

# Human Factor Analysis of Light Emitting Diode Technologies for Cabin

## Lighting in Manned Space Flight Applications

Todd H. Treichel<sup>1</sup>

*Orbital Technologies Corporation, Madison, Wisconsin 53717*

Advantages of transitioning to Light emitting diode (LED) technologies in spacecraft are reduced mass, reduced occupied volume, reduced power, improved color control, longer operating life, and lower cost associated with power consumption and disposal. According to Brainard et al (2012) newly designed U.S. spacecraft, and ISS fluorescent tube replacements, must utilize LEDs in lieu of traditional artificial light sources to take advantage of technology improvements. Light emitting diode technologies remain a controversial technology in the aerospace industry, where commercial manufacturers are the only source for procurement.

The first portion of this research effort was performed to investigate commercially manufactured LEDs, by measuring light output quality to see if the LEDs will meet NASA and DOD reliability requirements. The second portion of the research pertains to this paper for 2014 which applies to LEDs with the highest reliability from the first portion of the this research. A randomized block design has been constructed for evaluating human factor effects using soft white light, emitted from LEDs and a NASA qualified ISS fluorescent.

### Nomenclature

<i>COTS</i>	= commercial off the shelf
<i>DOD</i>	= department of defense
<i>GLA</i>	= general luminaire assembly
<i>HI-REL</i>	= high reliability
<i>ISS</i>	= international space station
<i>LED</i>	= light emitting diode
<i>LUX</i>	= lumens per meter squared
<i>MIL</i>	= military
<i>ORBITEC</i>	= orbital technologies corporation
<i>QML</i>	= qualified manufacturers list
<i>QPL</i>	= qualified parts list
<i>WSGC</i>	= wisconsin space grant consortium

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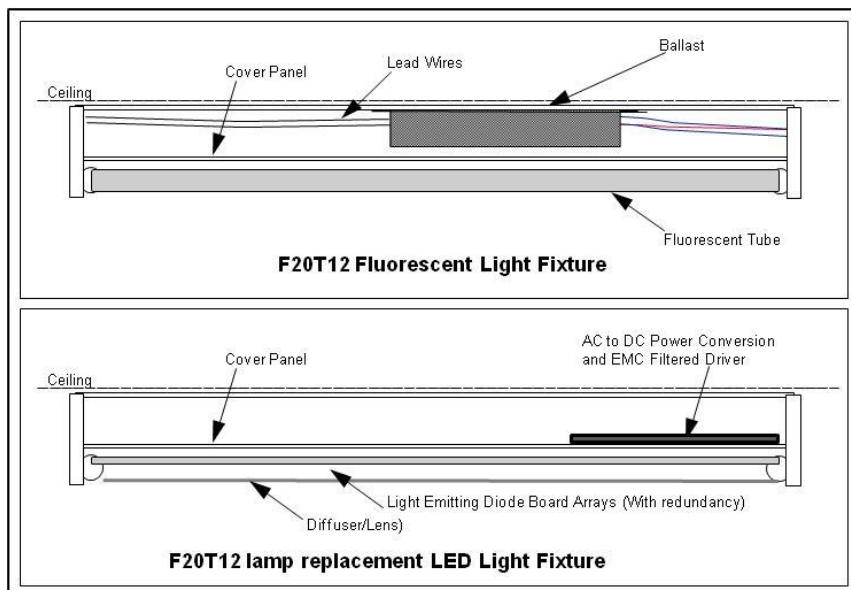
<sup>1</sup> Systems Engineer, Space Center, 1212 Fourier Drive, Madison, Wisconsin, USA.

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## Introduction

Technology in the electronics industry changes rapidly and engineers within the aerospace industry do not always have access to new technology due to high-reliability (HI-REL) requirements established in DOD and NASA procurement standards. Engineers designing for commercial products can experiment with new technologies with little or no restrictions in design component selection. Military and aerospace engineers are required to

manage product designs by making component selections from DOD and NASA approved part lists, where specific components have been tested extensively and heritage field data is cataloged for quality and reliability performance. New electronic technologies are being developed and by the time these technologies become available on a DOD quality parts list (QPL) or quality manufacturer's list (QML), the technology may have been replaced or improved in the commercial markets, thus making it difficult for aerospace engineers to select state-of-the-art design components without extensive testing. In 2013 WSGC member university UW-Madison was instrumental in providing mechanical engineering support where commercial LEDs were extensively tested in accordance with QML and NASA environmental requirements and deemed suitable for use in space flight applications. This paper covers phase two of LED industry/academic partnership for evaluating human factors for habitable spacecraft.



**Figure 1. Schematic of fluorescent light replaced with LED technology.**

## Light Emitting Diodes

Light emitting diodes are semiconductors that convert electrical energy into light energy. The color of the emitted light is designed into a specific semiconductor material composition for each component where individual LEDs may be selected for mixing of colors to obtain a desired color of light output. Light emitting diodes are classified into ultraviolet, visible, and infrared wavelengths depending on the technological application (Lenk & Lenk, 2011). Figure 2 illustrates the broad spectrum of white light critical to the suitability of human habitation in space that relies on 100 percent of artificial light.

Development of high-power LED technology involves challenges for design engineers in that LED lighting devices are subject to high temperatures that must be properly managed. Increased junction temperatures of the LED chip, causes stress on associated material and may cause earlier than expected light output degradation which will lead to an operational failure. Lenk and Lenk (2011) described two primary methods for producing high intensity white-light using LED technology: (1) one is to use individual LEDs that emit the three primary colors of red, green, and

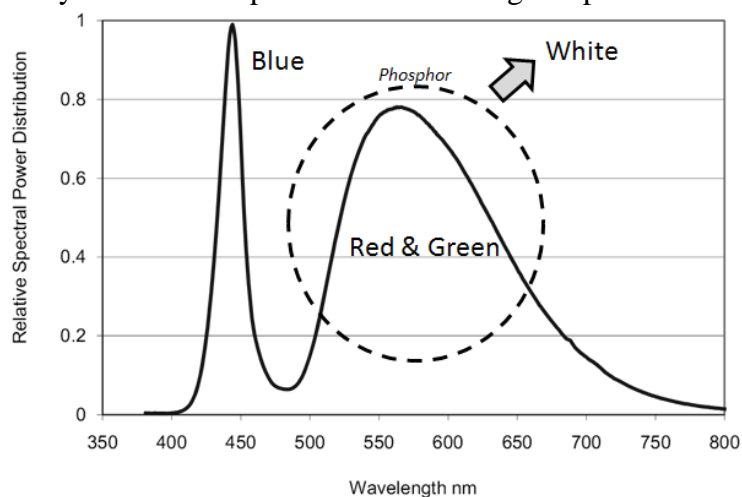
blue, and mix the three colors to produce white light, and (2) is to use a phosphor material to convert monochromatic light from a blue or ultraviolet (UV) LED to broad-spectrum white light. The latter of these two primary LED lighting methods is applicable to the investigation discussed herein (mixing three primary colors of red, green, and blue).

Light emitting diode technology can provide the military and space community with advantages when compared to the current use of incandescent light sources including: (a.) lower power consumption, (b) improved reliability by use of redundancy, (c) improved ruggedness for harsh environments, (d) lighter weight, (e) smaller size, (f) improved control over color and brightness and, (g) faster switching. Figure 1 illustrates the differences between a fluorescent light fixture, commonly used in military applications such as US Navy vessels, and the smaller, and lighter weight LED technology which may be retrofitted into an existing fluorescent light fixture.

### Purpose of Investigation

The International Space Station (ISS) contains fluorescent light technologies for illuminating the astronauts' research and living environments. NASA engineers have built a case for replacing fluorescent lighting with LED technology due to advantages such as: (a) lower heat generation, (b) lower power consumption, (c) less weight, (d) greater resistance to damage, (e) less toxic material, (f) elimination of fluorescent tube disposal, and (g) improved reliability. The fluorescent lamp technology on ISS is aging and there is an acceleration of failures which require replacement, due to a deficiency of NASA flight qualified fluorescent units, LED technologies provides an opportunity for retrofitting the ISS with lighting that has improved efficiency, no mercury, and improved reliability (Brainard et al., 2012). Little is known about which commercially available LED components are the most robust in accordance with aerospace requirements. This information will prove useful for future commercial space applications which may include both vehicles and habitable structures.

Howard, LaTasha, and Patrick (2010) revealed that NASA qualified fluorescent lights have failed more than three times the expected failure rate on the ISS. The high failure rate is of major concern to ISS program managers because the quantity of available spares are diminishing to a point where there will not be enough suitable replacements to coincide with the planned life of the ISS (Howard et al., 2010). President Barack Obama announced on January 8, 2014 that the ISS mission life has been extended to 2024 and that a qualified LED lighting source for replacement of existing fluorescents is of high importance. In July 2013 a search of approved parts listings published by NASA and DOD yielded no suitable sources for HI-REL selection of LED products intended for use in space and military applications. Unavailability of qualified LED



**Figure 2. Broad-spectrum white light color distribution model.**



**Figure 3. Current NASA qualified fluorescent General Luminaire Assembly (GLA) procured for human factors**

components prohibits spacecraft designers from utilizing the advantages offered by new technologies for integration into future manned space vehicles and space habitats (Lindenmoyer & Stone, 2010).

The research problem for this study is a government and private aerospace industry problem involving how LEDs cannot replace existing fluorescent lighting in manned space flight vehicles until such technology meets DOD and NASA requirements for manufacturer reliability, color reliability, robustness to environmental test requirements, and degradation effects from operational power, while providing comfortable ambient light free of fatigue, eye strain and/or headache in astronauts (Brainard et al., 2012; Meras et al., 2011). Commercial space designers are required to manage space flight designs in accordance with parts selections made from qualified parts listings approved by DOD and NASA agencies for reliability and safety (Lindenmoyer & Stone, 2010). Barriers for LED implementation involve challenges with aerospace engineers not having DOD or NASA qualified LED components to select from when referencing U.S. government qualified parts lists. Without researching these issues, the benefits of LED lighting including improved color control, longer operating life, lower cost associated with power consumption and disposal cannot be realized (Lenk and Lenk, 2012).

Spacecraft designed for human habitability must include accommodations that involve total human emersion into the habitat for extended periods of time (days and months); where on earth a particular human-habitat can be exited and reentered at random intervals (Hersman & Fowler, 2009). Light emitting diodes are considered an unproven technology in the aerospace industry and require further research and testing (Meras et al., 2011).

The purpose of this quantitative experimental study is to determine to what extent commercial LEDs can suitably meet NASA requirements for manufacturer reliability, color reliability, robustness to environmental test requirements, and degradation effects from operational power, while providing comfortable ambient light free of eyestrain to astronauts in lieu of current fluorescent lighting. Having selected two commercial LED manufacturers, as a result of the 2013 research WSGC grant, the second phase in this 2014 study is in progress and currently testing for human factor effects resulting from LEDs used for habitable task lighting inside a manned spacecraft. The three independent variables are: (a) ISS fluorescent, (b) white LED, and (c) blue LED that diffuses white light. The dependent variable is the overall satisfaction score recorded by human subjects exposed to experimental conditions. A randomized block design, as described by Montgomery (2013), shall be employed to test human factor effects of soft white light, created from LEDs (white light from white LEDs or blue LED light converted to white light) and a NASA qualified ISS fluorescent (see Figure 3Error! Reference source not found.), on human subjects to test whether white or blue LEDs cause retinal fatigue and eye strain. A total of 18 human subjects are planned for a laboratory experiment exposing each subject to experimental conditions, simulating space vehicle use. Participants are presently being recruited from University of Wisconsin - Madison, University of Wisconsin -Platteville, University of Wisconsin - Milwaukee, and other

WSGC affiliate institutions of higher learning. Data from this study will be used to assign LEDs a NASA TRL rating for technology readiness quantification that may be used by commercial and government personnel when designing space flight vehicles.

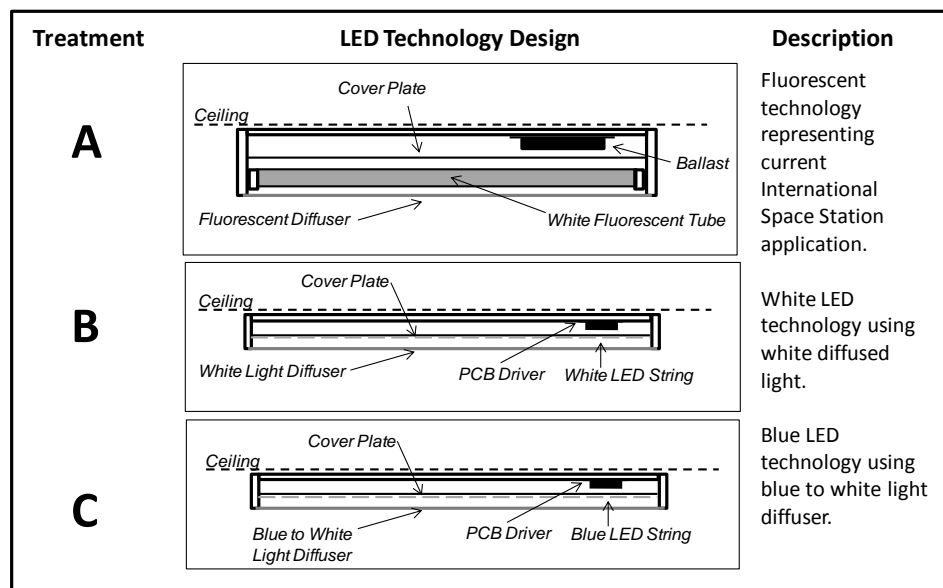
This WSGC 2014 research is in progress at the time of the publishing of this paper. Human subjects are currently being subjected to two hours

of uninterrupted exposure to either fluorescent or LED light sources. The researcher has randomized the test conditions and is currently asking human subjects to perform that involves detailed assembly using detailed instructions that involve discernment of colors. Upon completion of the test duration the test subjects are asked to fill out a survey about their experience. Lighting factors tested in the human experiment are human response to existing fluorescent light technology used on the ISS and two LED technologies selected from a factorial experimental design. The LED technology for white light and blue light are used to represent the highest reliability for each of the two colors. Figure 4 illustrates three lighting conditions administered in the quality of light survey (using LEDs characterized from the results of the 2013 WSGC grant research effort) where the same human subjects will be exposed to the three factors for two hours each.

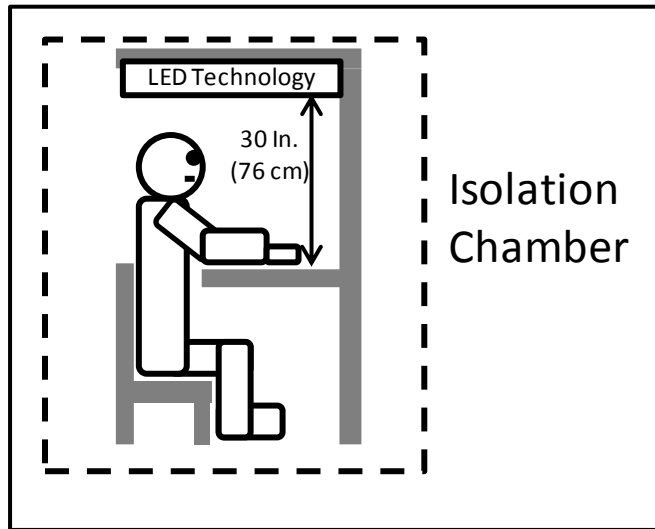
Table 1 illustrates a randomized block design containing randomized numbers in each cell to show an example of run order. Experimental blocks are A, B, and C where each human subject is exposed to each factor at some point in the experiment. The design is replicated four times using three different human subjects during each experimental replication. To assure research validity and reliability, each human subject is exposed to each factor on different test days (where possible) to remove bias from potential fatigue, boredom, and other unintended influences caused by continuous exposure to the designated test environment. A ground based capsule has been constructed (simulating the Boeing CST-100 capsule) for the purpose of maintaining a

**Table 1. Completely randomized block design showing random order of participants and factors.**

Human Subject	Factor Setting		
	A	B	C
a	1	3	6
b	4	2	9
c	7	8	5



**Figure 4. Schematic of fluorescent and LED experimental factors.**



**Figure 5. Schematic of isolation chamber for testing fluorescent and LED experimental factors.**

of actual component or system in a space environment (Mankins, 2009). The space environment may be achieved through laboratory testing which is represented in this analysis by subjecting LED technologies to NASA specified environmental stresses as an experimental factor. This research will examine the suitability of commercial LEDs for human space flight use in accordance with a technology readiness level of seven. Level seven TRL is a NASA rating achieved by successfully demonstrating that new technology suitably meets intended function while being subjected to rigors of the space flight environment (Mankins, 2009). This project will examine needed research in a literature gap in evaluating the unknown effects of LED lighting that may be adverse to astronaut long term living in a space habitat reliant on 100% artificial light.

consistent and relevant test environment that reduces any potential for introducing experimental bias across all human subjects.

The problem addressed by this research is that LED technologies remain a controversial technology in the aerospace industry, where commercial manufacturers are the only source for procurement. Aerospace engineers tasked with design and development activities of space flight hardware, will be required to manage to the NASA technology readiness level (TRL) system (Yiyuan et. al, 2011). A TRL level seven is achieved with successful demonstration



**Figure 6. Ground based isolation chamber for testing fluorescent and LED experimental factors.**



## Conclusion

The problem addressed by this research is that LED technologies remain a controversial technology in the aerospace industry, where commercial manufacturers are the only source for procurement. Aerospace engineers tasked with design and development activities of space flight hardware, will be required to manage to the NASA technology readiness level (TRL) system (Yiyuan et. al, 2011). A TRL level seven is achieved with successful demonstration of actual component or system in a space environment (Mankins, 2009). The space environment may be achieved through laboratory testing which is represented in this analysis by subjecting LED technologies to NASA specified environmental stresses as an experimental factor. This research will examine the suitability of commercial LEDs for human space flight use in accordance with a technology readiness level of seven. Level seven TRL is a NASA rating achieved by successfully demonstrating that new technology suitably meets intended function while being subjected to rigors of the space flight environment (Mankins, 2009). This project is currently in the process of examining needed research in a literature gap in evaluating the unknown effects of LED lighting that may be adverse to astronaut long term living in a space habitat reliant on 100% artificial light.

Cohen et. al (2011) stated that a robust LED system does no good to the user if the selected technology creates glare, resulting in unwanted eye strain and other effects which are undesirable for task lighting purposes when applied to a human user environment. This research will investigate selected LED technology and the effects on human subjects which support a business decision to use or not to use LED technology on future manned space flight applications. Research results will assist design engineers in making informed decisions about component selection in accordance with mission goals for safety, reliability, and compliance with human factor requirements. This research is empirically risky in that there may be an unexpected hypotheses result where the current ISS fluorescent light may be recommended as the better choice for astronaut health. A final publication of research findings will be presented at the WSGC 2015 Space Conference.



**Figure 7. Joe Klopotic from WSGC member institution University of Wisconsin - Madison.**

## Acknowledgement

The author would like to thank the Wisconsin Space Grant Consortium for their support of this academic partnership and recognize the University of Wisconsin –Madison and mechanical engineering student Joe Klopotic (see Figure 7) who was instrumental in configuring the LED test prototypes and was offered full time employment at Orbital Technologies Corporation in Madison, Wisconsin. Mr. Klopotic is currently employed at ORBITEC as a mechanical engineer as a result of this research effort.

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