



AEROSPACE RECOMMENDED PRACTICE

ARP7977

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Optical Equipment Safety in Aircraft Fuel Tanks

RATIONALE

This SAE Aerospace Recommended Practice (ARP) provides guidance for the design, installation, and maintenance of devices that generate and transport optical power inside and through aircraft fuel tanks and the equipment interfaces of said devices as required for safety and compliance to airworthiness standards.

1. SCOPE

The recommended practices of this document are intended for optical devices and associated optical cables and connectors installed inside transport category aircraft or environments of equivalent ignitability.

This document covers optical radiation in the wavelength range from 380 nm to 10 μ m. As explained in this document, wavelengths below this range are capable of igniting fuel-air mixtures through an ignition mechanism not considered at this issue of ARP7977. Use of wavelengths outside the range 380 nm to 10 μ m should be discussed with the relevant Certification Authority.

1.1 Purpose

Equipment that uses and transports optical energy designed for use in aircraft fuel tanks and other environments that may be flammable are being introduced to the aerospace market. Optical energy in flammable environments presents an ignition threat that requires appropriate design measures in order to mitigate the possibility of ignition. ARP7977 provides best practice recommendations and guidelines for engineers on safety compliance concerning fuel tank ignition risks in the design of equipment and systems that use optical power.

This ARP falls within the overall scope of ignition prevention of flammable environments on board commercial aircraft encompassed by the ARPs and ACs referenced herein. This ARP is written to provide a means to address the requirements of 14 CFR Part 25 Airworthiness Standards § 25.981 Fuel Tank Explosion Prevention and § 25.954 Fuel System Lightning Protection in consideration of devices and the associated optical cables and connectors that may generate and/or transmit optical power through aircraft fuel tanks. As with any concentrated form of energy, the transmission of optical power in a flammable environment creates the possibility of catastrophic ignition if proper design practices are not followed. This ARP discusses the physical mechanisms by which optical power is capable of producing ignition and compares and contrasts these mechanisms to other ignition sources of relevance to aircraft fuel systems, such as electric arcs and filament heating.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. 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, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR1662	Minimization of Electrostatic Hazards in Aircraft Fuel Systems
AIR5128	Electrical Bonding of Aircraft Fuel Systems
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP4242	Electromagnetic Compatibility Control Requirements Systems
ARP5412	Aircraft Lightning Environment and Related Test Waveforms

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E659	Standard Test Method for Autoignition Temperature of Chemicals
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2.1.3 FAA Publications

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

14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes
AC 25.954-1	Transport Airplane Fuel System Lightning Protection
AC 25.981-1	Fuel Tank Ignition Source Prevention Guidelines
DOT/FAA/AR-98/26 A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks	

2.1.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60079-11	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety “i”
IEC 60079-28	Explosive atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation.

2.1.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
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2.1.6 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 913	Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division I, Hazardous (Classified) Locations
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2.1.7 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-STD-810 Department of Defense Test Method Standard, Environmental Engineering Considerations and Laboratory Tests

2.1.8 Other Publications

Carleton, F.B., Bothe, H., Proust, C., and Hawksworth, S. (2000). *Prenormative Research on the Use of Optics in Potentially Explosive Atmospheres* (Report No. EUR 19617 EN). European Commission.

Dubaniewicz, T.H., Cashdollar, K.L., Green, G.M., and Chaiken, R.F. (2000). Ignition of methane-air mixtures by laser heated small particles. *Journal of Loss Prevention in the Process Industries*, 13(3-5), 349-359.

Dubaniewicz, T.H., Cashdollar, K.L., and Green, G.M. (2003). Continuous wave laser ignition thresholds of coal dust clouds. *Journal of Laser Applications* 15, 184-192.

Dubaniewicz, T.H. (2006a). Methane-air mixtures ignited by CW laser-heated targets on optical fiber tips: Comparison of targets, optical fibers, and ignition delays. *Journal of Loss Prevention in the Process Industries*, 19(5) 425-432.

Dubaniewicz, T.H. (2006b). Threshold powers and delays for igniting propane and butane-air mixtures by CW laser-heated small particles. *Journal of Laser Applications* 18, 312-319.

Lewis, B. and von Elbe, G. (1987). *Combustion, Flames and Explosions of Gases* (3rd ed.).

Magison, E. (1997). Are optical beams an explosion hazard? *Intech*, 44(9), 61-65.

Welzel, M.M., Schenk, S., Hau, M., Cammenga, H.K., and Bothe, H. (2000). Ignition of combustible/air mixtures by small radiatively heated surfaces. *Journal of Hazardous Materials*, A72.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5691 Guidance for the Design and Installation of Fuel Quantity Indicating Systems (FQIS)

ARP5414 Aircraft Lightning Zone

ARP5577 Aircraft Lightning Direct Effects Certification

ARP8615 Fuel System Components: General Specification For

2.2.2 FAA Publications

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

AC 25.1309-1 System Design and Analysis

AFAPL-TR-75-70 Summary of Ignition Properties of Jet Fuels and other Aircraft Combustible Fluids

2.2.3 Other Publications

Boettcher, P.A. (2012). *Thermal Ignition* [Doctoral dissertation, California Institute of Technology]. <https://thesis.library.caltech.edu/7037/>.

Mokrani, N. and Gillard, P. (2020). Laser induced breakdown in gas mixtures. Experimental and statistical investigation on *n*-decane ignition: Pressure, mixture composition and equivalence ratio effects. *Journal of Hazardous Materials*, 388.

2.3 Definitions

BLACK ABSORBER: A material that absorbs the optical radiation and may, if the optical radiation is of sufficient power, pose an ignition threat to aerospace fuel systems. For optical pulses of “short” duration (defined herein as total pulse time ≤ 1 ms), the absorber is a black reactive material such as carbon black. For optical pulses of “long” duration (defined herein as total pulse time > 1 ms), the absorber should be an inert material with an absorption coefficient $\geq 80\%$ over the entire range of wavelengths that may be used by the optical device. These absorbers result in the minimum required optical power to produce ignition.

CERTIFICATION AUTHORITY: The authority that is responsible for the original type certificate (TC). For example, the FAA is the Certification Authority for applicants and certificate holders in the U.S. The Certification Authority issues the final design approval or compliance finding for products designed in its country. The Certification Authority may document its approval by issuing a TC or supplemental type certificate (STC).

CRITICAL DESIGN CONFIGURATION CONTROL LIMITATIONS: A type of airworthiness limitations that defines those parameters and features of the design that must be maintained to ensure that ignition sources will not develop within the fuel tank. These parameters must be verified prior to initial installation in the aircraft and also during maintenance and overhaul as determined by the Component Maintenance Manual.

FUEL SYSTEM LIMITATION: A type of airworthiness limitation that defines the inspections, replacements, or any other mandatory maintenance tasks required to assure integrity of items identified as critical design configuration control limitations.

IRRADIANCE: Radiant optical power incident on a surface divided by the area of the incidence (illuminated area).

MINIMUM IGNITION ENERGY (MIE): The threshold quantity of energy stored in an electrical circuit that, when released into a flammable mixture by an electric arc, produces a propagating deflagration in the flammable mixture.

MINIMUM RADIATING POWER (MRP): The threshold optical power transmitted through a fiber-optic cable located in a flammable mixture such that, when the cable is cut and the cut-end is coated with a black absorber, is capable of producing deflagration in the flammable mixture.

OPTICAL FIBER: Optical waveguide.

OPTICAL FIBER CABLE: Assembly comprising one or more optical fibers or fiber bundles inside a common covering that is designed to protect them.

VALIDATION AUTHORITY: A National Authority that is responsible for validating the Certification Authority TC or STC for their country. These authorities may require additional validation activities.

VALIDATION CERTIFICATION: The process most commonly used to establish the compliance of an imported product to the importing state's applicable airworthiness standards. Validation is, in other words, a special form of certification. The validation process will depend on the bilateral agreement between the involved countries.

2.4 Acronyms

AC	Advisory Circular
CDCCL	critical design configuration control limitations
CFR	Code of Federal Regulations
CW	continuous wave
EASA	European Union Aviation Safety Agency
EME	electromagnetic effects
EMH	electromagnetic hazard
ESD	electrostatic discharge
FAA	Federal Aviation Administration
FSL	fuel system limitation
LED	light emitting diode
MIE	minimum ignition energy
MRP	minimum radiating power
NTC	negative temperature coefficient
STC	supplemental type certificate
TC	type certificate

3. DETERMINATION OF REQUIREMENTS AND APPLICABILITY

14 CFR Part 25 § 25.981 provides the fundamental requirement on optical devices in airplane flammable environments. When applying this requirement to optical devices, it is noted that for ignition to occur some fraction of the energy contained in the optical system must escape the system and the energy that does escape must be of sufficient magnitude for the surrounding environment, which is assumed flammable, to ignite. The practices recommended herein therefore focus on: (1) methods to prevent the optical energy from inadvertently leaving the optical system, (2) safe optical operating levels such that, even if the optical energy does escape the system, ignition of an airplane fuel tank environment is not possible, (3) optical harness design considerations that mitigate the possibility of ignition, potentially to the extent that the optical harness is intrinsically safe with respect to ignition hazards, and (4) meeting other safety non-optic-specific safety requirements (e.g., ESD, EMH for lightning).

The information analyzed and discussed below for optical systems in fuel tanks can be applied to, but not limited to, lasers, LEDs, or other optical generation equipment. The current technology that is the primary commercial source is the laser, and this terminology will be used within the document.

3.1 Requirements on the Containment of the Optical Power

An archetypal example of a system that utilizes optical power is shown in Figure 1. This system has components common to many optical devices and is included here to highlight failure modes by which optical power may enter the flammable environment. The mechanisms by which ignition may be produced are common to all optical components, but the explicit design practices through which ignition is prevented will differ.

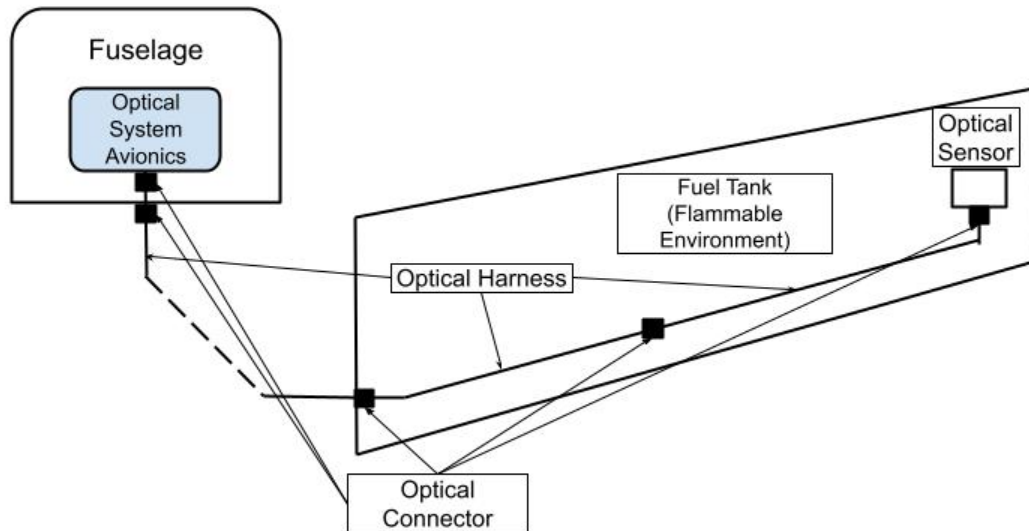


Figure 1 - Archetypal installation of a fiber-optic harness in which an optical sensor is connected to an aircraft fuselage by an optical harness that runs through the fuel tank

It is convenient to distinguish between direct and indirect methods by which optical power may enter the flammable environment.

- a. Direct optical power transmission occurs when the light exits the optical device and radiates into the flammable environment. This will result in optical power diffusing from the point of exit and propagating into the fuel tank until it is absorbed by the environment (e.g., by the fuel) or it impinges on the fuel tank wall, internal tubing, or equipment. Direct optical power transmission could occur at the location of a severed optical fiber or the inadvertent disconnection of optical connectors.
- b. Indirect power transmission occurs when the light does not enter the flammable environment and instead is illuminating an absorbing material. The absorber, which is in thermal contact with the flammable environment, heats up and transmits some portion of the thermal energy into the environment. Indirect optical power transmission could occur at the location of direct power transmission (e.g., a severed optical fiber), wherein the location of power leakage is coated in an optically absorbing material.

Although light only enters the flammable environment in the case of direct optical power transmission, both of these methods result in thermal energy entering the flammable environment and must be considered in the design of devices that generate and transport optical power inside and through aircraft fuel tanks. The specific methods by which these power transmission modes may lead to fuel tank ignition are addressed below.

3.2 Optical Ignition Mechanisms

The requirements on optical wavelength and maximum permissible optical power are motivated by the mechanisms by which optical power entering the fuel tank may produce ignition. As enumerated by Magison (1997), optical energy propagating through flammable environments may produce ignition through four main methods:

1. Ignition through thermal heating of an absorbing material. The absorbing material could be located at the broken or disconnected end of a fiber such that it would be indirect power transmission or far from the location of failure, in which case it would be direct power transmission.
2. Ignition through plasma created by focused light.
3. Ignition through thermal heating of an absorbing gas.
4. Ignition through photochemical dissociation.