Document No. WG-328

AC 20-53B

PRODUCED BY

THE LIGHTNING TASK GROUP

OF

EEHWG

JULY 22, 1995

Reformatted for release:
NOVEMBER 24, 1998

PROTECTION OF AIRCRAFT FUEL SYSTEMS AGAINST FUEL VAPOR IGNITION DUE TO LIGHTNING

20-53B
ACE-100

1. PURPOSE. This advisory circular (AC) provides information and guidance concerning an acceptable means, but not the only means, of compliance with parts 23, 25, 27, or 29 of the Federal Aviation Regulations (FAR), applicable to preventing ignition of fuel vapors due to lightning. Accordingly, this material is neither mandatory nor regulatory in nature and does not constitute a regulation. In lieu of following this method, the applicant may elect to establish an alternate method of compliance that is acceptable to the Federal Aviation Administration (FAA) for complying with the requirements of §23.954, 25.954, 27.954, and 29.954.

2. SCOPE. This advisory circular provides guidance for a means of showing compliance with regulations for protection against lightning fuel vapor ignition hazards to aircraft fuel systems of conventional design as well as for those involving advanced composite structures or other new technologies. The document incorporates information and references related to improvements in the state-of-the-art, with respect to lightning effects and verification methods that have taken place since the previous version of this advisory circular. Ignition hazards addressed include those due to direct effects (on fuel tank structure/components and plumbing) as well as indirect effects on wires or circuits in a fuel vapor cavity (such as fuel quantity probes). Guidance in this document applies to all fuel tanks and fuel systems. This guidance applies to systems included in the initial design as well as modifications, such as additional tanks or other fuel system components. Since externally mounted tanks are often located in direct lightning strike zones, they may be especially vulnerable to lightning hazards if not adequately protected.

NOTE: This advisory circular does not address the indirect effects (upset or damage) on either analog or digital electronic or electrical systems, except as they relate to fuel ignition hazards. See current revision of AC 20-136, "Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning."

3. CANCELLATION. Advisory Circular No. 20-53A dated April 12, 1985.

4. RELATED FAR SECTIONS. Part 23, §23.954; part 25, §25.954; part 27,

5. RELATED READING MATERIAL. A comprehensive discussion on this subject, with additional nonregulatory guidance information, is available in the current edition of the following document: User's Manual for AC 20-53, Report Number DOT/FAA/CT-83/3, "Protection of Airplane Fuel Systems against Fuel Vapor Ignition Due to Lightning." Another comprehensive reference is the "Lightning Protection Handbook," Report Number DOT/FAA/CT-89/22. These documents are available to the public by order through the National Technical Information Service, Springfield, Virginia 22161.

6. BACKGROUND.

a. Aircraft flying in and around thunderstorms are often subjected to direct lightning strikes as well as to nearby lightning strikes which may produce corona and streamer formations on the aircraft.

b. Elements of the fuel system are typically spread throughout much of an aircraft and occupy much of its volume. They include the fuel tanks themselves, as well as other areas that may contain fuel vapors, plus associated vents, transfer plumbing, electronic controls, and instrumentation. Careful attention to all of these elements is necessary for adequate protection.

c. For purposes of design and provisions of lightning protection, it is assumed that the properties of the fuel used by civil aircraft, both piston and turbine engine powered, are such that (without specific provisions otherwise) a combustible mixture is present in the fuel tank at all times. Therefore, the combination of the flammable fuel/air ratio and an ignition source at the time of a lightning strike could produce a hazardous condition for the vehicle. To prevent this condition from occurring, a review and elimination of the possible ignition sources within the fuel tank/fuel system should be conducted.

d. Assuming that flammable mixtures may exist in any part of the fuel system, some items and areas susceptible to fuel ignition include, but are not limited to, vent outlets, metal fittings inside fuel tanks, fuel filler caps and access doors, drain plugs, tank skins, fuel transfer lines inside and outside of the tanks, electrical bonding jumpers between components in a tank, mechanical fasteners inside of tanks, and electrical and electronic fuel system components and wiring.

e. User's manual contains further discussion and illustrations of hazardous areas and possible corrective measures.

f. Protection of fuel systems from lightning should be accomplished by one of the following approaches:

(1) Eliminating sources of ignition.

(2) Ensuring that allowable tank pressure levels are not exceeded if ignition does occur and/or that the fuel tank atmosphere will not support combustion.

g. The preferred approach is to prevent any direct or indirect source of ignition of the fuel by lightning. Accomplishment of this approach requires attention to detail because thousands of amperes of current are conducted, and a spark of approximately two-tenths of a millijoule may be all the energy that need be released inside a fuel tank to initiate a fire or explosion.

7. DISCUSSION.

a. Key considerations of the fuel system/lightning phenomena are:

(1) Flammable mixtures may exist in any part of the fuel system particularly in the tank and/or vent components.

(2) Flammable vapors in vent outlets may be susceptible to ignition by either streamering or direct strokes.

(3) Streamers or corona can contain sufficient energy to serve as an ignition source.

(4) Strike attachment to poorly conductive parts may contain enough energy to cause sparking on the inside of the fuel tank which, in turn, could ignite flammable vapors.

(5) Strike attachments may puncture the skin, heat fuel tank skins, or cause arcing in fuel tank structures.

(6) Lightning currents flowing in fuel system internal components, such as fuel and vent lines, conduits, or internal structural elements may produce electrical sparks capable of igniting flammable vapors.

(7) Lightning currents flowing in the airframe create voltage differences and electromagnetic fields which induce transient voltages and currents in fuel system electrical wiring and hardware.

(8) Strike attachment may cause deterioration of adhesives/structural bonds or fasteners to the extent that the tank integrity would, or could, be lost.

b. The excellent lightning safety record of civil aircraft is attributed to the high electrical conductivity of the aluminum alloys used in aircraft fuel tank construction and to designs which suppress interior sparking at severe lightning current levels.

c. Composite materials, such as carbon fiber composite (CFC), when used for fuel systems, often require, due to their lower electrical conductivity, design solutions different from those used on metallic structures to provide equivalent protection. Construction techniques which utilize adhesive bonding, may have limited lightning current conductivity affecting both metallic and non-metallic structures. Also, indirect effects, such as lightning induced voltages in fuel system electrical wiring and other conducting elements, may be of higher levels and different waveforms within composite structures than within conventional aluminum airframes.

d. Aircraft fuel system lightning interaction.

(1) Lightning can be a hazard to aircraft fuel systems if they are not properly designed. The protection of a properly designed system may be negated if it is not correctly fabricated and maintained.

(2) The effects of lightning on aircraft can range from severe damage (such as tearing and bending of aircraft skins resulting from high magnetic forces, shock waves, and blast effects caused by the high current, and melting of metal skins caused by the lower level longer duration currents of some lightning strikes) to seemingly insignificant sparking at fasteners or joints. However, if the sparking occurs in a fuel vapor space, ignition of the fuel vapor may result with unacceptable explosion damage.

(3) All or a portion of the lightning current may be conducted through fuel tanks or fuel system components. It is important to determine the current flow paths through the aircraft for the many possible lightning attach points so that current entry into the fuel system can be safely accounted for by appropriate protective measures.

(4) Metals, low electrical conductivity composite materials (e.g., carbon fiber reinforced composites), and electrical insulating materials (e.g., fiberglass and aramid reinforced composites) all behave differently when subjected to lightning. Yet each of these materials may be used in similar aircraft applications (e.g., wing skins or fuel tanks). The metals and CFC offer a relatively high degree of electrical shielding and some magnetic shielding, whereas the electrical insulating materials (dielectrics) offer almost no electrical or magnetic shielding. As a result of the latter properties, lightning does not have to come in direct contact with fuel systems to constitute a hazard. Lightning can induce arcing, sparking, or corona in fuel areas which may result in fuel ignition.

(5) The damage when using totally nonconducting materials, such as the fiberglass and aramid (e.g., Kevlar) reinforced composites, can be considerably more severe as the discharge can more easily penetrate into the interior and cause direct fuel vapor ignition.

(6) Lightning strikes can result in sparking and arcing within fuel systems unless they are designed to be spark free. Flammable vapors can be ignited in metal and semi-conducting fuel tanks by arcing and in dielectric fuel tanks by magnetic and electrical field penetration which can cause sparking, arcing, streamer, or corona discharge.

8. DEFINITIONS. See appendix 1 for a list of definitions.

9. APPROACHES TO COMPLIANCE. In general, the steps below outline an effective method to show compliance:

a. Determine the Lightning Strike Zones. Determine the aircraft surfaces, or zones, where lightning strike attachment is likely to occur, and the portions of the airframe through which currents may flow between these attachment points. The methods for determining lightning strike zone locations are defined in the Aircraft Lightning Zoning Standard, Eurocae/SAE Report No. TBD.

b. Establish the Lightning Environment. Establish the component(s) of the total lightning event to be expected in each lightning strike zone. The methods for determining the aircraft lightning environment are defined in the Aircraft Lightning Environment Standard, Eurocae/SAE Report No. TBD.

c. Identify Possible Ignition Sources. Identify systems and/or components that might be ignition sources to fuel vapor. Ignition hazards may include structures as well as fuel system mechanical and electrical/electronic components associated with the fuel tanks.

NOTE: In order to provide concurrence on the certification compliance, the above three sequential steps should be accomplished, reviewed with the appropriate FAA personnel, and an agreement reached prior to test initiation to prevent certification delays.

d. Establish Protection Criteria. Establish lightning protection pass/fail criteria for those items to be evaluated.

e. Verify Protection Adequacy. Verify the adequacy of the protection designs by similarity with previously proven installation designs, simulated lightning tests, or analysis. Any new material, design, or unique installation should follow the additional guidelines provided in step f to ensure that certification compliance can be accomplished. Where designs consist of unique characteristics or material, special conditions, issue papers, or other additional regulations may be imposed by the FAA. When analysis is utilized, appropriate margins to account for uncertainties in the analytical techniques should be identified in the certification plan referred to in step f. Developmental test data may be used for certification when properly documented and coordinated with the certification agency. See section titled "Comparison with Development Tests" of the User's Manual. Additional guidance can be found in the Aircraft Lightning Testing Standard, Eurocae/SAE Report No. TBD.

f. Listed below are the steps to be followed as appropriate in assuring compliance with the regulations:

(1) Generate a certification plan which describes the analytical procedures and/or the qualification tests to be utilized to demonstrate protection effectiveness. When the certification plan includes tests, test plans should be prepared which describe the production or test article(s) to be utilized, test drawing(s) as required, the method of installation that simulates the production installations, the lightning zone(s) applicable, the lightning simulation method(s) test voltage or current waveforms to be used, spark detection methods, and the appropriate schedules and location(s) of proposed test(s).

(2) Obtain FAA concurrence that the certification plan is adequate.

(3) Obtain FAA detail part conformity of the test articles and installation conformity of applicable portions of the test setup.

(4) Schedule FAA witnessing of the test.

(5) Submit a final test report describing all results and obtain FAA approval of the report.

g. Maintenance and Surveillance. When dedicated protection devices or specific techniques are required to provide the protection for a system or equipment on an installation, the periodic maintenance and/or requirements for surveillance of these devices or techniques should be defined to ensure the protection integrity is not degraded in service. Aircraft intentionally dispatched with faults present should be shown to retain adequate protection from the effects of lightning in each proposed dispatch configuration so that the aircraft is maintained in accordance with the manufacturers' instructions.

Items which rely on shield and connector electrical bonding, sealing materials, grounding jumpers, structural foil shield liners, etc. require an evaluation and determination that proper identification is provided to prevent degradation or accidental removal during normal aircraft maintenance that could negate or eliminate the designed protection.

In addition, the use of devices which may degrade with time due to corrosion, fretting, flexing cycles or other causes should be avoided where possible or dedicated replacement times identified. If sacrificial devices are utilized, the capacity or number of multiple lightning strikes that any device can withstand while maintaining the design level of direct and indirect effects protection should also be identified.

The techniques and time intervals for evaluating or monitoring the integrity of the system protection should be defined. Built in test equipment, resistance measurements, continuity checks of the entire system or other means may need to be identified to provide periodic surveillance of the system integrity.

APPENDIX 1. DEFINITION OF TERMS

A. Attachment Point. A point of contact of the lightning flash with the aircraft.

B. Corona. A luminous discharge that occurs as a result of an electrical potential difference between the aircraft and the surrounding atmosphere.

C. Direct Effects. Physical damage effects caused by lightning attachment directly to hardware or components, such as arcing, sparking, or fuel tank skin puncture.

D. Indirect Effects. Electrical transients induced by lightning in aircraft electric circuits.

E. Lightning Strike. Any attachment of the lightning flash to the aircraft.

F. Lightning Strike Zones. Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction.

G. Streamering. The branch-like ionized paths that occur in the presence of a direct stroke or under conditions when lightning strokes are imminent.