



AEROSPACE RECOMMENDED PRACTICE	ARP5416™	REV. B
	Issued 2005-03 Revised 2025-03	
	Superseding ARP5416A	
(R) Aircraft Lightning Test Methods		

RATIONALE

Significant advances in camera technology, new data about flammable gas testing, and lightning indirect effects methodology required an update to the lightning test method guidance. Additionally, guidance layout is better coordinated with ARP5415, ARP6205, and RTCA DO-160.

FOREWORD

This SAE Aerospace Recommended Practice (ARP) 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 Committee 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 ARP is a significant refinement and expansion of the basic material from these sources, providing a more thorough and updated description of the test techniques.

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1. SCOPE

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 RTCA DO-160/ED-14. 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 appropriate airworthiness 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.

The latest 14 CFR Part 25 and EASA CS-25 fuel system lightning protection regulations require specific test considerations, which are not defined in this ARP. ARP6205 ("Transport Airplane Fuel System Lightning Protection")/ED-303 ("User Guide for Lightning Protection of Fuel Tank Structures and Systems") contains supplemental guidance regarding test specimen design, inclusion of faults, and derivation of appropriate test levels. In addition to the test method guidance in [Section 8](#) of this ARP, users should refer to ARP6205/ED-303 if their project is subject to 14 CFR § 25.954 Amendment 25-146 and utilizing AC 25.954-1, or EASA CS-25 Amendment 28 and AMC 25.954.

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 manifest 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.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE and EUROCAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of publication of this document. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence unless the latest issue of the reference is after the date of publication of this document, where it is up to the reader which should take precedence. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained. 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 +1 724-776-4970 (outside USA), www.sae.org.

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

ARP5577 Aircraft Lightning Direct Effects Certification

ARP6205 Transport Airplane Fuel System Lightning Protection

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E659 Standard Test Method for Autoignition Temperature of Chemicals

2.1.3 Code of Federal Regulations (CFR) Publications

Copies of these documents are available online at <https://www.ecfr.gov>.

U.S. Code of Federal Regulations 14 CFR Parts 21, 23, 25, 27, and 29; Sections 25.581, XX.610, 23.867, XX.865, 25.899, XX.901, 25.903, XX.954, XX.1301, 23.1306, XX.1309, XX.1316, XX.1431, 23.1529, 23.2335, 23.2430(a)(2), 23.2510, 23.2515 (as applicable)

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 25.954-1 Transport Airplane Fuel System Lightning Protection Document Information

2.1.5 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

AMC 25.954 Fuel system lightning protection

CS Parts 21, 23, 25, 27, and 29; Sections 25.581, XX.610, 23.867, XX.865, 25.899, XX.901, 25.903, XX.954, XX.1301, 23.1306, XX.1309, XX.1316, XX.1431, 23.1529, 23.2335, 23.2430(a)(2), 23.2510, 23.2515 (as applicable)

2.1.6 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

EUROCAE ED-14 Environmental Conditions and Test Procedures for Airborne Equipment

EUROCAE ED-84 Aircraft Lightning Environment and Related Test Waveforms

EUROCAE ED-91 Aircraft Lightning Zoning

EUROCAE ED-105 Aircraft Lightning Test Methods

EUROCAE ED-113 Aircraft Lightning Direct Effects Certification

EUROCAE ED-158 User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning

EUROCAE ED-303 User Guide for Lightning Protection of Fuel Tank Structure and Systems

2.1.7 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60060-2 “High-Voltage Test Techniques - Part 2: Measuring Systems,” Rev. 3 issued November 2010

2.1.8 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 2808 Paints and Varnishes – Determination of Film Thickness

2.1.9 NFPA Publications

Available from National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 68 Standard on Explosion Protection by Deflagration Venting

2.1.10 RTCA Publications

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

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.11 Relevant Academic Publications

Lewis, B. and von Elbe, G. (2012). *Combustion, flames and explosions of gases* (3rd ed.). Elsevier.

Bane, S.P.M. (2010). *Spark ignition: Experimental and numerical investigation with application to aviation safety* [Doctoral dissertation, California Institute of Technology]. <https://resolver.caltech.edu/CaltechTHESIS:05272010-173243262>.

Hirano, Y., Sonehara, T., and Ogasawara, T. (2022). *Influence of discharge electrode shape on lightning test of composite laminate* [Conference paper]. International Conference on Lightning and Static Electricity (ICOLSE), Madrid, Spain.

Schefer, R.W., Kulatilaka, W.D., Patterson, B.D., and Settersten, T.B. (2009). Visible emission of hydrogen flames. *Combustion and Flame*, 156(6), 1234-1241. <https://doi.org/10.1016/j.combustflame.2009.01.011>.

2.1.12 Other Publications

Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, <https://imagej.net/ij/>, 1997-2018.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP4754 Guidelines for Development of Civil Aircraft and Systems

2.2.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

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

2.2.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20-53C	"Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning," Rev. C issued September 24, 2018
AC 20-136B	"Protection of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning," Rev. B issued September 7, 2011
AC 21-16G	"RTCA Document DO-160 versions D, E, F, and G 'Environmental Conditions and Test Procedures for Airborne Equipment'" issued June 22, 2011
AC 23.1309-1E	"Equipment, Systems, and Installations," Rev. E issued November 17, 2011
AC 25.1309-1B	"System Design and Analysis," Rev. B issued August 30, 2024
AC 27-1B	"Certification of Normal Category Rotorcraft, (Changes 1-9 Incorporated)" dated September 30, 2008
AC 29-2C	"Certification of Transport Category Rotorcraft," Change 9 issued June 23, 2023
AC 20.155A	Industry Documents To Support Aircraft Lightning Protection Certification
DOT/FAA/TC-22/11	Lightning Protection of Aircraft Handbook F.A. Fisher, J. A. Plumer Lightning Technologies 2023

2.2.4 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

EUROCAE ED-79B Guidelines for Development of Civil Aircraft and Systems

2.2.5 NFPA Publications

Available from National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 921 Guide for Fire and Explosion Investigations

2.2.6 Other Academic Publications

Boeck, L.R., Meijers, M., Kink, A., Mével, R., and Shepherd, J.E. (2017). Ignition of fuel–air mixtures from a hot circular cylinder. *Combustion and Flame*, 185, 265-277. <https://doi.org/10.1016/j.combustflame.2017.07.007>.

Essmann, S., Markus, D., and Maas, U. (2017). Investigation of the flame kernel propagation after ignition by a low energy electrical discharge (Paper 1006). *Proceedings of the 26th International Colloquium on the Dynamics of Explosions and Reactive Systems (ICDERS)*, Vol. 30.

Hattwig, M. and Steen, H. (Eds.). (2004). *Handbook of explosion prevention and protection*. Wiley-VCH.

Jones, S. and Shepherd, J. (2021). Thermal ignition by vertical cylinders. *Combustion and Flame*, 232, 111499. <https://doi.org/10.1016/j.combustflame.2021.111499>.

Martin, C.D. and Shepherd, J.E. (2020). *Autoignition testing of hydrocarbon fuels using the ASTM-E659 method* (Technical Report EDL2020.001). Graduate Aeronautical Laboratories, California Institute of Technology. <https://shepherd.caltech.edu/EDL/publications.html>.

Martin, C.D. and Shepherd, J.E. (2021). Low temperature autoignition of Jet A and surrogate jet fuel. *Journal of Loss Prevention in the Process Industries*, 71, 104454. <https://doi.org/10.1016/j.jlp.2021.104454>.

Martin, C.D. and Shepherd, J.E. (2022, July 11-15). *Thermal ignition: Effects of fuel, ambient pressure and nitrogen dilution* [Conference paper]. 14th International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. https://shepherd.caltech.edu/EDL/publications/reprints/ISHPMIE_2022_Martin_Shepherd_20March2022.pdf.

2.3 Definitions

ACTION INTEGRAL: The integral of the square of the time varying current over its 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.

APERTURE COUPLING: The process of inducing voltages or currents in avionics wiring or systems by electric or magnetic fields passing through apertures.

ARC: A specific kind of voltage spark through a gas. It is a luminous plasma channel that can result in the formation of vaporized metals or other materials due to the heating of the electrode surfaces.

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.

CARBON COMPOSITES SURFACE DISCHARGE: Voltage or thermal spark due to a breakdown of resin between carbon fibers or contact between carbon fibers where they run close enough to the surfaces of a composite ply matrix leading to an emission of light, potentially with some particles and/or hot gas ejections.

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 damage 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 currents in associated wiring, plumbing, and other conductive components.

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.

EDGE GLOW: Emission of light resulting from voltage or thermal sparks that occur at the edges of carbon fiber composite material when lightning current and voltage cause breakdown of resin between fibers, as defined in AC 25.954-1/AMC 25.954. Electrical contact between fibers at the exposed edges of carbon fiber composite materials can also cause edge glow. Edge glow can potentially result in particles and hot gas ejections.

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/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

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 ARP5412/ED-84.

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

FLASHOVER: The condition when an 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/HOT SURFACE: A surface that is heated to a sufficient temperature to ignite flammable materials including fuel/air mixture.

INDIRECT EFFECTS: Electrical transients induced by lightning in aircraft conductive components, such as electric circuits.

INDUCED TRANSIENTS: A voltage produced in a circuit by a changing magnetic field or by an electric field developed from current conducted through structural impedances.

INJECTED TRANSIENTS: Voltages or currents produced in a circuit resulting from lightning currents directly injected onto the aircraft wiring.

INTERNAL ENVIRONMENT: The electric and magnetic fields, currents, and voltages on and within the aircraft produced by a lightning strike to the aircraft.

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): Various standardized high voltage waveforms. For details, refer to ARP5412/ED-84.

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. Refer to ARP5414/ED-91.

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.

OUTGASSING: Escape of vaporized material in the form of hot gas and/or particles from an enclosed volume.

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

SHIELD: A conductor which is grounded to an equipment case or aircraft structure at both ends and is routed in parallel with and bound within a cable bundle. It usually is a wire braid around some of the wires or cables in the cable bundle or may be a metallic conduit, channel, or wire grounded at both ends within the cable 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.

SPARK: Colloquially, spark is often used to mean any potential ignition source emitting light.

STREAMER: Branch-like ionized paths that occur during the formation of a lightning leader.

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 SPARK: Thermal sparks are the result of burning particles emitted by rapid melting and vaporization of conductive materials carrying current through a point contact, as defined in AC 25.954-1/AMC 25.954.

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 (refer to ARP5415).

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 ARP5412/ED-84, ARP5415/ED-158, and RTCA DO-160/ED-14.

VOLTAGE SPARK: The result of electrical breakdown of a dielectric between two separated conductors, as defined in AC 25.954-1/AMC 25.954, often resulting in an arc.

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 ARP5414/ED-9.

2.4 Abbreviations

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

MΩ	megohms
nH	nanohenries
nm	nanometers
p	pressure
P	power
pF	picofarad
ps	picoseconds
Ω	ohms
Q	resonance characteristics
R	resistance
s	seconds
V	voltage or volts
W	watts
WF	waveform
Z	impedance

2.5 Acronyms

AC	Advisory Circular
AMC	Acceptable Means of Compliance
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 Union Aviation Safety Agency
EM	electromagnetic
EMC	electromagnetic compatibility
ETDL	equipment transient design level
EUROCAE	European Organisation 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
FOV	field of view
FRP	fiberglass reinforced plastic
HIRF	high intensity radiated fields
HC	high current
HV	high voltage
ICOLSE	International Conference on Lightning and Static Electricity
IEC	International Electrotechnical Commission
IMA	integrated modular avionics
IR	$I * R$ (structural current multiplied by 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
TCL	transient control level
WF	waveform (e.g., RTCA DO-160/ED-14 Waveform 1 = WF1)

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. In this document, the physical damage to the antenna, including any current directly injected into the antenna, will be treated as a direct effect, whereas the voltages and/or currents that are induced onto the antenna and the radio/radar equipment wiring system 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.

3.1.1 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.

3.1.2 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 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 $\int i^2 R \cdot dt$ (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 Potential Ignition Sources

Potential ignition sources occur when sufficient electrical stress (either voltage, current or current density) is present in the structural or system assembly exposed to lightning direct effects.

For more details, the definitions of the possible types of ignition sources are given in [2.3](#) of the document.

3.1.3 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.

3.1.4 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 = force

I = current

L = length of the wire

B = 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 atm. 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:

3.2.1 Apertures

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

3.2.2 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.

3.2.3 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.

3.2.4 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.

4. PLANNING OF LIGHTNING EFFECTS TESTS

Detailed planning is necessary before performing tests on airborne equipment and systems for lightning effects. 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 ARP to the particular hardware being evaluated. Since this ARP 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.

NOTE: The charging power supplies, energy storage equipment, and discharge circuit of the current generator(s) should be designed and maintained to avoid hazards to personnel safety. All test personnel and observers should be provided with appropriate eye and ear protection.

4.1 Test Object Conformity

Three types of tests are typically done:

1. 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.
2. Qualification: Data taken with quality assurance agreement as to the test setup and part number. Data is typically used for overall system certification. Test is run to specification and data approved by the appropriate airworthiness authority.
3. Certification: Contains all qualification data and part conformity paperwork. Test data is approved by the appropriate 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 appropriate airworthiness authority 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 appropriate airworthiness authority 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 appropriate airworthiness authority well in advance of the final formulation of the procedure.

Except as noted occasionally below, lightning tests are conducted under laboratory ambient conditions that do not include wetness/humidity, temperature, pressure, icing, and other in-flight conditions that are prevalent when lightning strikes occur to air vehicles. Comparisons of laboratory lightning test results with effects of in-flight lightning strikes on similar structures and systems show that laboratory test results closely represent results of in-flight strikes.

INTRODUCTION

- Scope
- Objective (include whether certification is goal)
- Test location
- Test witnessing

TEST OBJECT

- Description
- Conformity aspects

TEST EQUIPMENT

- Description
- Calibration

SAFETY CONSIDERATIONS

TEST REQUIREMENTS

- Detailed description of each test, using this ARP as the basis
- Pass/fail criteria
- Operating modes for electrical/electronic equipment and evaluation techniques

TEST REPORT REQUIREMENTS

4.3 Measurement Setup Waveform Verification and Quality

Test and measurement equipment requiring calibration should be calibrated traceable to national (e.g., NIST) or international standards (e.g., ISO) before lightning tests.

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

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

The choice of the measurement system (sensor, cables, recorders, etc.) should be done considering at least the following parameters:

1. Sensitivity adapted to the expected level to measure
2. Frequency bandwidth adapted to the signal to record
3. Temporal duration of the signal recorded considering associated phenomenon

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.

To minimize noise content in measurements, several precautions may be implemented throughout the tests such as:

- The measurement instrument, such as oscilloscope or network analyzer, should be placed inside a shielded enclosure.
- Probe lead lengths should be minimized.
- Probe lead should include electric field shields.
- Power supply of measurement equipment should be isolated from earth.
- Fiber-optic links should be considered to electrically isolate the measurement probes on the tested component from the measurement instruments in the shielded enclosure.

Instrument noise levels should be determined and measured at each test setup configuration planned for a lightning test. The results of the noise measurements should be compared to the expected measurements to ensure that there is adequate signal compared to the noise. For common mode wire voltage test points, noise levels are typically measured with the voltage probe disconnected from the test point and connected to the shield, and short-circuited to the test probe signal return. The test probe return should also remain attached to the ground. For wire current test points, noise levels are typically measured with the current transformer removed from the wire, placed adjacent to the wire, but electrically isolated from the wire. After completing the test, the results should be compared to the noise to ensure that there is adequate signal compared to the noise.

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. 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 reentry of personnel into the test area. Special consideration should be given to personnel safety, including the use of safety barriers/interlocks and 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 Setup

4.5.1 Test Object Design

It should be recognized that in the test object setup, 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 “foolproof” 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 setup is important to ensure 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 the surrounding structure may influence test object current distributions and affect test results.

Surface and corrosion inhibitive coatings are very important parts of the setup 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 setup, and it should be determined if they adequately represent the installation.

For example, a full wing-to-body fairing from a large airliner 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 (about 450 x 450 mm) is 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 test current amplitude may not be appropriate. Scaling the test current amplitude to apply representative currents to the tested fasteners may be done. However, simply scaling the current amplitude by the number of fasteners is not appropriate; a more detailed analysis is required.

4.5.3 Waveform Application

For high current direct effects and fuel system tests, the appropriate waveforms as identified in ARP5412/ED-84 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 over-tested 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.

5. DIRECT EFFECTS TEST METHODS

The Direct Effects Test Methods outlined in this section are:

- High Voltage Strike Attachment Tests (see [5.1](#))
 - Initial Leader Attachment Test (see [5.1.1](#))
 - High Voltage Test for Determining the Distance between Diverters (see [5.1.2](#))
 - Swept Leader or Channel Attachment Test (see [5.1.3](#))
 - High Voltage Strike Attachment Test on Models (see [5.1.4](#))
- High Current Physical Damage Tests (see [5.2](#))
 - Arc Entry Tests (see [5.2.1](#))
 - Aircraft Nonconductive Surfaces Test (see [5.2.2](#))
 - Conducted Current Test (see [5.2.3](#))
 - Current Transfer Test to Underlying Systems (see [5.2.4](#))
- Induced Transients in External Mounted Hardware (see [5.3](#))
 - Measurement of Injected Transients in External Hardware (see [5.3.1](#))
 - Voltage Stress Assessment of Circuit Insulation (see [5.3.2](#))

These tests evaluate direct effects protection and issues, except for fuel ignition considerations, which are addressed in [Section 8](#). The high voltage attachment tests are applied to determine specific lightning strike attachment points and breakdown paths across or through nonconducting 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 7](#) of this document, which 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 nonconducting materials.

5.1.1 Initial Leader Attachment Test

5.1.1.1 Test Purpose

The purpose of this test is to demonstrate the effectiveness of the lightning protection of exposed dielectric structures, such as radomes. Therefore, 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 ARP5414/ED-91. Examples are wing tips fabricated of nonconducting materials, radomes, and large antenna fairings. This test can be used to assess:

- Locations of possible leader attachment 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.

For the test to be valid, there are a number of criteria that need to be met, these are:

1. The high voltage generator must produce the required waveform, at a voltage that is sufficient to provide an alternate path from the lightning protection scheme of the test object in both polarities with the electrode used. If this is not achieved, then the test will produce a false positive as the arc does not have the voltage to take another path.
2. The orientation of the electrode relative to the test object must be a representative set of the likely angles of attachment defined by how the electric field could approach the aircraft in flight, and therefore how the leader would propagate away from the aircraft, i.e., normal to the surfaces of equipotential. In [Figures 1A](#), [1B](#), and [1C](#), the dotted lines denote the extent the surfaces of equipotential could reach for an attachment to the nose radome.

[Figures 1A](#) and [1B](#) show the maximum orientation of the electrode relative to the front of the aircraft based on the equipotential lines. The arrows denote the arc of other positions the electrode may be located. Examples of electrode positions that could be used during a test are shown in the five drawings of [Figure 1C](#). Note that this is only shown for the side-on orientation. Other orientations may need to be tested, however, to reduce the number of configurations symmetry can be used. If the antenna covered by the radome is capable of moving, then this needs to be replicated during the test with the antenna (or representative mock-up) placed in the locations most likely to result in a puncture for each electrode orientation. Typically, these are the orientations that place the antenna closest to the Inner Mold Line (IML) and if applicable furthest from the diverter strips.

3. There must be evidence of a leader coming from the test object, and the electrode; see [Figure 2](#) (see [5.1.1.3](#)).

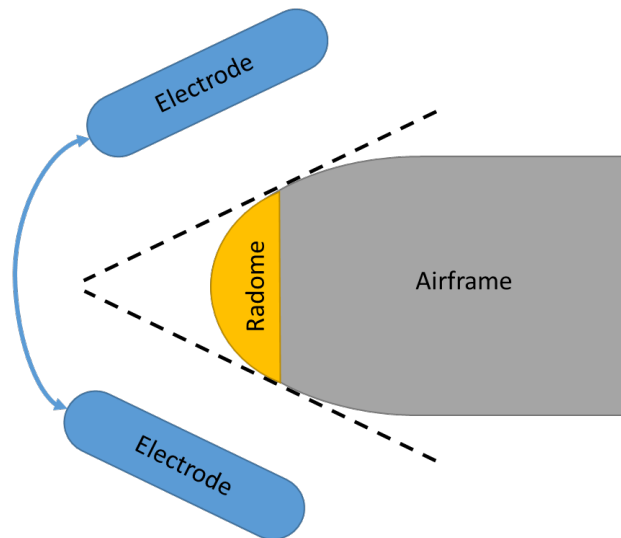


Figure 1A - Maximum electrode positions for bottom-up view

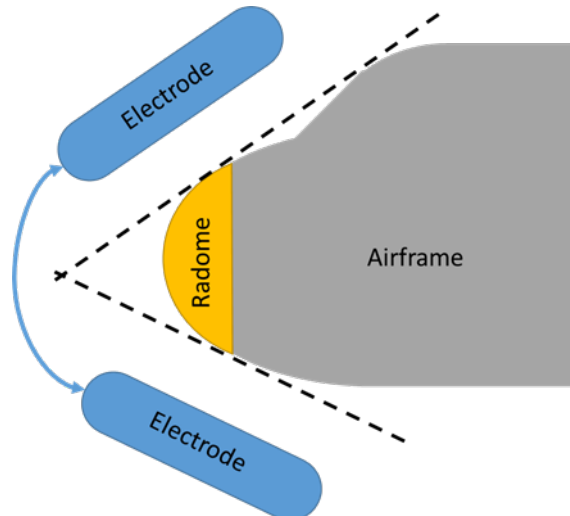


Figure 1B - Maximum electrode positions for side-on view

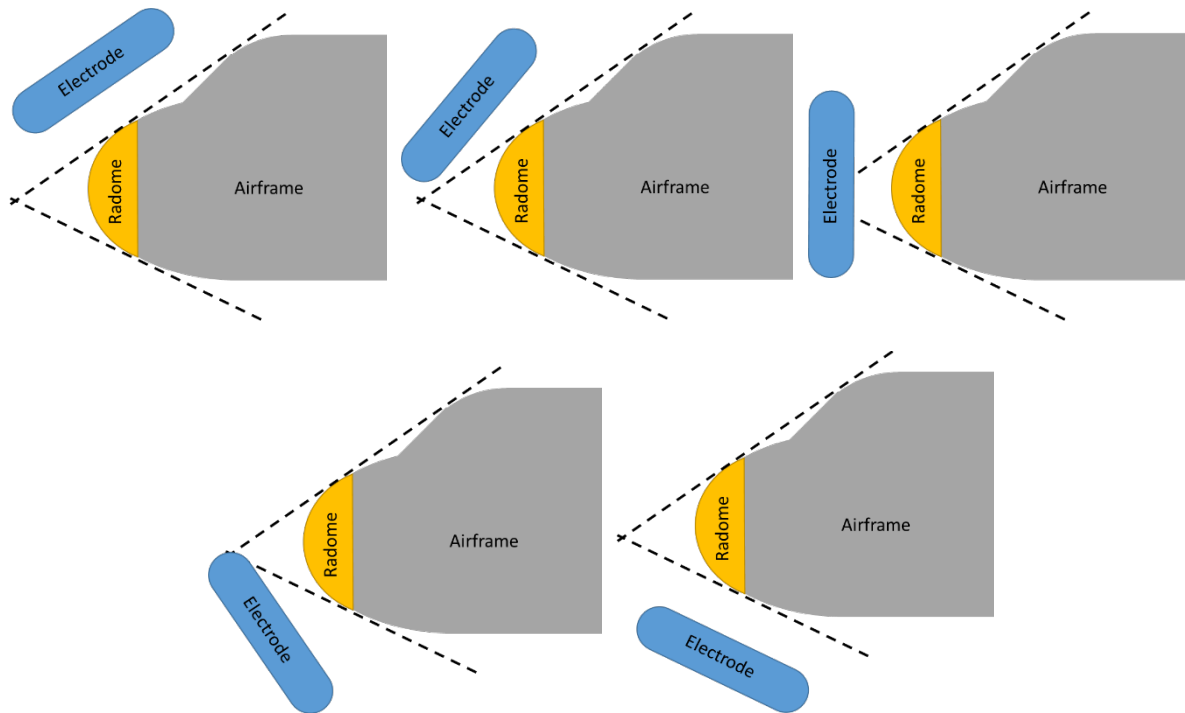


Figure 1C - An example of five locations the electrode could be positioned relative to the front of the aircraft. Electrode distance is for illustrative purposes only; the electrode must be at least 1 m away.

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/or streamering from the conducting elements.

Electrically conducting objects, such as antenna elements and lights, normally enclosed by nonconducting test objects must be represented during the test. 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 can be oriented in several positions or move, the positions chosen must include those most likely to result in a puncture. Normally, these are the positions that result in the smallest distances to the nonconducting 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 electrically 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. Each test arrangement is intended to result in initiation of electrical activity, such as corona inception and leader formation, 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 at the test object is initiated, the leader 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.

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 above the ground plane.

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 an alternative to Test Setup B when the use of a large electrode is not possible due to test constraints. The use of Test Setup C needs to be justified, as the likelihood that leaders will develop from the test object is greater with Test Setup A or B than with Test Setup C.

For Test Setups A, B, and C, the test object should normally be tested using a set of orientations that represent the different directions from which electric fields could approach the aircraft in flight. If only one or two orientations are tested, then this must be justified.

Any conductive elements underneath the test object should be positioned to minimize the distance between the edge of the element and the inner test object surface within the limits of what is representative in flight. The external electrode or suspended test object should be positioned to stress the area of the test object where the minimum distance exists.

Specific care shall be taken when the distribution and the size of the lightning diverters are not symmetrical. This may require multiple tests covering different possible approach angles that might stress different areas of the test object which are less protected even if the internal spacing between conductive elements and the inner test object surface is greater.

For Test Setups A, B, and C, the following conditions 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. The leader must come from both the test object and the electrode. Connection of the leaders must occur in the air away from the test object (this can be confirmed by imaging of the flashovers). The leader connection point is shown in [Figure 2](#). Failure to demonstrate this means that the test cannot be used as evidence.
 - a. Obtain photographic evidence of the leader connection point using the following guidance:
 - i. Place multiple cameras (two or three) around the test article with a field of view sufficient to see the whole high voltage discharge plus the test article.
 - ii. Cameras should be set for low light conditions with ambient light minimized.
 - iii. Adjustment of camera settings may be necessary, since the current amplitude in the high voltage discharge impacts the light intensity.
4. The leader from the external electrode should not originate from the edge of the electrode in Setup B, or in Setup C from the hanging or feed points of the electrode. This is to ensure that leaders originate from the electrode and test object. The leader is allowed to come from the “supportive structure” of the test object so long as it is representative of a feature on the aircraft and is not an edge of the supporting structure.

NOTE: If leaders originate from the edge of the electrode, it is recommended to reduce the distance from the test article to the electrode or elevate the test object further above the ground plane.

5. The generator peak voltage on the waveforms used needs to be sufficient to provide an alternate path from the lightning protection scheme of the test object for both polarities.
6. For Test Setups B and C, the aircraft end termination of the diverter strip or other conductive elements 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.

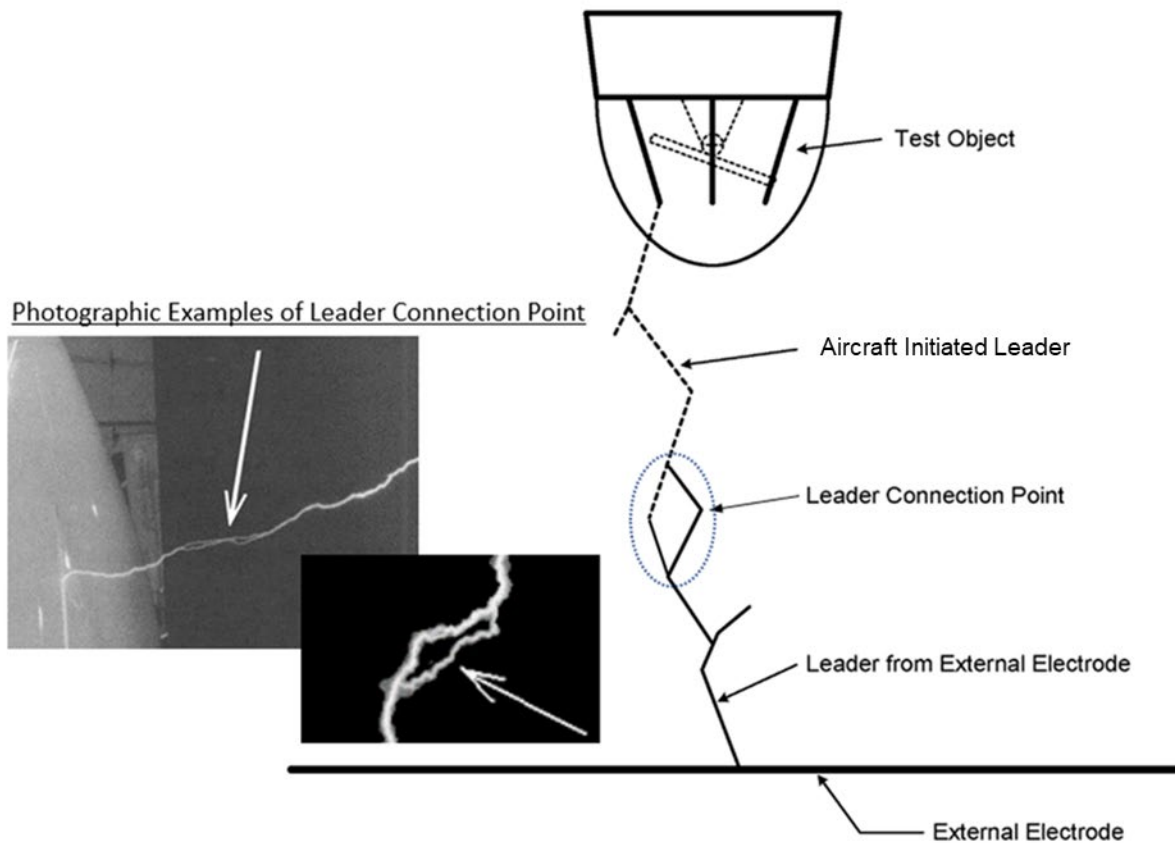


Figure 2 - Leader connection point

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

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 [Figures 3](#) through [5](#).

The general test arrangement for Test Setup A is illustrated in [Figure 3](#).

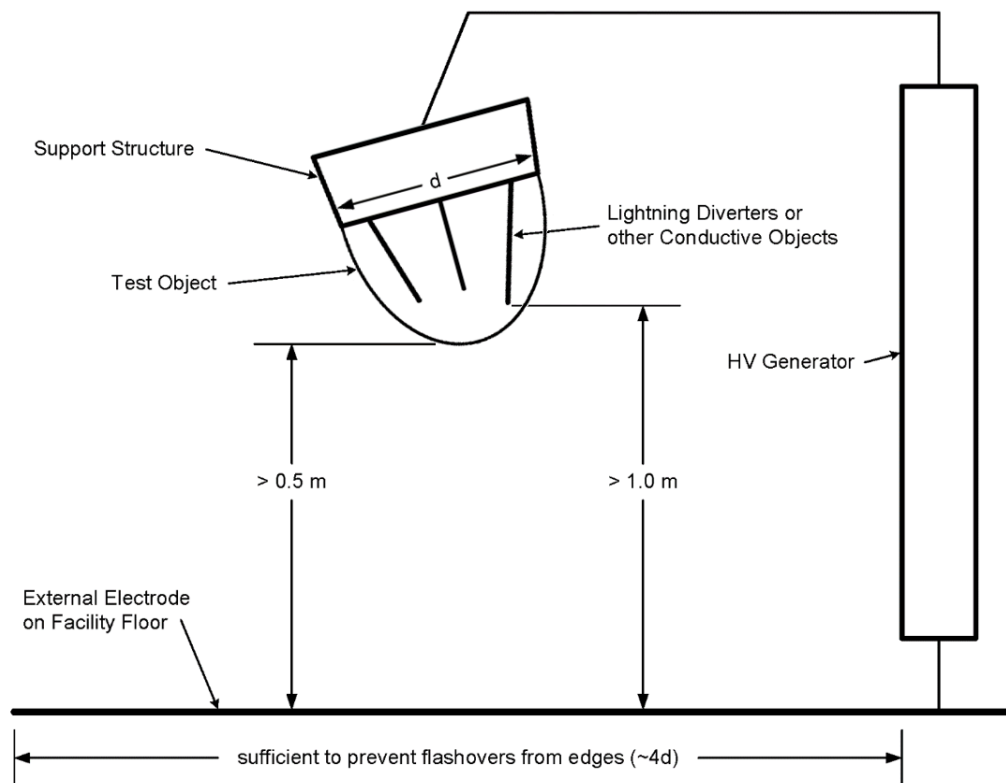


Figure 3 - Initial leader attachment Test Setup A

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 3](#).

The general test arrangement for Test Setup B is illustrated in [Figure 4](#).

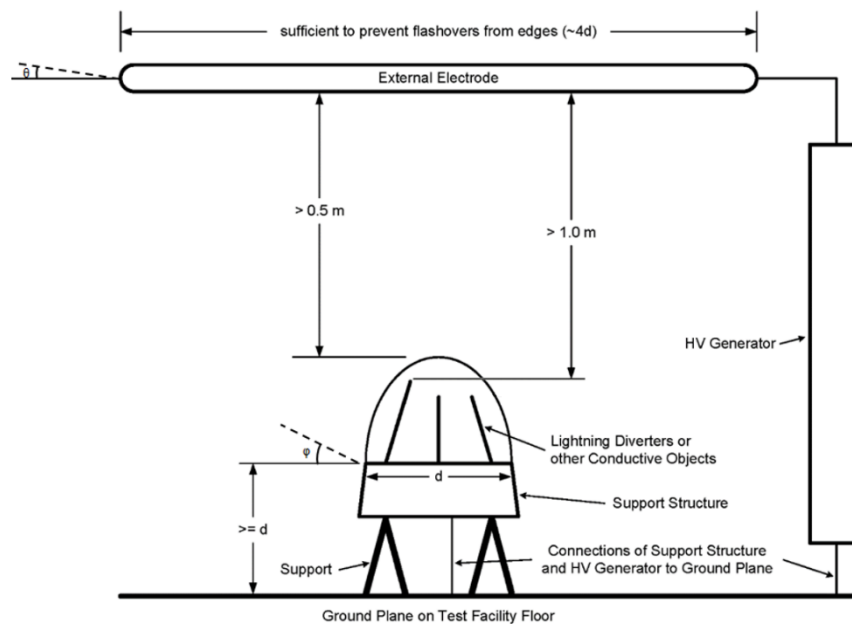


Figure 4 - Initial leader attachment Test Setup B

The external electrode orientation (angle θ) and/or the test object orientation (angle ϕ) shall be defined in order to maximize the exposure of the enclosed conductor(s) that is (are) being protected. 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 4](#). When increasing the electrode angle (θ), the shrinking distance between the edge of the electrode and the ground may cause flashover to ground to occur. If the electrode cannot be raised to prevent this from happening, then a change to Test Setup C may be necessary.

To reduce the chances of an arc originating from the edge of the electrode, it is recommended that the edge radius should be approximately 100 to 300 mm.

The general test arrangement for Test Setup C is illustrated in [Figure 5](#).

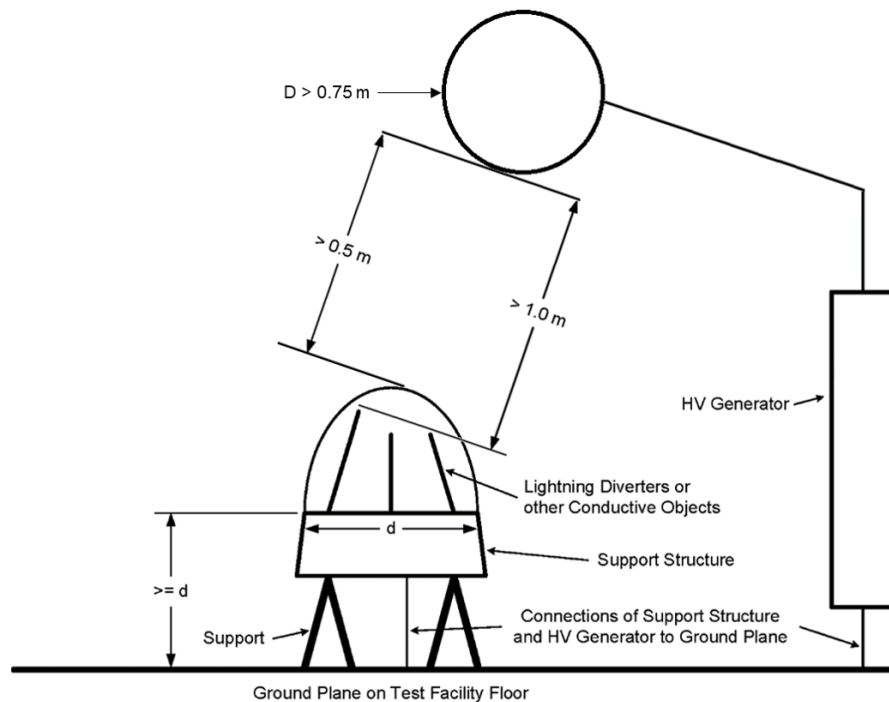


Figure 5 - Initial leader attachment Test Setup C

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 diameter of the electrode should be as large as possible within the constraints of the test setup, but no less than 3/4 of distance from the electrode to the test object’s closest conductive element. The size of the electrode shall ensure that it does not inhibit leaders developing from the test object by examining the setup photos to check that the connection of the streamers occurs in the air away from the test object. Note that this may not be achievable in both polarities.

Additional guidance for HV generator settings and test setup:

The objective of this test is to evaluate the test article protection against an undesired high-voltage breakdown. To accomplish this, discharges should occur to or around the test article and its representative aircraft structure. Attachments to non-representative structures, which cause high electric field concentrations, are not acceptable. Re-evaluating the test setup to minimize inappropriate test responses is desired. This may include extending or shielding the inappropriate structure in some manner or repeating tests with a more representative aircraft structure.

All Test Setups:

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.

Test Setup A:

1. 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 3](#).
2. Electrically connect the output of the HV generator to the support structure.

Test Setups B and C:

1. Elevate the supporting structure and test object above the ground plane. The distance from the test object to the ground plane, test object to the electrode, and nearest conducting surface to the electrode should be as described in [Figure 4](#) or [5](#) (as applicable).
2. Electrically connect the support structure to the ground plane.
3. Electrically connect the output of the HV generator to the external electrode.

Test Setups A, B, and C:

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.

NOTE: 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.

3. 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 leader development within the test object, may also be included.

5.1.1.4 Test Waveforms

Voltage waveform D as defined in ARP5412/ED-84 should be applied for Test Setups A, B, and C, since this is most representative of the electric field at an aircraft extremity during an initial leader attachment. The test voltage must be applied at both polarities. At least two discharges in each polarity must be applied in each test object and electrode orientation configuration.

The intent of this test is to evaluate initial attachment and not damage on the test article; therefore, it is recommended to use the minimum current necessary.

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.
- Photograph of the leader connection point from each test in both polarities
- 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 characteristics of each discharge showing polarity of the test object, 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 laboratory safety procedures according to local regulations (see [4.4](#)).
3. 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.
4. Verify the HV generator waveforms and instrumentation setup and operation as follows:
 - a. Drape the test object with a conductive foil and ground the foil to nearby generator return path.
 - b. 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 nonconducting 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.
 - c. If the waveform is not per the requirements of ARP5412/ED-84, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 - d. Repeat steps b and c as necessary to obtain the required conditions.
 - e. Remove the foil from the test object.
5. Clean the test object with an appropriate technique to remove dust, debris, and other contaminants which could affect test results.

6. 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.
7. 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.
8. Inspect the test object and document the results. Document the condition of the radome's surface at and around the test entry and exit point.
9. 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.
10. Repeat steps 5 through 9, if more than one test under the same conditions is required.

NOTE: Typically, two tests are necessary per polarity. Since the dielectric properties of the test object may progressively degrade, an acceptable number of tests at any particular combination of HV electrode and test object positions is two. If more data is required, the symmetry of the object may be used to relocate the HV electrode for additional tests.

11. Switch the polarity of the HV generator.
12. Repeat steps 5 through 10.
13. Reposition the HV electrode and test object, as required by the test procedure.
14. Repeat steps 5 through 13, 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 High Voltage Test for Determining the Distance between Diverters

5.1.2.1 Test Purpose

This test is to determine the maximum acceptable distance between lightning diverters (segmented or solid). On its own, this is an engineering test but can be used as supporting evidence for the tests defined in [5.1.1](#). This test is applicable to parts of aircraft that use diverter strips and can be located in initial leader attachment regions within Zones 1A and 1B, and swept leader and swept channel zones 1C, 2A, and 2B, as described in the ARP5414/ED-91. Examples are wing tips fabricated of nonconducting materials, radomes, and large antenna fairings. This test can be used to assess:

- Performance of exterior dielectric 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 diverter strips.

5.1.2.2 Test Object

The test object tends to be a flat dielectric panel, with at least two lightning protection devices applied at a specific distance apart. 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 nonconducting 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 relative to the panel. If the conducting objects can be oriented in several positions or move, the positions chosen must include those most likely to result in a puncture. Normally these are the positions that result in the smallest distances to the nonconducting skins, or the strongest electric field intensities in directions normal to the aircraft surface.

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.

Verify if environmental conditions that may affect the performance of the radome/diverter strips need to be taken into consideration during the test. For example, it has been observed that a buildup of ice on segmented diverter strips can affect their performance.

5.1.2.3 Test Setup

The test arrangement is intended to result in initiation of electrical activity, such as corona inception and leader formation, 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 at the test object is initiated, the leader 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.

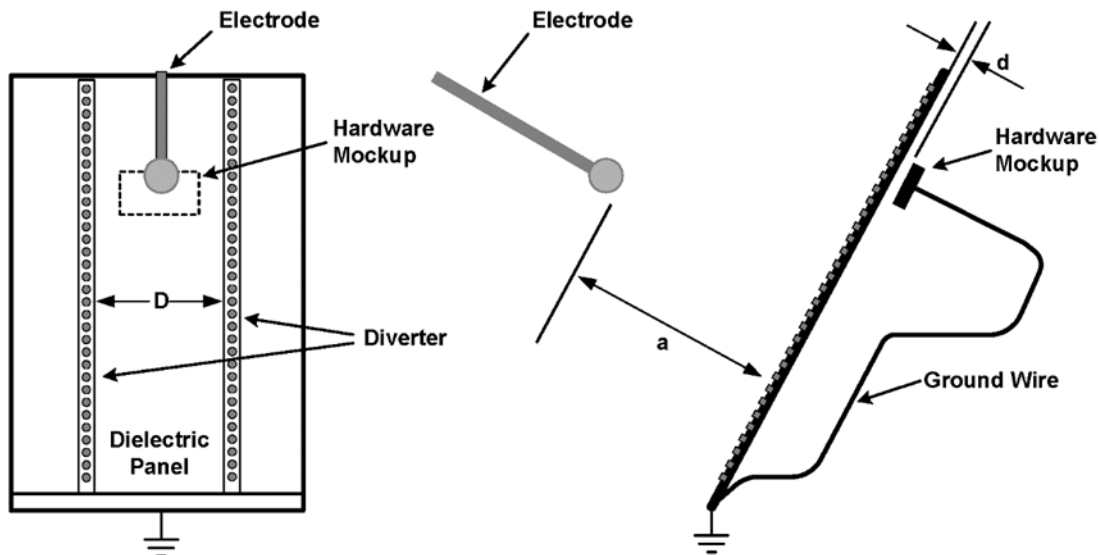
This test setup is most appropriate for developmental tests to evaluate skin panels and diverter strips. However, tests of flat panels should not be employed for certification of protection designs, since the flat panel specimens do not represent significant features of the nonconducting structures being verified.

Any conductive elements underneath the test object should be positioned to minimize the distance between the edge of the element and the inner test object surface within the limits of what is representative in flight. The minimum distance between the antenna edge and inner test object surface may also be reduced by an appropriate value in order to introduce some margin in the tests and to take into account in-flight motion. The external electrode or suspended test object should be positioned to stress the area of the test object where the minimum distance exists.

The general test arrangement is illustrated in [Figure 6](#).

In this arrangement, candidate protective devices and device locations on a nonconductive 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 m², although other sizes and shapes would be acceptable, as long as they are 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 distance “d” is the minimum distance between the antenna structure and the inner surface of the considered radome. Moreover, the curvature of the hardware mockup shall be representative of the antenna structure near to the inner radome surface. 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. For parts of aircraft located within initial attachment Zones 1A and 1B, 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. For swept channel Zones 1C, 2A, and 2B, the electrode elevation should be no more than 50 mm. 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

Experience has shown that diverter spacing determined from development tests, as illustrated in [Figure 6](#) and the following steps below, have proved successful in subsequent verification tests of test objects, such as radomes, employing similar diverter spacing. The recommended steps are:

1. Mount the test panel to nonconducting 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.
5. Electrically connect the HV generator return to the ground plane.
6. 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.

NOTE: 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.

7. 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 leader development within the test object, may also be included.

5.1.2.4 Test Waveforms

Either voltage waveform A or D can be applied. 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 must be applied at both polarities. At least two discharges in each polarity must be applied in each test object and electrode orientation configuration. The condition of the panel surface at and around the load locus should be checked and documented after each test.

The intent of this test is to evaluate initial attachment and not damage on the test article; therefore, it is recommended to use the minimum current necessary.

5.1.2.5 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 characteristics of each discharge showing polarity, voltage amplitude, and waveforms.

5.1.2.6 Test Procedure

The test procedure.

1. Measure laboratory environmental conditions.
2. Review and implement laboratory safety procedures according to local regulations (see [4.4](#)).
3. 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.
4. Verify the HV generator waveforms and instrumentation setup and operation as follows:
 - a. Drape the test object with a conductive foil and ground the foil to nearby generator return path.
 - b. 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 (+). Experience has shown that this condition results in a lower probability of puncture of nonconducting 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.
 - c. If the waveform is not per the requirements of ARP5412/ED-84, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 - d. Repeat steps b and c as necessary to obtain the required conditions.
 - e. Remove the foil from the test object.

5. Clean the test object with an appropriate technique to remove dust, debris, and other contaminants which could affect test results.
6. 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.
7. 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.
8. Inspect the test object and document the results.
9. 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.
10. Repeat steps 5 through 9, 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 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.

11. Switch the polarity of the HV generator.
12. Repeat steps 5 through 10.
13. Reposition the HV electrode and test object, as required by the test procedure.
14. Repeat steps 5 through 13, as required by the test procedure.

5.1.2.7 Data Interpretation

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

5.1.3 Swept Leader or Channel Attachment Test

5.1.3.1 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 leader or channel should use this test method. Refer to ARP5414/ED-91 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 ARP5414/ED-91. 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.

5.1.3.2 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 nonconducting 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.

5.1.3.3 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 with dimensions on the order of 0.25 m or more, tests usually are applied from several electrode positions. The size, geometry, shape, and material properties of the test object must be considered when defining the electrode positions. These test points shall include positions where the inner mold line of the dielectric is closest to metallic structures or equipment underneath the test object. Several test points may be considered in order to cover the aircraft movement relative to the established lightning channel, as the examples illustrated in [Figure 7](#) (a), (b), and (c). The sweep distance is defined as the distance from the closest forward channel attachment point (e.g., forward side of the test object, grounding point, lightning diverter, etc.) to the selected electrode positions. 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 setup and waveform verification.

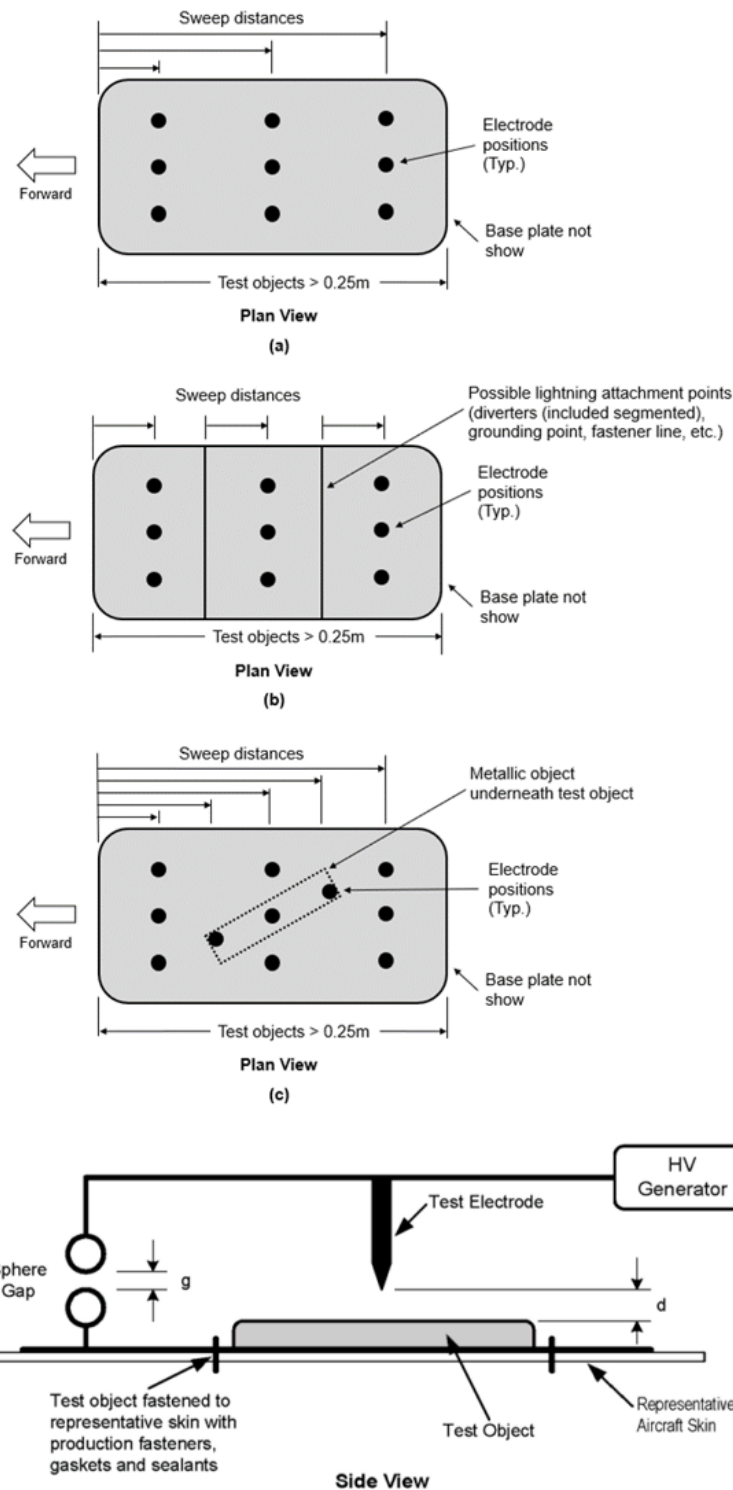


Figure 7 - Arrangement for swept channel test of large test objects

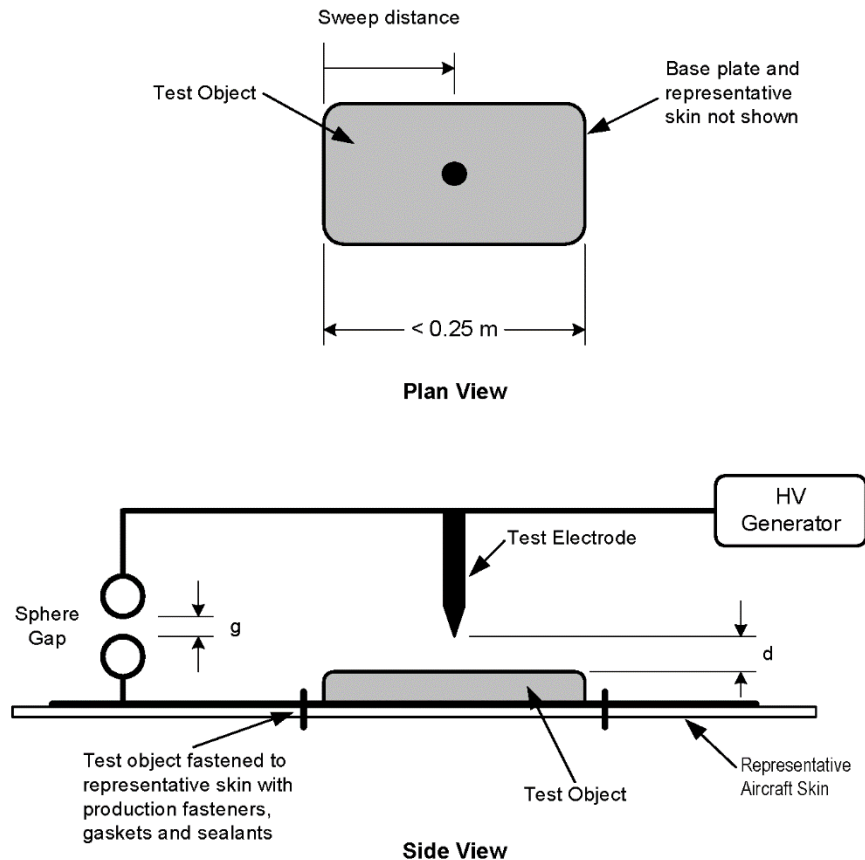


Figure 8 - Arrangement for swept channel test of small test objects

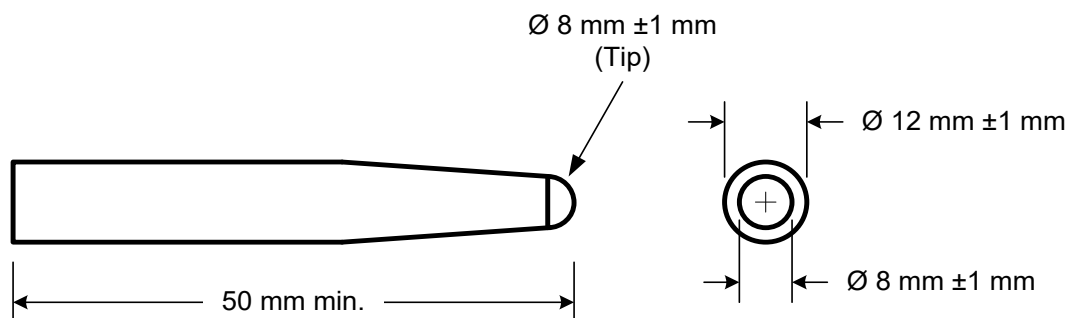


Figure 9 - Test electrode for swept channel test

- 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 $4 \text{ mm} \pm 0.5 \text{ mm}$.
- Set up equipment to measure and record the test voltage and current.

5.1.3.4 Test Waveforms

Refer to the latest versions of ARP5412/ED-84 and ARP5414/ED-91 for the correct test waveforms and lightning zones. Voltage waveform A as defined in ARP5412/ED-84 should be applied for this test, since this is most representative of the electric field associated with lightning re-attachment to aircraft surfaces, radomes, etc., located in swept leader and swept channel zones.

5.1.3.5 Measurements and Data Recording

- Photographs and description of each test setup and electrode position.
- Photographic records of all tests. Cameras should provide 360-degree coverage of the test object. One camera should enable immediate preliminary analysis of the test shot to be made so that any punctures are identified immediately.
- 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.
- Records of any deviations from the test procedure.
- Records of the results of each test showing voltage polarity, amplitude, and waveform.

5.1.3.6 Test Procedure

1. Measure laboratory environmental conditions.
2. Review and implement laboratory safety procedures according to local regulations (see [4.4](#)).
3. 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.
4. Verify the generator waveform and instrumentation setup and operation as follows:
 - a. Determine the desired test voltage based on a 140 kV/m multiplied by the sweep distance. For sweep distances less than 0.5 m, the desired test voltage shall be 70 kV. The high voltage generator shall be configured to produce voltage waveform A as defined in ARP5412/ED-84.

NOTE: High voltage generators configured to produce voltage waveform A may yield a noisy waveform at low test voltages. High voltage generators configured for waveform B with a high crest voltage may be used to maintain the 1000 kV/μs ± 500 kV/μs requirement of waveform A.
 - b. Set up the sphere gap “g,” as shown in [Figure 7](#) or [8](#), and set the sphere gap to spark over at a voltage that is 120 to 130% of the desired test voltage. Operate the high voltage generator such that a flashover occurs at the sphere gap. The sphere gap sparkover should occur on the wavefront of waveform A. Record the breakdown voltage for the sphere gap. If necessary, adjust the spacing of the sphere gap such that the sphere gap breaks down at 120 to 130% of desired test voltage and repeat the sphere gap breakdown voltage demonstration. If the required waveform is not correct, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 - c. Connect the output terminal of the high voltage generator to the high voltage test electrode. The test electrode should be as shown in [Figure 9](#).

- d. Install the test object underneath the test electrode such that the electrode is over one of the test locations. Ground the test object to the high voltage generator return. Place a sheet of metal foil over top of the test object and ground the foil to the high voltage generator return. The electrode should be placed 50 mm away from the surface “d” of the test object to represent the voltage applied by a lightning channel sweeping over the surface of the test object.
 - e. Operate the high voltage generator such that a flashover occurs at the test electrode. Record the breakdown voltage for the test electrode. For desired test voltages below 140 kV, the spacing “d” may need to be reduced such that the electrode breaks down at the desired test voltage (-0/+10%). Repeat the electrode breakdown voltage demonstration as needed. The maximum test electrode spacing “d” shall be 50 mm.
 - f. Remove the metal foil from the test object.
5. Clean the test object with an appropriate technique to remove dust, debris, and other contaminants which could affect test results.
 6. Apply test voltage to the electrode while measuring the applied voltage and taking photographs of any flashovers that occur.

NOTE: If no flashover occurs to the test object, the test has been successfully applied. This is an indication that insulating surfaces of the test object can successfully withstand the lightning channel voltage.

7. Inspect the test object and document the results. Mark and photograph any punctures or other effects on the test object.
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 for each of the tests, electrode polarities, and electrode positions called for in the test procedures.

NOTE: Since the dielectric properties of the test object may progressively degrade due to repeated electrical stressing, experience leads to the recommendation that an acceptable number of tests are two at each polarity at a particular electrode position.

5.1.3.7 Data Interpretation

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

5.1.4 High Voltage Strike Attachment Test on Models

High voltage strike attachment tests to aircraft scale models have been used successfully in the past to determine initial lightning strike attachment locations. However, the test method has limitations because the physics does not scale with scaling the size of the aircraft. For example, the corona processes and space charge distributions around the aircraft do not scale linearly with the model dimension. In addition, scale model tests are typically done without a representative net charge on the scale model. Moreover, the effects of airflow and altitude on space charge distributions and local pressure variations are not represented in model tests. It is recommended that the scale model test results for lightning attachment can be used as part of development of lightning attachment locations as part of a set of supporting evidence, along with analysis of historical data and/or simulation.

5.1.4.1 Test Purpose

The test is used to locate the initial leader attachment regions on an aircraft. This is the first step in the method for determining lightning zones by test, as described in ARP5414/ED-91. In some cases, tests on models need to be supplemented by other means to determine detailed initial leader attachment locations. This case is particularly true of aircraft involving large amounts of nonconductive structural materials, such as glass fiber reinforced plastics.

Two test setups are described to simulate either a naturally approaching leader or an aircraft-initiated strike. For aircraft with the largest dimension exceeding 50 m, both test setups are necessary and will double the scope of testing. For aircraft with the largest dimension that is less than or equal to 50 m, the full evaluation can be achieved by simply using the aircraft-initiated leader case test setup for all tests.

5.1.4.2 Test Object

The test object should be an accurate model of the vehicle exterior that is not less than 1 m in its largest dimension. Exterior surfaces of the model should be electrically conductive, even though some surfaces of the aircraft, such as a radome and windshields, are made of nonconducting materials. Model tests cannot determine detailed attachment locations on nonconductive surfaces. Therefore, the entire model is provided with conductive surfaces and the test determines which surfaces would be potentially susceptible to initial leader attachments. High voltage strike attachment tests of full scale nonconductive structures as described in [5.1.1](#) and [5.1.2](#) must be applied to establish detailed strike locations, surface flashover or puncture possibilities, or the effectiveness of protection devices.

If more than one vehicle configuration exists or is planned, the various possible configurations should be modeled separately.

5.1.4.3 Test Setup

- Mount the model on electrically insulated stand-offs or suspend it from nonconducting lines such that it is positioned in space between a high voltage electrode and a ground plane.
- To simulate a naturally occurring leader the upper electrode may be a rod or small sphere not exceeding 50 mm diameter to represent a leader approaching the aircraft.
- To represent an aircraft-initiated strike, a large, flat plate should be used to represent the ambient field condition preceding the formation of bidirectional leaders from the aircraft. The flat plate electrode should be sufficiently large so that field concentrations at electrode edges do not influence test results (i.e., flashovers should occur to the flat surfaces and not the edges of the electrode and ground plane). This typically requires that electrode and ground plane dimensions be a minimum of three times the largest dimension of the model. [Figure 10](#) shows a typical setup for the naturally occurring leader case. [Figure 11](#) shows the arrangement to represent the aircraft-initiated strike.

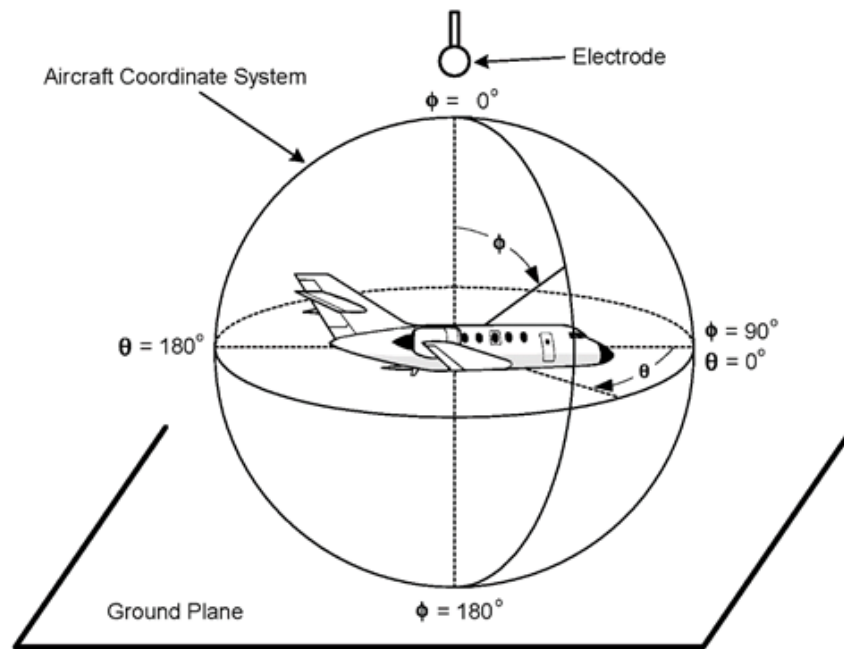


Figure 10 - Test setup to determine initial leader attachment locations on models. A naturally occurring leader simulation is shown.

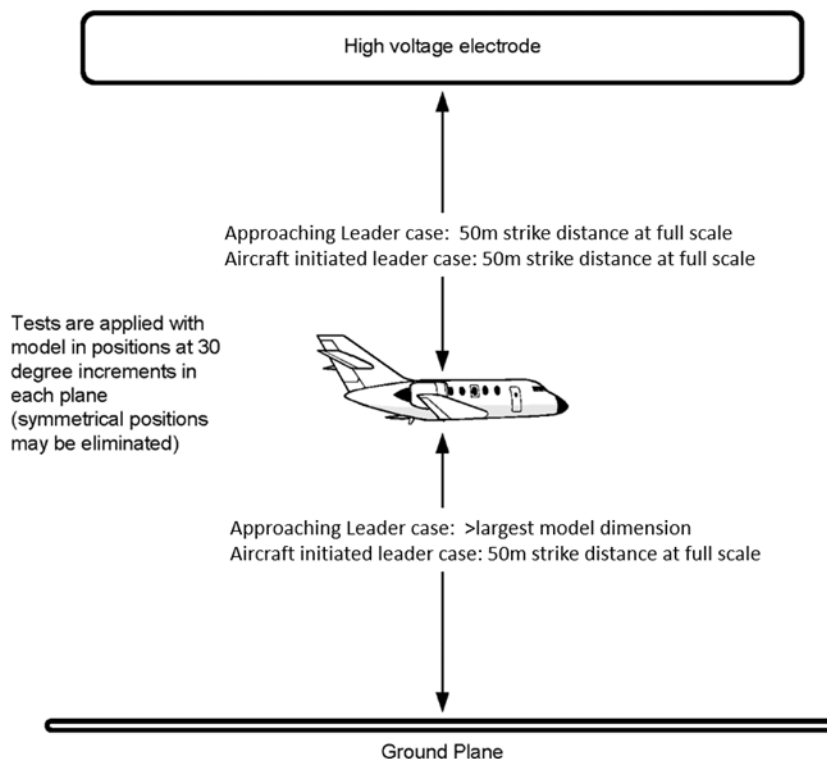


Figure 11 - Test setup to determine initial leader attachment locations on models. An aircraft-initiated strike simulation is shown.