concerns were expressed on the resolution of the hatch window, the camera system, and the overall lighting levels. A test was conducted in June 1993 to verify that the proposed design was adequate.
- The lighting system consisted of a bulkhead floodlight, a bulkhead-mounted overhead docking light, two truss-mounted docking lights, and two lights mounted inside the Orbiter docking adapter (see graphic below).
- During testing, the reflection of the lights off the unpainted docking target bolts were noticeable, but not a problem for docking.
- Six of the tests scored inadequately due to unacceptable shadowing under the various failed light conditions. In some of these cases, specifically failures of one centerline light, the shadow of the docking target standoff cross looks very similar to the standoff cross itself. Failures of other lights such as the truss lights or payload bay floods create shadowing, but not to an unacceptable level.
- The shadows were attenuated by providing light in locations which offset them. Assuming overall light levels are acceptable, this can be accomplished by operational workarounds. For example, if a particular light failure creates a bad shadowing effect, other lights could be turned off or on to alleviate this problem. Therefore, the existing light placement is acceptable for performance of a successful docking.





Payload Bay Top View
Floodlight Location



View Looking Down

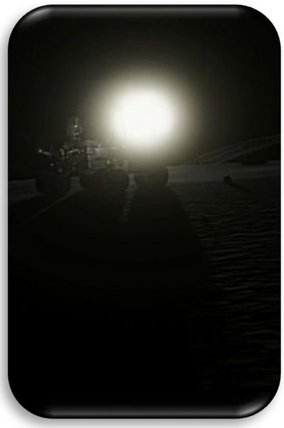
Source: Mongan, P.T. (1993). Orbital Docking System Centerline Color Television Camera System Test. *NASA Technical Memorandum 104783.*

Back-Up

Background

Example Lighting Environment at Artemis Base Camp

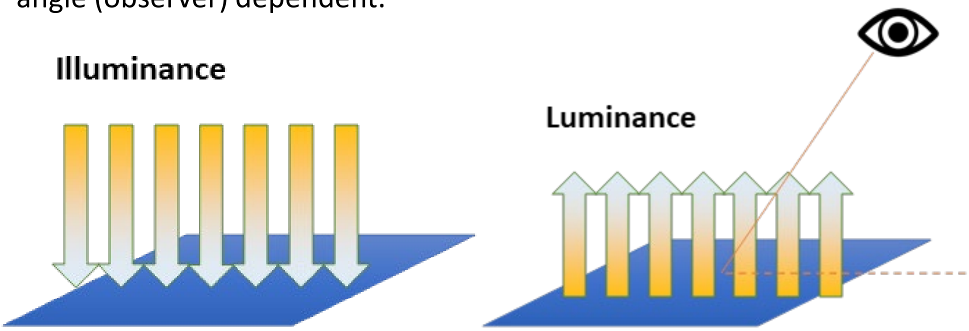
Note: These images are for illustrative purposes and are only intended to provide an example of expected lunar surface lighting conditions during Artemis missions. *Images courtesy of the NASA Scientific Visualization Studio.*



Background

Lighting Terminology

The following information represents basic concepts in lighting that are critical to the definition of lamp design and integrated application of active and passive lighting countermeasures.
Illuminance (lux) describes the amount of light flux incident on a plane (vertical or horizontal) per unit area. **Luminance** (candela/meters^2) describes the amount of light flux emitted from a unit area and is angle (observer) dependent.



When a quantity of light impacts surface(s), the **reflectance** properties of those surfaces impacts surface luminance and human perception of contrast.

Horizontal illuminance corresponds to a plane parallel with the ground.
Vertical illuminance corresponds to a plane normal to the ground.
Uniformity corresponds to the illuminance or luminance gradient. Safety and human performance are typically improved the more uniform the surface lighting is.
Beam distribution (beam pattern) refers to the flux intensity distribution per angle of a light source.
Photopic à **Mesopic** à **Scotopic** are terms describing, respectively, decreasing visual capabilities due to limitations of rods and cones and their mapping on the retina.

Glossary

Solid Angle: This is volumetric angular section from a unit sphere and is analogous to the well-known trigonometric concept of the unit circle. Units are in steradians (sr). An entire sphere equals 4p sr.

Beam Distribution: Sometimes called Beam Distribution, Beam Angle, or Beam Characterization. This represents a 90° hemisphere or 180° spherical characterization of the intensity of light at multiple angles from the source. Typically, illuminance measurements are captured at a fixed radius at multiple angles. Beam distribution is usually reported in relative percent intensity per angle with estimated lumen output, candela per angle, or illuminance per radius per angle.

HWHM: Acronym for shorthand numerical description of a lamp beam pattern. HWHM stands for half-width-half-maximum. If HWHM is given for a lamp, the number represents the half-angle (angle drawn from normal vector from center of the lamp) at which the lamp's beam distribution intensity falls to 50%.

Spectral Irradiance: Radiometric unit, analogous to illuminance, representing the radiant flux per surface area per wavelength. Units are in watts/meter^2/nanometer (W/m^2/nm).

Spectral Radiance: Radiometric unit, analogous to luminance, representing the radiant flux emitted by a given surface area per solid angle per wavelength. Units are in watts/steradian/meter^2/nanometer (W/sr/m^2/nm).

Background

Glossary (continued)

Spectral Power Distribution: Waveform representing energy (absolute or relative) emitted per a range of wavelengths. All light sources have a unique spectral power distribution (SPD) that is impacted by its chemistry. The SPD is an essential dataset for estimating metrics dependent on wavelength.

Chromaticity: This is a calculated metric where the format of the units can be different depending on which standard is used. Chromaticity describes the color of an object, whether that be a surface material or light source. Chromaticity can't be estimated without the usage of a spectrophotometer to measure the spectral power distribution of a light emitting source or reflectance spectrum of a material.

Color Fidelity: This is a calculated metric where the format of the units can be different depending on which standard is used. Color Fidelity describes the accuracy of a light source to render the appearance of colored materials accurately where the definition of perfect is how the Sun's renders the color of materials. Color Fidelity can't be estimated without the usage of a spectral radiance or spectral irradiance meter to measure the spectral power distribution of a light emitting source.

Goniophotometer: Specialized test equipment configuration that includes a rotation stage and is used collect beam distribution data for a light source. The type of goniophotometer is defined by the location of the rotation stage (lamp versus sensor).

Diffusion/Diffusor: A light diffusion material or diffusor is a material designed to scatter or redirect light that passes through it or it can also represent a rough surface that light impacts and scatters multiple directions from.

Reflectance/Reflector: The property of a material to reflect and scatter light. Reflectance of surface materials is an important lighting system property as it impacts how humans and cameras observe the environment and the efficiency of lighting systems to illuminate surfaces to sufficient levels to create the desired luminous contrast. Reflectance can be considered part of the architecture and can be used as a tool in the form of a reflector.

Uniformity: This is a property that is typically applied for surface illumination but can also be applied to the light emitting face of light sources. Uniformity is usually defined in the form of ratios such as maximum/minimum, and average/minimum with a defined sampling grid size. Uniformity is an important safety and usability metric to minimize human error due to uneven illumination. Uniformity is achieved through a combination of beam distribution design, lamp placement, and understanding of reflective surfaces for the operational area.

Glare: This is a property that describes various problems in human perception of light and the interaction of light with surfaces and materials within an operational environment. Distracting glare is an "annoyance" where, because of reflection and refraction, it creates visual artifacts making harder to see and resolve an object. Discomforting glare is caused by bright direct and reflected light that makes it hard to look at the object because of the brightness level. Disabling glare causes objects to appear to have lower contrast because of scatter inside the eye. Blinding glare is caused by a direct or indirect light source and is so bright that the observer can't see or is visually compromised.

Worksite or Work Zone: Area defined as the operational space for a task to be performed. This can be as small as the area immediately in front of a work stand and can also encompass a large operational area that has the same task performance constraints.

Major Changes Between Revisions

Rev A → Rev B

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev C and Volume 2 Rev D.

Original → Rev A

- Updated to include new External Lighting technical requirements.

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision D

[V2 3006] Human-Centered Task Analysis Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 3101] Iterative Developmental Testing Each human spaceflight program or project shall perform iterative human-in-the-loop (HITL) testing throughout the design and development cycle.

[V2 8051] Illumination Levels For interior architectures and exterior operations that do not include the presence of orbital sunlight, the system shall provide illumination levels to support the range of expected crew tasks, at minimum, per Table 8.7-1—Surface Illuminance Levels, that accommodate both human observers and remote camera systems.

[V2 8053] Emergency Lighting The system shall provide emergency lighting (interior and exterior) to maintain visibility in the event of a general power failure.

[V2 8056] Lighting Controls Lighting systems shall have on-off controls.

[V2 8057] Lighting Adjustability Interior lights shall be adjustable (dimmable).

[V2 8058] Glare Prevention The integrated system architecture including surrounding surfaces, support equipment, visualization tools, and supporting lighting systems shall work in conjunction to minimize visibility and eye-safety impacts from direct and indirect glare.

[V2 8060] Lighting Color Accuracy Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy shall have a score of 90 ±10 on a color fidelity metric that is appropriate for the utilized lighting technology, as designated by the Color Fidelity Metric (Rf) defined by IES TM-30, Method for Evaluating Light Sources Color Rendition methodology.

[V2 8103] Environmental Lighting Attenuation The integrated system architecture shall provide countermeasures to attenuate environmental lighting and complement existing active lighting architecture.

[V2 8104] Task-Specific Exterior Lighting for Operational Area Partially or Fully Lit by Sunlight For operational area that include shadowed areas illuminated by the Sun, the system shall provide passive and/or active solutions that reduce the contrast within shadowed areas of worksites/tasks to within 2 orders of magnitude of the predicted maximum surface luminance of objects, that accommodate both human observers and remote camera systems.

[V2 8105] Navigation and Wayfaring (Exterior) The system shall provide luminous powered and passive indicators that assist with proximity, navigation, and object recognition for validation of targets critical to the operation.

[V2 8059] Lighting Chromaticity Interior and exterior lighting intended for operational environments requiring human/camera color vision shall have a chromaticity that falls within the chromaticity gamut for white light for the Correlated Color Temperature (CCT) range of 2700 K to 6500 K as defined by ANSI C78-377, Electric Lamps—Specifications for the Chromaticity of Solid-State Lighting Products.

[V2 10150] Display Standards The system shall meet the Display Standard in Appendix F.

[V2 10048] Visual Display Parameters The system shall provide IVA displays that meet the visual display requirements in Table 10.4-2—Visual Display Parameters.

[V2 11018] Suited Field of Regard Suits shall provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.

[V2 11020] Suit Helmet Luminance Shielding Suit helmets shall provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.

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