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# **LIGHTNING TEST WAVEFORMS AND TECHNIQUES FOR AEROSPACE VEHICLES AND HARDWARE**

**Report of  
SAE Committee AE4L**

**June 20, 1978**

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This version supersedes SAE Special Task F Report "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware" dated May 5, 1976.

# LIGHTNING TEST WAVEFORMS AND TECHNIQUES FOR AEROSPACE VEHICLES AND HARDWARE

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## 1.0 INTRODUCTION

This document presents test waveforms and techniques for simulated lightning testing of aerospace vehicles and hardware. The waveforms presented are based on the best available knowledge of the natural lightning environment coupled with a practical consideration of state-of-the-art laboratory techniques. This document does not include design criteria nor does it specify which items should or should not be tested.

Tests and associated procedures described herein are divided into two general categories:

- o Qualification tests
- o Engineering tests

Acceptable levels of damage and/or pass-fail criteria for the qualification tests must be provided by the cognizant regulatory authority for each particular case.

The engineering tests provide important data that may be necessary to achieve a qualifiable design.

The term Aerospace Vehicle covers a wide variety of systems, including fixed wing aircraft, helicopters, missiles, and spacecraft. In addition, natural lightning is a complex and variable phenomenon and its interaction with different types of vehicles may

be manifested in many different ways. It is therefore difficult to address every possible situation in detail. However, the test waveforms described herein represent the significant aspects of the natural environment and are therefore independent of vehicle type or configuration. The recommended test techniques have also been kept general to cover as many test situations as possible. Some unique situations may not fit into the general guidelines; in such instances, application of the waveform components must be tailored to the specific situation.

The test waveforms and techniques described herein for qualification tests simulate the effects of a severe lightning strike to an aerospace vehicle. Where it has been shown that test conditions can affect results of the test, a specific approach is recommended as a guideline to new laboratories and for consistency of results between laboratories.

It is not intended that every waveform and test described herein be applied to every system requiring lightning verification tests. The document is written so that specific aspects of the environment can be called out for each specific program as dictated by the vehicle design, performance, and mission constraints.

## 2.0 LIGHTNING STRIKE PHENOMENA

### 2.1 Natural Lightning Strike Electrical Characteristics

Lightning flashes are of two fundamentally different forms, cloud-to-ground flashes and inter/intracloud flashes. Because of the difficulty of intercepting and measuring inter/intracloud flashes the great bulk of the statistical data on the characteristics of lightning refer to cloud-to-ground flashes. Aerospace vehicles intercept both inter/intracloud and cloud-to-ground lightning flashes as shown in Figure 2-1. There is evidence that the inter/intracloud flashes lack the high peak currents of cloud-to-ground flashes. Therefore, the use of cloud-to-ground lightning strike characteristics as design criteria for lightning protection seems conservative.

There can be discharges from either a positive or a negative charge center in the cloud. A negative discharge is characterized by several intermittent strokes and continuing currents as shown in Figure 2-2(A). A positive discharge, which occurs only a small but significant percentage of the time, is shown in Figure 2-2(B). It is characterized by both higher average current and longer duration in a single stroke and must be recognized because of its greater energy content. The following discussion describes the more common negative flashes.

#### 2.1.1 Prestrike Phase

The lightning flash is typically originated by a step leader which develops from the cloud toward the ground or towards another charge center. As a lightning step leader approaches an extremity of the vehicle, high electrical fields are produced at the surface of the vehicle. These electric fields give rise to other electrical streamers which propagate away from the vehicle until one of them contacts the approaching lightning step leader as shown on Figure 2-1. Propagation of the step leader will continue from other vehicle extremities until one of the branches of the step leader reaches the ground or another charge center. The average velocity of propagation of the step leader is about one meter per microsecond and the average charge in the whole step leader channel is about 5 coulombs.

#### 2.1.2 High Peak Current Phase

The high peak current associated with lightning occurs after the step leader reaches the ground and forms what is called the return stroke of the lightning flash. This return stroke occurs when the charge in the leader channel is suddenly able to flow into the low impedance ground and neutralize the charge attracted into the region prior to the step leader's contact with the ground. Typically, the high peak current phase is called the return stroke and is in the range of 10 to 30 kA (amperes  $\times 10^3$ ). Higher currents are possible though less probable. A peak current of 200 kA represents a very severe stroke, one that is exceeded only about 0.5 percent of the time. While 200 kA may be considered a practical maximum value of lightning current, it should be emphasized that in rare cases a larger current can occur. Reliable measurements are few, but there is circumstantial evidence that peak currents can exceed 400 kA. The current in the return stroke has a fast rate of change, typically about 10 to 20 kA per micro-

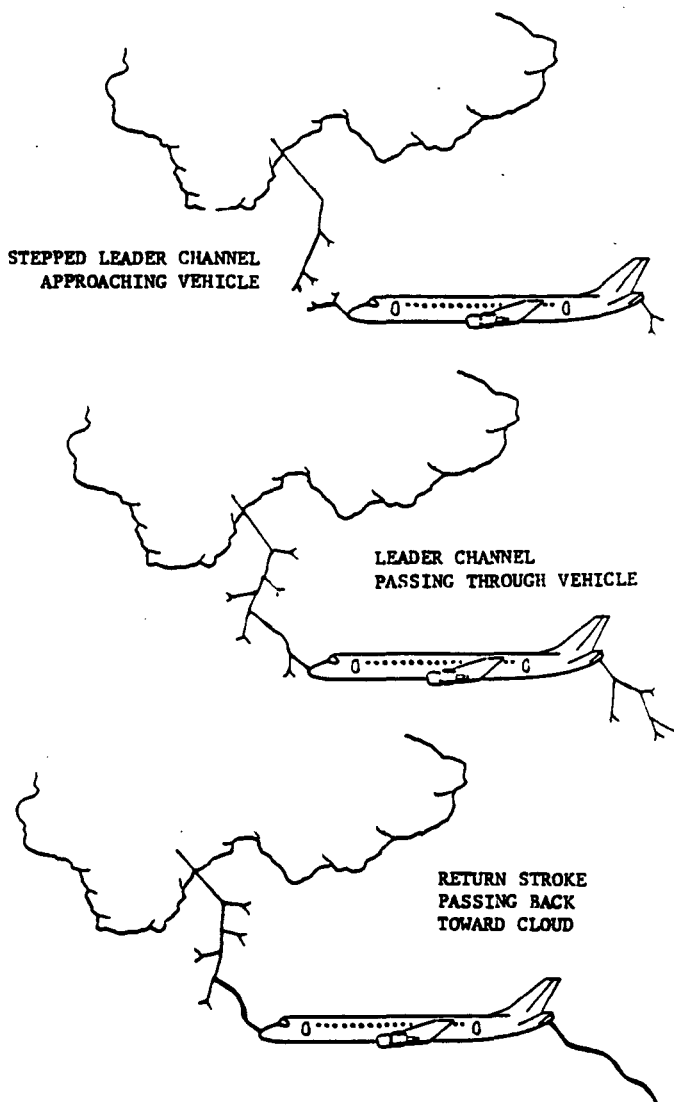


Fig. 2-1 Lightning flash striking an aircraft.

second and exceeding, in rare cases, 100 kA per microsecond. Typically the current decays to half its peak amplitude in 20 to 40  $\mu$ sec. No correlation has been shown to exist between peak current and rate of rise.

#### 2.1.3 Continuing Current

The total charge transported by the lightning return stroke is relatively small, a few coulombs. Most of the charge is transported in two phases of the lightning flash following the first return stroke. These are an intermediate phase in which currents of a few thousand amperes flow for times of a few milliseconds and a continuing current phase in which currents of the order of 200-400 amperes flow for times varying from about a tenth of a second to one second. The maximum charge transferred in the intermediate phase is about 10 coulombs and the maximum charge transported during the total continuing current phase is about 200 coulombs.

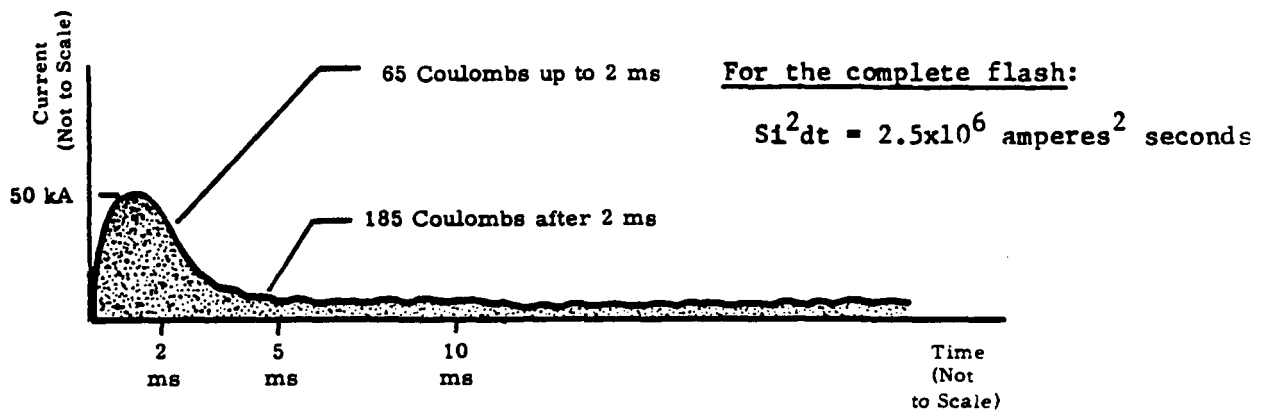
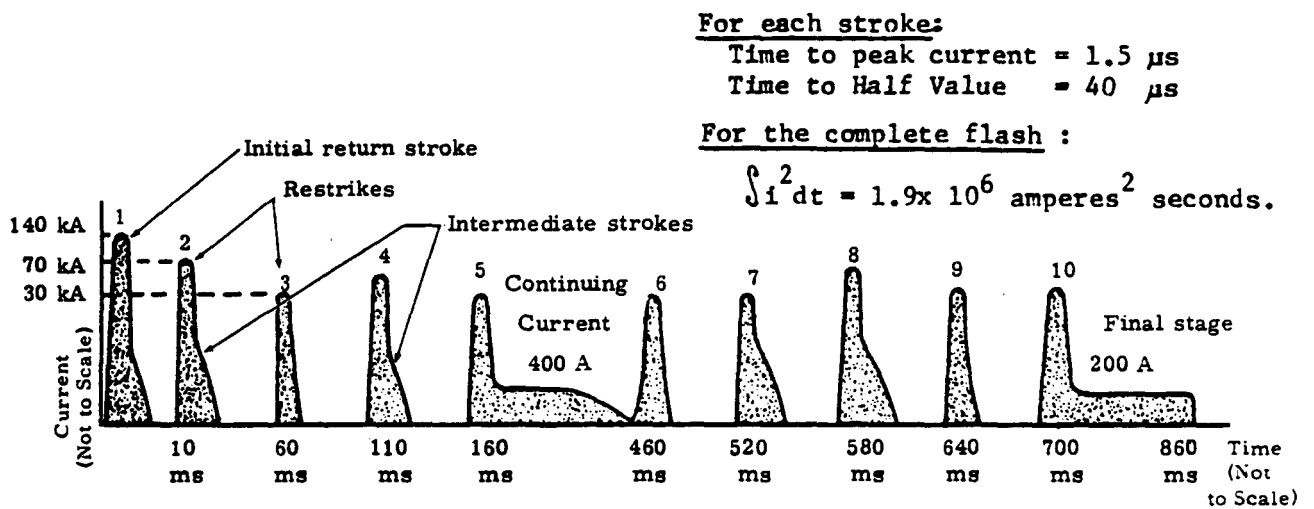


Figure 2-2 Lightning flash current waveforms.

#### 2.1.4 Restrike Phase

In a typical lightning flash there will be several high current strokes following the first return stroke. These occur at intervals of several tens of milliseconds as different charge pockets in the cloud are tapped and their charge fed into the lightning channel. Typically the peak amplitude of the restrikes is about one half that of the initial high current peak, but the rate of current rise is often greater than that of the first return stroke. The continuing current often links these various successive return strokes, or restrikes.

### 2.2 Aerospace Vehicle Lightning Strike Phenomena

#### 2.2.1 Initial Attachment

Initially the lightning flash will enter and exit the aircraft at two or more attachment points. There will always be at least one entrance point and one exit point. It is not possible for the vehicle to store the electrical energy of the lightning flash in the capacitive field of the vehicle and so avoid an exit point. Typically these initial attachment points are at the extremities of the vehicle. These include the nose, wing tips, elevator and stabilizer tips, protruding antennas, and engine pods or propeller blades. Lightning can also attach to the leading edge of swept wings and some control surfaces.

#### 2.2.2 Swept Stroke Phenomenon

The lightning channel is somewhat stationary in space while it is transferring electrical charge. When a vehicle is involved it becomes part of the channel. However, due to the speed of the vehicle and the length of time that the lightning channel exists, the vehicle can move relative to the lightning channel. When a forward extremity, such as a nose or wing mounted engine pods are involved, the surface

moves through the lightning channel. Thus the lightning channel appears to sweep back over the surface as illustrated in Figure 2-3. This is known as the swept stroke phenomenon. As the sweeping action occurs, the type of surface can cause the lightning channel attachment point to dwell at various surface locations for different periods of time, resulting in a skipping action which produces a series of discrete attachment points along the sweeping path.

The amount of damage produced at any point on the aircraft by a swept-stroke depends upon the type of material, the arc dwell time at that point, and the lightning currents which flow during the attachment. Both high peak current restrikes with intermediate current components and continuing currents may be experienced. Restrikes typically produce reattachment of the arc at a new point.

When the lightning arc has been swept back to one of the trailing edges it may remain attached at that point for the remaining duration of the lightning flash. An initial exit point, if it occurs at a trailing edge, of course, would not be subjected to any swept stroke action.

The significance of the swept stroke phenomenon is that portions of the vehicle that would not be targets for the initial entry and exit point of a lightning flash may also be involved in the lightning flash process as the flash is swept backwards across the vehicle.

#### 2.2.3 Lightning Attachment Zones

Aircraft surfaces can then be divided into three zones, with each zone having different lightning attachment and/or transfer characteristics. These are defined as follows:

**Zone 1:** Surfaces of the vehicle for which there is a high probability of initial lightning flash attachment (entry or exit).

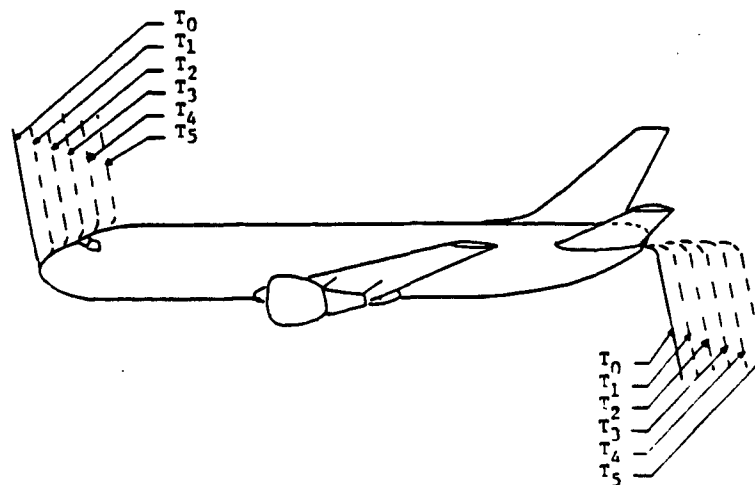


Figure 2-3 Swept stroke phenomenon.

Zone 2: Surfaces of the vehicle across which there is a high probability of a lightning flash being swept by the airflow from a Zone 1 point of initial flash attachment.

Zone 3: Zone 3 includes all of the vehicle areas other than those covered by Zone 1 and Zone 2 regions. In Zone 3 there is a low probability of any attachment of the direct lightning flash arc. Zone 3 areas may carry substantial amounts of electrical current but only by direct conduction between some pair of direct or swept stroke attachment points.

Zones 1 and 2 may be further divided into A and B regions depending on the probability that the flash will hang on for any protracted period of time. An A type region is one in which there is low probability that the arc will remain attached and a B type region is one in which there is a high probability that the arc will remain attached. Some examples of zones are as follows:

Zone 1A: Initial attachment point with low probability of flash hang-on, such as a leading edge.

Zone 1B: Initial attachment point with high probability of flash hang-on, such as a trailing edge.

Zone 2A: A swept stroke zone with low probability of flash hang-on, such as a wing mid-span.

Zone 2B: A swept stroke zone with high probability of flash hang-on, such as a wing inboard trailing edge.

## 2.3 Aerospace Vehicle Lightning Effects Phenomena

The lightning effects to which aerospace vehicles are exposed and the effects which should be reproduced through laboratory testing with simulated lightning waveforms can be divided into DIRECT EFFECTS and INDIRECT EFFECTS. The direct effects of lightning are the burning, eroding, blasting, and structural deformation caused by lightning arc attachment, as well as the high-pressure shock waves and magnetic forces produced by the associated high currents. The indirect effects are predominately those resulting from the interaction of the electromagnetic fields accompanying lightning with electrical apparatus in the aircraft. Hazardous indirect effects could in principle be produced by a lightning flash that did not directly contact the aircraft and hence was not capable of producing the direct effects of burning and blasting. However, it is currently believed that most indirect effects of importance will be associated with a direct lightning flash. In some cases both direct and indirect effects may occur to the same component of the aircraft. An example would be a lightning flash to an antenna which physically damages the antenna and also sends damaging voltages into the transmitter or receiver connected to that antenna. In this document the physical damage to the antenna will be discussed as a direct effect and the voltages or currents coupled from the antenna into the communications equipment will be treated as an indirect effect.

### 2.3.1 Direct Effects

The nature of the particular direct effects associated with any lightning flash depends upon the structural component involved and the particular phase of the lightning current transfer discussed earlier.

#### 2.3.1.1 Burning and Eroding

The continuing current phase of a lightning stroke can cause severe burning and eroding damage to vehicle structures. The most severe damage occurs when the lightning channel dwells or hangs on at one point on the vehicle for the entire period of the lightning flash, such as in Zone 1B. This can result in holes of up to a few centimeters in diameter on the aircraft skin.

#### 2.3.1.2 Vaporization Pressure

The high peak current phase of the lightning flash transfers a large amount of energy in a short period of time, a few tens of microseconds. This energy transfer can result in a fast thermal vaporization of material. If this occurs in a confined area such as a radome, a high pressure may be created which may be of sufficient magnitude to cause structural damage. The vaporization of metal and other materials and the heating of the air inside the radome, create the high internal pressure that leads to structural failure. In some instances entire radomes have been blown from the aircraft.

#### 2.3.1.3 Magnetic Force

During the high peak current phase of the lightning flash the flow of current through sharp bends or corners of the aircraft structure can cause extensive magnetic flux interaction. In certain cases, the resultant magnetic forces can twist, rip, distort, and tear structures away from rivets, screws, and other fasteners. These magnetic forces are proportional to the square of the magnetic field intensity and thus are proportional to the square of the lightning current. The damage produced is related both to the magnetic force and to the response time of the system.

#### 2.3.1.4 Fire and Explosion

Fuel vapors and other combustibles may be ignited in several ways by a lightning flash. During the prestrike phase high electrical stresses around the vehicle produce streamers from the aircraft extremities. The design and location of fuel vents determine their susceptibility to streamer conditions. If streamers occur from a fuel vent in which flammable fuel-air mixtures are present, ignition may occur. If this ignition is not arrested, flames can propagate into the fuel tank area and cause a major fuel explosion.