



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Advisory Circular

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**Subject:** FUEL TANK IGNITION  
SOURCE PREVENTION GUIDELINES

**Date:** 9/19/08  
**Initiated By:** ANM-112

**AC No:** 25.981-1C

**1. Purpose.** This advisory circular (AC) provides guidance for demonstrating compliance with the certification requirements for prevention of ignition sources within the fuel tanks of transport category airplanes. This guidance is applicable to transport category airplanes for which a new, amended, or supplemental type certificate is requested.

**2. Applicability.**

a. The guidance provided in this document is directed to airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) transport airplane type certification engineers, and their designees.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. On the other hand, if we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.

c. This material does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

**3. Cancellation.** Advisory Circular 25.981-1B, Fuel Tank Ignition Source Prevention Guidelines, dated April 18, 2001, is cancelled.

**4. Related Documents.** The following related documents are provided for information purposes and are not necessarily directly referenced in this AC.

a. Federal Aviation Regulations. Sections that prescribe requirements for the design, substantiation, and certification relating to prevention of ignition sources within the fuel tanks of transport category airplanes include:

- § 21.50 Instructions for continued airworthiness and manufacturer's maintenance manuals having airworthiness limitations sections.
- § 25.729(f) Protection of equipment in wheel wells.
- § 25.863 Flammable fluid fire protection.
- § 25.901 Installation. (Powerplant)
- § 25.954 Fuel system lightning protection.
- § 25.973 Fuel tank filler connection.
- § 25.981 Fuel tank ignition prevention.
- § 25.1301 Function and installation. (Equipment)
- § 25.1309 Equipment, systems, and installations.
- § 25.1316 System lightning protection.
- § 25.1353 Electrical equipment and installations.
- § 25.1529 Instructions for continued airworthiness.

Appendix H to part 25—Instructions for Continued Airworthiness

b. Advisory Circulars (AC). You can obtain any of the ACs listed below either electronically from the internet at <http://www.airweb.faa.gov/rgl/>, or from the U.S. Department of Transportation, Subsequent Distribution Office, M-30, Ardmore East Business Center, 3341 Q 75<sup>th</sup> Avenue, Landover, MD 20785.

- (1) AC 25-8 Auxiliary Fuel System Installations
- (2) AC 20-53B Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Caused by Lightning
- (3) AC 20-136A Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning
- (4) AC 25-16 Electrical Fault and Fire Prevention and Protection
- (5) AC 25-19 Certification Maintenance Requirements
- (6) AC 25.981-2A Fuel Tank Flammability Reduction Means
- (7) AC 25.1701-1 Certification of Electrical Wiring Interconnection Systems on Transport Category Airplanes

c. Society of Automotive Engineers (SAE) Documents. You can obtain the following documents from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

- (1) APR 4754, Aerospace Recommended Practice, Certification Considerations For Highly Integrated or Complex Aircraft Systems.
- (2) ARP 4761, Aerospace Recommended Practice, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.
- (3) ARP 4404, Aerospace Recommended Practice, Aircraft Electrical Systems (guidance document for design of aerospace vehicle electrical systems).
- (4) AIR 1662, Minimization of Electrostatic Hazards in Aircraft Fuel Systems.
- (5) ARP 5412A, Aircraft Lightning Environment and related test waveforms.
- (6) ARP 5414A, Aircraft Lightning Zoning.
- (7) SAE AS50881, Aerospace Vehicle Wiring (procurement document used to specify aerospace wiring, replaces MIL-W-5088).
- (8) ARP 5583, Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment.

d. Military Specifications. You can get a copy of these documents from the Department of Defense, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, WA 19111-5094, or on the internet at <http://assist.daps.dla.mil/online/start/>.

- (1) MIL-E-5272A, Environmental Testing of Aeronautical & Associated Equipment (Explosion Proof Equipment Qualification Tests).
- (2) MIL-STD-810E, Method 511.3, Explosive Atmosphere, dated September 1, 1993.

e. Other.

- (1) RTCA Document DO-160F, Environmental Conditions and Test Procedures for Airborne Equipment.
- (2) Underwriters Laboratories Inc., UL 913, Intrinsically Safe Apparatus and Associated Apparatus for use in Class I, II, III, Division 1, Hazardous (Classified) Locations.
- (3) FAA Transport Airplane Directorate Designee Newsletter, Edition 15, February 1993. Article, Electrical Wiring used in Commercial Transport Airplanes.

- (4) FAA Document DOT/FAA/AR-98/26, Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998. An electronic copy of this report is available on the Internet at <http://www.fire.tc.faa.gov>.
- (5) Kuchta, Joseph M., Summary of Ignition Properties of Jet Fuels and Other Aircraft Combustible Fluids, Air Force Aero Propulsion Laboratory Technical Report AFAPL-TR-75-70, U.S. Bureau of Mines PMSRC, 1975.
- (6) K. E. Crouch, "Aircraft Fuel System Lightning Protection Design and Qualification Test Procedures Development," FAA report DOT/FAA/CT-94/74, September 1994.
- (7) F. A. Fisher, J. A. Plumer, and R. A. Perala, "Aircraft Lightning Protection Handbook," FAA report DOT/FAA/CT-89/22, September 1989.
- (8) American Society of Testing and Materials, ASTM D 4865, "Standard Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems." A copy of this standard can be ordered electronically on the Internet at <http://www.ASTM.org>.
- (9) National Fire Protection Association, NFPA 77, Recommended Practice on Static Electricity, 1993 Edition A copy of this publication can be ordered electronically on the Internet at <http://www.NFPA.org>.
- (10) F. A. Fisher, "Some Notes on Sparks and Ignition of Fuels," NASA report NASA/TM-2000-210077, March 2000.
- (11) EUROCAE ED 107, Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment.

## 5. Definitions.

a. Auto-ignition Temperature. The minimum temperature at which an optimized flammable vapor and air mixture will spontaneously ignite when heated to a uniform temperature in a normal atmosphere without an external source of ignition, such as a flame or spark.

b. Auxiliary Tanks. Fuel tanks installed which make additional fuel available for increasing the flight range of that airplane. The term "auxiliary" means that the tank is secondary to the airplane's main fuel tanks; i.e., the functions of the main tanks are immediately available and operate without immediate supervision by the flightcrew in the event of failure or inadvertent depletion of fuel in an auxiliary tank. Auxiliary tanks are usually intended to be emptied of usable fuel during flight and have been installed in various locations including center wing structure, horizontal stabilizers, wings, and cargo compartments.

c. Barrier. A physical partition attached to airplane structure that separates one wire or group of wires from another wire or group of wires in order to prevent arcing, fire and other physical damage between wires or groups of wires.

d. Critical Design Configuration Control Limitations. Limitations that define those parameters of the design that must be maintained to ensure that ignition sources will not develop within the fuel tank.

e. Electrical Sparks. A spark that is initiated by a potential difference which causes an electrical breakdown of a dielectric, such as a fuel/air mixture, produced between electrodes which are initially separated, with the circuit initially carrying no current. The term voltage sparks is sometimes used interchangeably with the term electrical sparks.

f. Electrical Arcs. Electrical arcs occur between electrodes which are in contact with each other and carry excessive current which results in melting at the contact points. This may result in electric arc plasma and/or ejection of molten or burning material. The term thermal sparks is used interchangeably with the term electrical arcs.

g. Explosion Proof. Components designed and constructed so they will not ignite flammable vapors or liquids surrounding the component under any normal operating condition and any failure condition. Further information on possible failure conditions that should be considered is specified in § 25.981(a)(3).

h. Flammable. Flammable, with respect to a fluid or gas, means susceptible to igniting readily or to exploding (14 CFR part 1, Definitions). Further information on flammable fluids used in airplanes may be found in the documents identified in paragraph 4e of this AC.

i. Flash Point. The flash point of a flammable fluid is defined as the lowest temperature at which the application of a flame to a heated sample causes the vapor to ignite momentarily, or “flash.” The test standard for jet fuel is defined in the fuel specification.

j. Friction Spark. A heat source in the form of a spark that is created by mechanical contact, such as debris contacting a rotating fuel pump impeller.

k. Hot Short. Electrical energy introduced into equipment or systems as a result of unintended contact with a power source, such as bent pins in a connector or damaged insulation on adjacent wires.

l. Ignition Source. A source of sufficient energy to ignite combustion of a fuel/air mixture. Surfaces that can exceed the auto-ignition temperature of the flammable vapor under consideration are considered to be ignition sources. Electrical arcs, electrical sparks and friction sparks are also considered ignition sources if sufficient energy is released to initiate combustion.

m. Installation Appraisal. A qualitative appraisal of the integrity and safety of the installation.

n. Intrinsically Safe. Any instrument, equipment, or wiring that is incapable of releasing sufficient electrical or thermal energy under normal operating conditions, anticipated failure conditions (see § 25.981(a)(3)), and environmental conditions which could cause an ignition source within the fuel tank.

o. Latent Failure. A failure whose presence may not be readily apparent to the flightcrew or maintenance personnel. A significant latent failure is one that would, in combination with one or more specific failures or events, result in a hazardous or catastrophic failure condition.

p. Maximum Allowable Surface Temperatures. A surface temperature within the fuel tank (the tank walls, baffles, or any components) that provides a safe margin under all normal or failure conditions, which is at least 50 °F (10 °C) below the lowest expected auto-ignition temperature of the approved fuels. The auto-ignition temperature of fuels will vary because of a variety of factors (ambient pressure, dwell time, fuel type, etc.). The value accepted by the FAA without further substantiation for kerosene fuels, such as Jet A, under static sea level conditions, is 450 °F (232.2 °C). This results in a maximum allowable surface temperature of 400 °F (204.4 °C) for an affected component surface.

q. Qualitative. Those analytical processes that assess system and airplane safety in an objective, non-numerical manner.

r. Quantitative. Those analytical processes that apply mathematical methods to assess system and airplane safety.

s. Transient Suppression Device (TSD). A device that limits transient voltages or currents on wiring to systems such as the fuel tank quantity, fuel temperature sensors, and fuel level switches, etc., to a predetermined level.

t. Ground Fault Interrupter (GFI). A device that detects an electrical power short circuit-to-ground condition and interrupts electrical power to the ground fault.

u. Fuel System Limitation (FSL). Any inspection that is identified in the limitations section of the instructions for continued airworthiness as required to assure integrity of items identified as critical design configuration control limitations.

v. Line Replacement Unit (LRU). Any components that can be replaced while the airplane remains in operational service. Examples of fuel system LRUs include components such as cockpit and refueling panel fuel quantity indicators, fuel quantity system processors, and fuel system management control units.

## **6. Background.**

### **a. Regulatory History.**

(1) The regulatory standards of part 25 require that ignition sources not be present or develop in the fuel tanks of transport airplanes. Amendment 25-11, effective May 5, 1967, introduced § 25.981, Fuel tank temperature. This requirement was prompted by a need for protection of airplane fuel tanks from possible ignition sources because of advances in electrical system sealing. These advances made it possible to place electrical system components, such as pumps and fuel gauging elements, as well as the wiring to these components, in immersed locations within fuel tanks. Additionally, fuel tank walls were subject to local “hot spots” by the proximity of airplane equipment and compressor bleed air ducts that carry air at high temperatures.

(2) The need for a regulation was further demonstrated by the possibility that the surface temperature of the fuel tank internal wall, or the fuel system components within the fuel tank, could exceed the auto-ignition temperature. Section 25.981, as originally adopted, focused on preventing ignition of fuel vapors in the fuel tanks from hot surfaces. It required that the applicant determine the highest temperature allowable in fuel tanks that provided a safe margin below the lowest expected auto-ignition temperature of the fuel approved for use in the fuel tanks. In addition, this regulation established a requirement that no temperature at any place inside any fuel tank where fuel ignition is possible may then exceed that maximum allowable temperature.

(3) Other sections of part 25 require that ignition from lightning be prevented (§ 25.954), as well as ignition from failures in the fuel system (§ 25.901). Applicants have been required by § 25.901 to complete a safety assessment of the fuel system and show that “no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane....” However, service history has shown that ignition sources have developed in airplane fuel tanks due to unforeseen failure modes or factors that were not considered at the time of original certification of the airplane, including arcs, sparks, or hot surfaces within the fuel tanks.

b. Advisory Circular 25.981-1A, Guidelines for Substantiating Compliance with the Fuel Tank Temperature Requirements, issued in 1972, provided guidance that included failure modes that used to be considered when determining compliance with the fuel tank temperature requirements defined in § 25.981. This regulation originally focused on preventing ignition of fuel vapors in the fuel tanks from hot surfaces. The AC also stated the accepted practice of establishing a minimum 50 °F temperature margin below the lowest auto-ignition temperature of the approved fuels.

c. Amendment 25-102, issued on April 18, 2001, renamed § 25.981 as Fuel tank ignition prevention. That amendment also added new requirements to address causes of ignition sources within fuel tanks, and minimization of the development of flammable vapors in the fuel tanks or mitigation of the effects of an ignition of vapors in the tanks. The new

ignition source prevention standard requires a safety assessment of the fuel tank system that includes:

- consideration of single failures,
- probable combinations of failures,
- development of long-term instructions for continued airworthiness, including Critical Design Configuration Control Limitations (CDCCL), and
- maintainability of the airplane fuel tank system.

d. Special Federal Aviation Regulations (SFAR) No. 88, promulgated by Amendment 21-78, also issued on April 18, 2001, requires a one-time reassessment of the fuel tank systems of many in-service transport airplanes per the ignition source prevention requirements of §§ 25.901 and 25.981, Amendment 25-102.

e. Amendment 25-125, issued July 9, 2008, amended § 25.981 to add specific requirements for the fuel tank flammability. The requirements for CDCCL were expanded to include flammability reduction means and ignition mitigation.

## **7. Objective.**

a. The objective of this AC is to provide guidelines that address the prevention of possible sources of ignition in airplane fuel tanks. Analytical evaluation of the fuel tank system, including consideration of lessons learned from the transport airplane service history, provides insight into design features that should be carefully considered when determining compliance with the regulations that are intended to prevent ignition sources within fuel tanks. Prior to conducting a fuel system safety assessment, each applicant should assemble and review relevant lessons learned from the overall transport fleet history, as described in this AC, as well as their previous products, their suppliers, and any other available sources, to assist in identifying any unforeseen failures, wear, or other conditions that could result in an ignition source. Sources of information include airplane service records, flight logs, inspection records, and component supplier service and sales records. Guidance relating to the flammability requirements adopted in amended § 25.981 is provided separately in AC 25.981-2A.

b. Safety assessments of previously certificated fuel systems may require additional considerations. For these safety assessments, component sales records may assist in identifying if component failures and replacement are occurring. In addition, in some cases changes to components have been introduced following original type design certification without consideration of the possible effects of the changes on the system's compliance with the requirements to prevent ignition sources. For example, certain components within fuel pumps have been changed to improve pump life, which defeated the original fail-safe features of the pumps. Therefore, results of reviewing this service history information, and a review of any changes to components from the original type design, should be documented as part of the safety analysis of the fuel tank system.



c. The following list summarizes fuel tank system design features, malfunctions, failures, and maintenance/operational related actions that have been identified through service experience as resulting in a degradation of the safety features of airplane fuel tank systems. This list is provided as guidance and not inclusive of all failures that need to be considered in the failure assessment. They may assist in evaluating possible failure modes during evaluation of the fuel tank installation.

Pumps.

- Ingestion of pump inlet components (e.g., inducers, fasteners) into the pump impeller releasing debris into the fuel tank.
- Pump inlet case degradation, allowing the pump inlet check valve to contact the impeller.
- Failure of one phase of the stator winding during operation of the fuel pump motor together with subsequent failure of a second phase of the motor windings, resulting in arcing through the fuel pump housing.
- Arcing due to the exposure of electrical connections within the pump housing that have been designed with inadequate clearance to the pump cover.
- Omission of cooling port tubes between the pump assembly and the pump motor assembly during pump overhaul.
- Extended dry running of fuel pumps in empty fuel tanks, which was contrary to the manufacturer's recommended procedures.
- Use of steel impellers that may produce friction sparks if debris enters the pump.
- Debris lodged inside pumps.
- Pump power supply connectors have corroded resulting in fuel leakage and electrical arcing.
- Electrical connections within the pump housing have been designed with inadequate clearance or insulation from the metallic pump housing, resulting in arcing.
- Thermal switches aging over time resulting in a higher trip temperature.
- Flame arrestors falling out of their respective mounting.
- Internal wires coming in contact with the pump rotating group, energizing the rotor and arcing at the impeller/adaptor interface.
- Poor bonding across component interfaces.
- Insufficient ground fault current protection capability.
- Poor bonding of components to structure.
- Loads from the airplane fuel feed plumbing transferred into the pump housing resulting in failure of the housing mounts and subsequent failure of the pump case, which defeated the explosion proof capabilities of the pump.
- Premature failure of fuel pump thrust bearings allowing steel rotating parts to contact the steel pump side plate.

### Wiring to Fuel Pumps.

- Wear of Teflon sleeving and wiring insulation on wires in metallic conduits located inside fuel tanks, allowing arcing from wire through the conduits into fuel tank ullages.
- Damage to insulation on wiring routed adjacent to the fuel tank exterior surfaces that resulted in arcing to the metallic fuel tank surface.

### Fuel Pump Connectors.

- Electrical arcing at connections within electrical connectors due to bent pins or corrosion.
- Fuel leakage and subsequent fuel fire outside of the fuel tank caused by corrosion of electrical connectors inside the pump motor which led to electrical arcing through the connector housing (connector was located outside the fuel tank).
- Selection of improper insulating materials in connector design resulting in degrading of the material because of contact with fuel that is used to cool and lubricate the pump motor.

### Fuel Quantity Indicating System (FQIS) Wiring.

- Degradation of wire insulation (cracking).
- Conductive or semi-conductive (silver, copper or cadmium) deposits at electrical connectors inside fuel tanks.
- Inadequate wire separation between FQIS wiring and structure or other wiring, causing chafing of the wiring.
- Unshielded FQIS wires routed in wire bundles together with high voltage wires, creating the possibility of short circuit failures or induced current on the FQIS wires in excess of intrinsically safe levels.
- FQIS wiring that does not adhere to aircraft manufacturer's standard wiring practices (i.e., wires bent back along themselves with bend radius less than defined in the aircraft manufacturer's standard wiring practices, multiple splices lying next to one another, etc.).

### FQIS Probes.

- Conductive or semi-conductive corrosion (copper or silver sulfur deposits) causing reduced breakdown voltage in FQIS wiring.
- Damage to FQIS wire insulation resulting in reduced breakdown voltage as a result of wire clamping features at electrical connections on fuel quantity probes.
- Contamination in the fuel tanks creating an arc path for low levels of electrical energy between FQIS probe walls (steel wool, lock wire, nuts, rivets, bolts, and mechanical impact damage to probes).

Valve Actuators.

- Failure of one solenoid in a dual solenoid actuated valve resulting in overheating of one solenoid above the auto-ignition temperature.

Float Switch Systems.

- Conduits containing float switch wiring failing due to freezing of water that entered the conduit, allowing fuel leakage into the conduit and along the airplane front spar resulting in an engine tailpipe fire.
- Float switch wire chaffing observed which might have provided potential for subsequent electrical short to the conduit.
- Float switch sealing failure has allowed fuel/water to egress into the switch, compromising switch operation in an explosive environment.

Fuel Tubes, Vent Tubes, Conduits, Hydraulic Lines.

- Poorly conducting pipe couplings that may become electrical arc sources when exposed to electric currents, including lightning currents.
- Insufficient clearances between tubes and surrounding structure.
- Intermittent electrical bonding in flexible couplers.
- Bonded couplers unable to conduct expected lightning or power fault currents without arcing.

Electrical Generator Power Feeder Cables.

- Arcing of electrical power feeder cables to a pressurized fuel line resulting in fire adjacent to the fuel tank.
- Arcing of electrical power feeder cables to aluminum conduit resulting in molten metal dropping onto a pressurized fuel line causing leakage.

Bonding Straps.

- Corrosion of bonding strap wires resulting in failure to provide required current paths.
- Inappropriately attached connections (loose or improperly grounded attachment points).
- Static bonds on fuel system plumbing connections inside the fuel tank worn due to mechanical wear of the plumbing from wing movement, and corrosion.
- Corrosion of bonding surfaces near fuel tank access panels that could diminish the effectiveness of bonding features.
- Aging of self-bonding fuel system plumbing connections resulting in higher resistance bonding.
- Missing bonds.
- Loose or intermittent contacts between bond straps and other conductive components.

#### Pneumatic System Failures.

- Leakage of air from ducting located near fuel tanks due to duct failure resulting in undetected heating of tank surfaces above the auto-ignition temperature.

#### Electrostatic Charge.

- Use of a non-conductive type of reticulated polyurethane foam in only a portion of a fuel tank system that allowed electrostatic charge build-up and arcing in the unprotected portion of the system.
- Spraying of fuel through refueling nozzles located at the upper portion of the tank.

### **8. Fuel Vapor Ignition Sources.**

a. There are four primary phenomena that can result in ignition of fuel vapors from within airplane fuel tanks:

- electrical arcs and sparks.
- filament heating,
- friction sparks, and
- hot surface ignition or auto-ignition.

(1) The conditions required to ignite fuel vapors from these ignition sources vary with pressures and temperatures within the fuel tank and can be affected by sloshing or spraying of fuel in the tank. Due to the difficulty in predicting fuel tank flammability and eliminating flammable vapors from the fuel tank, the regulatory authorities have always assumed that a flammable fuel air mixture may exist in airplane fuel tanks and have required that no ignition sources be present.

(2) Any components located in or adjacent to a fuel tank must be designed and installed in such a manner that, during both normal and anticipated failure conditions, ignition of flammable fluid vapors will not occur. Compliance with this requirement is typically shown by a combination of component testing and analysis. Testing of components to meet the appropriate level of explosion-proof requirements may be carried out for various single failures, and combinations of failures, to show that arcing, sparking, auto-ignition, hot surface ignition, or flame propagation from the component will not occur. Testing of components has been accomplished using several military standards and component qualification tests. For example, military standard MIL-STD-810, Method 511, Procedure I and II, defines one method that has been accepted for demonstrating that a component is explosion proof. Section 9 of RTCA Document DO-160F has also been accepted for demonstrating that airborne equipment is explosion proof.

b. Electrical Sparks and Electrical Arcs.

(1) Laboratory testing has shown that the minimum ignition energy in an electrical spark required to ignite hydrocarbon fuel vapor is 200 microjoules<sup>1</sup>. Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as fuel quantity indicating systems, any electrical arcs or sparks that are created into any fuel tank should be less than 200 microjoules during either normal operation or operation with failures.

**NOTE:** In the past some components have been qualified to standards that allow 320 microjoules, but this level is not acceptable for showing intrinsic safety.

To ensure that the design has adequate reliability and acceptable maintenance intervals, a factor of safety should be applied to this value when establishing a design limit. Fuel tank systems should be designed to limit the allowable energy level to the lowest practical level. Systems with a maximum energy of 20 microjoules are considered technologically feasible. Normal systems operations at minimum ignition energies of up to 50 microjoules would be acceptable. Under failure conditions, the system should not have an ignition energy which would exceed 200 microjoules.

(2) Electrical transients caused by environmental conditions, such as lightning strikes, with the potential to create electrical sparks and arcs in the fuel tank, should be limited so that the energy from any electrical spark or arc from the electrical transient is less than 200 microjoules. Optical detection methods and combustible vapor ignition detection methods used to show compliance for electrical transients caused by environmental conditions should detect electrical sparks and arcs with energy levels of 200 microjoules or less. Optical detection methods consist of subjecting a fuel tank to a simulated lightning strike while a specific camera/lens/film configuration is positioned near the fuel system component, system or fuel tank with the shutter open. The test is passed if no spark or arc is visible on the developed film. Combustible vapor ignition detection methods use specific combustible gas mixtures that have high ignition probability at a specific electrical energy. Fuel system components, systems, or fuel tanks are tested in the presence of the combustible vapor. The test passes if the vapor does not ignite during the test, but does ignite using a standardized ignition energy source at the specified ignition energy. Acceptable test methods are found in SAE document ARP 5416.

c. Filament Heating Current Limit. Analyses and testing indicate a small piece of steel wool will ignite a flammable mixture when a current of approximately 100 milliamperes root-mean-square (RMS) is applied to the steel wool.<sup>2</sup> Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as fuel quantity indicating

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<sup>1</sup> The 200 microjoule level comes from various sources. The most quoted is Lewis and VonElbe, "Combustion, Flames and Explosions of Gases," that has a set of curves for minimum ignition energy for the various hydrocarbon compounds in Jet fuel, and they all have similar minimum ignition energy levels of around 220 microjoules.

<sup>2</sup> This data was from testing performed by the FAA Technical Center, Report number DOT/FAA/AR-TN05/37. Applicants may conduct testing to substantiate alternate values.

systems, the electrical current introduced into any fuel tank should be limited. Because there is considerable uncertainty associated with the level of current necessary to produce an ignition source from filament heating, a factor of safety should be applied to this value when establishing a design limit. A maximum of steady-state current of 25 milliamperes RMS is considered an intrinsically safe design limit for electronic and electrical systems that introduce electrical energy into fuel tanks. For failure conditions, limit the current to 50 milliamperes RMS and for lightning induced transients to 125ma peak current.

d. Friction Sparks. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, lockwire, roll pins, cotter pins, drill chips, and manufacturing debris, etc., have been inducted into fuel pumps and contacted the impeller resulting in the possibility of metallic deposits on rotating and stationary components within the pump. This condition has resulted in creation of friction sparks and should be an assumed failure condition when conducting the system safety assessment. Fail-safe features as described below in paragraph 10b(2) have been used to mitigate this hazard.

e. Hot Surface Ignition.

(1) Maximum Surface Temperature. Guidance provided in AC 25-8, as well as the original release of this AC, define surfaces that come within 50 degrees of the auto-ignition temperature of the fuel air mixture for the fluid as ignition sources. The FAA has historically accepted 400 °F for maximum surface temperatures for kerosene type fuels. (Maximum surface temperature considerations for areas outside the fuel tank are discussed later in this AC.) For remote failure conditions of limited duration, it is acceptable to provide substantiation of actual hot-surface ignition temperatures (note that this is different from the auto-ignition temperature of the fuel), and demonstrate a 50 °F margin below these temperatures.

(2) Flammable Fluid Properties. Fuels approved for use on transport category airplanes have differing flammability characteristics. The auto-ignition temperature of JP-4, as determined by ASTM Test Method D286, is approximately 468 °F at one atmosphere of pressure. By this method of testing, under the same atmospheric conditions the auto-ignition temperature of JET A (kerosene) is approximately 435 to 450 °F, and of gasoline, approximately 800 °F. The auto-ignition temperature of these fuels varies inversely with the ambient pressure. In view of this, factors affecting the pressure in the fuel tank should be taken into consideration when determining compliance with § 25.981.

f. Fuel System Electrostatics. Electrostatic charges are generated in liquid hydrocarbons when they are in motion with respect to another surface such as fueling hoses, filters, nozzles, fuel tank structure and aircraft plumbing. The references in paragraphs 4c(4) and 4e(9) of this AC provide information on this subject. During airplane refueling, jet fuel is loaded either from a tanker truck or from an airport hydrant system. Flowing fuel can generate an electrical charge especially through fuel filtration. The accumulation of charge in the fuel is a function of many factors. If the fuel conductivity is low, the relaxation time for dissipation of the electrical charge is long. As a consequence, the fuel may accumulate an electrical charge inside an aircraft fuel tank. This electrical charge may produce a high

potential on the fuel surface and an electrical discharge to structure. This is particularly a concern when large unbonded objects are located inside an airplane fuel tank. Smaller components may also become charged and this should be addressed in the safety assessment. If the vapor space fuel/air mixture is in the flammable range, ignition of the mixture is possible, resulting in a fuel tank explosion and fire.

(1) Charge accumulation is influenced by many factors. Without a static dissipator additive, typical Jet A fuel has a low electrical conductivity. A static dissipator additive will increase the charging rate of fuel but at the same time greatly improve the conductivity of the fuel to rapidly dissipate the developed charge. Contaminants, considered as ionic impurities, enhance the charging tendency of the specific fuel. Fuels from different parts of the world and from different refineries will therefore have different charging tendencies based on the types of contaminants present. Fuel static dissipator additives will increase the charging rate of fuel but at the same time greatly improve the conductivity of the fuel to rapidly dissipate the developed charge. Water contamination, however, increases the charging tendency of the fuel without a corresponding increase in conductivity. The water interacts with the additives or the naturally occurring contaminants in the fuel to provide this pro-static effect. Recognizing the dangers of water contamination, the National Fire Protection Association (NFPA) also cautions that when refueling, care should be taken to not disturb the interface between the fuel remaining in the tank and the possible layer of water below it. Disruption of this interface up into the tank ullage/vapor space may lead to an electrical discharge capable of igniting a flammable fuel vapor/air mixture. Fuel tank inerting is one method of precluding this ignition source. However, for transport airplanes, this phenomenon is usually addressed by incorporating an active water removal scavenge system for the fuel tanks and periodically sumping the tanks to remove the collected water to minimize the existence of the fuel/water interface.

(2) Methods of minimizing the magnitude of the developed charge have been developed and are in place on transport airplanes including:

(a) The refuel plumbing is sized and is orificed to maintain maximum flow rates in accordance with the electrostatic guidelines established by the NFPA and the ASTM; and

(b) Flow velocities of 6 to 7 meters per second are considered acceptable after the discharge port is covered with fuel. The guidelines also indicate that the flow velocity should be held to less than 1 meter per second until the discharge port is covered with fuel. This criterion may be met by incorporating multiple refueling discharge ports, lowering the flow velocity through the use of piccolo tubes that distribute the fuel at low velocities in the tank, and locating them at or near the bottom of the tank. Location of the refueling discharge at the bottom of the tank minimizes fuel spray, a contributor to static charge development, and provides for the ports to be covered by fuel reserves in main tanks and in the early stages of fuel flow as the refuel rate varies from 1 meter per second up to the full flow of 6 to 7 meters per second in normally emptied tanks.

**NOTE:** It may not be practical to develop a dual flow rate refueling system so limiting the refueling velocities to less than one meter per second through the use of multiple discharge points and piccolo tubes may be one way to address these design guidelines.

(3) Methods of relaxing the charge have also been developed. Bonding straps are used on fuel components and plumbing lines to allow the charge to dissipate to the tank structure. During refueling, the airplane is bonded to the refueling vehicle with a separate bonding wire to provide an electrical path back to fuel filtration, which is the principal electrostatic charge generator. A static dissipator fuel additive may also be used to increase fuel conductivity, to quickly dissipate the developed charge. However, the FAA does not require this type of additive, unless it is specified as part of the type design approval. Any limitations on use of an anti static additive would need to meet the requirements of §§ 25.1521 and 25.1557.

(4) Applications of the above methods and adherence to industry practices and guidelines on electrostatics should be identified for each airplane model. Airline operation and practices regarding airplane refueling should also be evaluated to verify that the procedures necessary for safe operation of the specific airplane model are in place and followed. Restrictions, if any, on refuel rates, fuel properties, and the requirement for fuel additives should be identified as CDCCL.

(5) Polyurathane reticulated foams used for ignition suppression within fuel tanks and other nonconducting objects may accumulate and retain charge. These items may have to be treated with antistatic additives to prevent charge accumulation.

## **9. Design Considerations.**

a. Accepted Design Practices for Minimizing Ignition Sources. The number of components and systems inside airplane fuel tanks whose failure could result in an ignition source within the fuel tank should be minimized. For example:

(1) Fiber Optics. Wiring entering the tank for such purposes as temperature monitoring and fuel quantity indication should be minimized. Use of new technology, such as fiber optics, may provide a means of reducing or eliminating electrical powered components from inside the fuel tanks.

(2) Routing of Pump Power Supply. If practical, fuel pumps should be located such that electrical power for the pumps is routed outside the fuel tanks in such a manner that failures in the electrical power supply cannot create a hot spot inside the tank or arc into the fuel tank. While routing of the fuel pump power supply outside of the fuel tank, and away from the fuel tank walls, may eliminate the potential for arcing directly into the fuel tank or heating of tank surfaces, the failure analysis should consider the need for electrical circuit protective devices. For example, arcing at the pump electrical connector has resulted in uncontrolled fuel leakage, an ignition source, and an uncontrolled fire outside of the fuel tank. This failure mode as well as any pump electrical failures, such as failure of the pump



internal electrical circuits, arcing of pump windings, etc., would need to be considered. If wiring is routed inside metallic conduit inside the fuel tank, redundant protection means would be required to prevent an arc of the wiring to the conduit from penetrating into the fuel tank. A practical means to achieve this is to provide sleeving of the wiring and an independent means such as a GFI or arc fault circuit breaker. Providing multiple layers of sleeving alone would not be considered acceptable since wear could defeat the multiple layer protection.

**NOTE:** Electromagnetic environment and lightning-induced transients that may damage the wiring or pump should be considered in the design of the pump wiring system and when showing compliance.

(3) Location of the Pump Inlet. Debris that may enter a fuel pump inlet can cause sparks inside the fuel tank. One means to address this ignition source has been to locate the pumps such that the pump inlet remains covered with fuel at any time the pump is operating within the airplane operating envelope. Another means has been preventing the propagation of any ignition from the pump into the fuel tank by use of flame arrester technology. (The performance of the flame arrester should be validated by test to verify its effectiveness at stopping a flame front.) Any protective means including those shown below should be effective under pitch, roll attitudes, and negative G conditions anticipated to occur in service.

(a) Main Feed Tanks. Installation of baffles in tank structure and use of collector tanks that are continually filled with fuel using ejector pumps are methods that have proven successful at keeping the pump inlets and pump housings submerged in fuel.

(b) Auxiliary Tanks. For auxiliary tanks that utilize motor driven fuel pumps and that are routinely emptied, accepted design practices include shutting off the motor driven pumps prior to uncovering the fuel pump inlet and installation of a flame arrester in the scavenge pump inlet line, or scavenging the remaining fuel with ejector pumps. (Note that installation of features such as a flame arrester in the fuel system would need to be shown to meet fuel system performance requirements in § 25.951.)

(4) Wiring. The following paragraphs on wiring represent acceptable approaches for dealing with wiring used in and near fuel tanks. For specific requirements and further guidance, the applicant should review the wiring installation and design requirements in the new Electrical Wiring Interconnect Systems (EWIS) rules, Amendment 25-123, and associated advisory circulars.

(a) Intrinsically Safe Wiring. All wiring that is intended to conduct intrinsically safe levels of electrical power into or through the fuel tanks should incorporate protective features that prevent exceeding the intrinsically safe levels discussed in paragraphs 8b and c of this AC. This wiring should also be protected from lightning and High Intensity Radiated Fields (HIRF) induced transients. The following protective features could be used to support that objective:

1 Separation and shielding of the fuel tank wires from other airplane wiring and circuits, and

2 Shielding for lightning, HIRF and other electromagnetic interference, and

3 Installation of transient suppression devices, to preclude unwanted electrical energy from entering the tank.

(b) Higher Energy Wiring. (Includes all wiring that is not intrinsically safe.)

1 Wiring should not be routed through metallic conduit inside the fuel tank or adjacent to fuel tank surfaces such that damage, inappropriate maintenance, or other failure/wear conditions could result in arcing to the conduit or metallic tank surface and development of an ignition source in the fuel tank. If metallic or other conductive conduit materials are used, the single failure of electrical arcing of the wiring to the conduit, adjacent tank surfaces, or structure should be assumed to occur. In addition, circuit protective features or other features should be incorporated to preclude development of an ignition source in the fuel tank. Methods that may be used to address this foreseeable failure condition include the use of circuit protective features such as dual conduits, thick wall conduit, and/or fast-acting ground fault interrupter (GFI) circuit breakers.

2 Where electric wires are routed through metallic conduits installed in a fuel tank, high surface temperatures or arcing through the conduit wall can be created by short circuits. All wiring conducting levels of power that exceed intrinsically safe levels (e.g., fuel pump power supply) into or through a fuel tank should be evaluated assuming arcing to adjacent surfaces such as metallic conduits or wing surfaces, unless fail-safe protective features are provided. A critical electrical wiring condition might be one in which the insulation is worn, cracked, broken, or of low dielectric strength, allowing intermittent or constant arcing to occur without consuming enough power to cause the circuit protection device to open. Inspection of wiring from in-service airplanes has shown that greater than expected wear may occur on sleeving and wiring insulation due to movement of the wire within the conduit. Roughness of the conduit material and variations in vibration levels for each installation may significantly increase wear. In addition, inspections have shown that protective sleeving has been missing, improperly installed, or the wrong sleeving material used, resulting in damage to the insulation. For these reasons, use of protective sleeving on wiring would not by itself be adequate for showing compliance. The design should be tolerant to these types of foreseeable failure or maintenance errors.

**NOTE:** Advisory Circular 25-8 addresses the use of metallic conduit as an acceptable means for routing of electrical power within airplane auxiliary fuel tanks. As indicated above, these past practices would not meet the fail-safe requirements of § 25.981 for any fuel tank, unless additional fail-safe features were incorporated. Therefore, the more recent guidance in this AC, and rulemaking in Amendment 25-102 supplements the guidance in AC 25-8.

(c) Wire Separation. Wiring designs used on transport airplanes vary significantly between manufacturers and models; therefore, it is not possible to define a specific universal separation distance or the characteristics of physical barriers between wire bundles to protect critical wiring from damage. Separation requirements for wiring and other components of EWIS are contained in § 25.1707, (the regulatory definition of an EWIS is provided in § 25.1701). Advisory Circular 25.1701-1, Certification of Electrical Wiring Interconnection Systems on Transport Category Airplanes, paragraph 5d, contains guidance on determining adequate separation distance between EWIS and between EWIS and airplane systems and structures. Even if § 25.1707 is not in the type certification basis of the airplane being modified, the guidance contained in the AC should still be applied, along with the guidance contained in this AC, when determining adequate separation distance. Intrinsically safe wiring for fuel tanks needs to be protected from induced currents caused by lightning, power system switching transients, or electromagnetic interference (EMI) due to close proximity to other airplane wiring. In addition, damage to wire insulation can result in unwanted electrical energy being transmitted into the fuel tank, if the damaged wire can come into contact with the conductor of another wire that is not intrinsically safe. Of particular concern is the possibility of a wire bundle fire that exposes and breaks wires that are not intrinsically safe and also damages the insulation of intrinsically safe wiring that is in close physical proximity. The broken wires may still be energized and could contact conductors of the damaged intrinsically safe wire. If physical separation is used to protect intrinsically safe fuel system wiring from other wiring or to protect fuel tank walls from high power wiring, the minimum physical separation must be established by the applicant. The applicant should conduct an analysis to verify that current and energies greater than those specified in paragraphs 8b and c of this AC will not be applied to intrinsically safe wiring, considering the factors listed below. The following is based on the guidance contained in paragraphs 5d(3) and (4) of AC 25.1701-1.

1 The electrical characteristics, power, and criticality of the signals in the wire bundle and adjacent wire bundles,

2 Installation design features including the number, type, fire resistance and location of support devices along the wire path of the intrinsically safe wire and adjacent higher power wires,

3 The maximum amount of slack wire resulting from wire bundle build tolerances and other wire bundle manufacturing variations,

4 Probable variations in the installation of the intrinsically safe fuel system wiring and adjacent wiring, including the position or omission of wire support devices and the amount of slack wire that is possible,

5 Expected operating environment including the amount of deflection or relative movement that can occur and the effect of a failure of a wire support device, or a broken wire, or other methods used to maintain physical separation,

6 The effects of wire bundle fires,

7 Maintenance practices as defined by the airplane manufacturer's standard wiring practices manual and the ICA required by §§ 25.1529, 25.1729, 26.11(b), and 26.11(c) as applicable, and

8 Possible EMI, HIRF, or induced lightning effects.

**NOTE:** Some areas of an airplane may have localized areas where maintaining the minimum physical separation distance is not feasible. This is especially true in smaller transport category airplanes. In those cases, other means of ensuring equivalent minimum physical separation may be acceptable, if testing or analysis demonstrates that safe operation of the airplane is not jeopardized. The testing or analysis program should be conservative and consider the worst possible condition not shown to be extremely improbable. The applicant should substantiate to the ACO that the means to achieve the necessary separation provides the necessary level of protection for wire related failures. Electromagnetic interference (EMI) protection must also be verified.

(d) Inspection. Means should be provided to allow for the visual inspection of the wiring, physical barriers and other physical means of protection. Non-destructive inspection aids may be used where it is impracticable to provide for direct visual inspection if it is shown that the inspection is effective and the inspection procedures are specified in the maintenance manual required by §§ 25.1529, 25.1729, 26.11(b), and 26.11(c).

(e) Identification. Means must also be provided so EWIS wires are readily identified and visible to maintenance, repair, or alteration personnel. The method of identification must remain legible throughout the airplane's operational life. The complete regulatory requirements for EWIS identification are contained in § 25.1711.

(f) Circuit Breakers. Service experience has indicated that thermal mechanical circuit breakers installed in the fuel pump circuits have not been shown to preclude arcing of electrical wiring through metallic barriers such as conduit, fuel pump housings, electrical connectors, or the tank wall into the fuel tank on some airplane designs. Evidence suggests that arcing from the wiring to metallic surfaces may not result in a hard short, which would trip the circuit breaker and may result in intermittent low level arcing that gradually arcs through the metallic barrier into the fuel tank. For these failure conditions circuit protective devices such as Arc Fault Circuit Breakers and Ground Fault Interrupters may be needed to provide fail safe features necessary to demonstrate compliance.

(g) Use of Nonmetallic Conduit. If nonmetallic conduit is used, compatibility with fuel should be demonstrated. The nonmetallic conduit should be evaluated for the effects of aging due to heat, corrosion at the connecting fittings, and resistance to heat damage from internal shorts of wires routed within the conduit.

(h) Wire Splices. Splices in fuel system wiring have been allowed as a standard repair procedure. The acceptability of splices will be based upon the system design

and fail-safe features. The safety assessment may show that splices in fuel tank system wiring, such as fuel quantity indicating wiring within the fuel tank and fuel pump windings, are prohibited. This would be defined as a critical design configuration control limitation.

(i) Use of Silver in Fuel Tanks. Silver can combine with sulfur or water and form silver-sulfide or oxide deposits between exposed conductors (terminal block connections, etc.). The silver-sulfide deposits reduce the resistance between conductors and can ignite fuel vapor when exposed to very low levels of electrical energy. If use of silver in electrical components and wiring in the tank is determined to be critical, it should be defined as a critical design configuration control limitation. The energy levels that have been shown to ignite fuel vapor during laboratory tests approach the levels normally used on fuel quantity indicating system wires and probes. This issue must be carefully addressed.

(j) Use of Steel Wool. Steel wool has been used as a cleaning tool to remove corrosion and clean parts inside the fuel tanks. Steel wool creates small conductive filaments that can cause ignition sources in the fuel tank if the steel wool comes in contact between conductors in fuel tank quantity gauging system components. For this reason design approval holders typically do not allow the use of steel wool inside fuel tanks and recommend using other abrasives.

## **10. Safety Analysis.**

a. Ignition Source Failure Analysis. Compliance with § 25.981 requires each applicant to develop a failure analysis for the fuel tank installation to substantiate that ignition sources will not be present in the fuel tanks. The requirements of this section are in addition to the more general propulsion failure analyses requirements of §§ 25.901 and 25.1309 that have been applied to propulsion installations.

(1) Section 25.981(a)(3) defines three failure scenarios that must be addressed in order to show compliance with the rule:

(a) Each single failure, regardless of the probability of occurrence of the failure, must not cause an ignition source.

(b) Each single failure, regardless of the probability of occurrence, in combination with any latent failure condition not shown to be at least extremely remote (i.e., not shown to be extremely remote or extremely improbable), must not cause an ignition source.

(c) All combinations of failures not shown to be extremely improbable must not cause an ignition source.

(2) Compliance with § 25.981 (Amendment 25-102) requires analysis of the airplane fuel tank system using analytical methods and documentation currently used by the aviation industry in demonstrating compliance with §§ 25.901 and 25.1309 with consideration of unique requirements included in the amendment.

(3) SAE document ARP 4761, System Design and Analysis, describes methods for completing system safety assessments (SSA). An assessment may range from a simple report that offers descriptive details associated with a failure condition, interprets test results, compares two similar systems, or offers other qualitative information, to a detailed failure analysis that may include estimated numerical probabilities. The depth and scope of an acceptable SSA depend upon:

(a) The complexity and criticality of the functions performed by the system under consideration,

(b) the severity of related failure conditions,

(c) the uniqueness of the design and extent of relevant service experience,

(d) the number and complexity of the identified causal failure scenarios, and

(e) the detectability of contributing failures.

**NOTE:** Sections 25.981 and 25.901 are intended to address system failures that may result in the presence of an ignition source in the fuel tanks. These regulations are not intended to address failures or conditions that could lead to ignition of fuel vapors from such sources as:

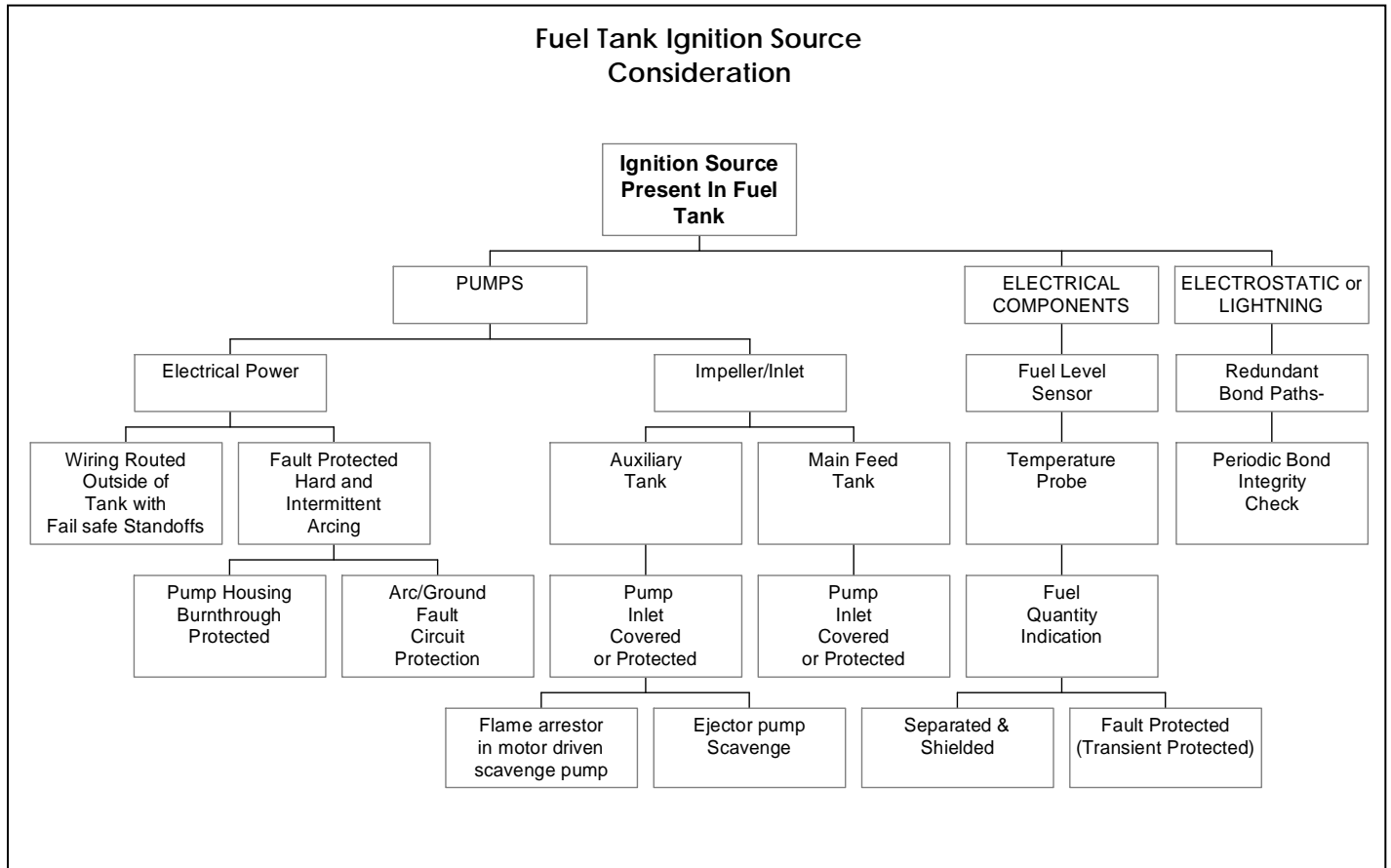
- uncontained engine debris,
- external engine fires following engine separation or failure,
- damage resulting from explosive materials, such as bombs,
- post crash fire heating of tank surfaces, or
- propagation of fire through the airplane vent system into the fuel tanks.

These hazards are addressed by other regulations.

b. Qualitative Safety Assessment.

(1) Typical airplane fuel tank systems have a limited number of possible ignition sources. Figure 1 shows some causes of ignition sources and methods that may be used to meet the fail-safe requirements. The level of analysis required to show that ignition sources will not develop will depend upon the specific design features of the fuel tank system being evaluated. Detailed quantitative analysis should not be necessary if a qualitative safety assessment shows that features incorporated into the fuel tank system design protect against the development of ignition sources within the fuel tank system. For example, if intrinsically safe FQIS wiring entering the fuel tanks and the associated LRU were shown to have protective features such as separation (including circuit separation in the LRU) and shielding and/or transient suppression/energy limiting devices, the portion of the compliance demonstration for the associated wiring would be limited to demonstrating the effectiveness of the features and defining any long-term maintenance requirements or critical design configuration control limitations so that the protective features are not degraded.

(2) Another example would be installation of a flame arrestor in the inlet line to a fuel pump. The compliance demonstration for the fuel pump may be limited to showing that the arrestor was effective at precluding propagation of the flame from the pump back down the inlet line into the tank, and showing that any anticipated failures or events could not violate the explosion-proof features of the pump assembly. In addition, revalidation of the fuel system to other regulations (e.g., icing and reduced flow due to contamination) would be required if modifications were incorporated into the fuel feed system. It may also be possible to show that fuel pumps installed such that the fuel pump inlet remains covered whenever the fuel pump is operating throughout the airplane operating envelope (as discussed earlier), including anticipated low fuel operations and ground conditions, would be a satisfactory method of meeting the fail-safe requirement for the failure mode of arcing into the tank ullage (consideration of other failure modes, such as the effects of electrical arcing external to the fuel tank, at the connectors, etc, would need to be addressed). The SSA criteria, process, analysis methods, validation, and documentation should be consistent with the guidance material provided in SAE document ARP 4761, utilizing the unique guidance specific to the fuel tank system as defined in this AC.



**Figure 1: Example of Fuel Tank System Fail-Safe Feature Considerations**

c. Assumptions and Considerations for Fuel Tank System Analysis. The analysis should be conducted based upon the following assumptions:

(1) Fuel Tank Flammability. The analysis should assume that the environment inside the fuel tank is always flammable. The conditions required to ignite fuel vapors from ignition sources vary with pressures and temperatures within the fuel tank and can be affected by sloshing or spraying of fuel in the tank. Due to the difficulty in predicting fuel tank flammability, the FAA has always assumed that a flammable fuel air mixture exists in airplane fuel tanks and has required that no ignition sources be present. The system safety analysis should be prepared considering all airplane in-flight, ground, service, and maintenance conditions, assuming that an explosive fuel air mixture is present in the vapor space of fuel tanks and vent systems at all times, unless the fuel tank has features that mitigate the effects of tank ignition (e.g., polyurethane foam).

(2) Failure Condition Classification. Unless design features are incorporated that mitigate the hazards resulting from a fuel tank ignition event (e.g., polyurethane foam, adequate structural margin), the SSA should assume that the presence of an ignition source is a catastrophic failure condition.



(3) Latent Failures.

(a) In order to eliminate any ambiguity as to the restrictions on latent failures, § 25.981(a)(3) explicitly requires that any anticipated latent failure condition not leave the airplane one failure away from a catastrophic fuel tank ignition. In addition to this § 25.981(a)(3) limitation on latency, § 25.1309(c) limits latent failure conditions to those that do not create an “unsafe system operating condition.” Consequently, if a latent failure condition is not extremely remote (i.e., it is anticipated to occur) and it creates an “unsafe system operating condition,” then “warning information must be provided to alert the crew...and to enable them to take appropriate corrective action.” These applicable regulatory restrictions on latency notwithstanding, there are practical limitations on the available means of compliance. For example, detecting a failure condition requires a finite period of time and there are not always “appropriate corrective actions” that can be taken during the flight. Consequently, for the purposes of compliance with § 25.981(a)(3), the period of latency for any anticipated significant latent failure condition should be minimized and not allowed to exceed one flight cycle. For the purposes of § 25.1309(c) compliance, any time the airplane is operating one failure away from a catastrophic fuel tank ignition should be considered an “unsafe system operating condition,” recognizing that sometimes the only “appropriate corrective action when problem detection is available is to continue on to your destination but not to initiate another flight without making appropriate repairs.”

(b) Another practical limitation on the available means of compliance is the technological feasibility of providing inherent failure detection within the design for all significant failures. Sometimes periodic inspection is the only practicable means of reliably detecting a failure condition. Consequently, when such inspections are identified within the analysis as the means of detection, the inspection method and frequency must be sufficient to conclude that the occurrence of the significant latent failure condition is extremely remote.

(c) Any inspection that is identified to assure integrity of items identified as critical design configuration control limitations should be identified in the limitations section of the instructions for continued airworthiness as a fuel system limitation (FSL). If this means is used, the limitations section should include the following:

1 A designation of the maintenance actions and alterations that must be inspected (critical inspections), including at least those that could result in a failure, malfunction, or defect endangering the safe operation of the aircraft, if not performed properly or if improper parts or materials are used.

**NOTE:** A validation inspection should be conducted to reaffirm all or a portion of the initial inspection requirements for those critical inspections that, if not performed properly or if improper parts or material are used, could result in a failure, malfunction, or defect endangering the safe operation of the airplane. For those air carriers that use a mechanic for the initial inspection, an inspector should be used to conduct the validation inspection. For those air carriers that use an inspector for the initial inspection, another qualified inspector should be used to conduct the validation inspection.

2 Procedures, standards, and limits necessary for critical inspections and acceptance or rejection of the items required to be inspected, and for periodic inspection and calibration of precision tools, measuring devices, and test equipment.

(4) Failure Conditions. When showing compliance with § 25.981(a)(3), the effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered. For the purpose of compliance with § 25.981, “extremely remote” failure conditions are those not anticipated to occur to each airplane during its total life, but which may occur a few times when considering the total operational life of all airplanes of one type. This definition is consistent with that developed by the Aviation Rulemaking Advisory Committee (ARAC) for a revision to FAA AC 25.1309-1A. “Extremely improbable” failure conditions are those so unlikely that they are not anticipated to occur during the entire operational life of all airplanes of one type. This definition is consistent with the definition provided in AC 25.1309-1A. Likely damage is damage that using engineering judgement or past experience would lead one to conclude that an occurrence is foreseeable. Examples of likely damage are: a wire bundle located where a mechanic could use it as a hand hold; an instrument located where if someone dropped a wrench, damage would result; or a fuel probe located where a mechanic could use it as a step in the tank, etc.

(a) The analysis should be conducted considering the deficiencies and anomalies listed in paragraph 7c of this AC, failure modes identified by the review of service information (including review of supplier service data), and any other failure modes identified by the functional hazard assessment of the fuel tank system. For example, the presence of conductive debris such as lockwire, steel wool, nuts, bolts, rivets etc., should be assumed. Section 25.981 specifically requires that the effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered when demonstrating compliance. Credit for fail-safe features must be substantiated. For example dual layers of insulation on wires or addition of sleeving has been claimed as providing fail-safe features.

(b) The level of manufacturing variability, aging, wear, corrosion, and likely damage that must be considered should be determined based upon evaluation of the detectability of degraded or out-of-specification configurations, and established and documented within the analysis. In-service and production functional tests, component acceptance tests, and maintenance checks may be used to substantiate the degree to which these states must be considered. For example, inspection of fuel tank system bonding on production airplanes has shown that some bonds were inadequate. Functional testing of all bonding was incorporated to address this deficiency. In some cases (e.g., component bonding or ground paths), a degraded state will not be detectable without periodic functional test of the feature. For these features, inspection/test intervals should be established based on previous service experience on equipment installed in the same environment. If previous experience on similar or identical components is not available, conservative initial inspection/test intervals should be established until design maturity can be assured.

(5) External Environment. The severity of the external environmental conditions that should be considered when demonstrating compliance with § 25.981 are those

established by certification regulations and advisory material (e.g., HIRF, lightning) regardless of the associated probability of exposure to any external environment. For example, the probability of lightning encounter should be assumed to be one.

(6) External Sources of Tank Auto-ignition. The possibility of fuel tank ignition due to surface-ignition sources created by external tank heating should be considered. This includes heating of the tank due to operation or failure of systems outside the tank within both the pressurized and unpressurized areas of the airplane, such as overloaded electric motors or transformers, failures in the pneumatic system and/or ducting that could cause localized heating of tank surfaces. In addition, the possibility of localized heating due to external fires must be considered.

(a) Section 25.967(e) requires that, “Each fuel tank must be isolated from personnel compartments by a fume proof and fuel proof enclosure.” Leakage of fuel or vapor into spaces adjacent to the fuel tank, where a secondary fuel and fume-proof barrier is not provided, has typically been assumed for areas such as:

- the wing leading (including any adjacent compartment such as the strut) and trailing edges,
- fairings located below the fuel tanks,
- fuel pump enclosures, and
- unpressurized areas of the fuselage surrounding fuel tanks located in the empennage.

Components located in these areas have been required to meet explosion-proof requirements. These components or systems must be included in the analysis. Examples of equipment include, but are not limited to, Environmental Control System (ECS) air conditioning packs, motors, power assisted valves, fuel pumps, hydraulic pumps/motors, certain flight control actuators, ECS controls, wiring and valves.

(b) A safety review of flammable fluid leakage zones adjacent to fuel tanks will be needed to determine that the design complies with the requirements of §§ 25.863(a) and 25.981. In general, the fire protection philosophy for any area considered a flammable fluid leakage zone is to assume that flammable vapors may be present in the zone and to minimize the probability of ignition of vapors (§ 25.863(a)). This has typically been accomplished by using combinations of the following design considerations:

- grounding and bonding of electrical equipment,
- qualification of electrical equipment as explosion proof,
- sealing of electrical connectors,
- proper support, protection and separation of wiring,
- drainage provisions in the leakage zone,
- ventilation of the leakage zone in-flight, and areas around auxiliary tanks, and

- immediate maintenance action to correct running leaks in these areas.

(c) Surface temperatures in areas adjacent to fuel tanks. The FAA has approved installations, where surfaces adjacent to the tank experience temperatures in excess of the internal fuel tank surface temperature limit. Manufacturers have substantiated that the conditions (ambient pressure, dwell time, fuel type, etc.) within these areas are such that a higher value may be used. For example, a maximum allowable surface temperature of 400 °F, with a transient excursion up to 500 °F for a maximum duration of two minutes, has been accepted for certain pneumatic system installations. The excursion above 400 °F occurs only during failure conditions such as failure of the engine pneumatic system to regulate temperature, or duct rupture. Approval of these elevated temperatures has been based on compensating design features, such as an over-temperature shutoff of the pneumatic system so that the surface temperatures adjacent to the tank cannot exceed the surface ignition temperature justified for the fluid type including the effect of local airflow and ventilation conditions within the zone, e.g., the 500 °F value. Internal tank surface temperatures resulting from the failure should not exceed the surface temperature limit for the fuel type used as described in paragraph 8e of this AC.

(7) Electrical Ignition Sources. The applicant should perform a failure analysis of all fuel systems and subsystems with wiring routed into fuel tanks. Systems that should be considered include fuel pump power and control and indication, fuel quantity indication, fuel temperature indication, fuel level sensors, and any other wiring routed into or adjacent to fuel tanks. The analysis should consider system level failures, failures within LRUs and component level failures discussed below. The analysis should include existence of latent failures and subsequent failures that may lead to an ignition source within the fuel tank. Examples include undetected failures of tank components or wiring, the undetected presence of conductive debris, damage to FQIS or level sensor probes, or corrosion, in combination with external failures such as hot shorts or induced transients (EMI and lightning). In addition, the applicant should provide a description of the protective means employed in the fuel system wiring. This should include a description of features such as separation/segregation, transient suppression devices, shielding of wiring, and methods employed to maintain configuration control of critical wiring throughout the life of the airplane.

**NOTE:** EMI protection is often a function of circuit and surrounding structural characteristics. Therefore care should be taken when determining the effects of exposing a system with faults present to some EMI threats especially lightning.

(8) Electrical Short-Circuits.

(a) One method that may provide protection of circuits that enter fuel tanks is the incorporation of a transient suppression device (TSD) on the circuit close to the point where those wires enter fuel tanks. Consideration should also be given to protection of wiring between the TSDs and the tank if the protection devices are not located at the tank entrance, and also to the possibility of transients being induced in the wiring between the

TSDs and the electrical devices in the fuel tanks. Caution should be exercised when using TSDs to be sure that the TSD addresses both voltage and current suppression.

(b) Another method of protection that has been used to provide a fail-safe design with respect to electrical shorts is separation of wiring to electrical devices in the fuel tanks from other electrical power wires and circuits, combined with shielding between wiring that enters fuel tanks and any other electrical power-carrying wires in the aircraft installation. The effects of electrical short circuits, including hot shorts, on equipment and wiring that enters the fuel tanks should be considered, particularly for the fuel quantity indicating system wiring, fuel level sensors, and probes. Latent failures from factors such as contamination, damage/pinching of wires during installation, or corrosion on the probes, connectors, or wiring should be considered when evaluating the effects of short circuits. The wire routing, shielding, and segregation outside the fuel tanks, including within the FQIS components (e.g., gauging units), should also be considered when evaluating the effects of short circuits. The evaluation should consider both electrical arcing and localized heating that may result from short circuits on equipment, fuel quantity indicating system probes, and wiring. The evaluation of electrical short circuits should include consideration of shorts within electrical equipment, and wiring from the equipment into the fuel tank. Prevention of fuel ignition from electrical shorts to wiring that enters fuel tanks may require specific wire and circuit separation and wire bundle shielding.

(9) Line Replacement Unit (LRU) Design Evaluation. The design review should include evaluation of the separation and/or protective features incorporated into any fuel system LRU whose failure could result in high level electrical power (above intrinsically safe levels) entering the fuel tank. For example, circuit board failures could cause the fuel quantity gauging system LRU power supply circuits to come into contact with circuits that lead into the fuel tank, resulting in a possible ignition source. Failures that can lead to violating separation within the LRU can be external and internal events. External failures include over voltage or over current, high humidity, temperature, vibration, shock, and contamination. Internal failures include manufacturing defects or flaws in the conductor, substrate or coating. To address these failures isolation and physical separation between critical signals should be provided, or adequate protective features, such as transient suppression devices as discussed earlier, should be provided to protect the circuits that enter the fuel tank. Any LRU that meets the design requirements identified in reference (3), paragraph 4e, of this AC, Underwriters Laboratories Inc., UL 913, Intrinsically Safe Apparatus and Associated Apparatus for use in Class I, II, III, Division 1, Hazardous (Classified) Locations, is considered acceptable, provided the following issues are addressed. Ideally, higher power circuits within the LRU should not be located on the same circuit board or in a wire harness or electrical connector with intrinsically safe circuits or wiring. There should be a physical barrier between circuit boards to isolate the intrinsically safe circuits from the effects of broken components or fire within the LRU. If limiting devices are installed on the same circuit board in series with system circuitry to limit the amount of power or current transmitted to the fuel tank, there should be three inches between the traces, unless the manufacturer can justify a smaller separation on the basis that the effects of fire on the circuit board will not compromise the intrinsically safe circuit(s).

(10) Electromagnetic Effects, including Lightning, Electromagnetic Interference (EMI), and High-Intensity Radiated Fields (HIRF).

(a) The effects of electrical transients from lightning, EMI, or HIRF on anything conductive (e.g., fuel tank plumbing, structure, fuel, equipment and wiring) within the fuel tanks should be considered, particularly for the fuel quantity indicating system wiring and probes. Latent failures from factors such as contamination, damage, or corrosion on the probes or wiring should be considered when evaluating the effects of electrical transients. The wire routing, shielding, and segregation of conductors (e.g., plumbing, component casings, wiring, etc.) outside the fuel tanks should also be considered when evaluating the effects of electrical transients, because the transient generation and coupling to conductors may occur outside the fuel tanks. The evaluation should consider both electrical sparks and arcs and localized heating that may result from lightning, EMI, and HIRF transients on the fuel tank system, fuel quantity indicating system probes, and wiring.

(b) Latent failure of electromagnetic protection features, such as shielding termination corrosion, shield damage, and transient limiting device failure should be considered and appropriate indication or inspection intervals established to prevent the existence of latent failure conditions. The failure of other system components may also affect EMI protection. Consequently, the effect of any anticipated failure on the continued environmental protection should be considered. For example, a normally high impedance electrical load that fails due to an electrical short, or a normally low impedance load that fails to an open state, can cause a significant redistribution of the lightning currents within a wire bundle; hence, the voltage induced at components within the fuel tank.

(c) The evaluation of electromagnetic effects from lightning, EMI, or HIRF should be based on the specific electromagnetic environment of a particular aircraft model. Standardized tests, such as those in RTCA DO-160, Sections 19, 20, and 22, are not sufficient alone, without evaluation of the characteristics of the specific electromagnetic environment and induced transient levels assigned to systems installed within a particular airplane model, to show that appropriate standardized RTCA document DO-160 test categories, procedures and test levels are selected. Simulation of various latent failures of fuel system components within the tanks may be required to demonstrate the transient protection effectiveness. Effectiveness of the transient protection features should be verified using the appropriate RTCA document DO-160 test procedures and test levels determined above.

(d) Prevention of fuel ignition due to electrical transients from lightning, EMI, or HIRF may require specific wire segregation and separation, wire bundle shielding, or transient suppression for wires entering fuel tanks. Effectiveness of the transient protection features should be verified using the appropriate RTCA document DO-160 test procedures and test levels determined above.

(e) Redundancy of bond paths. Failure of bonding jumpers is generally considered a latent failure, since there is no annunciation or indication of the bonding failure. The airplane fleet fuel tank inspections that occurred as a result of the TWA 800

investigation showed that failure of bonding jumpers, due to damage, wear, or manufacturing errors, was not unusual. Based on this, it would be difficult to show that failure of a single bonding jumper is extremely remote or extremely improbable. Therefore, the electrical bonding jumper or other bonding provisions would need to consider the consequences of these latent failures. This may result in designs that incorporate electrical bonding redundancy, if the failure of a single electrical bonding feature could create a fuel ignition source. Additionally, manufacturers would need to consider the use of appropriate maintenance to detect failed bonding jumpers. An example of such maintenance might include periodic inspections to limit latency.

(f) Self-bonding couplers. Early generation self-bonding flexible fuel couplers did not have multiple bonding paths. Thus these bonding couplers exhibited single-point failures which caused loss of function. These self-bonding flex couplers have failed because of missing bonding springs, anodizing on bonding surfaces, and incorrect installation. The safety assessment of newer designs incorporating multiple bonding paths must consider these failure modes and qualification testing should show no ignition sources are present in the full up and possible degraded condition with failure modes present within the couplings. For example, failure assessments of clam shell type self bonding metallic couplings in composite fuel tanks have shown arcing could occur during lightning conditions if a coupling was improperly latched, or became unlatched and fell to the bottom of the fuel tank. The design of the coupling would need to address these failure modes. Improper latching could be addressed through positive latching features with tactile and visual indication that the coupling is properly latched. Redundant fail safe features such as dual hinge pins, dual latching features, redundant bonding features, etc., would be needed to address other possible failure modes.

(g) Resistance or impedance limits of airplane electrical bonding provisions.

1 There is no specific FAA guidance on maximum resistance or impedance of airplane electrical bonding provisions. Electrical bonding within a fuel system should be tailored to the performance requirements of a particular airplane design. The electrical bonding should consider the electrical sources, such as electrical faults, fuel static electrification, and lightning. The electrical bonding should also consider the specific airplane fuel system design, which would include the structure material used (aluminum, carbon fiber composites, fiberglass composites, etc.), the configuration of the fuel system (routing of fuel tubes, wires, and hydraulic tubes), and the electrical bonding concept (intentional isolation, self-bonding fittings, separate bonding jumpers, etc.). Given the large variation in design approaches, and the close relationship between the design approach and the electrical bonding requirements, it is not practical for the FAA to provide specific guidance on maximum bonding resistance or impedance.

2 Some airplane TC holders have performed tests on their airplanes to determine the specific requirements for electrical bonding for threats such as lightning. Others, in the absence of specific airplane test data, have chosen conservative electrical bonding approaches. The approach is a decision each TC holder should make based on the specific situation for that TC holder's airplane models.

(h) Bonding integrity checks. Past experience has shown measurement of bond resistance is the desired method of assuring bond path integrity. During bonding resistance measurements, damage of protective finish of components may be caused in order to penetrate the insulating anodized surface layer, which may lead to subsequent corrosion damage. This concern has resulted in some TC holders defining non-intrusive inspections for electrical bonding. These inspections may include detailed visual inspections, if the quality of the electrical bonding feature can be adequately assessed by visual cues, such as visible corrosion, breakage, tightness or missing bonding provisions. For critical bonds this method would not by itself be adequate. Other inspection methods include inductively-coupled loop resistance measurements that eliminate the need to disconnect bonding jumpers or to penetrate corrosion-prevention coatings. The need for bonding inspections, the frequency of the inspections, and the determination as to whether the inspections must be an ALI, should be established as a result of the fuel tank system safety assessment.

(i) Bond Corrosion and Integrity.

1 Degradation of electrical bonding provisions, such as bonding jumpers, has occurred on in-service airplanes. Results from airplane fuel tank inspections conducted on a sample of airplanes by manufacturers and operators showed discoloration, corrosion, and damage to bonding jumpers. It is not clear if the discoloration indicates corrosion that will become more severe with time, or is simply a surface color change. The applicant must define CDCCLs and the bonding feature characteristics, such as visible corrosion, discoloration, jumper strand separation, and jumper strand breakage that will be used to distinguish discrepant bonding provisions.

2 The level of corrosion observed on bonding features, specifically on bonding jumpers, varied greatly across airplane fleets. While some airplanes within a fleet and certain locations within the fuel tanks showed no evidence of corrosion, other airplanes and locations exhibited higher levels of corrosion. Inspection results reported to the FAA indicate materials used in certain bonding jumpers (tin plated copper) may be more prone to corrosion. Nickel plated copper wire does not experience similar corrosion. Corrosion programs for airplane structure have long recognized the variability of corrosion within the fleet. Factors that influence the level of corrosion of bonding jumpers include fuel type (sulfur content, etc.), presence of water in the fuel tank, installation effects such as cracking of the tin plating when the jumper is installed, temperature, humidity, and chemicals used for preparation of the fuel tanks prior to airplane storage, etc. While certain levels of corrosion or discoloration may be acceptable between inspection intervals, demonstration of compliance should include substantiation that the materials used in the bonding jumpers are appropriate for use in the fuel tanks in consideration of proposed inspection intervals. This substantiation should include test data that considers the variability in corrosive environments and factors noted above that may exist on in-service and storage of airplanes in the fleet.

(j) Definition of major component. There is no specific FAA guidance on “major components” in § 25.901(b)(4). However, the term “major components,” as specified in § 25.901(b)(4) should not be used to limit the review of fuel system ignition sources as



required in § 25.981. Section 25.981, Fuel tank ignition prevention, states: “(a) No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors.” This stipulation is in addition to the provisions regarding major components in § 25.901(b)(4). For example, fuel tube flexible coupling and components as small as nuts, bolts and washers may develop sufficient charge to cause arcing due to electrostatics and lightning conditions if not properly accounted for in the design. Electrical bonding would need to be considered if these couplings are identified as ignition sources during the ignition source evaluation and assessment.

(11) Friction Sparks. The failure modes and effects analysis (FMEA) should include evaluation of the effects of debris entering the fuel pumps, including any debris that could be generated internally, such as any components upstream of the pump inlet. Industry fuel tank cleanliness practices and design features intended to preclude debris entering the fuel pumps have not been effective at eliminating debris. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, sealant, lockwire, etc. have been inducted into fuel pumps and contacted the impeller. This condition could result in creation of friction sparks and should be an assumed failure condition when conducting the system safety assessment. Fail-safe features should be incorporated into the fuel pump design to address this condition. Examples of means that may be incorporated into the fuel pump design to address this concern include:

- installation of inlet flame arrestors,
- use of reticulated foam,
- use/installation of jet fuel pumps without impellers to scavenge fuel, or
- maintaining fuel over the pump inlet throughout the airplane flight attitude envelope.

## **11. Component Qualification Considerations.**

a. Component Qualification Review. Qualification of components, such as fuel pumps, has not always accounted for unforeseen failures, wear, or inappropriate overhaul or maintenance. Also, incomplete use of the MIL specification explosion proof procedures has led to some fuel pumps entering airline service having never been run in an explosive environment. This combined experience suggests that more needs to be done to establish the capabilities of fuel pumps and other fuel system components to operate safely in an explosive environment. Such capability should be substantiated (or resubstantiated for the SFAR compliance) considering these factors in addition to the conditions noted in paragraph 7c of this AC. The amount of qualification review can be significantly reduced if the fail-safe features noted earlier in this AC are followed (e.g., not operating pumps in vapor spaces of the tank, incorporating ground fault protection on the electrical circuit, etc.). Therefore, an extensive evaluation of the qualification of components may be required if a qualitative assessment does not eliminate the component as a potential ignition source.

b. Maximum Component Temperature for Qualification of Fuel System Components. Maximum component temperatures may be determined experimentally. Tests should be conducted long enough for the component to reach the maximum temperature. All

foreseeable failures and malfunctions of the fuel tank components (including those failures and malfunctions that could be undetected by the flightcrew and maintenance personnel) should be considered when determining maximum temperatures.

(1) As discussed in AC 25.981-1, issued in 1971, components mounted adjacent to the exterior surface of the fuel tank can create a high localized temperature at the inner surface of the tank. This can be investigated by laboratory tests that duplicate the installation, or by a validated heat transfer analysis using the maximum potential temperature of the component.

(2) When engine bleed air ducting, ECS, and other airplane components or systems are located near fuel tanks, a FMEA should be done to determine failures of adjacent systems or components that could cause elevated surface temperatures. The maximum internal tank temperatures that can occur during normal and failure conditions should be determined. Systems, such as over-temperature protective devices, should be evaluated to determine if periodic health checks are necessary to assure that latent failures do not exist.

c. Possible Failure Modes for Determination of Maximum Component Temperatures. The following list, although it does not include all possible failure modes, suggests some conditions that should be explored in determining the maximum temperature expected for fuel tank components:

(1) Fuel Pumps.

(a) Normal fuel pump operation considering the highest hot day ambient and fuel tank temperatures.

(b) Single phase operation of three-phase electrical fuel pumps. In many cases fuel pump motors are protected by a (single) three-phase circuit breaker. In several instances, resetting of circuit breakers has resulted in arcing inside the fuel tank and the development of an ignition source. Therefore, the fuel pump circuit should also preclude development of an ignition source if the breaker is reset or forced in by a mechanic. Features such as non-resettable breakers or fuses are design features that would meet the fail-safe requirements of § 25.901 that apply to this failure condition.

(c) Two-phase operation of three-phase electrical fuel pumps. Failure of a single phase of a multiple-phase fuel pump may significantly increase the load on the remaining phases of the pump and generation of heat in the pump. In many cases thermal protection features within the pump have been incorporated to address this failure condition but these means have not been effective at preventing continued operation of a pump with a failed electrical phase. Another failure condition that should be considered is subsequent failure of a second phase of the pump and possible arcing or heat damage. In general, pumps should not be allowed to operate following failure of a single electrical phase of the pump if such operation could result in development of an ignition source. Automatic protective means, such as arc/ground fault interrupters or other means, should be provided to shut down

the pump when a single electrical phase failure occurs. Periodic inspections or maintenance of these features may be required.

(d) Dry operation of fuel pumps, including lack of lubrication. Service history has shown that flightcrews and maintenance personnel have inadvertently operated fuel pumps for long periods of time without fuel in the fuel tank. Fuel pumps are typically qualified for dry run operation for periods of time based upon assumptions made about possible duration of inadvertent operation, or failure conditions, that could result in dry running of the pump. For example, some pumps were operated during qualification testing up to a maximum of 8 hours continuously, with total accumulated dry run operation of 24 hours. These qualification tests were accomplished in order to demonstrate that fuel pump performance was still adequate following the dry pump operation. The tests were not demonstrated in an explosive environment and hence were not intended to qualify the pumps for such operation. In other cases previous approvals were predicated on the assumption that the fuel pump would not be dry run operated because the pump would be turned off by the flight/ground crew following a pump low-pressure indication. Indefinite dry operation of pumps may result in surface temperatures above the auto-ignition temperature of the fuel or expose the pump to dry run operation where debris from the fuel tank could enter the impeller and cause sparks. Manufacturers recommended procedures have not been shown to be adequate in preventing dry run operation. Therefore, additional fail-safe features are necessary to preclude dry run operation of airplane fuel pumps. One or more of the following fail-safe means should be considered for protection of fuel pumps:

1 Incorporate design features to keep the fuel pump inlet submerged in jet fuel to prevent dry running of the pump under all operating conditions.

2 Incorporate automatic pump shutoff features into the fuel pump or airplane to preclude dry run operation.

3 Other means such as installation of flame arrestors in the fuel pump inlet to preclude flame propagation into the fuel tank.

(e) Temperatures associated with the fuel pump following wet operation with wet mechanical components both at zero and reduced fluid flow.

(f) Temperatures considering the moving mechanisms that are locked or seized.

(g) Temperatures generated as a consequence of pump impeller slippage.

(h) Failed Bearings. The effects of wear on fuel pump features incorporated into the design to maintain explosion proof characteristics should be evaluated. For example, wear of bearings or failures, including spinning of any bushings, and possible effects on quenching orifices should be evaluated. In many cases fuel pump explosion proof features are not redundant and failure or degradation of the features is latent. If single or probable combinations of failures in the fuel pump can cause an ignition source, § 25.981 requires

incorporation of fail-safe features noted previously. If wear of the pump can cause degradation of fail-safe features, appropriate inspection, overhaul or life limiting of the pump should be included in the Limitations section of the Instructions for Continued Airworthiness.

(2) Fuel Quantity Indicating System (FQIS) wiring in the tank, with maximum voltage and current applied considering normal and failure conditions including the effects of high voltage systems outside the tank in proximity to the co-located FQIS wires.

(3) FQIS component in the normal and failed state with the above associated maximum voltages and fault currents applied.

(4) Float Switch System temperatures should be determined considering the maximum environment temperatures and the application of the applicable maximum voltage and fault currents.

(5) Temperatures of the fuel system components should also be evaluated considering the failure of bonding straps.

(6) Pneumatic system temperatures need to be evaluated for the effects of duct rupture impinging on the external tank surface, and radiation and conduction heat transfer associated with the tank and components affecting tank wall temperatures (see previous discussion of spaces adjacent to fuel tanks).

(7) Electrical defects that generate excessive heat. Arcing at the electrical connections to the pump housing or within the connector.

(8) Submerged heat exchangers. Operating under conditions of maximum heat rejection to the fuel.

(9) Failed or Aged seals. Spraying of fuel in the tank from any pressurized fuel source may cause electrostatic charging of components in the fuel tank and significantly lower the flammability temperature of the fuel tank vapor. Therefore, the design should not include features that result in spraying of fuel, such as fuel pump motor cooling flow return to the tank. In addition, use of sealant in connectors that is not compatible with the fuel may allow leakage into the connector and the possibility of a fire near the connector.

(10) Fuel Line Couplings. Aging of seals may result in hardening of the seal material and leakage and spraying of fuel within the fuel tank; therefore, fuel line coupling designs should be evaluated and a design life should be established for all seals that are shown to age and allow leakage that can cause unacceptable electrostatic charging of components.

(11) Fuel Pump Cooling Flow. Fuel used for cooling of fuel pumps may be sprayed from the fuel pump. Fuel pump cooling flow should not be sprayed into the fuel tank vapor

space. Means should be provided to distribute the cooling fuel into the fuel tank at or near the bottom of the fuel tank.

(12) Electrical Connector Sealant, Seals, and Explosion Proofness. Electrical connections to fuel pumps are typically located either inside or outside the fuel tank in areas of the airplane where the presence of flammable fuel vapors should be assumed because no secondary sealing of fuel is provided. Fuel leakage and corrosion at electrical connectors located outside the fuel tank has allowed the presence of both flammable vapors and electrical arcing at connectors, resulting in fires. In other applications, arcing has occurred at the pump connections inside the fuel tanks, requiring installation of appropriately sized steel shields to prevent arcing through the connector or pump housing into the fuel tank or areas where flammable vapor could exist.

(13) Arcing at the pump electrical connections should be assumed with fuel present in the safety assessment. The energy release during an arcing condition may be limited by installation of arc/ground fault protection features. The pump connector should be shown to contain any resultant arcing or fire and maintain all surface temperatures below the auto-ignition temperature of the fuel. Component manufacturer maintenance records and qualification test results should be reviewed to establish that the sealant is compatible with the fuel and to determine if a design life or periodic inspections for the pump connector are needed.

## **12. Instructions for Continued Airworthiness of the Fuel Tank System--§ 25.1529.**

a. Based upon the evaluations required by § 25.981(a), Amendment 25-102 also added a new requirement to § 25.981(b) to require that CDCCL, inspections, or other procedures, be established as necessary to prevent development of ignition sources within the fuel tank system, and that they be included in the airworthiness limitations section of the ICA required by § 25.1529. This requirement is similar to that contained in § 25.571 for airplane structure. Amendment 25-102 also added a new requirement to Appendix H to part 25, Instructions for Continued Airworthiness (ICA), to provide any mandatory fuel tank system inspections or maintenance actions in the limitations section of the ICA.

b. Critical design configuration control limitations include any information necessary to maintain those design features that have been determined by analysis of the fuel tank system as needed to preclude development of ignition sources. They may include any maintenance procedure that could result in a failure, malfunction, or defect endangering the safe operation of the airplane, if not performed properly or if improper parts or materials are used. This information is essential to ensure that maintenance, repairs, or alterations do not unintentionally violate the integrity of the original type design of the fuel tank system.

c. Any fuel tank system components that are determined to require periodic maintenance, inspection, or overhaul to maintain the integrity of the system or maintain protective features incorporated to preclude a catastrophic fuel tank ignition event must be defined and included in the Limitations section of the ICA. The inspection interval should be

established based upon the standard practices defined in AC 25.1309 for evaluation of component failures. Examples of such items include:

(1) Aging fuel line couplings seals/ o-rings. In certain instances, materials used in fuel line couplings may lose flexibility and harden with age. During suction feed or pressurized operation, the seal may allow air to enter the fuel line or leak, allowing spraying of fuel in the tanks or other areas of the airplane where spraying fuel could create a fire hazard. Repetitive inspections, functional checks, or mandatory replacement intervals may be required to prevent leakage.

(2) Wear of pump bushings, bearings, and seals may significantly affect the performance of fuel pumps and degradation of features necessary to maintain the explosive proof qualification. In most cases these failures conditions are latent, therefore incorporation of other fail-safe features, as discussed earlier in this AC, would be required. If fail-safe features are incorporated, such as installation of feeder tanks that are filled with ejector pumps, functioning of those features would need to be assured by indications or periodic functional tests. Installation of fuel level sensors in the feeder tanks would provide continuous monitoring of the function. Another means could be installation of flow indicators in the flow line of the ejector pump that can be viewed by maintenance personnel and a mandatory periodic inspection of this function is one example of a method of mandatory maintenance action.

(3) Fuel pump protective features. If failure of an arc/ground fault protective feature and/or a thermal fuse (closed) is latent and this feature is needed to maintain fail-safe features, periodic checks would likely be needed.

(4) Transient suppression/energy limiting devices. If failure of the device is latent and this feature is needed to maintain fail-safe features, periodic checks will be needed.

(5) Wire shield grounding.

(6) Component grounds and wires will likely require inspections and measurements to determine proper grounding.

(7) Fuel tank access panel/door seals leakage, resistance checks.

(8) Fuel pump connectors, corrosion, wear.

(9) Fuel pump electrical supply conduit structural, sealing integrity.

d. Maintainability, both in the design and procedures (i.e., Master Minimum Equipment List (MMEL, Airplane Maintenance Manual, etc.), should be verified. This should include, as a minimum, verification that the system and procedures support the safety analysis assumptions and are tolerant to anticipated human errors, and that any critical procedures are highlighted for consideration as required inspection items. (See 14 CFR 121.369(b) for considerations of a "required inspection item.")

e. Visible Identification of Critical Design Configuration Control Limitations.

(1) Section 25.981(b) states that "...visible means must be placed in areas of the airplane where maintenance, repairs, or alterations may violate the critical design configuration control limitations." The design approval holder should define a method of ensuring that this essential information will be communicated by statements in appropriate manuals, such as Wiring Diagram Manuals, and be evident to those that may perform and approve such repairs and alterations.

(2) An example of a CDCCL that would result in a requirement for visible means would be maintaining wire separation between FQIS wiring and other high power electrical circuits where separation of the wiring was determined to be a CDCCL. Acceptable methods of providing visible means would include color coding of the wiring and labeling. For retrofit of markings onto existing wiring, placement of identification tabs at specific intervals along the wiring would be acceptable. Industry and regulatory authorities are currently developing standards for color coding of wiring for various systems. Standardization within the industry of color coding of wiring used for the fuel tank system would assist maintenance personnel in functional identification of wiring. Pink wiring has been used by some manufacturers for fuel tank system wiring. Use of this color as a standard for fuel tank system wiring is recommended by the FAA.

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