# *Federal Aviation Agency*

# ADVISORY CIRCULAR

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| **AC NO:** AC 20-53 | |
| AIRCRAFT | |
| **EFFECTIVE:** 10/6/67 | |

**SUBJECT:** PROTECTION OF AIRCRAFT FUEL SYSTEMS AGAINST LIGHTNING

1. This circular sets forth acceptable means, not the sole means, by which compliance may be shown with fuel system lightning protection airworthiness regulations (Section 25.954).

2. CANCELLATION. Advisory Circular No. 25-3A, effective November 10, 1966, is canceled.

3. BACKGROUND. Airplanes flying in and around thunderstorms are often subjected to direct lightning strikes, and, also, to nearby lightning discharges which may produce corona and streamer formations on the aircraft.

4. KEY FACTS RELATIVE TO LIGHTNING PROTECTION.

   a. Fuel System/Lightning Phenomena Relationship.

      (1) Flammable mixtures may exist in any part of the tank vent system.

      (2) Vent outlets may be susceptible to ignition of vapors by either streamering or direct strokes.

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

      (4) Stroke attachment to semi-insulated parts may contain enough energy to cause sparking on the inside of the fuel tank which, in turn, could ignite flammable vapors.

b. Lightning Strike Zones. In connection with the foregoing fuel system/lightning phenomena relationship, the FAA has conducted a series of experiments and studies with respect to existing aircraft and has found the following to be areas of high probability. For the purpose of these experiments and studies the airplanes were divided into the following zones. These may be areas warranting investigation for future airplanes.

(1) Zone 1.

(a) All surfaces of the wing tips located within 18 inches of the tip measured parallel to the lateral axis of the aircraft, and surfaces within 18 inches of the leading edge on wings having leading edge sweep angles of more then 45 degrees.

(b) Projections such as engine nacelles, external fuel tanks, propeller disc, and fuselage nose.

(c) Tail group: within 18 inches of the tips of horizontal and vertical stabilizer, trailing edge of horizontal stabilizer, tail cone, and any other protuberances.

(d) Any other projecting part that might constitute a point of direct stroke attachment.

(2) Zone 2. Surfaces for which there is a probability of strokes being swept rearward from a Zone 1 point of direct stroke attachment. This zone includes surfaces which extend 18 inches laterally to each side of fore-and-aft lines passing through the Zone 1 forward projection points of stroke attachment. All fuselage and nacelle surfaces, including 18 inches of adjacent surfaces, not defined as Zone 1 are included in Zone 2.

(3) Zone 3. Surfaces other than those covered by Zones 1 & 2. Ignition sources in these areas would exist only in the event of streamering.

c. In connection with the foregoing the following definitions apply:

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

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

(3) Swept Stroke: A series of successive direct strikes swept across the surface of the airplane by the motion of the airplane.

(4) Direct Stroke Attachment: Contact of the main channel of a lightning stroke with the aircraft.

5. GENERAL GUIDELINES FOR LIGHTNING PROTECTION OF FUEL SYSTEMS. Effective fuel system lightning protection is obtained if:

a. In Zone 1: The protection takes into account all fuel system parts, direct strikes, and possible penetration; vent outlets are protected against the effects of direct stroke attachment; and semi-insulated fuel system parts are designed to prevent sparking where flammable vapors can exist.

b. In Zone 2: Vent outlets and semi-insulated fuel system parts are protected in the same manner as for Zone 1.

c. In Zone 3: Vent outlets having a protruding configuration are protected to avoid ignition of fuel vapors by streamering or corona.

A tabular description of zones and protection guidelines is given in Table I.

6. USEFUL METHODS FOR DETAIL DESIGN EVALUATION. The following methods are useful in evaluating the protection measures provided in following the guidelines of paragraph 5.

a. Access Doors and Fillercaps. Those parts which are usually designed for ready removal, either for servicing or for accessibility for inspection and repair, normally constitute parts semi-insulated electrically from the main structure. Even though no deliberate measures are taken to isolate the parts electrically, conventional construction methods usually result in a rather poor electrical path between the part and the surrounding metallic structure. Paint films, anodizing, and other corrosion protection treatments usually also serve as electrical insulators. Two basic solutions to prevent internal arcing and sparking have been used: One, to provide a continuous electrical contact around the entire periphery of the part, or, secondly, to design the part in such a way that any arcing or sparking which might occur would take place on the outside of the fuel-containing vessel rather than on the inside. Experience to date indicates that one acceptable means for evaluating the capability of the design to avoid internal sparking is by specimen testing using typical parts and applying the test method shown in paragraph 7.a. below. The use of ohmmeters for measuring resistance across a joint has not produced useful results in evaluating the adequacy of the electrical connection between access plates and the surrounding structure. Although resistance measurements are useful for determining the adequacy of electrical bonding, they are ineffective in examining the design for the probable behavior of the high currents with high frequency characteristics produced as a result of a lightning strike (see Table II).

b. Fuel Vent Outlet Designs. Fuel vent outlets are of three classes and can generally be described by their relationship to the fuel vapor egress and the boundary layer:

(1) Class 1 - Vapor discharging into wake caused by boundary layer;

(2) Class 2 - Vapor discharging into the free air stream (vent projects through the boundary layer);

(3) Class 3 - Vapor discharging into surface boundary layer.

For a diagrammatic presentation of the three classes see Attachment 3.

c. Vent Outlet in Zones 1 and 2. The evaluation of venting systems having outlets located in Zones 1 and 2, regardless of outlet configuration, involves consideration of all conditions resulting from a strike at or near the outlet. Various means to prevent ignition or to arrest flame propagation are feasible; however, the actual performance of the protective means should be evaluated. Some examples of protective means are:

(1) Dilution of vented vapors with fresh air to keep the mixtures in the "too-lean" range.

(2) Acceleration of the vented vapors by ram air to an exit speed above the flame propagation speed.

(3) Flame arresters.

(4) Fire and explosion suppression devices.

(5) Use of an inert atmosphere in the venting system.

d. Vent Outlets in Zone 3. For vent outlets which are located in Zone 3, the flush designs (Class 3) are considered relatively immune from streamering and corona formations, whereas the protruding types (Classes 1 and 2), are considered to be likely points for these formations and protection of the vent against flame propagation is important. A flame arrester could furnish this protection; however, the design conditions for the flame arrester would not be as severe as in the case of vents located in Zones 1 and 2 because of the absence of the blast pressure effects. In evaluating the flame propagation characteristics through vent outlets located in

Zone 3, tests may be conducted using a low-energy source for ignition, that is, just sufficient energy to ignite a flammable mixture.

e. Flame Arresters. The primary problem in flame arrester design is usually that of determining the most practical type of construction necessary to arrest the movement of the flame front with the particular venting system being studied. The effectiveness of each particular configuration of flame arrester depends upon its location with respect to the vent outlet and termination of the vent pipe in the fuel tank. A reliable method for determining the capability of a flame arrester design is to test it in a manner similar or equivalent to that described in paragraph 7.b. below. The test setup involves a reasonably accurate reproduction of the actual vent design including tubing bends, obstructions, and outlet shape. Evaluation of the flame arrester also includes the determination that no hazards are otherwise introduced by the addition of the flame arrester such as plugging by ice formations.

f. Resistance to Skin Penetration. The skin should be sufficiently thick to provide protection against lightning penetration. Experience has shown that alumimum alloy sheet of .080 inches or greater thickness has the requisite qualities.

In addition to penetration resistance, the possibility of "hot spots" as a source of fuel vapor ignition should be considered. These "hot spots" could occur because of the relatively poor heat dissipating qualities of the particular material.

g. Non-Metallic Wingtip Fairings and Tip Fuel Tanks. Non-metallic materials, such as resin-bonded glass fiber materials, are sometimes used for wingtip fairings and for wingtip fuel tanks. Experience with lightning strikes to aircraft having such parts indicates that there is a tendency for a lightning strike channel to penetrate and damage these materials on its way toward the metallic extremities of the wingtip. In a sense, the stroke does not "see" the non-metallic parts.

h. Various methods of protecting non-metallic parts against damage have been developed and tested. One example is the application of metal foil strips on the outside of radomes to serve as conducting paths to metallic structure. For parts which do not need to serve as electromagnetic "windows" an external conductive coating could serve the same purpose. Evaluation of a particular construction to withstand lightning strikes without damage could be made by tests with simulated strikes as described in paragraph 7.c. below.

i. The extent of the areas termed as Zone 1 (see paragraph 4.c.) is measured in a lateral direction from the outermost end of the metallic structure when non-metallic wingtip parts are used which do not incorporate electrically conducting elements.

7. USEFUL TESTING METHODS:

a. Access Doors, Fillercaps, and Similar Parts.

(1) To simulate a lightning strike, it will be acceptable to use electrical conditions having the following successive components applied to the outer surface of the test specimen:

(a) An initial component rising from zero to a crest value of 200,000 amperes in not more than 15 microseconds and decaying to 50,000 amperes in not more than 30 microseconds from initiation.

(b) A second component consisting of a charge transfer of at least 500 coulombs having a duration of two to five seconds. If the component being tested is designed so as to prevent such a current transfer, it should then be substantiated that the initial component has not disturbed this design and that an applied voltage for two seconds will not damage the cap.

(2) The following test apparatus has been used successfully for testing fuel filler caps (see attachment 2):

(a) Sixty kva power supply.

(b) Capacitors (total capacitance 14 microfarads).

(c) Current limiting resistors (not required if self-contained in power supply).

(d) Switches (as necessary).

(e) High current shunt.

(f) Brass electrode.

(g) Test chamber.

(h) D. C. generator.

(i) Isolating Induction coil.

(j) Oscilloscope.

(k) Camera.

(l) Miscellaneous hardware for interconnecting, rigging, and operating the various components listed above.

(3) The following procedure was used to obtain the desired electrical components using the equipment listed above:

(a) Mount test article in cabinet.

(b) Position camera and set shutter stop.

(c) Close test cabinet access door and remotely open camera shutter.

(d) Position the electrode.

(e) Open switch between capacitors and electrode.

(f) Close switch connecting high voltage power supply to capacitors. Charge capacitors.

(g) If power supply is not designed to handle the high inverse peak voltage that will result subsequent to discharging the capacitors, disconnect the power supply from the capacitors after charging them.

(h) Shut down power supply.

(i) Activate and calibrate oscilloscope.

(j) Place d.c. generator on the line.

(k) Close switch from capacitors to electrode.

(l) After a sufficient time has elapsed to substantiate the second component, shut down generator.

(m) Ground high voltage side of capacitor.

(n) Develop film.

(o) Examine test article.

(4) Some safety precautions that should be used are:

(a) Provide a system that requires two operators to charge the capacitors: one operator to hold open a switch that will ground the capacitors when released, the other operator to charge the capacitors. This will prevent one person from charging the capacitors and leaving the charged capacitors unattended.

(b) Provide a booth for the operators that is effectively isolated from high voltage arcing during charging and the possibility of hazards from the high voltage discharge.

(c) Provide a backup ground rod to be used by the operator as added assurance that the capacitors have been grounded. Grounding can be effected by bridging the rod between the high voltage and ground connections of the capacitor (s).

(d) Do not use personnel that have not been trained in the handling of high voltage equipment.

(5) Prior to evaluating the test article, it should be determined from the oscilloscope trace or other suitable measuring equipment that the electrical conditions specified in paragraph 7.a (1) have been achieved. The evaluation of the test article consists of a visual examination of the article, an examination of the photograph, and a pressure test (if applicable) to determine whether the sealing capability has been affected. As an aid in evaluating the photograph, it would be helpful to have a monitor hole, Drill No. 70 (.028), drilled in the cabinet near the test article. This will confirm that the film has been exposed and that the print is valid.

(6) WARNING - HAZARDOUS: Only competent technical personnel should operate the apparatus described herein. The testing apparatus described in this circular is a high voltage, high current setup and could result in a fatal accident to any person attempting to operate it without being completely skilled and qualified to do so, or if operated without observing normal and necessary safety precautions.

b. Flame Arresters. An acceptable means for substantiating flame arresters is by using a test procedure similar or equivalent to the arrangement explained in FAA Technical Report ADS-18, "Lightning Protection Measures for Aircraft Fuel Systems Phase II", dated May 1964, Document No. AD-603232. The test apparatus essentially consists of a drive tube arrangement which produces a moving flame front having pressure characteristics similar to the conditions likely to be encountered from a natural lightning stroke. The tests are to show that the arrester is effective in arresting a flame front under the conditions expected to prevail during a lightning strike, taking into account that the vent is a flowing system which may alternate between inflow and outflow.

c. Simulation of Lightning Strikes. Artificial lightning generator facilities may be used to reproduce the characteristics of natural lightning discharges which would be of most significance in determining the effectiveness of particular protection designs. Such testing is used for evaluating designs on which insufficient information is available from previous experience, previous test work, or established designed criteria to ensure a satisfactory design.

One acceptable generating facility is shown in Section 2b of FAA Technical Report ADS-17, "Lightning Protection Measures for Aircraft Fuel Systems Phase I," dated May 1964, Document No. AD-603232. This document and the one mentioned in paragraph 7b. may be procured from the Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22151. The price of ADS-17 is $4.00 and ADS-18 is $6.00.

K. R. [signature]
acting Director
Flight Standards Service

**TABLE I**

| FUEL SYSTEM PART | ZONE 1 | ZONE 2 | ZONE 3 |
| --- | --- | --- | --- |
| Tank skin | Aluminum Alloy thicker than .080 or equivalent | ---- | ---- |
| Flush or recessed fuel vent outlets (Class 3) | Protect against direct strokes and streamering | Protect against direct strokes and streamering | ---- |
| Protruding types of fuel vent outlets (Classes 1 & 2) | Protect against direct strokes and streamering | Protect against direct strokes and streamering | Protect against streamering |
| Access doors, filler caps and other semi-insulated parts. | Protect against direct stroke attachment | Protect against direct stroke attachment | ---- |

# TABLE II

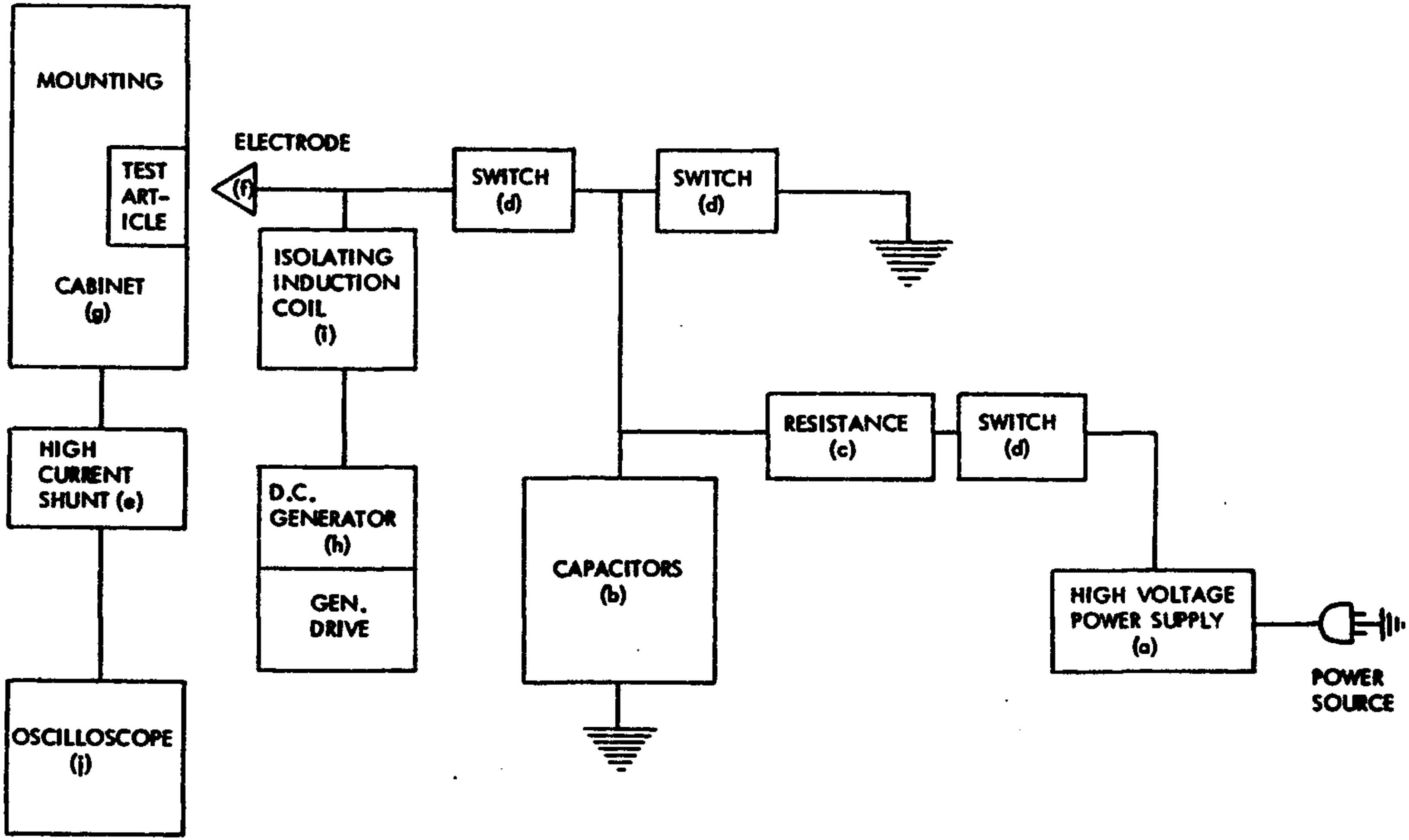
## Characteristics of Natural Lightning Discharges to Aircraft

| | Probable Average | Probable Maximum |
|---|---|---|
| Current - Amperes | 50,000 | 500,000 |
| Rate of current rise - Amps/u-second | 10,000 | 200,000 |
| Charge Transfer - Coulombs | 50-200 | 600 |
| Voltage-Megavolts | 100 | 500 |

NOTES:

a. Lightning strike reports indicate that a number of direct strikes are sometimes received during a single thunderstorm passage. Such multiple strikes, however, usually occur within a time period of a few minutes.

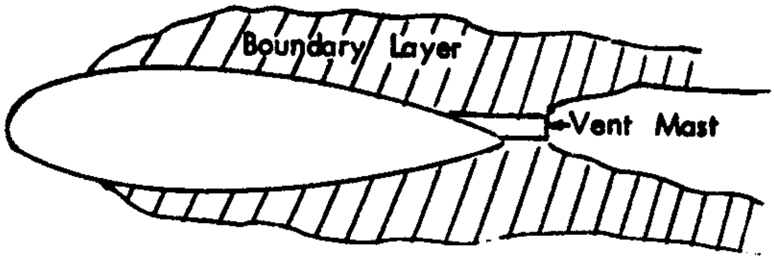
b. Streamer formations on aircraft being subjected to the intense electromagnetic fields of thunderstorm conditions are believed to persist over relatively long time periods during a single flight -- for example, 30 minutes or more.



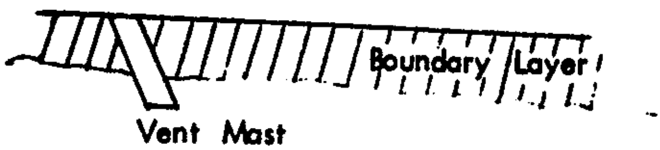

Note: paranthetical letters in blocks correspond to lettering in paragraph 7(a)(2) of the advisory circular.

SCHEMATIC-HIGH VOLTAGE TEST CIRCUIT

CLASS I
VENT MAST DISCHARGING INTO WAKE




CLASS 2
VENT MAST DISCHARGING INTO FREE STREAM




CLASS 3
FLUSH VENT DISCHARGING INTO SURFACE BOUNDARY LAYER