SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP6253

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LEDs and Aircraft Applications

RATIONALE

LED technology is finding widespread use in aviation applications. Given the significant differences between LED light sources and traditional technologies, developing successful products with LEDs requires a different design approach. This document provides general guidance on using LEDs. It therefore can serve to provide a basis for design evaluation and help designers avoid common pitfalls.

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1. SCOPE

This document presents minimum criteria for the design and installation of LED assemblies in aircraft. The use of “shall” in this specification expresses provisions that are binding. Non-mandatory provisions use the term “should.”

1.1 PURPOSE

The purpose of this SAE Aerospace Recommended Practice (ARP) is to recommend minimum design criteria which will lead to adequate performance standards for LED products in and on aircraft. This document recommends design and performance criteria for developing products subject to CFR Parts 23, 25, 27, and 29 certification that use light emitting diodes (LED) as their primary source of light for luminance and illuminance applications. It is intended as guidance for the certifying authority and lighting design engineers. This document includes but is not limited to commercial aircraft.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE PUBLICATIONS

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AIR512 Aircraft Cabin Illumination

AIR1106 Some Factors Affecting Visibility of Aircraft Navigation and Anti-collision Lights

AIR1151 Flight Compartment Glare

AIR6042 LED Landing, Taxiing, Runway Turnoff, and Recognition Lights

ARP693 Landing and Taxiing Lights - Design Criteria for Installation

ARP378 Passenger Reading Lights

ARP991 Position and Anti-collision Lights - Turbine Powered Fixed-Wing Aircraft?

ARP1048 Instrument and Cockpit Illumination for General Aviation Aircraft

ARP1088 Aircraft Indicating Systems

ARP1161 Crew Station Lighting - Commercial Aircraft

ARP1283 Cargo Compartment Lighting for Transport Category Aircraft and Rotorcraft

ARP1782 Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays

ARP1798 Portable Emergency Lighting Systems for Airline Crew Members

ARP1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

ARP4087 Wing Inspection Lights - Design Criteria

ARP4156 Color-Coded Incandescent Flange Base T-1 and T-1 ¾ Lamps for Voltage Identification

ARP4168	Night Vision Goggle (NVG) Compatible Light Sources
ARP4169	Night Vision Goggle (NVG) Filters
ARP4260	Photometric and Colorimetric Measurement Procedures for Airborne Electronic Flat Panel Displays
ARP4822	Night Vision Imaging System (NVIS) Compatible Illuminated Pushbutton Switches and Indicators
ARP493	Knobs, Control Aircraft, Recommended Design
ARP4967	Night Vision Imaging Systems (NVIS) Integrally Illuminated Information Panels
ARP498	Design, Layout, Criteria - Plastic Integrally Lighted Panels (NONCURRENT Sep 2007)
ARP503	Emergency Evacuation Illumination
ARP5297	Recommended Qualification Tests for Halogen Miniature Lamps Less Than 35 Watts for Aircraft Applications
ARP582	Lighting, Integral, For Aircraft Instruments: Criteria for Design of Red Incandescent Lighted Instruments (NONCURRENT Aug 2006)
ARP5873	LED Passenger Reading Light Assembly
ARP711	Illuminated Signs
ARP712	Galley Lighting
ARP881	Lamps for Aircraft Lighting
ARP922	Electroluminescence, Design Criteria and Recommendations for Use in Aerospace Vehicle Crew Station Areas
ARP924	Specification and Inspection of Glass for Integrally Lighted Aerospace Instruments
ARP5414	Aircraft Lightning Zoning
ARP5563	Measurement of Aircraft Passenger Cabin LED Luminaires
AS18276	Lighting, Aircraft Interior, Installation of
AS25027	Light Assembly, Cockpit, Fixed
ARP4103	Flight Deck Lighting for Commercial Transport Aircraft
AS4156	Color-Coded Incandescent Flange Base T1 and T-1 ¾ Lamps for Voltage Identification (Cancelled Jul 1998, Superseded by ARP4156B)
AS4914	Aircraft Fluorescent Lighting Ballast/Fixture Safety Design Standard
AS50571	Lights, Instrument, Individual, General Specification For
AS5452	Night Vision Goggles (NVG) Compatible Lighting for Civil Aircraft
AS7768	Light, Desk, Aircraft
AS7768/1	Light, Desk, Aircraft

AS7788 Panels, Information, Integrally Illuminated

AS8017 Minimum Performance Standard for Anticollision Light Systems

AS8037 Minimum Performance Standard for Aircraft Position Lights

TSB 003 Rules for SAE Use of SI (Metric) Units

2.2 ANSI Documents

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org

ANSI/NEMA ANSLG C78.377-2008 American National Standard for Electric Lamps—Specifications for the Chromaticity of Solid State Lighting Products

ANSI/IESNA RP-27.3-96 Photobiological Safety for Lamps - Risk Group Classifications and Labeling

2.3 CIE (Commission Internationale De L'Eclairage) Publications

Available from http://www.techstreet.com/ciegate.tmpl, or by contacting CIE Central Bureau, Kegelgasse 27, A-1030 Vienna, Austria.

Supplement No. 2 to CIE Publication No. 15:2004 - Colorimetry

CIE 13.3-1995 Method of measuring and specifying colour rendering properties of light sources

CIE S 009/E:2002 Photobiological Safety of Lamps and Lamps Systems

CIE 177:2007 Colour Rendering of White LED Light Sources

2.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

TSO-C30c AIRCRAFT POSITION LIGHTS

TSO-C96a ANTICOLLISION LIGHT SYSTEMS

AC20-30B AIRCRAFT POSITION LIGHT AND ANTICOLLISION LIGHT INSTALLATIONS

AC20-74 Aircraft Position and Anticollision Light Measurements

2.5 International Electrotechnical Commission (IEC) Publications

Available from IEC, 3, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +44-22-919-02-11, www.iec.ch.

IEC 60810-1 Lamps for Road Vehicles

2.6 NIST Publications

Available from National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

CQS Davis AbstractEvaluation of color difference formulae for color rendering metrics

CQS Davis Ohno AbstractNIST Facility for Color Rendering Simulation

CQS Davis OhnoDevelopment of a Color Quality Scale

Ohno and DavisRationale of Color Quality Scale

2.7 RTCA Publications

Available from RTCA Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Electronics/Electrical Equipment and Instruments

RTCA DO-178 Software Considerations in Airborne Systems And Equipment Certification

RTCA DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.8 U. S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

CFR references are available at the Government Printing Office website: http://www.gpoaccess.gov/crf/index.html.

CFR references are available at the FAA home page at: http://www.acquisition.gov/far

STANDARDS

MIL-HDBK-217 Reliability Prediction of Electronic Equipment

MIL-HDBK-310 Global Climatic Data for Developing Military Products.

OTHER PUBLICATIONS

Code of Federal Regulations Title 14, Part 25

Some applicable sections may include, but are not limited to the following:

Code of Federal Regulations Title 14, Part 23, 25, 27, 29

Some applicable sections may include, but are not limited to the following:

§ 23.1383 Taxi and landing lights.

§2-.1385 Position light system installation.

§2-.1387 Position light system dihedral angles.

§2-.1389 Position light distribution and intensities.

§2-.1391 Minimum intensities in the horizontal plane of forward and rear position lights.

§2-.1393 Minimum intensities in any vertical plane of forward and rear position lights.

§2-.1395 Maximum intensities in overlapping beams of forward and rear position lights.

§2-.1397 Color specifications.

§ 23.1399 Riding light.

§ 23.1401 Anticollision light system.

Code of Federal RegulationsTitle 21, Part 1040, Subpart J

CFR 1040.10Radiological Health, Performance Standards for Light Emitting Products

2.9 Other Publications

Available from IES, 120 Wall Street, Floor 17 New York, NY 10005.

IESNA Lighting Handbook

TM-16-05, IESNA Technical Memorandum on Light Emitting Diode (LED) Sources and Systems

IES LM-80-08, Approved Method: Measuring Lumen Maintenance of LED Light Sources

Journal of the Optical Society of America, Visual Sensitivities to Color Differences in Daylight, David L. MacAdam, May 1942.

Rensselaer Lighting Research Center Passenger Reading Light Study
http://www.lrc.rpi.edu/programs/solidstate/pdf/SAELEDreadinglightstudy4-25-05.pdf

Royal Society for the Prevention of Accidents (RoSPA)

"Temperatures of Touchable Surfaces - a personal burn hazard"

http://www.rospa.com/homesafety/adviceandinformation/product/temperatures-touchable-surfaces.aspx

2.10 Definitions

Color Quality Scale (CQS): A metric under development at NIST to evaluate aspects of the quality of the color of objects illuminated by a light source. The metric involves several facets of color quality, including color rendering, chromatic discrimination, and observer preferences.

Color Rendering Index (CRI): A metric used to evaluate the relative spectral content of a light source compared with a reference source.

GENERAL LIGHTING: Diffuse lighting intended to illuminate a room or a space.

GLARE: Undesirable light that interferes with the ability to see desired objects.

L50%: The operating time in hours in the anticipated environmental and installation conditions that result in 50% of the initial lumens.

L70%: The operating time in hours in the anticipated environmental and installation conditions that result in 70% of the initial lumens.

Light Emitting Diode (LED): A solid state device capable of converting electric power to visible light.

National Institute of Standards and Technology (NIST): A non-regulatory US federal agency within the U.S. Department of Commerce that advances measurement science, standards, and technology.

TASK LIGHTING: A lighting system that concentrates light in a defined region such as a work surface or work area to facilitate visual activities.

USEFUL LIFE: Useful life is the duration for which the light is expected to meet the minimum intensity requirements.

VISIBILITY: Capable of being seen by the eye.

3. RECOMMENDATIONS

3.1 Key Considerations

Lighting Design. The lighting design begins with establishing requirements for the intended application. Information contained within this document is to serve as guidance for both interior and exterior lighting applications. Examples of exterior applications are landing lights, position lights, and logo lights. Exterior lights may signal position and/or orientation; or be used for illumination of the exterior environment. For interior applications, there is a further subdivision into passenger cabin, cargo, service, flight deck, and crew rest areas. Examples of interior lights are reading lights, passenger cabin lights such as ceiling, sidewall lights, accent lights, galley lighting, lavatory lighting, stairway lighting, entry lights, emergency lights. Flight deck lighting consists of area and display lighting. Area and flood lights can be categorized into two basic groups: task lighting and general lighting. Examples of task lights are reading lights and galley lights while ceiling lights and sidewall lights are examples of general lights.

General Considerations. The optical performance of a Lighting Assembly can be significantly affected by the LED selection and how this device affects the fundamental performance and architecture of the overall lighting system. It should be understood that these aspects of LED lighting and their design from the component level on through to the system design have significant impact on the electronic circuit design and complexity; the mechanical, environmental and thermal design, choice and implementation of the optical design and a variety of performance considerations, including long term intensity, color performance, and lifetime. The electrical drive circuit must be designed to consider the LED's operating limitations. Electrical overstress can reduce life. The LED drive current has a direct relationship to the LED junction temperature. Some examples of these impacts are identified in section 3.1.1 and 3.1.2

3.1.1 Key Considerations for LED Selection

The long term performance of the LED device type(s) and the fundamental light source architecture(s) should be well understood before making a LED design selection.

a. LED Variability. There is significant variability within each part number for every LED device. These manufacturer variations include luminous flux, color, thermal resistance, and forward voltage. The impact of these variations can be minimized through careful scrutiny of specific vendors and their products.

b. Color shift. LED color can change as a function of time, temperature, and viewing angle. This can affect performance and can be relevant as a design consideration depending upon the color sensitivity of the application. Common methods of addressing LED color shift in sensitive applications can include binning and optical feedback. In many cases, specifying color bins is sufficient to address the issue.

c. LED degradation; LEDs may experience component and materials degradation when exposed to UV and other types of electromagnetic radiation. Discoloration and embrittlement of the light source and optical components are some of the potential impacts. There are many potential sources of UV light including common sources such as fluorescent and HID lamps, sunlight, or UV LEDs.

d. Lumen depreciation. The total luminous flux produced by the LED can diminish significantly over time.

e. LED Intensity over temperature. LED performance can vary significantly with temperature.

3.1.2 Key Considerations for Fixture Design

The light assembly design should be developed with regard for these characteristics to ensure acceptable optical performance of each light assembly over the expected life and utilization environment.

a. The LED assembly fixture designs should account for LED variations in intensity, forward bias voltage, color, etc. that will be experienced with a single manufacturer or multiple manufacturers of any specific device.

b. Factors affecting light output. The illuminance requirements and performance need to be considered over the expected life and total environment per 3.10. This should take sun load and wind into account, if applicable, as well as ambient temperatures. The lamp thermal construction can also impact LED light output; since the LED luminous flux is a function of the LED's junction temperature. For this reason, it is very important to give diligent consideration to the heat sink design.

3.2 Light Color Definition

The required color of LED lights varies greatly depending upon the application. The specifications for the appropriate application should be consulted prior to initiating a new design.

3.2.1 White Light

LED light assemblies should meet SAE aviation white as specified in AS8037, AS25050, AS8017 or CFR parts 23.1397, 25.1397, 27.1397, 29.1397 depending upon the application. The required color of LED light assemblies varies greatly depending upon the application. The specifications for the appropriate application should be consulted prior to initiating a new design. LEDs are binned for color, flux, and forward voltage. There is significant variation in perceived color even within a single bin and generally LED manufacturers will require acceptance of multiple bins. At the time of the publication of this document, there are no universally accepted binning standards. An example of a color binning scheme is shown in ANSI/NEMA ANSLG C78.377-2008. These parameters should be considered when selecting a particular LED for an application.

3.2.2 Monochromatic Light

Monochromatic LED's can experience color shift and intensity variations over time and temperature. The amount of change is a function of the LED technology.

3.2.3 White Resulting from use of Phosphor

A common method for producing white light LEDs uses a blue or ultraviolet LED with a phosphor layer. The phosphor layer converts the shorter wavelengths into the desired broadband spectrum light. Light assembly designs that utilize White (Photo-Conversion) LEDs can experience a reduction in the phosphor conversion efficiency over operational time. A conversion efficiency loss can be accelerated by exposure to heat. This can result in a color shift as well as light intensity reduction.

3.2.4 White Resulting from Color Mixing Red, Green, and Blue

Light assembly designs that utilize red-green-blue (RGB) or similar color mixing architectures experience color shift over time and temperature because the different color LEDs degrade in intensity and/or shift wavelength at various rates. Since the requisite color relies on the correct combination and ratio of light intensity from each contributing color, electronic control circuitry that utilizes color sensing feedback and independent led drive control such that each LED can be adjusted individually is prudent for sensitive applications.

3.2.5 Color Rendering Properties

Color rendering is the effect of the spectrum of a light source on the appearance of the color of an object. The Color Rendering Index (CRI) of a light source is a measurement of the amount of color shift relative to a standard light source. CRI needs to be considered for lighting that is illuminating objects that contain color information, such as flight charts, airport markings, etc. Different light sources, such as incandescent, fluorescent, HID, and LED have substantially different CRI characteristics. CRI relevance is application dependent.

3.2.6 Color Uniformity

The LED luminaire should have color consistency requirements for color temperature and color coordinates throughout its range. There should not be visible color fringing, halo, or other noticeable change in color.

3.3 Warm Up and Stabilization

For purposes of demonstrating compliance with this specification, all photometric and color measurements shall be made after the longer of 30 minutes as a minimum, or until the LED luminaire has reached thermal stabilization. Thermal stabilization shall be defined as the point in which light output does not change by more than 3% over a 15 minute period. This time can be reduced by determining a relationship between luminous flux variations over time for the LED or the LED assembly that demonstrates an equal level of measurement confidence.

3.4 Mean Time Between Failure (MTBF)

End of useful life for LEDs is predominantly a result of reduced intensity and not of catastrophic failure like in incandescent or halogen reading light sources.

3.5 Lumen Maintenance

The luminous intensity of an LED is inversely related to operational usage time and thermal exposure. The LED luminaire shall be capable of meeting its luminous intensity (general lighting), illuminance (task lighting), or luminance (perceived brightness) over its useful life as specified by the purchasing authority. Lumen Maintenance and useful lifetime, as used herein, shall be time until the LED luminaire is no longer capable of meeting the requirements of the applicable photometric specifications. An industry standard for lumen depreciation is $L_{70\%}$ and $L_{50\%}$. These are the respective photometric degradation permissible for general applications. These may be used for non-critical aviation applications. See section 3.1.2 b.

3.5.1 Factors affecting Operating Lifetime

Environmental and installation conditions affect Operating Lifetime. In the case of LED based lights, lumen maintenance is a function of junction temperature. Lumen maintenance for typical laboratory ambient conditions (T = 23 °C ± 5 °C) and other elevated or lower expected flight test temperatures and their exposure times (50 °C, 71 °C with a 3 knot wind for 3 hours per day, for example) can be used to help estimate actual Operating Lifetimes for particular flight patterns. This data would be used to define the aircraft's installation environment.

Continuing airworthiness can be achieved by a number of methods, some of which are:

- Limiting Operating Lifetime based on an estimation of component laboratory life with adjustments which take into account actual operating conditions on-the-ground and in-flight, or;
- Limiting Operating Lifetime based on active feedback from an integrated light sensor or;
- Requiring Aircraft operators to measure intensity levels at reqularly scheduled maintenance intervals to insure compliance.

3.6 Dimming

The LED luminaire may be stepped or continuously dimmable. If it is dimmable, perceived brightness changes should vary linearly with the input control, and the color temperature, color coordinates, beam pattern geometry and illuminance distribution should not change appreciably over the dimming range. The transfer characteristic of the human visual system is logarithmic and not linear. LEDs may be dimmed by several mechanizations, e.g. pulse width modulation, or forward current. The light output curve should be matched to the intended application. LED's have unique dimming characteristics (output/voltage, output/current) when compared to non-LED sources. When LED's and non-LED sources are combined on the same dimming bus, care should be taken to match the dimming profiles as close as possible.

3.7 Glare

To minimize glare, the design should consider the range of adjustability, aiming, shielding, and placement with respect to the application. Refer to AIR1151 for information and detailed design guidance on glare.

3.8 Input Power

The LED luminaire should operate from one of the industry standard aircraft power buses. Some common power buses are defined in RTCA-DO-160 and MIL-STD-704, including the voltages shown below. Care should be taken that the luminaire will meet all the performance requirements as specified herein over the entire normal operating voltage range. For example, the normal voltage range as specified in RTCA DO-160 for 28 VDC is 22.0 to 30.3 VDC. The design should consider the effects of low voltage operation on light output and variation in light output resulting from changes in voltage.

- 28 VDC
- 28 VAC, 400 Hz
- 115 VAC, 400 Hz
- 115 VAC, variable frequency
- 14 VDC
- 5 VAC 400 Hz

3.9 Abnormal Conditions

The LED luminaire assembly shall meet all the performance requirements as specified herein except for abnormal conditions of power and temperature. For abnormal conditions, as defined in RTCA DO-160 or the aircraft manufacturer requirements, degradation of light output may be permissible depending upon the application, aircraft manufacturers requirements, and any applicable regulatory requirements. However, no damage to the LED light assembly shall occur and the light assembly shall recover and provide rated operation when normal conditions recover.

3.10 Environmental Requirements

LED assemblies shall meet the environmental requirements of RTCA DO-160, aircraft manufacturers requirements, and any applicable regulatory requirements.. Categories and levels will depend on the location and function of the assembly.

3.11 Electronic Requirements

Light assemblies shall meet the requirements of DO-254 Design Assurance Guidance for Airborne Electronic Hardware. The level depends upon the application. Light assemblies using software shall comply with RTCA DO-178. The software level will depend on a system FHA (Failure Hazard Assessment).

3.11.1 Transient protection

The electrical design shall contain provisions to protect the LED lighting assembly from damage due to typical aircraft voltage transients. Categories and levels will depend on the location and function of the assembly.

3.11.2 Voltage Polarity

DC powered LED luminaires shall not be damaged by reverse polarity. Polarity shall be clearly indicated.

3.12 Reliability

Reliability calculations should be computed in accordance with MIL-HDBK-217.