CS 25.945 Thrust or power augmentation system

ED Decision 2003/2/RM

(a) *General*. Each fluid injection system must provide a flow of fluid at the rate and pressure established for proper engine functioning under each intended operating condition. If the fluid can freeze, fluid freezing may not damage the aeroplane or adversely affect aeroplane performance.

(b) *Fluid tanks.* Each augmentation system fluid tank must meet the following requirements:

(1) Each tank must be able to withstand without failure the vibration, inertia, fluid, and structural loads that it may be subjected to in operation.

(2) The tanks as mounted in the aeroplane must be able to withstand without failure or leakage an internal pressure 1·5 times the maximum operating pressure.

(3) If a vent is provided, the venting must be effective under all normal flight conditions.

(4) Reserved.

(5) Each tank must have an expansion space of not less than 2% of the tank capacity. It must be impossible to fill the expansion space inadvertently with the aeroplane in the normal ground attitude.

(c) Augmentation system drains must be designed and located in accordance with CS 25.1455 if –

(1) The augmentation system fluid is subject to freezing; and

(2) The fluid may be drained in flight or during ground operation.

(d) The augmentation liquid tank capacity available for the use of each engine must be large enough to allow operation of the aeroplane under the approved procedures for the use of liquidaugmented power. The computation of liquid consumption must be based on the maximum approved rate appropriate for the desired engine output and must include the effect of temperature on engine performance as well as any other factors that might vary the amount of liquid required.

FUEL SYSTEM

CS 25.951 General

ED Decision 2013/010/R

(a) Each fuel system must be constructed and arranged to ensure a flow of fuel at a rate and pressure established for proper engine functioning under each likely operating condition, including any manoeuvre for which certification is requested and during which the engine is permitted to be in operation.

(b) Each fuel system must be arranged so that any air which is introduced into the system will not result in –

(1) Reserved.

(2) Flameout.

(c) Each fuel system must be capable of sustained operation throughout its flow and pressure range with fuel initially saturated with water at 26.7°C (80°F) and having 0.20 cm^3 of free water per litre (0.75 cm^3 per US gallon) added and cooled to the most critical condition for icing likely to be encountered in operation.

[Amdt 25/12]
[Amdt 25/13]

CS 25.952 Fuel system analysis and test

ED Decision 2003/2/RM

(a) Proper fuel system functioning under all probable operating conditions must be shown by analysis and those tests found necessary by the Agency. Tests, if required, must be made using the aeroplane fuel system or a test article that reproduces the operating characteristics of the portion of the fuel system to be tested.

(b) The likely failure of any heat exchanger using fuel as one of its fluids may not result in a hazardous condition.

CS 25.953 Fuel system independence

ED Decision 2003/2/RM

Each fuel system must meet the requirements of CS 25.903(b) by –

(a) Allowing the supply of fuel to each engine through a system independent of each part of the system supplying fuel to any other engine; or

(b) Any other acceptable method.

CS 25.954 Fuel system lightning protection

ED Decision 2020/024/R

(See AMC 25.954)

(a) For the purposes of this paragraph—

(1) A critical lightning strike is a lightning strike that attaches to the aeroplane in a location that, when combined with the failure of any design feature or structure, could create an ignition source.

(2) A fuel system includes any component within either the fuel tank structure or the fuel tank systems, and any aeroplane structure or system components that penetrate, connect to, or are located within a fuel tank.

(b) The design and installation of a fuel system must prevent catastrophic fuel vapour ignition due to lightning and its effects, including:

(1) Direct lightning strikes to areas having a high probability of stroke attachment;

(2) Swept lightning strokes to areas where swept strokes are highly probable; and

(3) Lightning-induced or conducted electrical transients.

(c) To comply with subparagraph (b) of this paragraph, catastrophic fuel vapour ignition must be extremely improbable, taking into account the flammability, critical lightning strikes, and failures within the fuel system.

(d) To protect design features that prevent catastrophic fuel vapour ignition caused by lightning, the type design must include critical design configuration control limitations (CDCCLs) identifying those features and providing information to protect them. To ensure the continued effectiveness of those design features, the type design must also include inspection and test procedures, intervals between repetitive inspections and tests, and mandatory replacement times for those design features used in demonstrating compliance with subparagraph (b) of this paragraph. The applicant must include the information required by this subparagraph in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 25.1529.

[Amdt 25/18]
[Amdt 25/26]

AMC 25.954 Fuel system lightning protection

ED Decision 2020/024/R

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1 PURPOSE

This AMC describes the tasks that should be accomplished to show compliance with CS 25.954 for lightning protection of the aeroplane fuel system. These tasks may be accomplished in a different order than that listed below, and some tasks may require iterations.

This AMC also provides a method of compliance appropriate for reliable fault-tolerant and non-fault-tolerant protection for lightning ignition sources. Any non-fault-tolerant lightning protection in an aeroplane fuel system will, in order to comply with the method of compliance set forth in this AMC, need a thorough assessment for the likelihood of failures, lightning strikes and attachment locations, and fuel tank flammability.

2 APPROACH TO COMPLIANCE

2.1 Summary

The method in this AMC divides the design features for fuel system lightning protection into three categories: intrinsically safe, fault tolerant, and non-fault tolerant. It also describes how applicants should develop material for the Airworthiness Limitations Section of the ICA.

2.1.1 Guidance for incorporating intrinsically safe design features into the fuel tank system is provided in paragraph 2.9.4.1.

2.1.2 Section 3 provides guidance on compliance with CS 25.954(b) for fault-tolerant lightning protection designs.

2.1.3 Section 4 provides guidance on compliance with CS 25.954(b) for non-fault-tolerant lightning protection designs.

2.1.4 Section 5 provides guidance on developing CDCCLs and other tasks that must be placed in the Airworthiness Limitation Section of the ICA.

2.2 Compliance tasks

The applicant should accomplish the following tasks to comply with CS 25.954:

— Identify the design features and elements of the fuel system that require lightning assessment (paragraph 2.3);

— Determine the lightning strike zones (paragraph 2.4);

— Establish the aeroplane lightning environment (paragraph 2.5);

— Develop a lightning protection approach and design lightning protection features (paragraph 2.6);

— Identify the potential failures of the design and protection features (paragraph 2.7);

— Identify the potential ignition sources associated with the design features and potential failures (paragraph 2.8);

— Perform a safety assessment to determine fault tolerance and non-fault tolerance (paragraph 2.9);

— Provide reliable fault-tolerant protection for lightning ignition sources (paragraph 3);

— Assess non-fault-tolerant protection for lightning ignition sources (paragraph 4); and

— Establish the Airworthiness Limitations (paragraph 5).

2.3 Identify the design features and elements of the fuel system that require lightning assessment

To comply with CS 25.954(b), the applicant should identify the fuel system design features and elements for the fuel tank structure, system components, and equipment that require lightning assessment to show that the ignition of fuel vapour within the systems due to lightning and its effects is prevented. The design features and elements may be categorised into design groups that share characteristics that have similar lightning protection performance. The applicant should provide a detailed description of the fuel system, including:

— structural members and fasteners exposed to direct and swept lightning attachment;

— structural joints and fasteners exposed to conducted-lightning current resulting from lightning attachment;

— access doors, vents, drain valves, fuel filler ports, and other parts and components of the fuel system exposed to direct lightning attachment or conducted lightning currents; and

— electrical, mechanical, hydraulic, and fuel plumbing system installations within the fuel tank or connected to the fuel tanks exposed to direct lightning attachment or conducted lightning current.

2.4 Determine the lightning strike zones

Lightning strike zones define locations on the aeroplane where lightning is likely to attach and structures that will conduct lightning current between lightning attachment points. The applicant should determine the lightning strike zones for the aeroplane configuration, since the zones will be dependent upon the aeroplane geometry and operational factors. Lightning strike zones often vary from one aeroplane type to another.

EUROCAE document ED-91A, 'Aircraft Lightning Zoning', dated January 2019 and the equivalent SAE ARP5414B dated December 2018, are acceptable standards providing guidelines on determining the lightning strike zones for the aeroplane, the areas of direct lightning strikes, areas of swept lightning strokes, and areas of conducted electrical transients. When determining the probability of lightning attachment to certain regions of the aeroplane, applicants should use data from similar aeroplane configurations to substantiate any assumed strike attachment rate for the region.

2.5 Establish the aeroplane lightning environment

The fuel tank structure, system components, and equipment that are located in lightning zones 1 and 2 should be designed for lightning direct-attachment waveforms. EUROCAE document ED-84A, 'Aircraft Lightning Environment and Related Test Waveforms', dated July 2013, and the equivalent SAE ARP5412B dated January 2013, are acceptable standards providing guidelines on acceptable lightning current and voltage waveforms for lightning zones 1 and 2. The fuel tank structure, system components, and equipment that are exposed to conducted currents should be assessed to determine the appropriate lightning current and voltage waveforms and amplitudes, using the conducted current waveforms for zone 3 in EUROCAE ED-84A/SAE ARP5412B. The applicant may use analyses or tests to assess the conducted currents and voltages for the structure, system components, and equipment. Margins should account for any uncertainty of the analysis or test. Simple analyses of the lightning currents and voltages should incorporate larger margins than the lightning currents and voltages that were calculated using detailed computational models that have been validated by tests.

2.6 Develop a lightning protection approach and design lightning protection features

The applicant should develop the lightning protection approach and design lightning protection features required to provide effective lightning protection for all the fuel system design features and elements identified in paragraph 2.3 of this AMC. See paragraphs 3.2 and 4.1.2 for further guidelines on how to demonstrate an effective protection. The lightning protection features can include specific installation requirements, such as hole-size tolerance for fasteners or surface cleaning for sealant application. Other lightning protection features can include specific protection components, such as metal mesh incorporated into the outer surface of composite structures. The design should provide reliable lightning protection that prevents lightning–related ignition sources if a potential failure occurs in the lightning protection features. When possible, the design should place fuel system components — such as fuel tank vents, drain valves, jettison tubes, filler ports, and access doors — in lightning attachment zone 3, so they are less likely to be exposed to direct lightning attachment.

2.7 Identify potential failures of the design and protection features

2.7.1 The applicant should:

— identify the potential failures, due to causes that include manufacturing escapes*, operational deterioration**, and accidental damage***, that may lead to the loss or degradation of lightning protection;

— identify, by analysis or test, the design elements that could degrade the effectiveness of lightning protection;

— identify failures through a detailed review of manufacturing processes, material properties, structural design, systems design, and reliability and maintainability processes;

— use the available manufacturing discrepancy reports, in-service failure reports, and developmental tests to identify potential failures; and

— account for failures such as structural cracking, corroded or failed electrical bonding features, and mis-installed electrical bonding features that occur during manufacturing or maintenance.

**Manufacturing escapes for fuel tank structure include fastener selection issues (incorrect fastener sizes, types, finishes, or coatings), fastener assembly issues (misalignment, incorrect torque, hole size or quality, missing or extra washers), and installation issues (inadequate or improperly adhered sealant, missing cap seals, incorrectly installed electrical bonds). Manufacturing escapes for fuel system components and equipment include design configuration issues (incorrect fasteners, wrong or missing clamps or brackets, inadequate or improperly adhered sealant, missing or incorrect finishes), bonding issues (a missing or improperly installed electrical bond or wiring shield), and clearance issues (insufficient tube or wiring clearance to adjacent systems or structure).*

***Structural failures due to operational deterioration during intended operation include broken or cracked elements (fasteners or washers), corrosion, degradation of applied materials (sealants, fastener head coating, edge glow protection, or bonded joints), and fatigue issues (loose fasteners or structural cracks). System failures due to operational deterioration include failures of support features (loss of fasteners, brackets, or clamps that support tubes, EWIS or components) and degradation of electrical bonds, wire insulation or shielding due to corrosion, ageing, or wear.*

****Structure or system failures due to accidental damage include impact from foreign object debris (FOD) or inadvertent damage incurred during alterations, repairs, or inspections.*

2.7.2 The severity or types of failures should be defined and can be based on service history, where appropriate, and laboratory test data. The severity of the failure should be consistent with or bounded by the assumptions made for the structural and systems certification analyses. The severity or types of failures due to manufacturing escapes should be based on manufacturing discrepancy reports, such as rejection tags, manufacturing process escape assessments, and assessments of process improvements.

2.7.3 Manufacturing variability and environmental conditions should be considered in conjunction with failures. Combining worst-case conditions for all manufacturing variabilities and environmental conditions is overly conservative and not necessary. Failures due to operating or environmental conditions other than those required for certification do not need to be considered. Combinations of failures where one failure also causes a second failure to occur should be considered as a single failure condition (i.e., a common cause or cascading failure).

2.8 Identify potential ignition sources associated with the design features and potential failures.

2.8.1 Fuel system fasteners, structures, equipment, and components that are exposed to direct lightning attachment in lightning zones 1 and 2 should be assessed using the lightning waveforms identified in paragraph 2.5 of this AMC. Fuel system fasteners, structures, equipment, and components should also be assessed for conducted lightning currents. If the aeroplane uses novel or unusual materials, structures, or configurations, the applicant should evaluate the fuel system fasteners, structures, equipment, and components on the outside surface of the aeroplane located in lightning zone 3 using the nominal zone 3 direct lightning attachment waveforms defined in EUROCAE ED-84A/SAE ARP5412B. The use of materials that are not highly conductive for the structure of fuel tanks is considered unusual. Lightning attachment in zone 3 is defined as unlikely in EUROCAE document ED-91A, 'Aircraft Lightning Zoning', dated January 2019, and the equivalent SAE ARP5414B dated December 2018, so the evaluation does not need to consider failures in combination with such an attachment, but should demonstrate that no catastrophic effect will occur when no failures are present.

2.8.2 The following paragraphs list ignition source types and examples of how ignition sources might occur:

2.8.2.1 Voltage sparks are the result of the electrical breakdown of a dielectric between two separated conductors. Voltage sparking might occur, for example, between the fastener and its hole or through an insulation layer between the base of a nut and a conductive surface. A voltage spark could occur between a fuel tube and the adjacent structure if the separation is insufficient or the bonding to minimise the voltage potential has failed. If this spark is exposed to fuel vapour, an ignition may result. Laboratory tests have shown that the minimum ignition energy in a voltage spark required to ignite hydrocarbon fuel vapour is 200 microjoules*.

**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.*

2.8.2.2 Thermal sparks are the result of burning particles emitted by the rapid melting and vaporisation of conductive materials carrying current through a point contact. Thermal sparks can occur when there is a small contact area between a fastener and the hole material, or between a fastener collar and the underlying structure. Thermal sparks can occur at a point contact between a fuel tube and the adjacent structure if the contact point conducts a high current. When sealant or caps are used to contain sparks, failures could result in the internal pressures from the heat of thermal sparks that force hot particles past the sealant or cap, resulting in sparks in the fuel vapour area.

2.8.2.3 Analyses and tests indicate that a small piece of steel wool will ignite a flammable mixture when a transient current of approximately 100 milliamperes (mA) peak is applied to the steel wool*.

**This data was from testing performed by the FAA Technical Center, Report DOT/FAA/AR-TN05/37, Intrinsically Safe Current Limit Study for Aircraft Fuel Tank Electronics. Applicants may conduct testing to substantiate alternate values.*

2.8.2.4 Edge glow includes voltage or thermal sparks that occur at the edges of carbon-fibre composite material when lightning current and voltage cause a breakdown of the resin between fibres. Failures of the protection features to prevent edge glow should be identified.

2.8.2.5 Fuel vapour ignition due to lightning near fuel vent outlets can result in flame propagation into the fuel system. When lightning attaches near fuel vent outlets, the ignition of fuel vapour results in a high-speed pressure wave that can travel through the flame arrestor without sufficient time for the flame arrestor to quench the flame front. The vent outlets should be located outside the lightning direct-attachment zones of the aeroplane. If the vent outlets are located in lightning direct-attachment zones, flame arrestors have been used to prevent lightning-ignited fuel vapour from propagating into the fuel system. Specific lightning tests and unique design features are typically needed to demonstrate the effectiveness of the lightning-protection for these installations. (Lightning effects are not addressed in the fuel tank vent fire protection requirements of CS 25.975(a)(7).

2.9 Perform a safety assessment to determine fault-tolerance and non-fault-tolerance

2.9.1 The applicant should perform a safety assessment to determine whether the fuel system design provides acceptable fuel system lightning protection based on the design features and potential ignition sources due to failures of the design features identified in the previous steps. The applicant may perform the safety assessment on groups of fuel system design elements and lightning protection features with similar physical and electrical characteristics. For non-fault-tolerant features, an assessment must show, per CS 25.954(c), that the sum of the probability of failures from potential ignition sources in combination with the probability of a critical lightning strike and the fuel tank being flammable does not exceed extremely improbable. The applicant should provide its rationale for assigning design elements and lightning protection into groups.

2.9.2 The safety assessment should address all the fuel system design elements identified in paragraph 2.3 of this AMC, the lightning environment at the locations for those elements identified in paragraphs 2.4 and 2.5 of this AMC, and the failures identified in paragraph 2.7 of this AMC. The applicant should also use the safety assessment to identify where analyses or tests are necessary to demonstrate the prevention of fuel system ignition sources.

2.9.3 The applicant should use a rigorous and structured safety assessment approach. The structured safety assessment and associated fault-tolerance assessment and test reports should be part of the substantiating data. Failure modes and effects analyses are acceptable structured safety assessment tools, particularly for non-fault tolerant lightning protection features. All the failure modes and effects analyses (FMEAs) and fault tree analyses (FTAs) should be included and thoroughly annotated. The applicant should substantiate and document all the assumptions used in performing the safety assessment.

2.9.4 The safety assessment should divide all the lightning protection features of the fuel system into the following three categories:

2.9.4.1 Intrinsically safe lightning protection

Some fuel system design elements provide effective lightning protection with no foreseeable failure modes that would render them ineffective. These design elements have no failures or combinations of failures that can result in an ignition source. This can be due to reliable design or to a very low lightning voltage or current in that specific location. The applicant should identify any intrinsically safe fuel system design elements. An example of an intrinsically safe design element would be highly conductive fuel tank skins with sufficient thickness to ensure that lightning attachment to the skin will not result in hot-spot or melt-through ignition sources in the tank. Another example would be a structural element designed with sufficient margins that fatigue cracking is not foreseeable. A third example could be fasteners or joints located in the fuel tank structure where the lightning current density is so low that an ignition source will not result even when failure conditions are present.

2.9.4.2 Fault-tolerant lightning protection

Fuel system design elements that are not intrinsically safe and require design features to provide lightning protection should be designed so that a failure associated with these elements or features will not result in an ignition source. Reliable fault-tolerant prevention of lightning ignition sources, in combination with the control of fuel tank flammability required by CS 25.981 and the statistics of lightning strikes to aeroplanes, is acceptable for showing compliance with CS 25.954(c). Detailed guidance for showing compliance for reliable fault-tolerant lightning protection is provided in Section 3 of this AMC.

2.9.4.3 Non-fault-tolerant lightning protection

Experience has shown that it is impractical to provide fault-tolerant features, or indications of failures, for some failures that occur in the aeroplane structure. Certain fuel system design elements and lightning protection features could have conditions where a single failure of these elements or features results in an ignition source when combined with a critical lightning strike. These fuel system design elements, lightning protection features, and failures require detailed and thorough safety assessment to determine whether the fuel system design complies with CS 25.954(b). It is likely that the aeroplane fuel system design and lightning protection can have only a very small number of these non-fault-tolerant lightning protection conditions and still show that the risk of a catastrophic event is extremely