



The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Équipement de l'Aviation Civile

AIRCRAFT LIGHTNING TEST METHODS

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ED-105A

July 2013

Supersedes ED-105

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FOREWORD

1. This document was prepared jointly by EUROCAE Working Group 31 "Lightning" in cooperation with SAE AE-2 "Lightning Committee", and was approved by the Council of EUROCAE on 3 July 2013.
2. EUROCAE is an international non-profit making organisation in Europe. Membership is open to manufacturers and users of equipment for aeronautics, trade associations, national civil aviation administrations, and, under certain conditions, non-European organisations. Its work programme is principally directed to the preparation of performance specifications and guidance documents for civil aviation equipment, for adoption and use at European and world-wide levels.
3. The findings of EUROCAE are resolved after discussion amongst Members of EUROCAE and in collaboration with RTCA Inc, Washington D.C., and/or the Society of Automotive Engineers (SAE), Warrendale PA, U.S.A., through their appropriate committees.
4. EUROCAE performance specifications and other documents are recommendations only. EUROCAE is not an official body of the European Governments. Its recommendations are valid as statements of official policy only when adopted by a particular government or conference of governments.
5. With the original release of the document, many new test methods were provided to account for aircraft operational experience and changing aircraft technology, including more reliance on electronic data and control systems and increasing use of composite materials in aircraft structures. As experience is gained with these test methods, some changes and clarifications are needed to ensure consistency across test organizations, particularly regarding high voltage tests and integrated system functional upset tests. Also, ignition source detection methods have historically relied upon the use of Polaroid film as the standard. Since this film's source of supply is rapidly disappearing, photographic methods using modern camera technologies needs to be included in the recommended practice.
6. This document has its origins in the SAE AE-4L Committee's "Blue" book issued in 1978 and titled "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware." Subsequent to the issuance of the "Blue" book, the SAE AE-4L developed MIL-STD-1757 for the United States military dated 1981 and titled "Lightning Qualification Techniques for Aerospace Vehicles and Hardware." In MIL-STD-1757, the committee placed the test methodology contained in the "Blue" book into a more formalized format. This EUROCAE Document (ED) is a significant refinement and expansion of the basic material from these sources, providing a more thorough and updated description of the test techniques.
7. Copies of this document may be obtained from:

EUROCAE
102, rue Etienne Dolet
92240 MALAKOFF
France

Telephone: 33 1 40 92 79 30

Fax: 33 1 46 55 62 65

Email: eurocae@eurocae.net

Website: www.eurocae.net

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CHAPTER 1

SCOPE

This document is one of a set covering the whole spectrum of aircraft interaction with lightning. This document is intended to describe how to conduct lightning direct effects tests and indirect system upset effects tests. Indirect effects upset and damage tolerance tests for individual equipment items are addressed in ED-14 / DO-160. Documents relating to other aspects of the certification process, including definition of the lightning environment, zoning, and indirect effects certification are listed in Section 2.

This document presents test techniques for simulated lightning testing of aircraft and the associated systems. This document does not include design criteria nor does it specify which items should or should not be tested. Acceptable levels of damage and/or pass/fail criteria for the qualification tests must be approved by the cognizant certification authority for each particular case. When lightning tests are a part of a certification plan, the test methods described herein are an acceptable means, but not the only means, of meeting the test requirements of the certification plan.

Each test method is set out in a uniform format, describing the test purpose, test object, test setup, test waveforms (voltage and/or current), measurements and data recording, test procedure and data interpretation. Guidance is provided on how to select the appropriate test or series of tests, and how the test results can be assessed.

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 not intended that every 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.

CHAPTER 2

REFERENCES

2.1 APPLICABLE DOCUMENTS

The documents below provide various sources of information relevant to aircraft lightning testing including descriptions of the external lightning environment applicable to aircraft, methods of determining lightning zoning of aircraft, regulatory requirements, and guidance on certifying aircraft by analysis and test.

NOTE: *Whenever a reference document appears in this Recommended Practice, it carries the minimum revision level of the reference document acceptable to meet the intended requirements. Later versions of the reference document are also acceptable but earlier versions are not acceptable. In all cases, other documents shown to be equivalent to the referenced document are also acceptable.*

2.1.1 SAE PUBLICATIONS

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

- | | |
|------------------|---|
| ARP4754 | Guidelines for Development of Civil Aircraft and Systems |
| ARP5412 | Aircraft Lightning Environment and Related Test Waveforms |
| ARP5414 | Aircraft Lightning Zone |
| ARP5415 | User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning |
| Report AE4L-76-1 | "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware", (Blue Book), dated June 20, 1978 |
| Report AE4L-81-2 | "Test Waveforms and Techniques for Assessing the Effects of Lightning Induced Transients", (Yellow Book), dated December 15, 1981 |

2.1.2 FEDERAL AVIATION REGULATIONS (FAR)

Available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, www.faa.gov.

US Code of Federal Regulations 14 CFR Parts 21, 23, 25, 27 & 29; Sections x.581, .610, .867, .899, .901, .903, .954, .1301, .1309, .1316, .1431 and .1529 (as applicable)

2.1.3 FAA ADVISORY CIRCULARS (AC)

Available from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, www.faa.gov.

- | | |
|-----------|--|
| AC 20-53A | "Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning", dated April 12, 1985, Rev B issued June 5, 2006. Contains zoning definitions and procedures that are used for direct effects protection and is used as a guide to describe zoning as it applies to indirect effects. |
| AC 20-136 | "Protection of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning", dated March 5, 1990, Rev B issued September, 7, 2011 |

AC 21-16D	RTCA Document DO-160D, dated July 21, 1998, Rev G issued June 22, 2011
AC 23.1309-1C	"Equipment, Systems, and Installations", dated March 12, 1999, Rev 1E issued November 17, 2011
AC 25.1309-1A	"System Design Analysis", dated June 21, 1988
AC 27-1B	"Certification of Normal Category Rotorcraft", dated September 30, 1999, Change 3 issued September 30, 2008
AC 29-2C	"Certification of Transport Category Rotorcraft", dated September 30, 1999, Change 3 issued September 30, 2008

2.1.4 RTCA, INC. PUBLICATIONS

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160D "Environmental Conditions and Test Procedures for Airborne Equipment", dated July 29, 1997, including Change No. 1, dated December, 2000, Change No. 2, dated June, 2001 and Change No. 3, dated December, 2002, Rev G issued December 8, 2010

2.1.5 EASA PUBLICATIONS

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS Parts 21, 23, 25, 27 & 29; Sections x.581, .610, .867, .899, .901, .903, .954, .1301, .1309, .1316, .1431 and .1529 (Parts and Sections as applicable)

2.1.6 EUROCAE PUBLICATIONS

Available from EUROCAE, 102, rue Etienne Dolet, 92240 Malakoff, France, Tel: +33.1.40.92.79.30, www.eurocae.net.

EUROCAE ED-14D "Environmental Conditions and Test Procedures for Airborne Equipment", dated July, 1997, including Change No. 1, dated December, 2000, and Change No. 2, dated June, 2001 and Change No. 3, dated December, 2002, Rev G issued May, 2011

EUROCAE ED-79 "Certification Considerations for Highly Integrated or Complex Aircraft Systems", dated April, 1997, Rev A issued December, 2010

EUROCAE ED-81 "Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning", dated May, 1996, including Amendment No. 1, dated August 26, 1999

EUROCAE ED-84 "Aircraft Lightning Environment and Related Test Waveforms Standard", dated August, 1997, including Amendment No. 1, dated October 19, 1999, including Amendment No. 2, dated May, 2001, including Amendment No. 3, dated June, 2006

EUROCAE ED-91 "Aircraft Lightning Zoning Standard", dated July, 1998, including Amendment No. 1, dated September 6, 1999, including Amendment No. 2, dated June, 2006

2.1.7 ANSI PUBLICATIONS

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI Z540.1 "General Requirements for Calibration Laboratories and Measuring and Test Equipment", dated 1994

2.1.8 IEC PUBLICATIONS

Available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112.

IEC 60060-2 “High-Voltage Test Techniques - Part 2: Measuring Systems”, dated November, 1994

2.2 DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

2.2.1 Definitions

ACTION INTEGRAL: The integral of the square of the time varying current over its time of duration. It is usually expressed in units of ampere squared seconds (A^2s).

ACTUAL TRANSIENT LEVEL (ATL): The level of transient voltage and/or current that appears at the equipment interfaces as a result of the external environment. This level may be less than or equal to the transient control level but should not be greater.

APERTURE: An electromagnetically transparent opening.

ARC ROOT: The location on the surface of a conducting body at which the lightning channel is attached while high current flows.

ATTACHMENT POINT: A point of contact of the lightning flash with the aircraft.

CABLE (WIRE) BUNDLE: A group of wires and/or cables bound or routed together that connect two pieces of equipment.

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

DIRECT EFFECTS: Any physical effects to the aircraft and or equipment due to the direct attachment of the lightning channel and/or conduction of lightning current. This includes dielectric puncture, blasting, bending, melting, burning and vaporization of aircraft or equipment surfaces and structures. It also includes directly injected voltages and current in associated wiring, plumbing, and other conductive components. Direct effects also include shock and flash blindness to personnel.

DISCHARGE: Relative to High Voltage (HV) or High Current (HC) impulse generators, the transfer of charge from the storage capacitors. This action may or may not cause an electrical breakdown of the gap between the electrodes connected to the output terminals of the generator.

EQUIPMENT INTERFACE: A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an electrical item, or wire bundles that interconnect equipment.

EQUIPMENT TRANSIENT DESIGN LEVEL (ETDL): The peak amplitude of transients to which the equipment is qualified.

EXTERNAL ENVIRONMENT: Characterization of the natural lightning environment for design and certification purposes as defined in ED-84 / ARP5412.

FACILITY GROUND: Reference ground plane (electrical) for the experiment or test configuration.

FLASHOVER: The condition when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.

GAP BREAKDOWN: The electrical breakdown of the gap between the electrodes connected to the generator output terminals. This breakdown is caused by the discharge of the capacitors of an HV or HC impulse generator.

GENERATOR: A set of equipment (waveform synthesizer amplifiers, couplers, etc.) that delivers a voltage or current waveform, via direct or indirect coupling to the equipment under test (EUT).

HOT SPOT: A surface in contact with fuel/air mixtures that is heated by the conduction of lightning currents to a temperature which will ignite the mixtures.

INDIRECT EFFECTS: Electrical transients induced by lightning in aircraft electric circuits.

INTERNAL ENVIRONMENT: The fields and structural IR potentials inside the aircraft produced by the external environment.

LIGHTNING FLASH: The total lightning event. It may occur within a cloud, between two clouds, or between cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.

LIGHTNING HIGH VOLTAGE WAVEFORMS (A, B, C, AND D): Different standardized high voltage waveforms. For details refer ED-84 / ARP5412.

LIGHTNING STRIKE: Any attachment of the lightning flash to the aircraft.

LIGHTNING STRIKE ZONES: Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction. See ED-91 / ARP5414 for reference.

LIGHTNING STROKE (RETURN STROKE): A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

LOCAL GROUND: Any ground strap or conductor that is connected to the equipment and the same part of airframe structure in which that equipment is installed. The ground strap or conductor would, therefore, be bonded to the same ground plane that the equipment is mounted to and, during a lightning strike, would be at the same potential as the equipment.

MULTIPLE BURST: A randomly spaced series of bursts of short duration, low amplitude current pulses, with each pulse characterized by rapidly changing currents (i.e., high dI/dt). These bursts may result from lightning leader progression or branching, and are associated with the cloud-to-cloud and intra-cloud flashes. The multiple bursts appear to be most intense at the time of initial leader attachment to the aircraft.

MULTIPLE STROKE: Two or more lightning return strokes occurring during a single lightning flash.

PUNCTURE: Localized irreversible breakdown of insulation properties of a solid dielectric material.

SHIELD: A conductor that is grounded to an equipment case or aircraft structure at both ends and is routed in parallel with and bound within a wire bundle. It usually is a wire braid around some of the wires or cables in the wire bundle or may be a metallic conduit, channel or wire grounded at both ends within the wire bundle. The effect of the shield is to provide a low resistance path between equipment so connected.

SHIELDED CABLE (WIRE) BUNDLE: A wire bundle that contains one or more shields. Such wire bundles may include SOME unshielded wires.

STREAMER: Branch-like ionized paths that occur in the presence of a direct stroke or under conditions when lightning strokes are imminent.

STRUCTURAL IR VOLTAGE: The portion of the induced voltage resulting from the product of the distributed lightning current (I) and the resistance (R) of the aircraft skin or structure.

SYSTEM: A combination of two or more parts or equipment, generally physically separated when in operation, and such other units, assemblies, and basic parts necessary to perform an operational function or functions.

SYSTEM FUNCTIONAL UPSET: An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

THERMAL SPARKS: Burning particles emitted by rapid melting and vaporization of conductive materials carrying current through a point contact.

TRANSIENT CONTROL LEVEL (TCL): The maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external environment.

UNSHIELDED CABLE (WIRE) BUNDLE: A wire bundle that contains no shields.

UPSET: (See System Functional Upset).

V_{OC} AND I_{SC} : Open circuit voltage and short circuit current from a test generator for a particular primary excitation of the generator. The ratio (V_{OC}/I_{SC}) of the two quantities denotes the source impedance (see ARP5415 for reference).

VOLTAGE AND CURRENT TEST/LIMIT LEVELS (V_T , I_T , V_L AND I_L): Voltage and current excitation thresholds for generators used for testing of systems and equipment. For details, refer to ED-84 / ARP5412, ARP5415, and ED-14 / DO-160.

VOLTAGE SPARK: An electrical breakdown of a gaseous dielectric between two separated conductors.

ZONING (1A, 1B, 1C, 2A, 2B, AND 3): The process (or end result of the process) of determining the location on an aircraft to which the components of the external environment are applied. For details, refer to ED-91 / ARP5414.

2.2.2

Abbreviations

A	amperes
AC	alternating current
C	capacitance
cm	centimeters
d or D	distance or diameter
dB	decibel
DC	direct current
f or F	frequency
ft	feet
GΩ	gigaohms
Hg	mercury
Hz	hertz
i or I	current
K	constant
kA	kiloamperes
kHz	kilohertz
kV	kilovolts
L	inductance
m	meter
mA	milliamperes
MHz	megahertz
μH	microhenries
μJ	microjoules
μs	microseconds
mm	millimeters

mmHg	millimeters of mercury
MΩ	megohms
nH	nanohenries
p	pressure
P	power
pF	picofarad
ps	picoseconds
Ω	ohms
Q	resonance characteristics
R	resistance
s	seconds
V	voltage or volts
W	watts
Z	impedance

2.2.3

Acronyms

AC	Advisory Circular
ANSI	American National Standards Institute
AOA	Angle-Of-Attack
ARP	Aerospace Recommended Practice
ATL	Actual Transient Level
CFC	Carbon Fiber Composite
CFR	Code of Federal Regulations
CFRP	Carbon Fiber Reinforced Plastic
CN	Coupling Network
CS	Certification Specification
CW	Continuous Wave
EED	Electro-Explosive Device
EASA	European Aviation Safety Agency
EFIS	Electronic Flight Information System
EM	Electromagnetic
EMC	Electromagnetic Compatibility
ETDL	Equipment Transient Design Level
EUROCAE	European Organization for Civil Aviation Equipment
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FFT	Fast Fourier Transforms
FHA	Functional Hazard Assessment

FRP	Fiberglas Reinforced Plastic
HIRF	High Intensity Radiated Fields
HV	High Voltage
ICAS	Integrated Crew Alerting System
ICOLSE	International Conference on Lightning and Static Electricity
IEC	International Electrotechnical Commission
IMA	Integrated Modular Avionics
IR	$I * R$ (structural current times resistance)
LISN	Line Impedance Stabilization Network
LRU	Line Replaceable Unit
MIL-STD	Military Standard
NIST	National Institute of Standards and Technology
RF	Radio Frequency
RTCA	RTCA, Inc., formerly Radio Technical Committee on Aeronautics
SLPM	Standard Liters Per Minute
SSA	System Safety Assessment
TCL	Transient Control Level
TLD	Time-Limited Dispatch

CHAPTER 3

LIGHTNING EFFECTS

The lightning effects to which aircraft are exposed and the effects that should be reproduced through laboratory testing with simulated lightning waveforms can be divided into direct and indirect effects.

Direct effects include burning, eroding, blasting and structural deformation caused by lightning arc attachment, which includes high-pressure shock waves, magnetic forces and thermal effects produced by the associated high currents.

Indirect effects are those resulting from the interaction of the electromagnetic fields accompanying lightning with electrical/electronic equipment in the aircraft. These fields are the results of aperture coupling and structural IR (current times resistance) voltage rise due to lightning currents in aircraft.

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 injects large currents directly into the transmitter or receiver signal and power lines. In this document the physical damage to the antenna will be treated as a direct effect, whereas the voltages and/or currents that couple from the antenna into the radio/radar equipment will be treated as an indirect effect.

3.1

DIRECT EFFECTS

The major examples of direct effects due to lightning are categorized and listed below.

a. Dielectric Puncture

The puncture of a dielectric skin covering electrically conductive elements may cause holes ranging from pinholes to large diameter holes. These holes may result in the direct attachment of the lightning channel to the enclosed equipment. The likelihood of puncture is a function of the distance to the conductor underneath the dielectric, the thickness and dielectric strength of the skin, the condition of the dielectric surface, and the proximity of other conductors. A puncture of the dielectric skin will generally occur unless the voltage to puncture the dielectric at any point is significantly greater than the voltage required to cause flashover to the nearest conducting point on the airframe.

b. Arc Root Thermal Damage and Heating Effects

Burn through and material erosion can occur at the arc root. In metal, this is a function of current and time. In the arc root area, there is a large thermal input from the arc root itself, as well as a concentration of ohmic heating due to the high current densities. Most of the energy is generated at or very close to the surface of the metal. If the heat generated in the immediate arc root area is in excess of that which can be absorbed into the metal by conduction, then the excess is either lost in melting and vaporizing the metal or is re-radiated. There is a minimum charge transfer within a minimum time for a given thickness of any given metal below which melt-through cannot occur.

In carbon fiber composites the thermal effects are more pronounced. The thermal conductance and electrical resistance cause resin melting, vaporization, and ply delamination. This leads to an increase in "affected-area" in relation to the physical depth of damage. The arc root burning voltage of carbon is higher than that of metals. This effect, plus the high bulk resistivity, generates more heat in the immediate arc root area and the hot spots remain for a longer period than for most metals.

For metallic surfaces it is primarily the combination of the intermediate and continuing current phase of the lightning flash that can exceed the minimum requirements of both current and duration for burn through or severe erosion. In the case of carbon fiber composites, however, short duration high action integral pulses as well as low current, long duration pulses produce high thermal inputs, and so all phases of the lightning flash are significant.

(1) Hot Spot Formation

Hot spot formation may occur on the inner surface of the aircraft skin opposite to the lightning attachment point. The effects of hot spots are significant primarily with regard to ignition of fuel and other highly flammable vapors.

(2) Ohmic Heating

The energy dissipated as heat in a conductor due to an electrical current is $\int i^2 R dt$ (watt-seconds). Where 'i' is the time varying current and 'R' is the ohmic resistance of the conductor. The ohmic heating generated by the complete lightning pulse is the ohmic resistance of the lightning path through the aircraft multiplied by the action integral of the pulse and is expressed in Joules or watt-seconds. In a lightning discharge, the high action integral phases of the lightning flash are of too short a duration for any heat generated in an aircraft structure by ohmic heating to disperse significantly.

(3) Exploding Conductors (Disruptive Forces)

Conductors may vaporize explosively if they have insufficient cross sectional area to carry lightning currents. The associated shock wave can give rise to severe damage particularly in confined spaces. This failure mechanism is particularly significant in electric wiring connected to external equipment (e.g., navigation lights, antennas, pitot tube heaters, etc.). If these are not adequately protected and are confined in or pass through closed compartments in the aircraft, they can present a significant hazard.

(4) Direct Effects Sparking

Two types of sparking can occur: thermal sparking and voltage sparking. Thermal sparks occur when currents pass through the interface joint between two parts and there is insufficient cross-sectional area to support the current. Voltage sparks occur when the voltage between two separated electrodes exceeds the breakdown level and discharge results. Voltage sparks are usually the result of induced voltages in the structure or wiring.

Most thermal sparking occurs near the edges of high spots on the mating surfaces where the interface pressure is at or close to zero. The primary causes are high current density and inadequate interface area and pressure. Thermal sparks consist of burning electrode material.

c. Acoustic Shock Wave Damage

The interaction of the arc and the aircraft surface can also produce a shock wave. The severity of the shock is dependent upon both the peak current value and the rate of rise of the current. In general, the damage due to acoustic shock wave is not significant on metal skins. Metal skins may be dented but generally not punctured. Stiff composite skins can suffer cracking and ruptures.

d. Magnetic Force

Charged particles in motion in a magnetic field experience a force that for a current flowing in a wire can be expressed as $F = (I \times B) L$, where F is the force, I is the current, L is the length of the wire, and B is the magnetic field. F , I , and B are vectors. For lightning currents flowing in aircraft, this force can manifest itself in various ways. One is a force on the surface of a conductor carrying lightning current. This effect can be explained as an element of current on one portion of the conductor producing a magnetic field that causes all other current elements to experience a force. The equation yields a force that is directed inward on all sides of the conductor. This force is only significant when the surface current density is greater than several kilo-amperes per millimeter. For example, a conductor of 5 mm diameter carrying a pulse of 200 kA peak current would experience a surface pressure of 1000 atmospheres. In some cases even relatively small forces can be significant. One such case is that of metal braid bonding straps. These can be compressed to near solid conductors leading to metal embrittlement and subsequent mechanical failure.

Another more common concern is that considerable magnetic forces can exist from currents flowing on separate conductors or from different sections of the same conductor where the lightning current is forced to change direction. The action of the force is to draw the separate conductors together or straighten out the single conductor. This force can also exist between current in the aircraft and the arc channel. This force is usually only of significance where the lightning current is confined to small-cross section conductors as might occur in some externally mounted equipment. Due to a change in current magnitude affecting both terms on the right side of the equation, the peak value of the force is proportional to the square of the peak current (i^2). The ultimate effect on the test object depends on the mechanical response of the test object.

3.2

INDIRECT EFFECTS

Indirect effects are the result of the interaction of the electromagnetic fields accompanying a lightning flash with the aircraft which creates a transient lightning internal environment for the duration of the flash. This internal environment causes voltages and currents on interconnecting wiring which, in turn, appear at equipment interfaces.

Indirect effects result from the following coupling mechanisms:

a. *Apertures*

Apertures are defined as electromagnetically transparent openings in the structure. Examples include windows, canopies, radomes, gaps, non-conductive panels, etc. Coupling of voltages and currents to internal wiring results from the fields that pass through apertures.

b. *Diffusion*

Diffusion is the process by which electromagnetic fields penetrate through the thickness of a conductive material. It results in internal fields that reflect a lengthened waveform of the external driving current to the vehicle. For highly conductive structures like aluminum, this generally results in a coupled current of insignificant amplitude. For more resistive materials like carbon fiber composites, the amplitude of the coupled current can be significant.

c. *Structural IR Voltages*

These result from the current flow through the impedance of the structure between two ends of an electrical circuit. For highly conductive structures like aluminum the magnitude of this voltage is generally insignificant. For more resistive structures like carbon fiber composites, the magnitude of this voltage can be significant.

d. *Conductive Penetrations*

Any conductor that is partially external and partially internal to the structure can form a path to directly conduct currents to the interior of the vehicle. Examples are wiring from external elements such as antennas, lights and heaters, and mechanical cables or tubing that is conductive. If such penetrations are not well bonded or isolated at penetration points, they can conduct significant currents inside the vehicle.

CHAPTER 4

PLANNING OF LIGHTNING EFFECTS TESTS

Before conducting tests on airborne equipment and systems for lightning effects, careful planning for conducting the tests should be accomplished. Many aspects of the testing need to be determined in advance to ensure a high quality and valid test. Some of these items are determination of the lightning zone where the hardware is located, the waveforms that need to be applied, the type(s) of configuration(s) and number of samples for each configuration, the location and number of test points, and success criteria. Other hardware items that are needed to simulate an actual installation such as adjacent support structure or objects located under dielectric surfaces need to be located or manufactured.

An important part of the planning process involves developing documentation to support the actual testing. This documentation may include a separate “test plan” and “test procedure,” or the concepts of both may be combined in a single document. A test plan will typically provide the purpose, general scope and aspects of the planned testing to help various program and customer personnel deal with issues associated with planning, budgeting for, and supporting the test. The test procedure typically is a much more involved document that provides details on the test object, zoning, applicable waveforms, laboratory test equipment, success criteria, step-by-step procedures for each individual test, and any other relevant aspects. The test procedure should adapt and refine the applicable tests contained in this ED to the particular hardware being evaluated. Since this ED deals with details of testing, it generally refers to material that should be contained in a test procedure rather than a test plan. It should be recognized that the terms “test procedure” and “test plan” have often been used interchangeably in the past. Past documents have also used a test plan to define ‘Why’ and ‘What’ is being tested and a test procedure to define ‘How’ the test article is being tested.

4.1 TEST OBJECT CONFORMITY

Three types of tests are typically done:

- a. *Development - Evaluation of non-conformed, built-up or off the shelf parts. Data from these tests does not meet the requirements of qualification or certification tests, but may lead to further refinements in design intended for certification.*
- b. *Qualification - Data taken with quality assurance agreement as to the test set-up and part number. Data typically used for overall system certification. Test is run to specification and data approved by the cognizant airworthiness authority.*
- c. *Certification - Contains all qualification data and part conformity paperwork. Test data approved by the cognizant airworthiness authority and submitted as a part of aircraft lightning certification package.*

Engineering or evaluation testing may be performed on any system or unit prior to a certification. However, when conducting a certification test the system is required to meet conformity requirements. Test objects which are of a computer nature must have verified and documented software installed. The process of conformity can take some time. The applicant is advised to start the process early in order to ensure that the proper levels of conformity requirements have been achieved prior to conducting the test. If not addressed early it may impact the test schedule or proper credit for test results may not be obtained. Due to the fact that conformity requirements may vary depending upon the type of testing being conducted as well as the type of certification sought, it is recommended that the applicant coordinate these requirements with the certification authorities with a view to reach an agreement, well in advance of actual testing.

Any differences between the configuration of the test article and the final production configuration should be analyzed to show that the differences do not impact the test. Conformity requirements should be reviewed in detail prior to discussion with the authorities and submission of the test documentation and test schedule.

4.2

TEST PROCEDURE

An outline of a typical test procedure is shown below. The content of a specific test procedure may contain more or less material, based on the nature of the testing. It is recommended that the applicant coordinate with the certification authorities well in advance of the final formulation of the procedure.

- a. INTRODUCTION
 - Scope
 - Objective (include whether Certification is goal)
 - Test Location
 - Test Witnessing
- b. TEST OBJECT
 - Description
 - Conformity Aspects
- c. TEST EQUIPMENT
 - Description
 - Calibration
- d. SAFETY CONSIDERATIONS
- e. TEST REQUIREMENTS
 - Detailed Description of each Test, using this ED as the basis
 - Pass/Fail Criteria
 - Operating Modes For Electrical/Electronic Equipment and Evaluation Techniques
- f. TEST REPORT REQUIREMENTS

4.3

MEASUREMENT SET-UP CALIBRATION

Test and measurement equipment requiring calibration should be calibrated before lightning tests.

The outputs of generation apparatus such as HV generators and amplifiers should be verified before every test sequence.

Background levels should be verified and noise levels minimized. In addition, care should be taken to avoid spurious coupling, for example, by the use of optical fibers.

Some examples of calibration methods can be found in IEC 60060-2.

4.4 TEST SAFETY ASPECTS

Testing for the direct and indirect effects of lightning requires high-energy electrical equipment that will be charged to lethal voltages during their operation. Therefore, all safety precautions relevant to this test apparatus must be complied with. All tests should be conducted in a controlled access area by personnel experienced in high voltage/high current testing. Special consideration should be given to personnel safety including the use of safety barriers/interlocks, well-documented safety procedures and logs, as well as eye and ear protection. In addition, relevant signage and audible warning of impending discharges may be appropriate. Fire suppression equipment may be required by local or company ordinances, and are recommended for any test where explosions and fire may occur.

4.5 TEST SET-UP

4.5.1 Test Object Design

It should be recognized that the test object set-up, design (size, build-up, coating) is one of the most important aspects of any test, whether it is an engineering test, or certification test. While utilizing full scale, built to drawing parts may seem the easiest and most 'fool proof' way of testing, it can be very expensive. Tests should be run on representative part build-ups, of appropriate size and shape, to accurately mimic the actual design and installation. Test object set-up is important to insure that bonding and grounding are properly implemented so test currents flow along representative paths and that test part mounting is consistent with actual installation of the part. This is of particular importance on smaller test objects where edge effects and surrounding structure may influence test object current distributions and affect test results.

Surface and corrosion inhibitive coatings are very important parts of the set-up process. Surface coatings can affect the way in which the arc disperses across the test object, and corrosion inhibitive coatings will affect the bond paths and grounding of surfaces and parts. These aspects should be reviewed prior to test set-up and it should be determined if they adequately represent the installation.

For example, a full large airliner wing to body fairing need not be tested to determine whether a Zone 2A current waveform will punch through the lightning protection and panel. Reasonably sized and grounded panels will suffice for the direct attachment test. A panel of sufficient size built to represent the thinnest portion of the middle of the panel may be adequate (worst case build-up). Because current would theoretically be flowing in all directions from the point of attachment, circumferential grounding may be fine. Experience has shown that 18 x 18 inches is of a large enough size of a flat panel to give reasonable data. Smaller sizes are acceptable if one recognizes that blast pressures and edge effects may skew test results.

4.5.2 Waveform Scaling

Multiple joint build-up parts should also be carefully constructed to mirror the actual intended installation. In addition, installation location and sizing must be taken into account in case current level scaling is required. For example, if a part is going to be tested with two fasteners holding two parts together that represents an installation of many fasteners holding two parts together, a full scale waveform may not be appropriate. Scaling the waveform to show what the effect of the current division among the fasteners would be appropriate.

4.5.3 Waveform Application

For high current direct effects and fuel system tests, the appropriate waveforms as identified in ED-84 / ARP5412 are typically applied in combination for a given test shot. For example, a Zone 2A direct arc attachment test would consist of a current component D followed by the B and C* current components within the same test shot, rather than applied as individual, distinct test shots. The purpose of this is to more closely simulate possible combinations of effects that may occur due to a real lightning event. For high voltage direct effects tests only one waveform is applied at a time, though more than one waveform may ultimately be applied to the test configuration to assess different conditions. For indirect effects tests, typically one waveform or waveform set is applied for a given test except that multiple pulses or repetitions are often required as called out in the test methods.

4.5.4 Concurrent Testing

Using the same test object for two concurrent test conditions may be difficult. If a Zone 1B arc entry test and a Zone 3 conducted current test is to be performed concurrently on a test specimen representing a large control surface that has many latches but the test panel has only two latches, the latches will be overtested because only two are available to carry the current. If the actual installation only has two latches holding it on, then, this would be a valid test. This is assuming all surfaces and surrounding structures were included in the test.

CHAPTER 5

DIRECT EFFECTS TEST METHODS

The Direct Effects Test Methods outlined in this section are:

- High Voltage Strike Attachment Tests (5.1)
- Initial Leader Attachment Test (5.1.1)
- Swept Channel Attachment Test (5.1.2)
- High Voltage Strike Attachment Test on Models (5.1.3)
- High Current Physical Damage Tests (5.2)
- Arc Entry Tests (5.2.1)
- Aircraft Non-Conductive Surfaces Test (5.2.2)
- Conducted Current Test (5.2.3)
- Induced Transients In External Mounted Hardware (5.3)
- Measurement of Injected Transients in External Hardware (5.3.1)
- Voltage Stress Assessment Of Circuit Insulation (5.3.2)

These tests evaluate direct effects protection and issues, except for fuel ignition considerations which are addressed in Section 7. The high voltage attachment tests are applied to determine specific lightning strike attachment points and breakdown paths across or through non-conducting materials. Since the currents that flow during these tests are typically low, the attachment tests are not intended to show possible damage from a lightning strike. The high current physical damage tests are used to assess actual damage from lightning currents. The high current transient tests address cases where electrical wiring installed within structures or externally mounted hardware may be susceptible to direct injection of lightning currents. However, the effects due to indirect coupling onto wiring (indirect effects) are addressed in Section 6 of this document. This section includes testing that can be applied to both an overall aircraft and particular components on aircraft.

5.1 HIGH VOLTAGE STRIKE ATTACHMENT TESTS

These tests are used to determine lightning attachment points and breakdown paths across or through non-conducting materials.

5.1.1 Initial Leader Attachment Test

5.1.1.1 Test Purpose

This test is normally applicable to parts of aircraft that are located in initial leader attachment regions within Zones 1A and 1B, as described in the ED-91 / ARP5414. Examples are wing tips fabricated of non-conducting materials, radomes, and large antenna fairings. This test can be used to assess:

- locations of possible leader attachment locations on full size structures,
- evaluation of radome wall materials,
- optimization of the location of protection devices,
- flashover or puncture paths, along or through dielectric surfaces, and/or
- performance of protection devices, such as radome diverter strips.

5.1.1.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. Any paint finishes, in particular any coats of anti-static paint or dielectric coverings on electrically conductive elements, should be included to ensure realistic development of corona and streamering from the conducting elements.

Electrically conducting objects, such as antenna elements and lights, normally enclosed by non-conducting test objects should be represented within the test objects. These may be actual devices, or geometrically correct mockups whose surfaces are at least as electrically conductive as the items they represent. These items must be positioned at the same locations within the test object as they would be in the aircraft installation. If the conducting objects may be oriented in several positions, those that represent worst cases should be represented in the tests. Normally these are the positions that result in the smallest distances to the non-conducting skins, or the strongest electric field intensities in directions normal to the aircraft surface.

Other conductors such as mounting fasteners, frames, hinges and latches must also be represented.

All conducting objects that are normally bonded (i.e., grounded) to the airframe must be electrically connected to the support structure and mocked up adjacent aircraft surfaces. Anti-static paint should be bonded to the support structure in a representative manner.

5.1.1.3 Test Setup

There are three test arrangements, designated Test Setup A, Test Setup B and Test Setup C, that can be used. Test Setups A and B are most appropriate for tests on complete production or prototype test objects, such as a radome. Test Setup C is most appropriate for developmental tests to evaluate skin panel construction and diverter strip configurations. Each test arrangement is intended to result in initiation of electrical activity, such as corona and streamering, at the test object (and not at the external electrode) as occurs in flight just before a lightning strike attachment. Once ionization of the air in the test object is initiated, the streamer will progress toward the other electrode which is to be a large geometry shape intended to represent an electric field equipotential surface some distance from an aircraft extremity. In this way the influence of the external test electrode on test results is minimized.

Overviews of the test arrangements showing the high voltage generator, test object, and external electrode in Test Setups A, B, and C are illustrated in Figure 1 through Figure 6.

The general test arrangement for Test Setup A is illustrated in Figure 1.

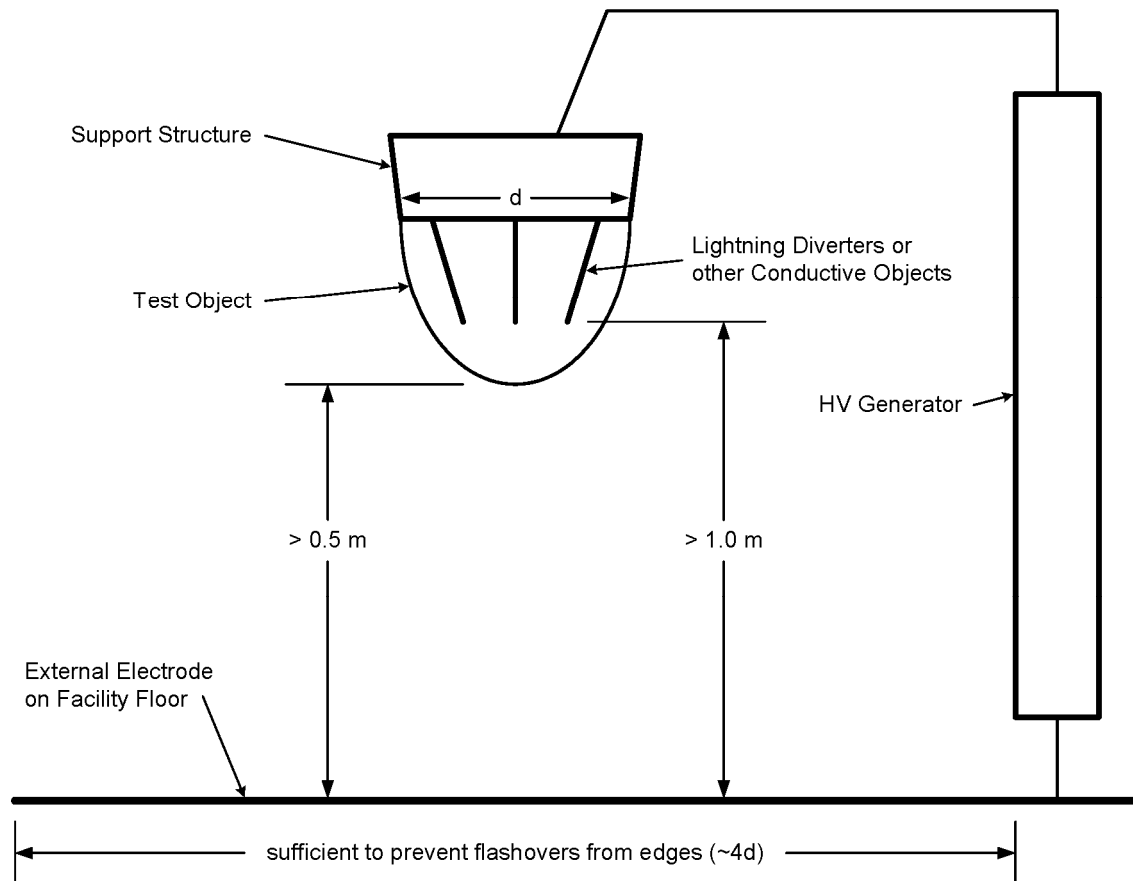


FIGURE 1: INITIAL LEADER ATTACHMENT TEST SETUP A

The test object is elevated above the external electrode which is a large area ground plane placed on the facility floor. The dimensions of the ground plane and spacing between the test specimen and the ground plane are dependent upon the size of the test object, as indicated in Figure 1. The test object should normally be tested with two or more orientations, to represent electric field directions that this part of the aircraft may experience in flight.

Four conditions should apply for a valid test:

- (1) The external electrode should be at least 1 m from the closest conductive element (inside or outside of the test object).
- (2) The external electrode should be at least 0.5 m from the test object skin.
- (3) Connection of the streamers should occur in the air away from the test object (this can be confirmed by photographs of the flashovers. The leader connection point is shown in Figure 2).
- (4) The streamer from the external electrode must not originate from the edge of the electrode.

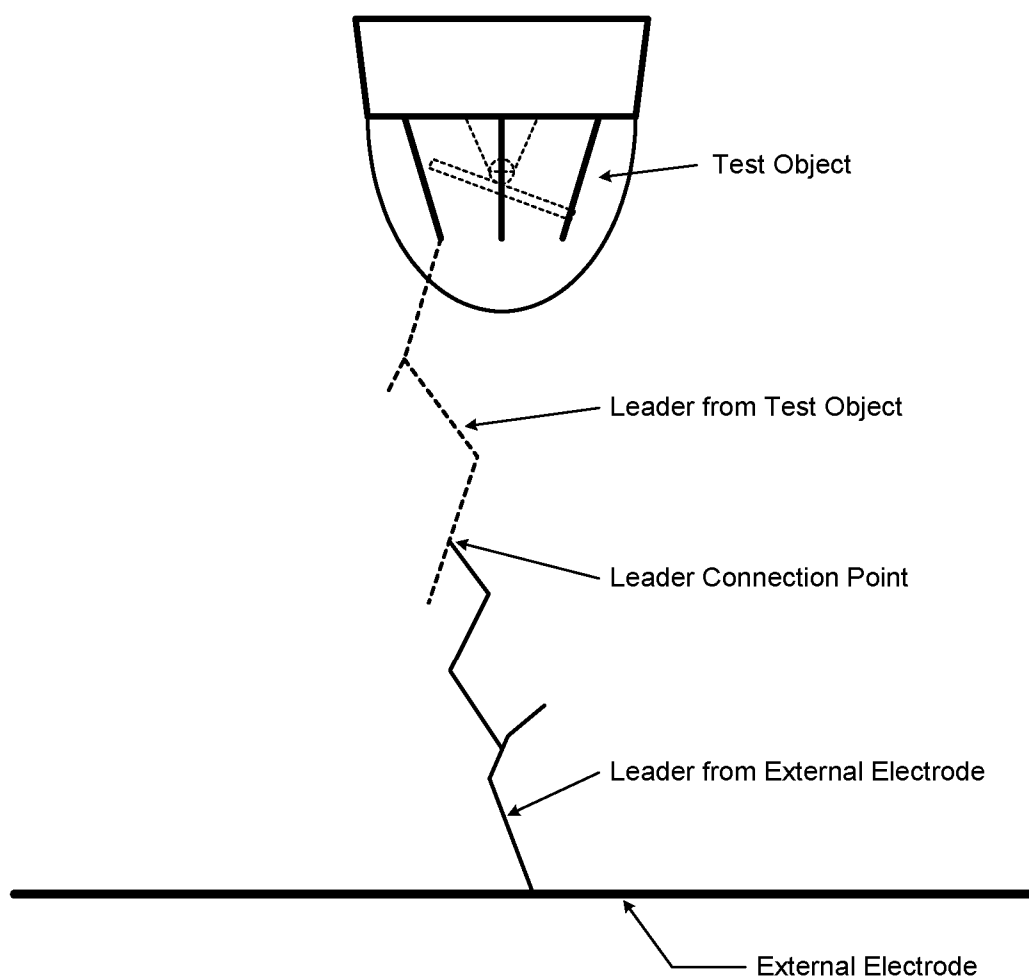


FIGURE 2: LEADER CONNECTION POINT

Specific dimensions and test object orientations should be described in the test procedures.

The general test arrangement for Test Setup B is illustrated in Figure 3.

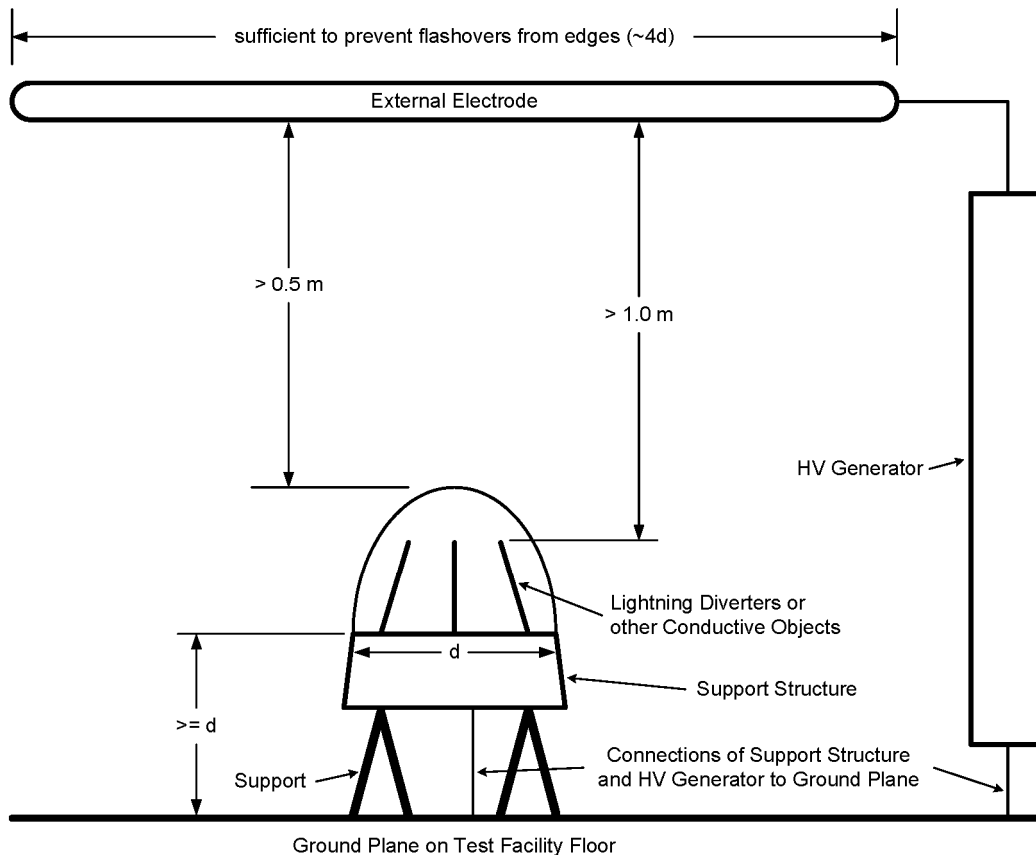


FIGURE 3: INITIAL LEADER ATTACHMENT TEST SETUP B

The test object is elevated above the ground plane on supports by a distance greater than the width of the test object 'd' to minimize influence of the ground plane on test results. The external electrode is suspended above the test object and at high potential when the test is applied. The dimensions of the external electrode and spacing between the test object and the external electrode are dependent upon the size of the test object, as indicated in Figure 3. The test object should normally be tested with two or more orientations, to represent the possible electric field directions that this part of the aircraft may experience in flight.

Small test objects such as low profile antennas have sometimes been mounted on a flat plate electrode for test as shown in Figure 3. To prevent flashovers from the edges of the high voltage electrode, increasing the size of this electrode as suggested in Figures 1 and 3 may be insufficient as flashovers may still occur from the edges. For such cases the high voltage electrode may be lowered until flashovers are initiated at the test object. This modification is acceptable if the connection between leaders originating at the test object and at the high voltage electrode are observed to connect in the air gap between test object and electrode.

Alternately, the fixture on which the test object is mounted should be profiled in a representative manner or have de-stressed edges.

Figures 4 and 5 show an example of test setup for externally mounted equipment. Width/diameter of the HV should be sufficient such that flashovers from its edges do not occur.

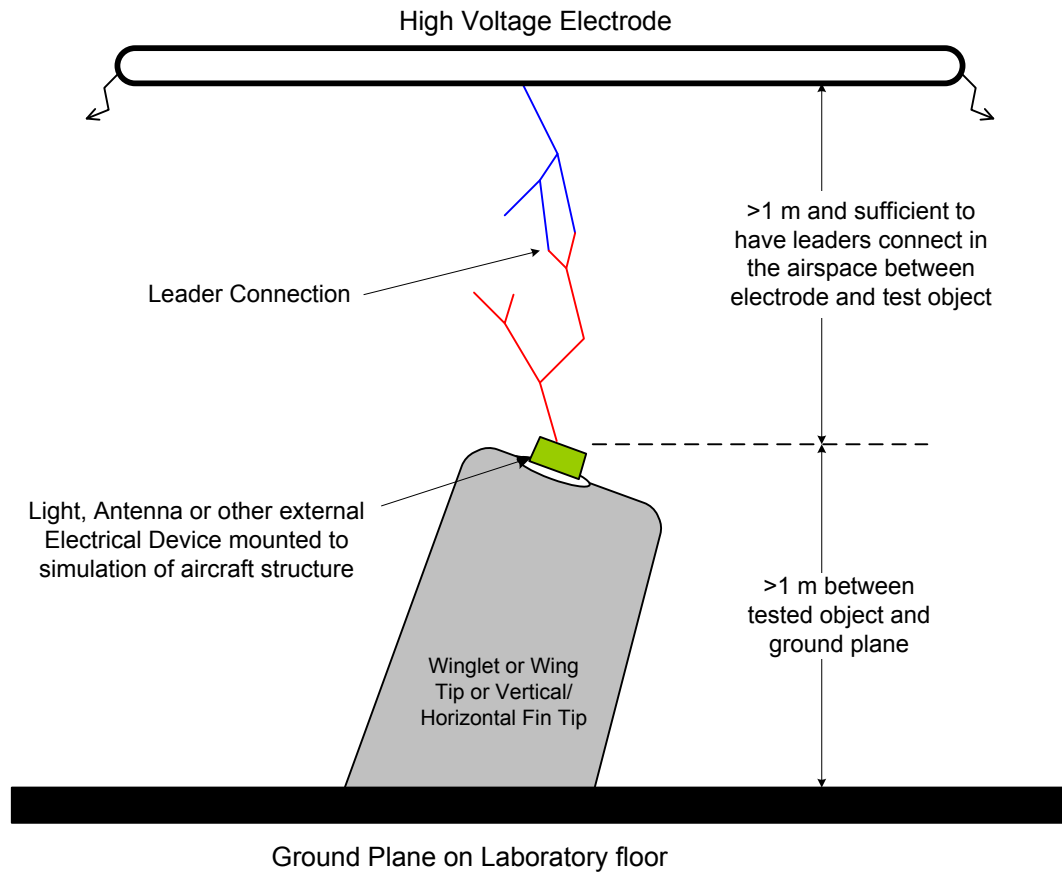


FIGURE 4: INITIAL LEADER ATTACHMENT TEST SETUP B, OF EXTERNALLY MOUNTED EQUIPMENT

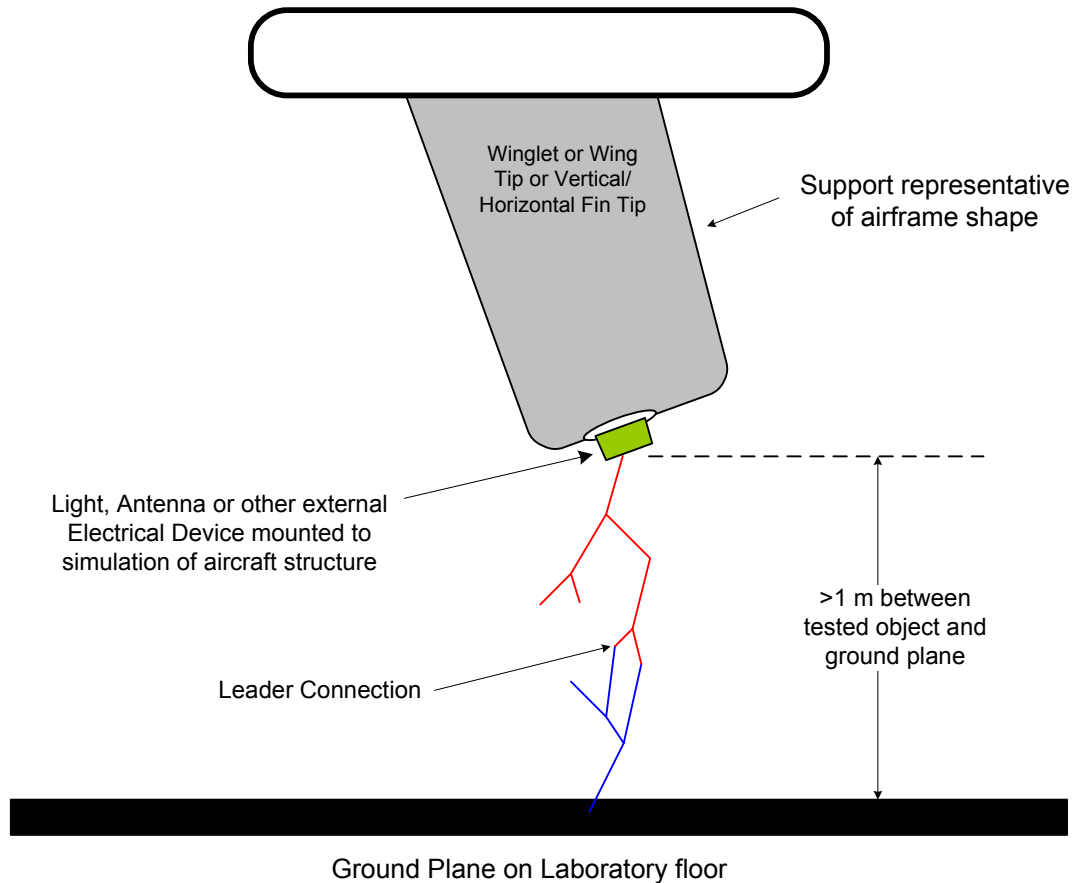


FIGURE 5: INITIAL LEADER ATTACHMENT TEST SETUP B, OF EXTERNALLY MOUNTED EQUIPMENT SUSPENDED ABOVE GROUND PLANE

Five conditions should apply for a valid test:

- (1) The external electrode should be at least 1 m from the closest conductive element (inside or outside of the test object).
- (2) The external electrode should be at least 0.5 m from the test object skin.
- (3) Conjunction of the streamers should occur in the air away from the test object, as illustrated in Figure 2.
- (4) The streamer from the external electrode must not originate from the edge of this electrode.
- (5) The aircraft end termination of the diverter strip or other conductive object must be elevated above the ground plane by a distance greater than the width of the test object 'd' to minimize influence of the ground plane on test results.

Additional guidance for HV generator settings:

- (a) When the flat HV electrode shown in Figure 3 or 4 is at positive polarity, the average electric field required to produce a flashover is ~950 kV/m. This will often produce leaders from the edges of the HV electrode in Figure 3 or 4 that will make this arrangement impractical unless the test specimen is mounted on a simulated aircraft structure that extends ~1 m above the ground plane as illustrated in Figure 5. If the support structure is not de-stressed (resulting in attachment to the support structure), the gap may be reduced until flashovers occur to the test object rather than the support structure.

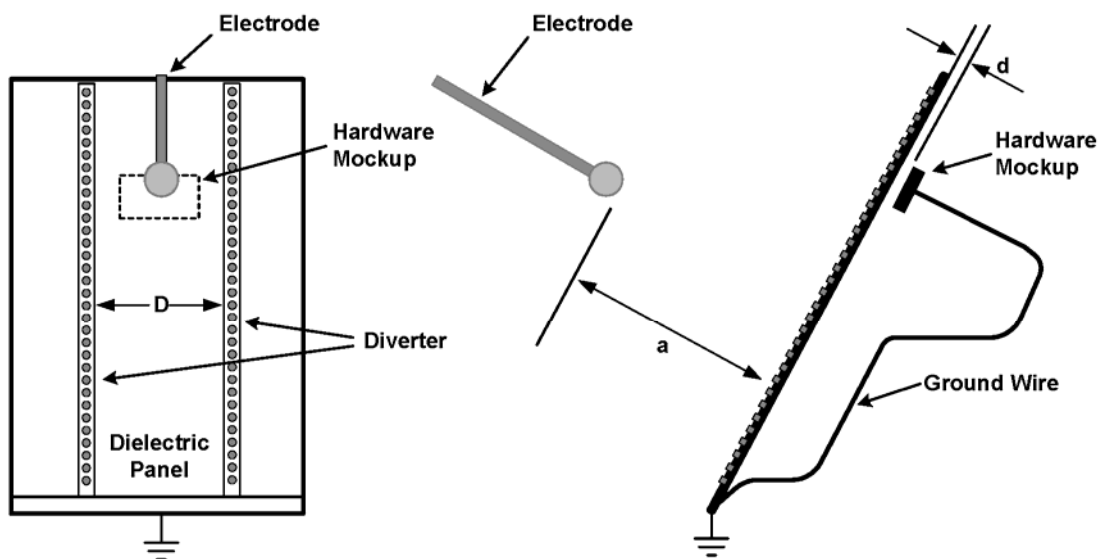
- (b) When the HV electrode as shown in Figure 3 or 4 is at negative polarity, the average electric field required to produce a flashover is ~ 500 kV/m.

Specific dimensions and test object orientations should be described in the test procedures.

The general test arrangement for Test Setup C is illustrated in Figure 6.

In this arrangement candidate protective devices and device locations on a non-conductive skin specimen can be evaluated prior to establishing a protection design and installing such devices on a production or prototype test object.

A typical skin panel would be 1 m square, although other sizes and shapes would be acceptable, sufficient to accommodate a full scale arrangement of protection devices. Production - like skin materials, surface finishes and paints should be applied. A typical use of this test is to determine the spacing 'D' of diverter strips to be installed on a radome or antenna fairing. The diverters should be as long as they would be in the aircraft installation. A mockup of any conductive items behind the protective surface should be placed at an appropriate position behind the skin at the distance 'd'. The protection devices are normally at facility ground potential and the electrode is at high potential. In order to apply a realistic test condition, experience has shown that the electrode should be positioned midway between the diverter strips, as in the example of Figure 6, to prevent attachment around the edge or an unrealistic result. The electrode should be elevated above the panel surface by a distance equal to the dimension of the panel if square, or the smaller dimension of a rectangular panel. The diverter strips may be repositioned at a greater or smaller spacing to optimize the design and still prevent puncture.



Determining Distance 'D' as a Function of Proximity 'd' to an Internal Conductor
Distance 'a' is the shorter dimension of the panel's width or height

FIGURE 6: ARRANGEMENT FOR PROTECTION DEVICE EVALUATIONS TEST SETUP C

The arrangement of Figure 6 is not equivalent to the verification test arrangement of Test Setups A and B, but experience has shown that diverter spacing determined from development tests as illustrated in Figure 6 have proved successful in subsequent verification tests of test objects, such as radomes, employing similar diverter spacing.

Test Setup A is the most desirable arrangement, since it usually allows a larger dimension external electrode (i.e., a conductive surface on the laboratory floor) to be provided; however this arrangement necessitates that the test object be suspended from the laboratory ceiling.

Test Setup B is intended to create a similar electric field arrangement about the test object while allowing larger or heavier test objects and support structures to be placed on the laboratory floor. In this arrangement a large diameter electrode must be suspended above the test object.

Test Setup C is most appropriate for developmental tests to evaluate skin panels and diverter strips. However, tests of flat panels should not be employed for verification of protection designs, since the flat panel specimens do not represent significant features of the non-conducting structures being verified.

Test Setup A

- (1) Mount the test object to a support structure containing mocked-up surfaces (or actual structure if available) representative of the adjacent vehicle surfaces. Ensure that electrical bonding of the test object to the support structure represents the actual installation.
- (2) Electrically connect all conductive hardware on or within the test object that is normally grounded to the airframe to the support structure.
- (3) Suspend the supporting structure and test object above the ground plane. The distance from the test object to the ground plane should be as described in Figure 1.
- (4) Electrically connect the output of the HV generator to the support structure.

Test Setup B

- (1) Mount the test object to a support structure containing mocked-up surfaces (or actual structure if available) representative of the adjacent vehicle surfaces, as for Test Setup A. Ensure that electrical bonding of the test object to the support structure represents the actual installation.
- (2) Electrically connect all conductive hardware on or within the test object that is normally grounded to the airframe to the test support structure.
- (3) Elevate the supporting structure and test object above the ground plane. The distance from the test object to the ground plane should be as described in Figure 3.
- (4) Electrically connect the support structure to the ground plane.

Test Setup C

- (1) Mount the test panel to non-conducting support structure. A mockup of any conductive items behind the panel should be placed an appropriate distance behind the panel at the appropriate position. Place the test panel and support structure on a conducting ground plane.
- (2) Position the HV electrode above the test panel as shown in Figure 6.
- (3) Electrically connect all conductive hardware on or behind the test panel that is normally grounded to the airframe to the ground plane.
- (4) Electrically connect the output of the HV generator to the HV electrode.

All Test Setups

- (1) Electrically connect the HV generator return to the ground plane.
- (2) Be sure that the elevated connections between the HV generator and the test object are farther away from the ground plane than the test object.
- (3) Note that whereas it is necessary for all electrical connections normally present between the test object and the aircraft to also be included in the test setup, it is not necessary that any specified electrical bonding resistances be met for these high voltage strike attachment tests. Electrical continuity is important, but connections via low resistance bonds are not.

- (4) Set up sensing and recording equipment. This includes a HV divider, a recording oscilloscope and cameras to photograph the flashovers. Additional instrumentation, to measure discharge current and to photograph streamering within or behind the test object may also be included.

5.1.1.4 Test Waveforms

Voltage waveform D as defined in ED-84 / ARP5412 should be applied for Test Setups A and B, since this is most representative of the electric field at an aircraft extremity during an initial leader attachment. Either voltage waveform A or D should be applied for Test Setup C. Waveform A is added since this is most representative of the electric field associated with lightning re-attachment to aircraft surfaces, radome, located in swept leader and swept channel zones. The test voltage should be applied at both polarities. Normally, two discharges in each polarity should be applied in each test object or electrode orientation.

If the HV generator discharge current exceeds the range of typical leader current of up to 2000 A it may produce unrealistic effects which are beyond the scope of this test.

5.1.1.5 Measurements and Data Recording

- Photographs and description of each test setup.
- Waveform plots of the test voltage and, if appropriate, current waveforms.
- Photographic records of all high voltage discharges. These should have complete coverage of the tested surface. One camera should enable immediate preliminary analysis of the test shot to be made so that any punctures are identified immediately.
- Photograph of each electrode configuration.
- Photographs of puncture locations or other significant effects.
- Records of laboratory environmental data (such as temperature, pressure and humidity), dates of testing, personnel performing and witnessing the tests, and test location.
- Record of any deviations from the test procedure.
- Records of the results of each discharge showing polarity, voltage amplitude, and waveforms.

5.1.1.6 Test Procedure

This test procedure is applicable to all test setups (A, B, and C).

- (1) Measure laboratory environmental conditions.
- (2) Review and implement safety procedures. Some areas of concern are as follows. Test areas must be safe and clear of personnel prior to charging of test equipment. Capacitor banks must be shorted out after tests and prior to re-entry of personnel into the test area. Eye and ear protection must be appropriate.
- (3) Calibrate the HV generator and instrumentation as follows:
 - (a) Carefully inspect the test object for any blemishes that might later be confused with effects of the tests, and identify these so that they are not confused with subsequent test results.
 - (b) Drape the test object with a conductive foil.

- (c) Select the initial polarity and initiate a test to the foil, while measuring the applied voltage. It is advisable for the initial test object polarity to be positive (+), regardless of being in Test Setup A or Test Setup B. Experience has shown that this condition results in a lower probability of puncture of non-conducting materials since streamers originating from the test object protective devices progress further into the air gap before being joined by opposing streamers from the negative electrode. In some cases, Test Setup B will not allow proper attachments when configured for positive polarity. If this is the case, then it is allowable to reconfigure the test object to Test Setup A for the positive polarity test.
 - (d) If the waveform is not per the requirements of ED-84 / ARP5412, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 - (e) Repeat steps (c) through (d) as necessary to obtain the required conditions.
 - (f) Remove the foil from the test object.
 - (4) Clean test object with appropriate technique to remove dust, debris, and other contaminants which could affect test results.
 - (5) Apply a discharge to the test object, while measuring the applied voltage and taking photographic evidence of the path of the flashover. Ensure that the discharge still occurs on the rising wave front before the crest of the voltage waveform.
 - (6) If environmental conditions and materials are such that static charge may accumulate on the dielectric surfaces, charge levels should be measured with a field mill and, if significant, be removed with a grounding stick before proceeding.
 - (7) Inspect the test object and document the results.
 - (8) If puncture has occurred, perform an assessment to determine if the test object has failed. If it is deemed to have failed, then the test sequence may need to be terminated.
 - (9) Repeat steps (5) through (8), if more than one test under the same conditions is required.
- NOTE:** *Since the dielectric properties of the test object may progressively degrade, the total discharges should be limited to two (2) at any particular combination of HV electrode and test object positions. If more data is required, the symmetry of the object may be used to relocate the HV electrode for additional tests.*
- (10) Switch the polarity of the HV generator.
 - (11) Repeat steps (4) through (7).
 - (12) Reposition the HV electrode and test object, as required by the test procedure.
 - (13) Repeat steps (4) through (11), as required by the test procedure.

5.1.1.7

Data Interpretation

Test objects should undergo a thorough post-test evaluation to determine the adequacy of the design against the acceptance criteria.

5.1.2 SWEPT CHANNEL ATTACHMENT TEST

5.1.2.1 Test Purpose

This test is normally applicable to parts of an aircraft that are located in Zone 1A but not exposed to initial leader attachment. That is, those portions of Zone 1A where initial leader attachment is predicted should use test method as described in 5.1.1; those extensions of Zone 1A defined by aircraft movement relative to the established lightning channel should use this test method. See ED-91 / ARP5414 for guidance on defining initial leader attachment locations and Zone 1A extensions due to sweeping leader effects. This test is also applicable to areas in Zones 1C, 2A, or 2B that are exposed to the effects of sweeping lightning channels as described in ED-91 / ARP5414. This test can be used to assess:

- possible puncture locations on non-conducting (i.e., dielectric) surfaces,
- flashover paths over non-conducting surfaces, or
- performance of protection devices, such as diverter strips on antenna fairings.

This test is normally conducted with a high voltage generator that is not capable of producing the current components that would flow into the test object in accordance with the lightning strike zone that the test object is to be located within. However, if equipment is available to produce the required test voltage followed by the applicable current components, then the high current physical damage test of 5.2 can be conducted together with this test.

5.1.2.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. Any paint finishes, including any coats of anti-static paint or dielectric coverings on electrically conductive elements, should be provided to ensure realistic development of corona and streamering from the conducting elements. Anti-static paint should be bonded to conducting structure in a representative manner.

The test object may also be a non-conducting surface, such as an access cover or antenna fairing that is integral with the airframe. In this case the test object would also be a production item or representative prototype, installed in a panel that is representative of the surrounding aircraft surface.

5.1.2.3 Test Setup

- An overview of a typical test arrangement showing the test object and typical test electrode position is illustrated in Figures 7 and 8. For large test objects, of dimensions on the order of 0.25 m or more, tests usually are applied from several electrode positions, as illustrated on Figure 7. Smaller test objects can usually be tested from one test electrode location centered over the test object, as illustrated in Figure 8. The sphere gap spacing, g , and the test electrode spacing, d , are determined during the test set-up calibration.

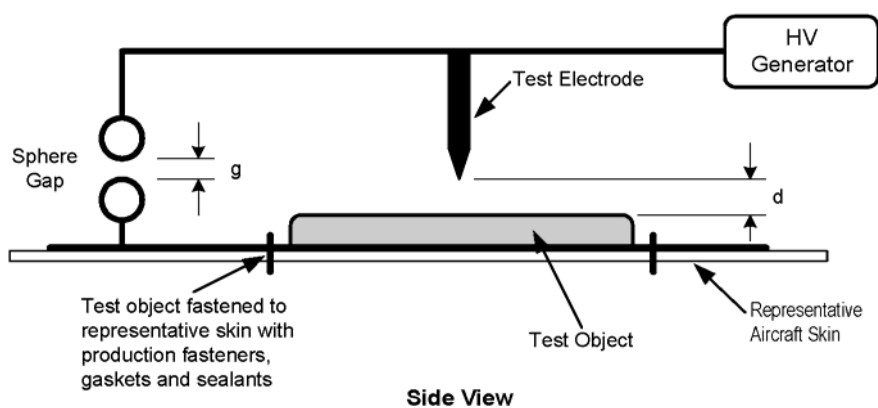
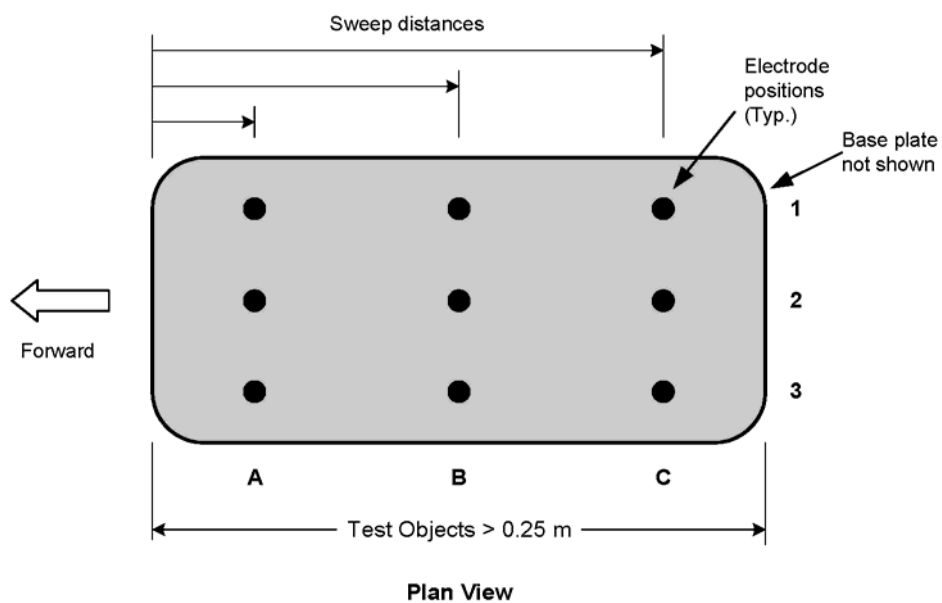


FIGURE 7: ARRANGEMENT FOR SWEEP CHANNEL TEST OF LARGE TEST OBJECTS

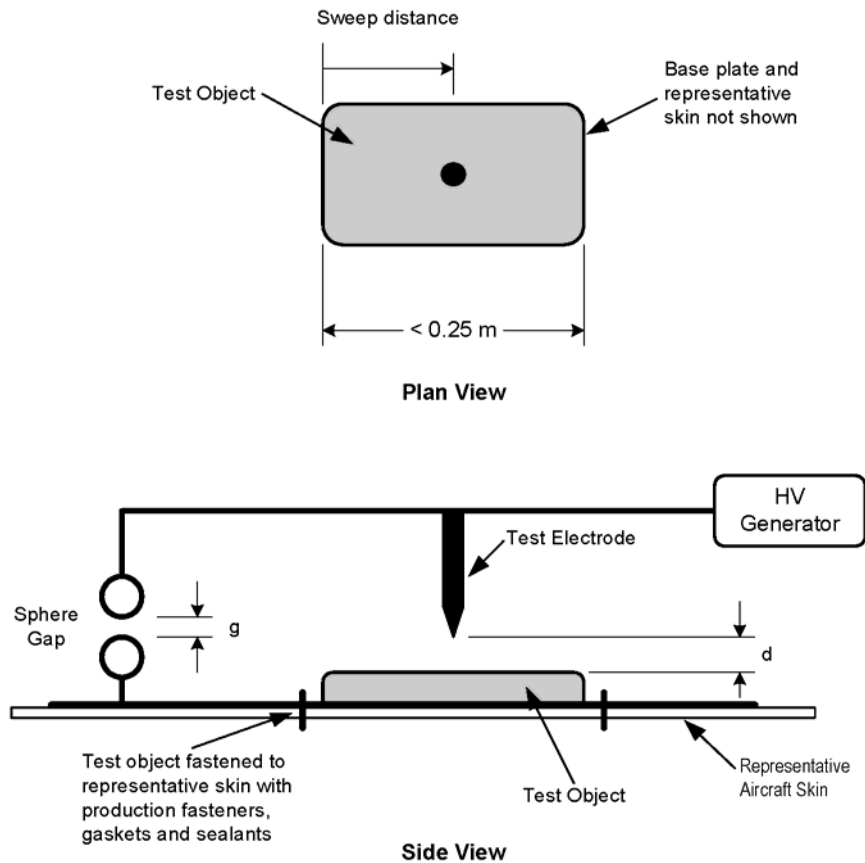


FIGURE 8: ARRANGEMENT FOR SWEEP CHANNEL TEST OF SMALL TEST OBJECTS

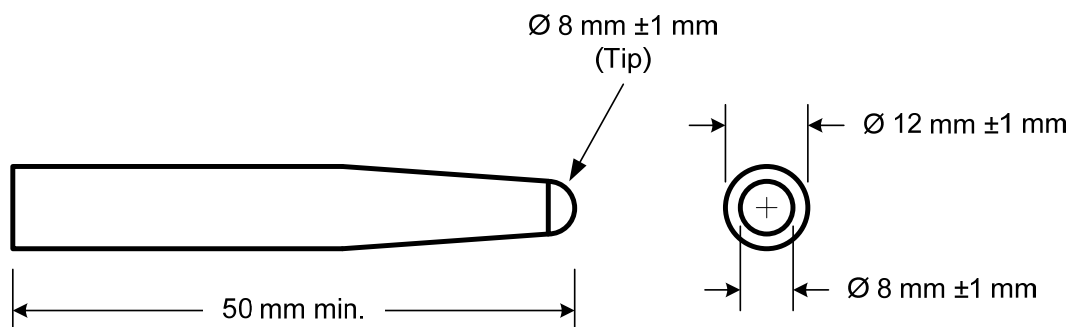


FIGURE 9: TEST ELECTRODE FOR SWEEP CHANNEL TEST

- Mount the test object to a surface representative of the actual vehicle region under test. Ensure that electrical bonding to the surrounding surface represents the actual installation. Production hinges or fasteners, surface finishes, gaskets and sealants should be present.
- Ground all hardware to the test object structure that is normally grounded to the airframe or electrically connected to other equipment in the aircraft installation.
- Connect the output terminal of the HV generator to the high voltage electrode. The test electrode should be as shown in Figure 9, with an electrode tip radius of $4 \text{ mm} \pm 0.5 \text{ mm}$.
- Setup equipment to measure and record the test voltage and current.