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# AEROSPACE INFORMATION REPORT

Society of Automotive Engineers, Inc.  
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

AIR 1406

Issued February 1976  
Revised

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LIGHTNING PROTECTION AND STATIC ELECTRIFICATION

OCT. 1993

This Aerospace Information Report (AIR) presents a brief summary of the environment and the present state of the art of lightning protection and static electrification reduction for aerospace systems.

For further information on these subjects see SAE Aerospace Information Report, AIR 1208, a selected bibliography.

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## 1. ATMOSPHERIC ELECTRICAL ENVIRONMENT

- 1.1 General Summary of Electrostatic Conditions: Cloud electrical activity is generally present in active or decaying showers and thunderstorms. Electrostatic field components tend to range from 100 to 1000 volts/cm with some localized intense charge regions producing fields to about 4000 volts/cm. There may be regions several miles in length with charges of the same polarity. Changeovers in polarity occur very rapidly with distance and are generally associated with differences in the precipitation and draft features in the cloud. The small intense charge centers involved in lightning strikes are about 500 meters in diameter. Several of these may be present in the storm. The average radius of detectable electrical disturbance for Florida storms was 20 kilometers.
- 1.2 Lightning Currents: Most of the data on lightning currents have been obtained from surface measurements. These have been concerned with properties of a cloud-ground strike as measured at its contact terminal with the earth. The bulk of the peak-current data has been obtained from magnetic links on power system towers and overhead ground wires. These have a threshold current sensitivity of several thousands of amperes; hence, cumulative frequency curves usually tend to indicate too large a percentage of high current strikes. A somewhat similar situation exists with estimates of currents in strikes to aircraft, in that a damaging strike must have occurred before a report is made of the incident. The variations in lightning parameters, such as currents and total charge transfers, are thought to approximate a logarithmic normal distribution. That is, the logarithm of the quantity follows the Gaussian bell-shaped error curve. The AIEE Committee values published in 1950 for ground strikes indicate a mean of log 18 KA and standard deviation of log 2.1 KA for this distribution. The tail of the curve extends to beyond 200 KA. Recent data from Dr. E. T. Pierce and Dr. N. Cianos indicate a probable average damaging current of 20 KA (50% exceed this value) and a near maximum current of 40 KA (2% exceed this value). (See Table I).
- 1.3 Charge Transfer: Estimates of total charge transfer through aircraft have been made through laboratory simulation of damage to metallic sections. Probable average damaging charges range from 50 to 200 coulombs. A probable maximum estimate is 600 coulombs. Some magnetometer data taken on cloud-ground strikes tends to support the above estimates. Tests have shown that actual effects on aircraft depend on the time intervals in which the charge is transferred.
- For example, mechanical twisting of metal may occur during the initial peak current surge; intense heating and blast effects are most evident in the time following the peak; pitting and erosion effects are associated with a continuing or decaying current of long duration. These parameters are summarized in Table I.
- 1.4 Rise and Fall Times: The performance of solid state digital and analog systems will be adversely affected by rapidly rising waveforms of lightning unless they are properly designed and shielded against magnetic field coupling effects. Most data on rise times have been measured on ground terminals. The fastest reported is 50 nanoseconds, associated with a 230 KA/ $\mu$ sec rise rate. Median rise times for first strokes are 1-3  $\mu$ sec, but subsequent dart leaders are associated with rises of from 0.3 or less to 1  $\mu$ sec. Times for the current to decay to half of peak range from 30 to 60  $\mu$ sec as median values. Limited data from an instrumented aircraft indicate a peak rise rate of 5 KA/ $\mu$ sec in contrast to normal values of 10-20 KA/ $\mu$ sec in ground strikes.

TABLE I  
LIGHTNING PARAMETERS

| <u>Component of Stroke</u>                  | <u>Current</u>       | <u>Duration for<br/>Indicated Transfer</u> | <u>Charge</u>                                       |
|---------------------------------------------|----------------------|--------------------------------------------|-----------------------------------------------------|
| Stepped Leader                              | 100 Amperes          | 10 - 50 Milliseconds                       | 5 Coulombs                                          |
| Dart Leader                                 | 1000 Amperes         | 1 Millisecond                              | 1 Coulombs                                          |
| Ground Return Stroke                        |                      |                                            |                                                     |
| (a) Electric Field                          |                      | 1 Millisecond                              | 0.2 - 19 Coulombs                                   |
| (b) Magnetic Field                          |                      |                                            | Generally 2-3 times<br>as large as data<br>from (a) |
| (c) Direct Current                          | 0 to 200 Kiloamperes | 2 Milliseconds                             | 0 - 130 Coulombs                                    |
| Continuing Currents                         | 40-300 Amperes       | 40 - 500 Milliseconds                      | 3 - 80 Coulombs                                     |
| Duration of Effect on<br>In-Flight aircraft |                      | 0.1 - 1.5 Seconds                          |                                                     |
| Total Charge Transfers                      |                      |                                            | Several reports to<br>300 - 400 Coulombs            |

Reference: N. Cianos and E. T. Pierce, "A Ground-Lightning Environment for Engineering Usage," Final Report, Stanford Research Institute Project 1183, Menlo Park, California.

## 2. FUEL SYSTEMS

Prevention of fuel ignition hazards due to lightning is one of the predominant problems for the designer concerned with aircraft lightning protection. Aircraft with integral wing fuel tanks are particularly problematical since the exterior skin serves as part of the fuel tank as well as a conductor for the large currents that result from lightning strikes to the wing. The energies required to ignite fuel are extremely low when compared to the energies possible within a lightning discharge. A flammable fuel/air mixture can be ignited with energies as low as 0.2 millijoules, whereas lightning can have energies on the order of  $10^9$  joules or  $10^{10}$  joules. A protection system that successfully diverts all but a seemingly insignificant amount of current away from a flammable vapor cavity can still create an ignition source. In addition, electro-magnetic coupling to internal components, such as fuel tank wiring, can result in an ignition hazard despite the fact that the coupling may be inefficient. The fact that such a low level of energy is capable of igniting fuel emphasizes the need to scrutinize fuel systems for lightning induced ignition hazards.

Aircraft lightning related ignition sources can be grouped into the following five general categories.

- 2.1 Puncture of Fuel Tank Skins: Lightning strikes can attach to, or sweep back over, an airfoil surface. As it dwells on the surface, it is possible for the intense energies inherent in lightning to puncture the skin surface, potentially subjecting fuel vapors to the hot arc, whose temperatures can reach as high as 30,000°C (8). A puncture of this type can occur in metals, dielectrics, and composite materials. Fuel tank skin thicknesses of 0.080 inch (2.03 mm) of aluminum are generally considered adequate (Reference 1) to prevent a puncture with stroke sweeping action, i.e., provided that it is located in an area where the stroke will be swept. Other materials and hybrid designs, such as dielectric and metallic honeycomb sandwich, are permissible if they are equivalent to 0.080 inch (2.03 mm) of aluminum in resistance to lightning puncture. Paints and other coatings must be considered in determining equivalencies because they tend to change the time a swept lightning stroke will dwell on a given surface. Test criteria and techniques are described in References 1 and 2.
- 2.2 Backside Heating of Fuel Tank Skins: A small surface or hot spot of 1320°C can ignite an optimum hydrocarbon fuel/air vapor. Materials like aluminum which have melting points below 1320°C (660°C for aluminum) cannot cause hot spot ignition but must instead be punctured to create this type of ignition hazard. Titanium, on the other hand, has a melting temperature of 1700°C and therefore can provide a hot spot ignition source without being punctured. For unpainted titanium sheets, 0.063 inch (1.60 mm) is considered an adequate thickness for ignition hazard prevention (Reference 2), provided it can be determined that less than 100 coulombs of continuing current charge (or equivalent) can enter such skins at any single lightning attachment point, i.e., that the stroke is swept over the skin. One hundred coulombs of charge delivered to 0.060 inch (1.60 mm) unpainted titanium at a rate of 115 amperes will ignite a fuel-air mixture beneath (Reference 8). Other high melting point materials, such as stainless steel, should be evaluated for hot spot thickness criteria in the manner described in Reference 3 and 8.
- 2.3 High Current Arcing and Sparking at Structural Interfaces: Lightning discharge currents can be as high as 200,000 amperes and rates of current rise approaching 100,000 A/μsec are possible (Reference 4). Because of these phenomenally high values, arcing and sparking can occur at electrical discontinuities in the structure and if a fuel vapor mixture is present, a potential hazard is created. Fuel tank access doors are a prime example of this category of ignition suspect which includes drip sticks, sump drains and over-the-wing filler caps. Generally, the doors do not carry a structural load and there is relative motion between them and the wing mating surfaces. This fact and the need for frequent removal results in contact conductivity that is less than ideal and unless precautions are taken may cause ignition sources due to lightning currents through the wing or swept stroke contact to the door. A practical method of eliminating the mating surface spark hazard is by isolating the mating surface from the fuel vapor cavity by effectively keeping the sparking mating surface external to the fuel tank. Wing skin joints and structural interfaces are generally less of a potential problem than access door interfaces but they must also be evaluated for ignition hazards, especially when interface sealants are used. AC and DC impedance measurements are not adequate impedance evaluation techniques because of the multiplicity of frequencies inherent in a lightning waveform; also because of variation in heat capacities of the various parallel paths, such as burs, actual tests with artificial lightning discharges, as recommended by Reference 1, have proven to be the only valid test technique for this type of hazard.

Although bonding jumpers are frequently used to prevent mechanical damage or thermal erosion of structure in areas free of fuel, they are almost categorically inadequate as an interface bonding technique in a fuel area subject to lightning effects. Their inherent impedance and small contact surface result in electrical discontinuities that are prone to lightning created arcing and sparking.

- 2.4 Induced Voltage Arcing and Sparking: The intense electromagnetic fields associated with lightning can inductively and capacitively couple into electrical and electronic systems, causing transient suppression problems. The effect of this phenomenon on electrical and electronic systems is well documented (References 6, 7, 8 and 9). Isolated metallic components within the fuel tank also have capacitive and inductive effects and may therefore result in ignition hazards under the influence of a lightning environment if non-metallic access door or skin sections are used. Good design practices dictate the electrical bonding of metallic sections within a fuel tank not only for the prevention of lightning ignition hazards (References 4 and 10) but also to reduce the hazard due to fuel electrification during high pressure refueling (Reference 11).

Dielectric surfaces within the fuel tank can create an additional hazard. Electrified fuel entering the tank can impinge upon the surfaces or induce, under intense DC fields, charges upon the surfaces which are limited only by their puncture voltages of surface flash over characteristics. Epoxies, acrylics, and polyurethanes are particularly good dielectrics that could, when used within a fuel tank, constitute a hazard. Reference 12 has an excellent discussion of this phenomenon which states that "These materials should be used in aircraft fuel tanks with great caution but they can be safely used if the basic parameters of charging rate, dielectric strength, resistivity and coating thickness are properly balanced to limit the energy storage to values well below the minimum fuel ignition energy."

- 2.5 Open Arc Attachment: Lightning arc attachment to a fuel vent or fuel jettison tube can ignite effluxing fuel vapors creating a flame front which can, under rather stringent conditions, propagate into the fuel tank. Fortunately, most jettison systems are so constructed that flames cannot propagate upstream through the discharging liquid fuel and the shut-off valve when closed will stop the flame front. In any given case, this fact should be verified with tests. Hazards to the fuel vent and jettison tube can be avoided by locating them in an area not subject to direct or swept lightning strikes and by designing them lightning-streamer free (Reference 1). A fuel-space inerting system may also be used to alleviate the hazard.

Exterior arcs can even create an additional problem because the blast pressures associated with lightning can blow past O-rings and environmental seals, resulting in another source of flammable vapor ignition. Components such as access doors, drip sticks, sump drains, and filler caps should be evaluated for these effects as well if they are used in an area subject to direct or swept lightning discharges.

In essence, a good fuel tank design involves keeping lightning out of the fuel cavity by providing sufficient skin thickness to prevent puncture, by avoiding electrical discontinuities, and by keeping fuel vents free from lightning strike areas. Any departure from a test-proven design should be verified for protection adequacy with artificial lightning discharges in the manner recommended by Reference 1.

### 3. STRUCTURES - PLASTIC

- 3.1 General: A lightning stroke step leader nearing the aircraft creates an intense electric field. The streamers produced by this field leave the aircraft from high gradient points to meet the step leader. High gradient points can occur along the edges of metallic components located within the plastic structure. Streamers initiating from these edges can puncture the structure at several places and connect with the main stroke. Whereas the streamers produce only pinholes, the main stroke to which they connect may pass down the streamer, through the plastic structure and cause extensive damage by fast heating of gases or vaporization of material. The primary function of the lightning protection device is to prevent the lightning discharge from causing explosions within the structure by keeping the lightning currents on the exterior or by carrying them safely through the interior with conductors of adequate cross sectional areas. The protection system also prevents:

3.1 (Cont'd)

- a. damage to control surfaces, engines, and other parts of the aircraft from resulting debris
- b. creation of an excessive aerodynamic drag at a critical point in flight
- c. changes to the air flow near pitot tubes resulting in erroneous speed indications.

3.2 Design Considerations: The airplane lightning stroke zones are defined, generally, as three regions on the external surface which have different stroke probabilities. These zones (See Fig. 1) are defined as follows:

- Zone 1: Surfaces of the airplane for which there is a high probability of direct stroke attachment.
- Zone 2: Surfaces for which there is a probability of strokes being swept rearward from a Zone 1 point of direct stroke attachment.
- Zone 3: Surfaces for which there is a low probability of either direct or swept strokes. All the zones may be involved in transferring lightning currents from the entry to the exit point on the aircraft.

If a plastic structure is located in an area of the aircraft that is vulnerable to lightning strokes, two questions should be answered in determining whether lightning protection for the particular structure is required. These questions are:

- a. What are the hazards to the aircraft if lightning does rupture the structure and strike the antenna or other equipment housed within the structure?
- b. What is the frequency of occurrence of a lightning strike to the area where the structure is located and the cost of repair?

If there are no hazards to the safety of the aircraft and if the cost of repair is less than the cost of installing and maintaining the lightning protection system, the decision may be to forego a lightning protection system. If there is a hazard to the aircraft, lightning protection should be provided.

Reinforced plastic aircraft structures such as radomes, antennas, fairings, fillets, and primary structural components can be adequately protected from lightning damage by a variety of protective systems.

3.3 Lightning Protection Systems: The lightning protection systems available for plastic structures are diverter strips, diverter rods, coatings, metal grids, and sheets of metal. These systems are briefly described as follows:

a. Diverter Strips:

- (1) Thin foil strip - the thin foil strip vaporizes when struck by lightning, providing an ionized channel through which the main stroke travels to the fuselage. This strip has good aerodynamic characteristics but provides only one-stroke protection and can cause radio interference from cracking if not adequately maintained.
- (2) Thick conductor strip (minimum of 20,000 circular mils in cross section) - The thick conductor type strip provides multistroke protection but has less desirable drag characteristics than the thin foil strip.

### 3.3 (Cont'd)

- (3) Segmented strip - the segmented strip consists of a series of conductive segments connected by a resistance material. This strip is designed to reduce the effects of the strips on antenna radiation patterns and to minimize the mechanical forces associated with the high peak currents traveling through the continuous conductor.
- (4) External flush diverter buttons - connected by interior conductors.
- b. Diverter Rods: Diverter rods are used to establish high gradient points to which lightning can attach and travel to a grounded point on the fuselage. The diverter rod can protect a conical space adjacent to the rod.
- c. Coatings: Coatings are usually of a high resistance type with good flashover characteristics.
- d. Sheets of Metal: Metal can be laminated to the plastic structure preventing lightning strokes from damaging the structure and other components housed within the structure. Metal coating methods include plasma flame spray and electrolytic deposition, and adhesive bonding of foil sheet.
- e. Metal Grids: Metal grids protect a structure in a manner similar to the metal sheets. The conductors have the maximum spacing to save weight while still providing necessary lightning protection.

#### 3.3.1 Zone 1 Applications:

- a. Radomes: Devices available for protecting radomes from lightning damage in Zone 1 areas include the metal foil strips, thick metal "strips" and segmented metal/resistance strips.

Selection of the type of lightning protection strip for a particular radome design takes into consideration the radome outer skin thickness, aerodynamic drag requirements, and the operational frequencies of nearby antennas.

- b. Thick Conductor Strip: The thick conductor strip is considered as a permanent installation because it has a minimum cross section of 20,000 circular mils and will withstand repeated lightning strikes. The recommended installation is a one-eighth by three-eighths inch (3.17 by 9.52 mm) aluminum bar that can be attached to the radome with steel screws and plastic inserts. The strip dimensions recommended allow holes and countersinks to be made in the strip without reducing the cross section to less than 20,000 circular mils. The plastic inserts encapsulate the threaded portion of the screws, preventing arcing from the screws to the antenna during lightning encounters. The plastic inserts are designed so the dielectric strength between the screws and the antenna is at least equivalent to the dielectric strength between the lightning strip and antenna. A maximum spacing between screws of three inches (76.20 mm) should be used to prevent arching (bending) of the strips during maximum lightning strokes.

The permanent type strips are usually installed in the airstream on the outside of the radome even though there is a small drag penalty. The drag can be minimized by orienting the strips parallel to the airstream (when acceptable from an antenna radiation pattern standpoint) or by shaping the cross section of the strips aerodynamically.