Executive Summary

Spacecraft lighting systems—inside and outside the vehicle—have a large number of contributing variables and factors to consider. Careful planning and consideration should be given to the development and performance verification of light sources, and for the system architecture integration and control of the lighting system. Improperly integrated lighting systems impact task and behavioral performance of the crew and can impact the performance of automated systems that rely on cameras.

Relevant Standards

NASA-STD-3001 Volume 2, Rev C

[V2 3006] Human-Centered Task Analysis
[V2 8051] Illumination Levels
[V2 8052] Exterior Lighting
[V2 8053] Emergency Lighting
[V2 8059] Lighting Chromaticity
[V2 8060] Lighting Color Accuracy
[V2 8055] Physiological Effects of Light (Circadian Entrainment)
[V2 8056] Lighting Controls
[V2 8057] Lighting Adjustability
[V2 8058] Glare Prevention
[V2 10047] Visual Display Legibility
[V2 10048] Visual Display Parameters
[V2 10062] Label Display Requirements

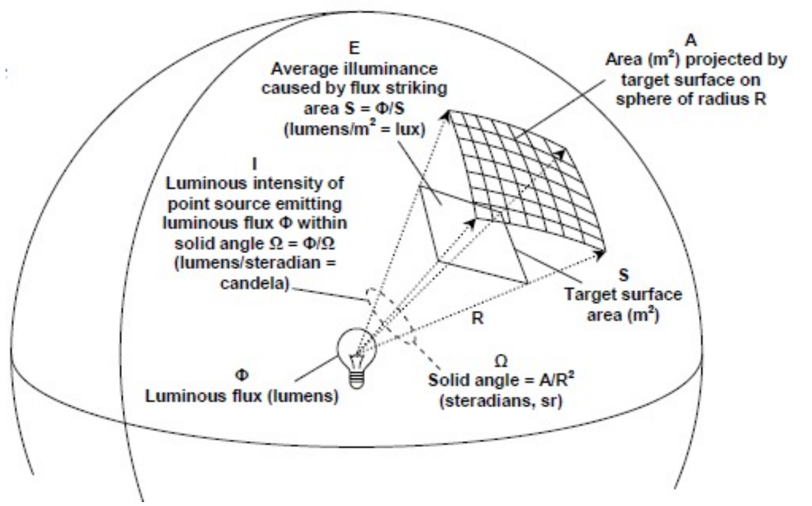
Background

Lighting is important to spacecraft design because visual perception provides the crewmember's primary source of information about the environment. A lighting system can also impact the operation of sensors that are sensitive to light such as cameras, scanners, and sensors that use light as their primary means of operation. As such, it has been a crucial consideration since the earliest crewed programs.

Many different factors must be balanced in order to produce a lighting environment that is conducive to crew health and mission success. Light has a large effect on the human circadian rhythm. For example, blue light inhibits the production of melatonin, and should be avoided before crewmembers go to sleep. Since space missions will not necessarily follow a 24-hour day, vehicle lighting must facilitate comfortable rhythms for the crew.

Units and Terms

- Illuminance: total luminous flux falling on a surface per unit area, measured in Lux or Foot-Candles
- Lumen: measure of total quantity of visible light emitted by a source
- Lux: unit of illuminance; 1 lux = 1 lumen per square meter
- Candela: lumens per steradian
- Chromaticity: color balance



Risks

If lighting levels are inadequate or inappropriate, crewmembers run the risk of performing tasks poorly (or failing them outright), interrupting their circadian rhythm (which poses its own risks, see OCHMO Behavioral Health technical brief), and injuring themselves. Injuries or discomfort to the eye can result from light sources and specular glare. Some lamps run hot, which can pose a touch-temperature risk to crew or fire risk to nearby material.

System Development Risks

A good lighting system requires integration and support by experts from a wide range of fields.

- Light sources and lighting systems are a part of a larger architectural system that impacts human perception of the environment, human behavior, human safety or error rates, and artificial vision and sensor systems for remote monitoring.
- Several factors and environmental conditions pose performance risks on lighting system electronics, such as power, weight, radiation, thermal, electromagnetic interference, and vibration.
- Conflicts may arise between lighting systems and the sensors as a result of insufficient light levels, electromagnetic spectrum wavelengths, and/or pulse frequencies that play havoc with successful operation of their systems.

A light source, whether it is a lamp, an indicator, or display, is an optical system that requires specialized test equipment and facilities to accurately document and refine optical performance. These resources and services may require use of all of the following:

- Controlled dark room facility
- Spectral irradiance meter to document spectrum at known distances
- Spectral radiance meter to document spectral brightness
- Spectral reflectance meter to test material surface properties for integrated architectures
- Goniophotometer for beam pattern measurements
- Imaging colorimeter for lamp and display contrast and uniformity verification


Goniophotometer


Lab testing of suit lighting

System Design

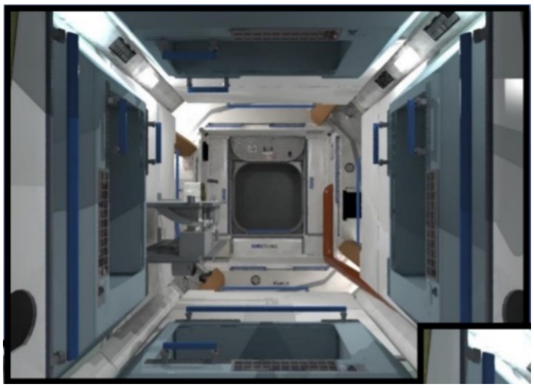
An integrated design, simulation, and test process for subsystem lamp and system lighting is necessary to avoid risks for an incompatible habitat solution. Computer based optical design and simulation tools reduce risk by developing light source solutions and then integrating them into architectural lighting models. This computer based optical analysis process can be used to reduce risk when considering the following trades:

- How do small changes in physical properties of light sources impact various optical and spectral properties of a deployed lighting system?
- How do different light source beam pattern configuration options work together to provide a uniformly lit operational environment at desired light levels? This feedback can in turn drive sub-system lamp performance guidelines and help the developer drive out power and weight issues.
- Considering where different fixed and mobile cameras are located, will the proposed integrated lighting architecture provide lighting environment required for a fully functional imaging system?
- When factoring in human body postures for a range of percentile sizes, how well does the lighting system address shadowing, illumination at predicted human body locations, and glare?
- When factoring exterior surface reflectance and direction of collimated light from the sun, how can exterior artificial lighting systems be optimized to maximize visibility for the crew?
- The NASA Johnson Space Center Lighting Lab uses a forward ray tracer, ZemaxOptics Studio Premium, and a reverse ray tracer, Radiance, for computer lighting simulations.

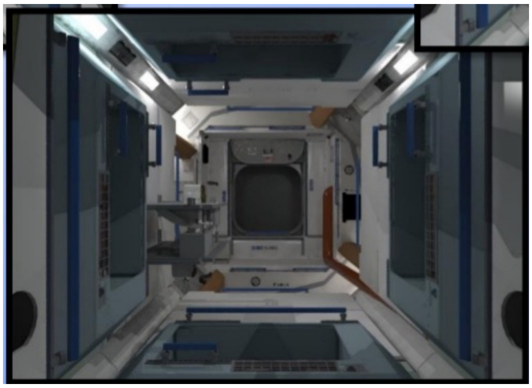

Light Source Beam Distribution testing

System Design

Testing
Testing for integrated lighting system design typically consists of a combination of methods that include: computer simulation, subjective measures from human in the loop testing and objective measures utilizing specialized test equipment.



General lighting



Presleep lighting

Computer Simulation
Computer simulation by means of optical ray tracing software can do a lot of the legwork involved in balancing tradeoffs and meeting parameters. Once designed, the lighting system in question is placed in a vehicle mockup, where an illuminance meter is used to measure whether the desired lighting levels are being met.

Computer Modeling of Interior Lighting Environments
Solid State Lighting Assembling's - ISS Node 2 perceived light intensity images (right) developed using Radiance lighting analysis software. *Source: Addressing Challenges to the Design & Test of Operational Lighting Environments for the International Space Station, Clark, T.A., Presentation 03/2016*

Objective Testing for Product Development
Objective measurement of optical properties provides an "unforgiving" grading tool for evaluation of products produced as a result of end-item subsystem requirements, such as lamps, backlit panels, display devices, indicator panels, and manufactured surfaces. The following lighting testing should be considered:

- Testing of optical properties should be done in a controlled environment, such as a dark room.
- A high quality spectral irradiance meter can document lamp intensity at a distance, and lamp spectrum which can impact human perception of colored objects and camera white balance.
- A spectral radiance meter can be used to document luminous contrast, glare, off-angle-viewing-luminance & color changes for displays, and verification of non-ionizing visible radiation requirements.
- Radiance and irradiance meter spectral ranges are typically 350 –780 nanometers, but investing in meter that goes to 1000 nanometers provides a means to document issues with near-infrared light sources that are typically used for line-of-site wireless sensor & communication suites.
- When developing beam patterns, goniophotometer testing can confirm beam pattern properties.

Application Notes

Task Lighting Design Considerations

Task analysis: cabin area and workstation illumination design are based on planned crew tasks and their visual task needs.

- Intensity/illumination: crew needs to be able to see in order to perform tasks. Different tasks require different levels of lamination, it can range from 20 lux for night activities, 100-300 lux for nominal activities and to over 1000 lux for high precision activities. Refer to the Illumination Engineering Society Handbook for guidance.
- Color/chromaticity: certain experiments and indicator lights convey color-coded information and rely on color fidelity.
- Placement of light sources: work and living areas need to be illuminated.
- Distribution of light/beam pattern: a light that is too tightly or broadly focused can interfere with mission duties.
- Characteristics of task area surface materials -reflectivity, absorptivity: especially important to consider if light glares off a surface.
- Behavioral health: circadian rhythm is largely dependent on lighting brightness and spectrum, and it plays a role in crew alertness/behavioral health. Blue light can be used in the “morning” to help wake the crew up, and red light can be used in the “evening” before bed to help promote melatonin production.

Task Lighting Examples

Task lighting is supplemental lighting which may be fixed or portable. Task lighting must be designed to support and be compatible with crew tasks. E.g., lighting directed at task surfaces without impeding crew task performance. Consider beam pattern, glare, control & dimming.

Example visual tasks and lighting design considerations

- Body waste & hygiene tasks—area lighting needed for locating and identifying hardware interfaces and supplies. More intense and positionable lighting needed for body and clothing inspection.
- Food prep—area lighting needed to locate and identify food in stowage, read preparation instructions, operate food warming or rehydration hardware, and clean food prep area and waste.
- See following page for extreme environment examples.

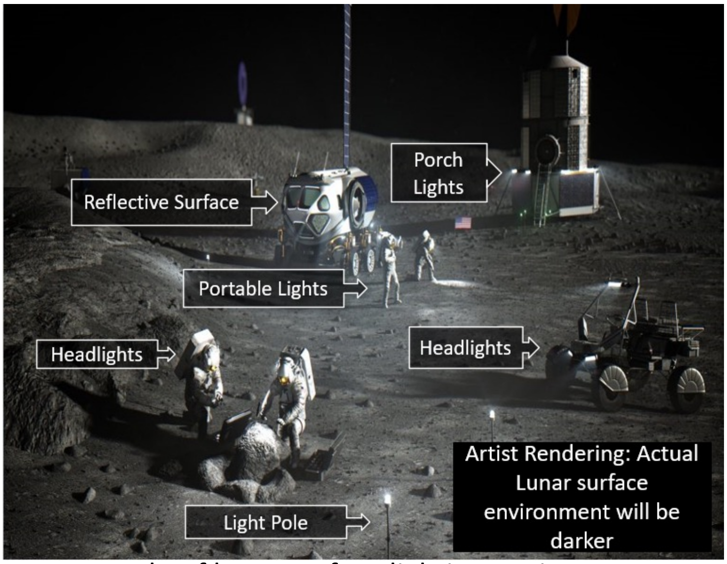
Application Notes

Extreme Environments

Extreme and critical lighting environments are those environments where high risks exist because of harsh lighting conditions with the added challenge of failures impacting human life, vehicle safety, and mission performance. The following list outlines typical scenarios and recommendations to mitigate risks:

- Window Viewing of Spacecraft Operations: Window observations are primarily impacted by glare from direct and indirect light sources from both sides of the window. Impacts can be mitigated through the use of system integration of surface reflectance, architectural shapes, and artificial light sources for planned viewing area.
- Crewed EVA Servicing of Spacecraft: EVA suits have lights, but the suit's lighting system may not be sufficient to illuminate large areas for complicated servicing and exploration tasks. Additional spacecraft surface lighting increases visibility for both the crew and any remote monitoring of crewed activities.
- External Spacecraft Robotic Operations: Robotic operations heavily rely on embedded vision systems and remote camera monitoring. Lighting needs to be sufficient at both the end-effector worksite and from a larger distance to observe potential collision issues between robotic elbow joints and spacecraft structure.
- Manual docking or planetary landing: Directed lighting is needed to locate and identify docking target and/or landing area surface features. Lighting for camera or electronic sensor views must accommodate and be compatible with selected hardware and consider environmental conditions of the target scene.
- Lunar: The lunar lighting environment will have unforgiving perpetual glare and shadowing from collimated sunlight. All imagers requiring visible light for timely docking operations will need supplemental lighting to facilitate dynamic range and signal to noise ratios.

These scenarios may require integrated testing with collimated sunlight; a solar simulator that can produce 125,000 lux at the task surface, with a narrow beam angle and a solar-type spectrum is beneficial.



Example of lunar surface lighting environment

Back-Up

Major Changes Between Revisions

Original → Rev A

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

Referenced Standards

NASA-STD-3001 Volume 2 Revision C

[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 8051] Illumination Levels The system shall provide illumination levels to support the range of expected crew tasks.

[V2 8052] Exterior Lighting The system shall provide exterior lighting to aid the crew in assembly, maintenance, navigation, rendezvous and docking, ingress and egress, EVA operations, and external task operations.

[V2 8053] Emergency Lighting The system shall provide emergency lighting for crew egress and/or operational recovery in the event of a general power failure.

[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 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 8055] Physiological Effects of Light (Circadian Entrainment) The system shall provide the levels of light to support the physiological effects of light in accordance with Table 17, Physiological Lighting Specifications.

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

[V2 8057] Lighting Adjustability Interior lights shall be adjustable (dimmable) from their maximum output level to their minimum luminance.

[V2 8058] Glare Prevention Both direct and indirect glare that causes discomfort to humans or impairs their vision shall be prevented.

[V2 10047] Visual Display Legibility Displays shall be legible in the viewing conditions expected during task performance.

[V2 10048] Visual Display Parameters Displays shall meet the visual display requirements in Table 32, Visual Display Parameters.

[V2 10062] Label Display Requirements Labels shall meet the requirements of visual displays (section 10.3.3, Visual Display Devices, in this NASA Technical Standard), except font height ([V2 10066] Label Font Height in this NASA Technical Standard).

Reference List

1. Illumination Engineering Society Handbook, 2010 or latest edition. https://www.ies.org/standards/ies-standards-cross-reference/?_ga=2.4500787.145208125.1640725049-1965823099.1640725049
2. NASA-STD-3000 Man-System Integration Standards. https://msis.jsc.nasa.gov/
3. Human Integration Design Handbook (HIDH). (2014). NASA/SP-2010-3407/REV1. https://www.nasa.gov/sites/default/files/atoms/files/human_integration_design_handbook_revision_1.pdf
4. Addressing Challenges to the Design & Test of Operational Lighting Environments for the International Space Station, Clark, T.A., *Presentation 03/2016.*