(c) Reserved.

(d) To protect design features that prevent catastrophic ignition sources within the fuel tank or fuel tank system according to subparagraph (a) of this paragraph, and to prevent increasing the flammability exposure of the tanks above that permitted in subparagraph (b) of this paragraph, the type design must include critical design configuration control limitations (CDCCLs) identifying those features and providing instructions on how to protect them. To ensure the continued effectiveness of those features, and prevent degradation of the performance and reliability of any means provided according to subparagraphs (a) or (b) of this paragraph, the type design must also include the necessary inspection and test procedures, intervals between repetitive inspections and tests, and mandatory replacement times for those features. The applicant must include information required by this subparagraph in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 25.1529. The type design must also include visible means of identifying the critical features of the design in areas of the aeroplane where foreseeable maintenance actions, repairs, or alterations may compromise the CDCCLs.

[Amdt 25/1]
[Amdt 25/6]
[Amdt 25/9]
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AMC 25.981(a) Fuel Tank Ignition Source Prevention

ED Decision 2020/024/R

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1 PURPOSE

This AMC describes how to show compliance with CS 25.981, which provides the certification requirements for the prevention of ignition sources, other than lightning, within the fuel tanks of transport category aeroplanes. This AMC includes guidelines for the prevention of failure conditions created from ignition sources other than lightning. It describes a means of compliance, using circuit-protective devices such as an arc-fault circuit-breaker (AFCB) or ground fault interrupter (GFI), to provide fail-safe features that have been accepted as showing compliance with CS 25.981. This AMC does not apply to the flammability requirements in CS 25.981(b).

2 SYSTEM SAFETY ASSESSMENT (SSA)

2.1 Before conducting an SSA of the fuel system, each applicant should assemble and review the relevant lessons learned from the overall transport fleet history, as well as from its previous products and suppliers and any other available sources to assist in identifying any unforeseen failures, wear, or other conditions that could result in an ignition source. The sources of information include aeroplane service records, flight logs, inspection records, and component supplier service and sales records.

2.2 Safety assessments of previously certified fuel systems may require additional considerations. For these safety assessments, component sales records may assist in identifying whether component failures and replacements are occurring. In addition, in some cases, changes to components have been introduced following the 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 (e.g., thrust washers) have been changed to improve the life of the pumps, which defeated the original fail-safe features of the pumps. Therefore, the 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.

2.3 The following lists summarise the design features, malfunctions, failures, and maintenance/operational-related actions that have been identified through service experience as resulting in degradation of the safety features of aeroplane fuel tank systems. These lists are provided as guidance and are not inclusive of all the failures that need to be considered in the failure assessment. They may assist in evaluating possible failure modes during the evaluation of a fuel tank installation.

2.3.1 Pumps

1. The ingestion of pump inlet components (e.g., inducers, fasteners) into the pump impeller, releasing debris into the fuel tank.
2. Pump inlet case degradation, allowing the pump inlet check valve to contact the impeller.
3. A failure of one phase of the stator winding during operation of the fuel pump motor, together with a subsequent failure of a second phase of the motor windings, resulting in arcing through the fuel pump housing.
4. Arcing due to the exposure of electrical connections within a pump housing that has been designed with inadequate clearance to the pump cover.
5. The omission of cooling port tubes between the pump assembly and the pump motor assembly during a pump overhaul.
6. Extended dry running of fuel pumps in empty fuel tanks (e.g. caused by a failure of the fuel pump relay in the on position).
7. The use of steel impellers that may produce friction sparks if debris enters the pump.
8. Debris lodged inside pumps.
9. Pump power supply connectors that have been damaged, worn, or corroded, resulting in arcing within the connector that damages the hermetic seal, causing fuel leakage.
10. Electrical connections within the pump housing that have been designed with inadequate clearance or insulation from the metallic pump housing, resulting in arcing.
11. Thermal switches ageing over time, resulting in a higher trip temperature.
12. Flame arrestors falling out of their respective mountings.
13. Internal wires coming in contact with the pump rotating group, energising the rotor, and arcing at the impeller/adapter interface.
14. Poor bonding across component interfaces.
15. Insufficient arc-fault or ground-fault current protection capability.
16. Poor bonding of components to the structure.
17. Loads transferred from the aeroplane fuel-feed plumbing into the pump housing, resulting in a failure of the housing mounts and a subsequent failure of the pump case, which defeated the explosion-proof capabilities of the pump.
18. A premature failure of the fuel pump thrust bearings, allowing steel rotating parts to contact the steel pump side plate.

19. Erosion of the fuel pump housing, causing a loss of the fuel pump explosion-proof capability and exposure of the fuel pump wiring to the fuel tank.

2.3.2 Wiring to fuel pumps

1. Wear of Teflon or other insulating sleeving and wiring insulation on wires in metallic conduits located inside fuel tanks, allowing arcing from the wire through the conduits into fuel tank ullages.
2. Damage to the insulation on wiring routed adjacent to the fuel tank exterior surfaces, resulting in arcing to the metallic fuel tank surface.

2.3.3 Fuel pump connectors

1. Electrical arcing at connections within electrical connectors due to bent pins, wear, manufacturing variability (e.g. tolerances), or corrosion.
2. Fuel leakage and a subsequent fuel fire outside the fuel tank caused by corrosion or wear of electrical connectors to the pump motor, leading to electrical arcing through the connector housing (the connector was located outside the fuel tank).
3. Selection of improper insulating materials in the connector design, resulting in degradation of the material because of contact with the fuel that is used to cool and lubricate the pump motor.

2.3.4 Fuel quantity indicating system (FQIS) wiring

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

2.3.5 FQIS probe installation

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

2.3.6 Valve actuators

A failure of one solenoid in a dual solenoid actuated valve, resulting in overheating of one solenoid to a temperature above the auto-ignition temperature.

2.3.7 Float switch systems

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

2.3.8 <u>Fuel tubes, vent tubes, conduits, and hydraulic lines.</u>

1. Poorly conducting pipe couplings that may become electrical arc sources when exposed to electric currents.
2. Insufficient clearances between tubes and the surrounding structure.
3. Intermittent electrical bonding in flexible couplers.
4. Bonded couplers unable to conduct the expected power fault currents without arcing.

2.3.9 Electrical generator power feeder cables

1. Arcing of electrical power feeder cables to a pressurised fuel line, resulting in a fire adjacent to the fuel tank.
2. Arcing of electrical power feeder cables to an aluminium conduit, resulting in molten metal dropping onto a pressurised fuel line and consequently causing leakage of pressurised fuel.

2.3.10 Bonding straps

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

2.3.11 Pneumatic system failures

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

2.3.12 Electrostatic Charge

1. The use of a non-conductive type of reticulated polyurethane foam in only a portion of the fuel tank system, which allowed electrostatic charge build-up and arcing in the unprotected portion of the system.

2. Spraying fuel through refuelling nozzles located in the upper portion of the tank.

3 FUEL VAPOUR IGNITION SOURCES

3.1 Overview

There are four primary phenomena that can result in the ignition of fuel vapour within aeroplane fuel tanks:

— Electrical sparks and arcs,

— Filament heating,

— Friction sparks, and

— Auto-ignition or hot surface ignition.

3.1.1 The conditions required to ignite fuel vapour from these ignition sources vary with the 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 vapour from the fuel tank, it should be assumed that a flammable fuel/air mixture may exist in aeroplane fuel tanks, and it is required that no ignition sources be present.

3.1.2 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 vapour 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 should 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. The testing of components may be accomplished using several military standards and component qualification tests. For example, Method 511.6, Procedures I and II, of Military Standard MIL-STD-810H 'Environmental Engineering Considerations and Laboratory Tests' dated January 2019 defines one method that can be used for showing that a component is explosion proof as defined in Appendix C of this AMC. Section 9 of EUROCAE ED-14G Change 1, dated January 2015, 'Environmental Conditions and Test Procedures for Airborne Equipment', and the equivalent RTCA, Inc., Document No DO-160G dated December 2010, can also be used for showing that airborne equipment is explosion proof.

3.2 Electrical sparks and electrical arcs

3.2.1 Laboratory testing has shown that the minimum ignition energy in an electrical spark required to ignite hydrocarbon fuel vapour is 200 microjoules*. Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as FQISs, the energy of any electrical arcs or sparks that are created in any fuel tank should be less than 200 microjoules during either normal operation or operation with failures.

** The 200-microjoule level comes from various sources. The most quoted is from Lewis and von Elbe's book, Combustion, Flames and Explosions of Gases (Florida: Academic Press, Inc., 1987; (orig. publ. 1938)). It 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 greater than 200 microjoules.*

Note: Standards that allow 320 microjoules are not acceptable for showing intrinsic safety. ('Intrinsically safe' is defined in Appendix C, paragraph C.19, of this AMC).

3.2.2 To ensure that the design has adequate reliability and acceptable maintenance intervals, a safety factor 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 system operations at minimum ignition energies of up to 50 microjoules would be acceptable. Under failure conditions, the system should have an ignition energy of less than 200 microjoules.

3.3 Filament heating current limit

Analyses and testing indicate that a small piece of steel wool will ignite a flammable mixture when a current of approximately 100 milliamperes (mA) root mean square (RMS) is applied to the steel wool. Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as FQIS, 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 safety factor should be applied to this value when establishing a design limit. A maximum steady-state current of 25 mA RMS is considered an intrinsically safe design limit for electronic and electrical systems that introduce electrical energy into fuel tanks. For failure conditions, the system should limit the current to 50 mA RMS, and induced transients to 125 mA peak current.

3.4 Friction sparks

Pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, lockwire, roll pins, cotter pins, drill chips, manufacturing debris, and so forth may be drawn into fuel pumps and contact the impeller, resulting in the possibility of metallic deposits on the rotating and stationary components within the pump. This condition has resulted in the creation of friction sparks, and this should be an assumed failure condition when conducting the SSA. Fail-safe features as described in paragraph 5.2.19.2.2 of this AMC have been used to mitigate this hazard.

3.5 Maximum allowable surface temperatures

CS 25.981(a)(1) and (2) requires applicants to:

(1) Determine the highest temperature allowing a safe margin below the lowest expected auto-ignition temperature of the fuel in the fuel tanks.

(2) Demonstrate that no temperature at each place inside each fuel tank where fuel ignition is possible will exceed the temperature determined under subparagraph (a)(1) of this paragraph. This must be verified under all probable operating, failure, and malfunction conditions of each component whose operation, failure, or malfunction could increase the temperature inside the tank.

3.5.1 Auto-ignition temperatures of fuels

Fuels approved for use on transport category aeroplanes have differing auto-ignition temperatures. The auto-ignition temperature of JP-4 (wide-cut jet fuel) is approximately 242 °C (468 °F) at one atmosphere of pressure. Under the same atmospheric conditions, the auto-ignition temperature of JET A (kerosene) is approximately 224 °C (435 °F) to 232 °C (450 °F), and of gasoline (i.e. petrol) is approximately 427 °C (800 °F). The auto-ignition temperature of these fuels varies inversely with the ambient pressure. Also, as stated in ASTM E659, Standard Test Method for Autoignition Temperature of Chemicals, 'the autoignition temperature by a given method does not necessarily represent the minimum temperature at which a given material will self-ignite in air. The volume of the vessel used is particularly important since lower autoignition temperatures will be achieved in larger vessels.' In view of this, the factors affecting the pressure in the fuel tank should be taken into consideration when determining compliance with CS 25.981.

3.5.2 Maximum surface temperature

A surface whose temperature reaches a value 27.8 °C (50 °F) below the auto-ignition temperature of the fuel air mixture is accepted without further substantiation as providing a safe margin below the lowest auto-ignition temperature of the fuel. A temperature of 204 °C (400 °F) is accepted as the maximum surface temperature inside fuel tanks for kerosene type fuels without further substantiation. Higher maximum surface temperatures may be accepted, provided that it is substantiated that the higher surface temperature will not become an ignition source in the installation. (Maximum surface temperature considerations for areas outside the fuel tank are discussed in paragraph 5.3.6.3 of this AMC.)

3.5.3 Transient higher surface temperature

The conditions (ambient pressure, dwell time, fuel type, etc.) within fuel tanks are such that a higher value may be used as a transient surface temperature limit. For example, a maximum allowable fuel tank surface temperature of 204 °C (400 °F), with a transient excursion that reduces the safe margin below 232 °C (450 °F) (i.e., the lowest expected auto-ignition temperature) for a maximum of two minutes, can be used for kerosene type fuels. The excursion above 204 °C (400 °F) occurs only during failure conditions such as a failure of the engine pneumatic system to regulate the temperature, or a duct rupture. Utilising elevated temperatures has been based on specific design features, such as an overtemperature shutoff of the pneumatic system so that the temperature cannot reach or exceed the accepted auto-ignition temperature of 232 °C (450 °F) for kerosene type fuels. Applicants should submit comprehensive test data and an analytical rationale substantiating any transient excursion in order to show that they are maintaining a safe margin below the lowest expected auto-ignition temperature of the fuel.

3.6 Fuel system electrostatics

3.6.1 Electrostatic charges are generated in liquid hydrocarbons when they are in motion with respect to another surface such as fuelling hoses, filters, nozzles, fuel tank structure, and aeroplane plumbing. The documents referenced in Appendix B, paragraphs B.3 and B.5 of this AMC, provide information on this subject. For example, during aeroplane refuelling, 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. Additionally, if the conductivity of the aeroplane structure is low, as it is commonly in composite wings, the relaxation time of the fuel bulk charge to structure may be longer than it would be for a traditional metallic wing structure. Some composite structures have a lower conductivity than traditional metallic structures. A comparison can be made of the conductivity of the fuel with the conductivity of the aeroplane structure. Jet fuel typically has significantly lower conductivity than composite structures, meaning that the conductivity of the jet fuel dominates the charge relaxation rate and consequently results in similar charge relaxation rates between the different types of aeroplane structures. Regardless, the fuel will accumulate an electrical charge inside an aeroplane fuel tank. This electrical charge may produce a high potential on the fuel surface, and an electrical discharge to the structure. This is particularly a concern if large unbonded objects are located inside an aeroplane fuel tank. Smaller components may also become charged, and the applicant should address this in the safety assessment. If the vapour space fuel/air mixture is in the flammable range, ignition of the mixture is possible, resulting in a fuel tank explosion and fire.

3.6.2 Charge accumulation is influenced by many factors. Without an electrical conductivity improver (also referred to as a dissipator/dissipater, static dissipater additive, electrical conductivity additive, or conductivity improver additive), typical Jet A fuel has a low electrical conductivity. An electrical conductivity improver 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.

3.6.3 Water contamination, however, increases the charging tendency of the fuel without a corresponding increase in conductivity. Water interacts with the additives or the naturally occurring contaminants in the fuel to provide this pro-static effect.

When refuelling, 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/vapour space may lead to an electrical discharge capable of igniting a mixture of flammable fuel vapour and air.

3.6.4 Methods for minimising the magnitude of the developed charge have been developed, and are in place on transport category aeroplanes, including the following methods:

3.6.4.1 The refuel plumbing is sized and includes an orifice to maintain maximum flow rates in accordance with the electrostatic guidelines established by the National Fire Protection Association (NFPA) (NFA 77) and the ASTM (D4865).

3.6.4.2 Guidelines have been published (e.g. by ASTM) to limit flow velocities to 6 to 7 metres per second while the discharge port is covered with fuel. These guidelines also indicate that the flow velocity should be held to less than 1 metre per second until the discharge port is covered with fuel. These guidelines were developed with gasoline (i.e. petrol) in mind and are, therefore, conservative when applied to the kerosene type fuels used in commercial aviation. The design guidelines for commercial aircraft in SAE AIR1662 limit velocities to 6 to 9 metres per second in fuel plumbing and 3 metres per second at the exit nozzle. Limiting the flow velocity may be achieved by incorporating multiple refuelling 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 refuelling discharge at the bottom of the tank minimises 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 metre per second up to the full flow of 6 to 7 metres per second in normally emptied tanks.

Note: It may not be practical to develop a dual flow rate refuelling system, so one way to address these guidelines may be to limit the refuelling velocities to less than 1 metre per second through the use of multiple discharge points and piccolo tubes.

3.6.5 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 refuelling, the aeroplane is bonded to the refuelling vehicle with a separate bonding wire to provide an electrical path back to the fuel filter, which is the principal electrostatic charge generator. An electrical conductivity improver may also be used to increase fuel conductivity to quickly dissipate the developed charge. However, EASA does not require this type of additive, unless it is specified as part of the type design approval. Any limitations on the use of an electrical conductivity improver would need to meet the requirements of CS 25.1521, Powerplant limitations, and CS 25.1557, Miscellaneous markings and placards.

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

3.6.7 Polyurethane reticulated foam used for ignition suppression within fuel tanks and other non-conducting objects may accumulate and retain charge. These items may have to be treated with antistatic additives to prevent charge accumulation.