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MILITARY SPECIFICATION

BONDING; ELECTRICAL (FOR AIRCRAFT)

This specification was approved on the above date by joint action of the Air Force and Navy Departments for use in the procurement of aeronautical supplies.

1. SCOPE

1.1 This specification provides requirements for the application and testing of electrical bonding on all-metal aircraft. For aircraft which are not of all-metal construction, the bonding requirements shall be determined by reference to the Procuring Service.

2. APPLICABLE SPECIFICATIONS, OTHER PUBLICATIONS, AND DRAWINGS

2.1 Specifications.- The following specifications of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein:

Air Force-Navy Aeronautical

AN-J-1	Jumpers; Bonding and Current Return
AN-L-37	Lacquer; Clear, Aluminum-Clad Aluminum Alloy Surfaces
AN-W-14	Wiring; Installation of Aircraft

2.2 Other publication.- The following publication of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein:

Air Force-Navy Aeronautical Bulletin

No. 143	Specifications and Standards; Use of

2.3 Drawings.- The following drawings of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein:

Air Force-Navy Aeronautical Standard Drawings

AN735	Clamp - Loop Type Bonding
AN742	Clamp - Loop Type Support
AN749	Jumper - Bonding
AN751	Jumper - Disconnect Bonding
AN752	Jumper - Current Return

(Copies of this publication and copies of applicable publications thereto required for Government procurement, and the Index of Military Aeronautical (AN or MIL) Standards may be obtained upon application to the Commanding General, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio; or to the Commander, U. S. Naval Air Development Center, Johnsville, Pennsylvania. Military Specifications (aeronautical AN or MIL), ANA Bulletins, Qualified Products Lists, and ANA Drawings are available for purchase from the above agencies, acting as agents for the Superintendent of Documents. The price may be obtained from the Index of Military Aeronautical (AN or MIL) Standards or upon application to either of the above agencies, and payment shall be made by check or money order, payable to the Superintendent of Documents or the Treasurer of the United States.)

3. REQUIREMENTS

3.1 Materials.- Materials shall conform to applicable specifications as specified herein. Materials that are not specifically designated shall be of the best quality, of the lightest practicable weight, and suitable for the purpose intended.

3.1.1 Selection of materials.- Specifications and standards for all materials, parts, and Government certification and approval of processes and equipment, which are not specifically designated herein and which are necessary for the execution of this specification shall be selected in accordance with ANA Bulletin No. 143, except as provided in the following paragraph.

3.1.1.1 AN and JAN Standard parts.- AN and JAN Standard parts shall be used wherever they are suitable for the purpose, and shall be identified on the drawing by their part number. Commercial utility parts such as screws, bolts, nuts, cotter pins, etc., may be used, provided they develop suitable properties and are replaceable by the AN or JAN Standard parts without alteration, and provided the corresponding AN or JAN part numbers are referenced in the parts list and if practicable, on the contractor's drawings. In case there is no suitable corresponding AN or JAN Standard part in effect on date of invitation for bids, commercial parts may be used provided they conform to all requirements of this specification.

3.1.2 Jumpers.- Bonding jumpers shall be in general accordance with Specification AN-J-1 and, wherever practical, in accordance with Drawing AN749, AN751, or AN752.

3.2 General requirements.-

3.2.1 Purposes of bonding.- The bonding shall be so designed and so executed as to achieve the following results:

(a) Protect the aircraft and personnel from hazards associated with lightning discharges.

(b) Provide power current return paths.

(c) Provide a constant homogeneous counterpoise for radio transmission and reception.

(d) Prevent the development of r-f potentials on conducting frames and enclosures of electrical and electronic equipment and on conducting objects adjacent to unshielded transmitting antenna lead-ins.

(e) Protect personnel from the shock hazard resulting from equipment internally power faulted.

(f) Prevent the accumulation of static charge which would produce radio interference or explosion hazard by periodic spark discharge or would constitute a shock hazard.

3.2.2 Extent of bonding.- The number of bonding jumpers to be installed shall be reduced to a minimum by careful design to meet the purposes of this specification.

3.2.2.1 Parts impractical to bond with jumpers.- Where bonding is necessary but bonding by jumper types may cause fouling or mechanical malfunction, other suitable means shall be employed which are in accordance with good engineering practice.

3.2.2.2 Intermittent electrical contact.- Intermittent electrical contact between conducting surfaces which may become part of the counterpoise or current path referred to in (b), (c), and (d) of paragraph 3.2.1 shall be prevented either by an adequate bond, or by insulation if bonding is not necessary to meet other requirements of this specification.

3.2.2.3 Parts inherently bonded.- Bonding requirements are considered as being met inherently by permanent metal-to-metal joints made by welding, brazing, sweating, or swaging or by semipermanent metal-to-metal joints of machined metal surfaces held together by lock-threaded devices, riveted joints, tie rods, or structural wires under heavy tension, pinned fittings driven tight and not subjected to wear, and clamped fittings normally permanent and immovable after installation if all insulating finishes are removed from the contact area before assembly. Insulating finishes need not be removed to comply with paragraph 3.3.6 if the resistance requirement is met without such removal.

3.2.3 Applications of bonds.- Bonding connections shall be so installed that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connection nor loosen them to such an extent that the reistance will vary during the movement or increase above the permissible maximum value. Bonding connections should be located in protected areas insofar as practicable, and, whenever possible, they shall be located near a hand hole, inspection door, or some other accessible location, to permit ready inspection and replacement.

3.2.3.1 Parts shall be bonded directly to the basic aircraft structure rather than through other bonded parts insofar as practical.

3.2.3.2 Bonding jumpers shall not be installed in such a manner as to interfere in any way with the operation of movable components of the aircraft.

3.2.3.3 All bonding jumpers shall be kept as short and direct as possible and, when practicable, shall not exceed 3 inches in length. The use of two or more standard length jumpers in series to make up the necessary length will not be allowed without approval of the Procuring Service.

3.2.3.4 Bonding of structural members shall be accomplished without weakening any vital structure of the aircraft. Bonding clamps on flexible metallic conduit or hose shall be so installed as not to crimp or damage the conduit or hose.

3.2.3.5 Dissimilar metals.- In bonding, the necessity for joining dissimilar metals is frequently unavoidable. In such cases the jumpers and other elements of the bonding connection shall be so selected as to minimize the possibility of corrosion and if possible, to insure that if corrosion does occur, it will be in replaceable elements such as jumpers, washers, or separators rather than in the aircraft structure. Washers should not be surface treated or coated in any manner that would impair electrical conductivity and unprotected nonstainless steel shall not be used as a washer.

3.2.3.5.1 The table below indicates acceptable methods of making up connections between bonding jumpers and structure of various metals. Note that the metals are listed in order of decreasing activity in salt water, and the higher metal in the series will be the one attacked in the case of galvanic action between any two. In general, the greater the separation between any two listed metals, the more violent the corrosive activity to be expected. The screws and nuts to be used in making the connection are indicated as type (1), cadmium or zinc plated, or aluminum; and type (2), stainless steel. Where either type screw is indicated as acceptable, the type (2) is preferred from a corrosion standpoint.

Metal Structure	Connection for Aluminum Jumper		Connection for Tinned Copper Jumper	
Magnesium & Mg base alloys	Direct or Mg washer	Type (1) screw	Al or Mg washer	Type (1) screw
Zinc, Cadmium, Aluminum and Al alloys	Direct	Type (1) screw	Aluminum washer	Type (1) screw
Steel (except stainless steel)	Direct	Type (1) screw	Direct	Type (1) screw
Tin, Lead & Pb-Sn solders	Direct	Type (1) screw	Direct	Type (2) or (1) screw
Copper & Cu base alloys	Tinned or cadmium-plated washer	Type (2) or (1) screw	Direct	Type (2) or (1) screw
Nickel & Ni base alloys	Tinned or cadmium-plated washer	Type (2) or (1) screw	Direct	Type (2) or (1) screw
Stainless Steel	Tinned or cadmium-plated washer	Type (2) or (1) screw	Direct	Type (2) or (1) screw
Silver, Gold & precious metals	Tinned or cadmium-plated washer	Type (2) or (1) screw	Direct	Type (2) or (1) screw

3.2.3.6 Self-tapping screws.- The use of self-tapping screws shall be kept to a minimum, and they shall be used only when the use of machine screws is definitely impracticable. They shall not be used if they will be subject to frequent removal or replacement.

3.2.3.7 Jumper connections shall not be compression fastened through plywood or other nonmetallic material.

3.2.4 Finish.- When necessary to remove any protective coating on metallic surfaces to meet the requirements of this specification, the completed assembly shall be refinished with its original finish or other suitable protective finish within 24 hours after inspection and within 1 week after removal of the finish. A clear finish, in accordance with Specification AN-L-37, may be used if desired to facilitate subsequent inspection. If abrasives or scrapers are used to remove any protective finish, they shall be of such a nature as to produce a clean, smooth surface without removing excessive material under the protective finish. Abrasives which will cause corrosive action if particles imbed themselves in the metal shall not be used.

3.2.5 Quick-disconnecting jumpers.- Quick-disconnecting jumpers shall be used only for bonding parts which are frequently removed for servicing.

3.2.6 Clamps.- When the member to be bonded is of tubular or cylindrical cross-section, the bonding jumper, when used, shall be fastened to the member to be bonded by means of a plain clamp, in accordance with Drawing AN735 or AN742. Cushion clamps are not acceptable.

3.3 Detail requirements.-

3.3.1 Bonding requirements for lightning protection (except on antenna systems).- The detailed requirements given below are designed to achieve a lightning bonding system such that a lightning discharge current may be carried between any two extremities of the aircraft without risk of damaging flight controls or of producing voltages within the aircraft in excess of 500 volts. (These requirements are based upon a lightning current surge which reaches a crest value of 100,000 amperes at 10 microseconds and drops to 50,000 amperes at 20 microseconds.)

3.3.1.1 Individual bonding jumpers for lightning protection shall be not less, in cross sectional area, than 6475 circular mils in case of tinned copper stranded cable, nor less than 10,000 circular mils in case of stranded aluminum cable.

3.3.1.2 To insure a low impedance path so that the voltage drop developed across the jumper system by the lightning discharge is minimized, bonding jumpers shall be as short as possible (of minimum impedance).

3.3.1.3 To prevent burning, contact resistance between the jumper terminal and the object or structure shall be made a minimum by cleaning the contact surfaces until they are thoroughly bright and then effecting a positive mechanical connection.

3.3.1.4 Control surfaces and flaps shall have a bonding jumper across each hinge and in any case shall have not less than a total of two jumpers. Lightning currents flowing from such surfaces to structure will divide between the jumpers, hinges, and also the control cables and levers attached to such surfaces. The division of current can be expected to vary inversely with impedance, or roughly inversely with the respective length of the discharge paths from the point of stroke to the basic structure. In order to protect the control cables and levers it may be necessary to add additional jumpers between the control surface and structure so that the length of a discharge path through the control system is at least 10 times the length of the path through the jumper or jumpers.

3.3.1.5 All external electrically isolated conducting objects, except antennas, which protrude above the aircraft surface, shall have a bonding jumper to the aircraft skin or structure.

3.3.1.6 Large nonconducting projections essential to flight or housing personnel, such as vertical stabilizers, wing tips, astrodomes and canopies, shall have a suitable lightning path externally disposed over their exposed area and leading to the aircraft skin. The path shall be installed so as not to impair the structural integrity of the projection. If conductors are used, they shall have a circular mil area of not less than 6475 for copper, nor 10,000 for aluminum. Any conducting object including personnel inside the protrusion shall lie within the protective zone formed by the conductive path; the protective zone being as defined, and illustrated in figure 1. If a semiconducting surface or nonlinear graded surface resistance is used to initiate a lightning path, the voltage gradient at any point along the path to the skin must be less than the breakdown gradient to any grounded object within, and the resistive path must be at least 1 inch wide. In the case of projections enclosing antennas, this shall be considered a design objective and the Procuring Service may waive the requirement if it is considered impractical to achieve with the present state of the art.

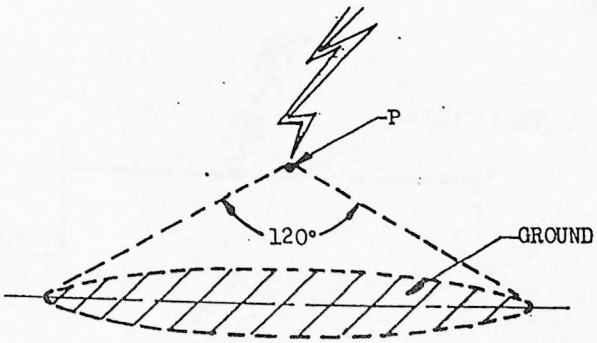

FIG. 1-A LIGHTNING PROTECTIVE ZONE CREATED BY A SINGLE CONDUCTIVE POINT P, SUITABLY GROUNDED

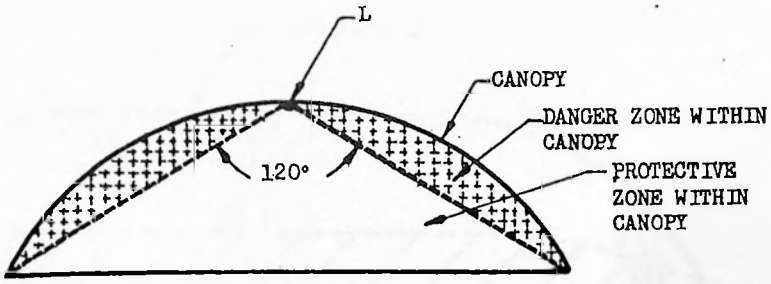

FIG. 1-D SECTIONAL VIEW TAKEN THROUGH FIG. 1-C AT S-S, SHOWING INADEQUATE PROTECTIVE ZONE CREATED WITHIN CANOPY WITH BUT A SINGLE CONDUCTOR L, INSTALLED AS SHOWN HERE AND IN FIG. 1-C.

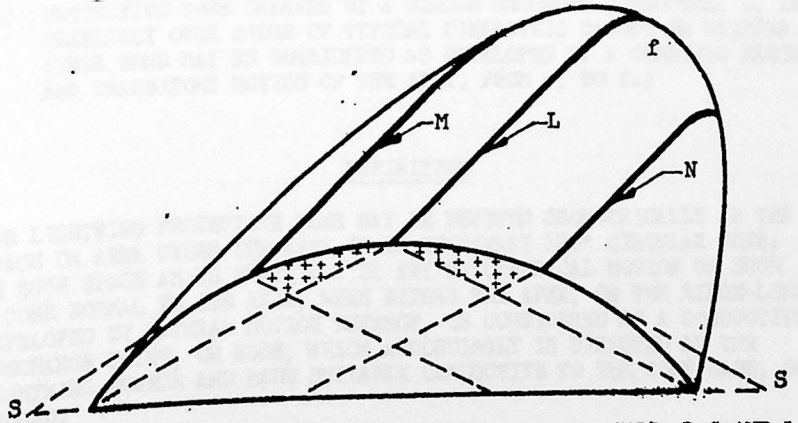

FIG. 1-E— PERSPECTIVE OF SECTION, S-f-S, SHOWN IN FIGS. 1-C AND 1-D, SHOWING HOW A COMPOUND PROTECTIVE ZONE MAY BE BUILT UP BY INSTALLATION OF ADDITIONAL GROUNDED CONDUCTORS, M AND N, WHICH PRODUCE OVERLAPPING PROTECTIVE ZONES.

FIGURE 1. Typical Protective Zones

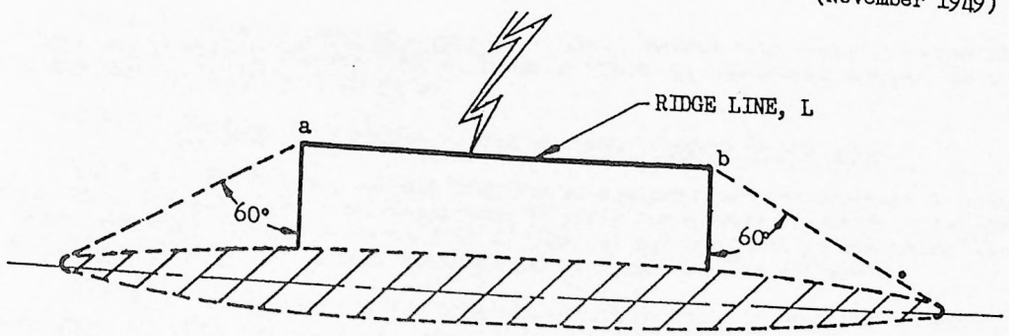

FIG. 1-B PROTECTIVE ZONE CREATED BY A CONDUCTIVE RIDGE LINE, L, SUITABLY GROUNDED. (THIS ZONE MAY BE CONSIDERED AS DEVELOPED BY A SIMPLE MOTION OF TRANSLATION OF THE CONE IN FIG. 1-A FROM POINT a, TO POINT b, ABOVE.)

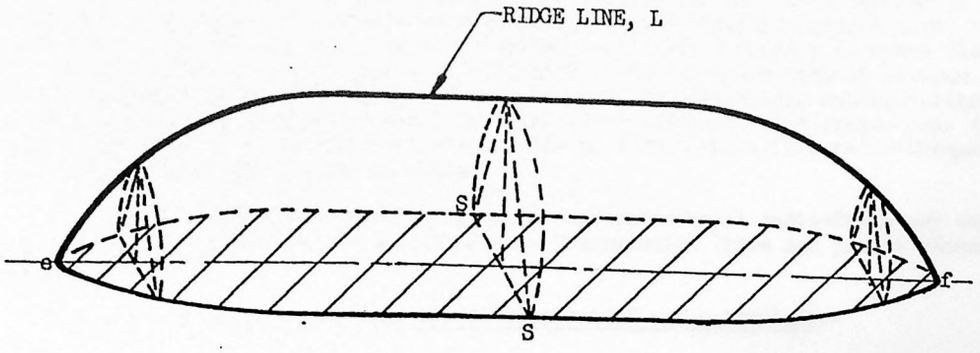

FIG. 1-C PROTECTIVE ZONE CREATED BY A SINGLE GROUNDED CONDUCTOR, L, LAID CENTRALLY OVER RIDGE OF TYPICAL DIELECTRIC CANOPY OR BLISTER. (THIS ZONE MAY BE CONSIDERED AS DEVELOPED BY A COMBINED RADIAL AND TRANSITORY MOTION OF THE APEX, FROM e, TO f.)

DEFINITION

THE LIGHTNING PROTECTIVE ZONE MAY BE DEFINED GEOMETRICALLY AS THE SPACE OR AREA UNDER THE APEX OF AN IMAGINARY 120° CIRCULAR CONE; OR SUCH SPACE AS IS SWEPT OUT BY ANY HYPOTHETICAL MOTION OF SUCH A CONE NORMAL TO ITS AXIS, WHEN EITHER THE APEX, OR THE RIDGE-LINE DEVELOPED BY LATERAL MOTION THEREOF, IS CONSIDERED AS A CONDUCTIVE DISCHARGE POINT, OR EDGE, WHICH ACCORDINGLY IS DIRECTED AT THE LIGHTNING SOURCE AND MADE SUITABLY CONDUCTIVE TO THE CONE BASE, OR GROUND.

FIGURE 1. Typical Protective Zones - (Continued)

3.3.1.7 Riveted skin construction.- Close riveted skin construction which divides any lightning current over a number of rivets is considered adequate to provide a lightning discharge current path.

3.3.2 Bonding requirements to provide power current return paths.-

3.3.2.1 The bonding between articles of equipment and the aircraft structure shall be of adequate cross-sectional area to carry the necessary current. The power current carrying capacity of a bond is defined as that specified by Specification AN-W-14 for cable conductor of the same material and of equal circular mil area.

3.3.2.2 The bonding of the aircraft structure shall be adequate to permit the structure to carry the required power return currents without exceeding the voltage drop requirements of Specification AN-W-14.

3.3.3 Bonding of antenna installations.-

3.3.3.1 Radiating elements, exclusive of radar scanners and similar types, where the counterpoise is actually a part of the equipment, shall be so installed as to be provided with a homogeneous counterpoise, or ground plane, of negligible impedance within the operating frequency ranges of the electronic equipments involved, and of adequate dimensions to insure obtaining satisfactory radiation patterns.

3.3.3.2 Antennas so designed that their efficient operation depends on a low resistance, low reactance return current path from a homogeneous ground plane to metal portions of the antenna shall be so installed that radio-frequency currents flowing on the external surface of the aircraft will have a low impedance path of minimum length to the appropriate metal portions of the antenna. In particular, mating surfaces designed to be electrically continuous shall be clean metal surfaces, free from anodic film, grease, paint, lacquer, or other high-resistance film to insure negligible radio-frequency impedance between the adjacent metal parts.

3.3.3.3. Provisions shall be made for circumferential radio-frequency continuity between outer conductors of coaxial antenna transmission lines and ground planes of antennas.

3.3.4 Bonding to prevent the development of r-f potentials.-

3.3.4.1 Equipment containing electrical circuits which may produce radio frequencies, either desired or undesired, must be installed so that there is a continuous low impedance path from the equipment enclosure to the aircraft structure. Bonding shall be accomplished by bare, clean, metal-to-metal contact of all mounting plate, rack, shelf, bracket, and structure mating surfaces so as to form a continuous, low impedance ground from the equipment mounting plates. Bonding jumpers shall not be used. The bond from the equipment enclosure to the mounting plate furnished with it shall comply with these requirements also, except that suitable jumpers may be used across any necessary vibration mounts.

3.3.4.2 All conducting items having any linear dimension greater than 12 inches that are within 3 feet of unshielded transmitting antenna lead-ins shall have a low impedance bond to structure. Direct metal-to-metal contact with structure is desired, but if a jumper must be used, it shall be as short as possible.

3.3.5 Bonding to prevent shock hazard resulting from equipment internally power faulted.-

3.3.5.1 Metallic conduit carrying electrical wiring shall have a low resistance bond of less than one ohm to structure at each terminating and break point. The bonding path may be through the equipment at which the conduit terminates.

3.3.5.2 Exposed conducting frames or parts of electrical or electronic equipment shall have a low resistance bond to structure. If the equipment design includes a ground terminal or pin which is internally connected to such exposed parts, a ground wire connection to such terminal will satisfy this requirement. If compliance with paragraph 3.3.4.1 is necessary due to the nature of the equipment, this requirement will be considered to be met as well.

3.3.6 Bonding to prevent the accumulation of static charge.- All isolated conducting items (except antennas) having any linear dimension greater than 3 inches, shall have a mechanically secure electrical connection to the aircraft structure having a resistance of less than one-half megohm.

4. INSPECTION AND TESTING

4.1 General.- Inspection or testing of bonding of a subassembly shall in no case be construed as waiving the inspection and testing of the complete assembly. Conformance with the resistance requirements alone shall in no case be considered as sole proof of satisfactory bonding. The length of jumpers, methods and materials used, and the possibility of loosening of connections in service use shall be taken into consideration as well.

4.2 Resistance.- The resistance of bonding, where required by this specification, shall be measured on the first five of any type aircraft model in such a manner as to determine that the bonding meets the requirements of this specification. Thereafter 1 aircraft in each group of 10 shall be tested or 1 aircraft per month whenever production is less than 10 aircraft per month. Visual inspection shall be conducted on all other aircraft to determine that no change in method or materials has been made that would affect conformance with this specification.

4.3 Refinishing.- If, during the testing of the bonding, the finish of any part is damaged, the part shall be suitably refinished.

5. NOTES

5.1 Definitions.- For the purpose of this specification the following definitions shall apply:

(a) Bond (noun).- A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them.

(b) Bonding or to bond.- Aircraft electrical bonding is defined as the process of obtaining the necessary electrical conductivity between the component metallic parts of the airplane.

(c) Bonding Connector.- A bonding connector provides the necessary electrical conductivity between metallic parts in an airplane not in sufficient electrical contact. Examples of bonding connectors are: bonding jumpers, bonding clamps, and conducting rubber grommets.

(d) Conducting Surfaces or Objects.- Conducting surfaces or objects, for the purpose of this specification, shall include all objects having a resistivity of less than one megohm-centimeter.

(e) Lightning Protective Zone.- The lightning protective zone may be defined geometrically as the space or area under the apex of an imaginary 120° circular cone; or such space as is swept out by any hypothetical motion of such a cone normal to its axis, when either the apex, or the ridge line developed by lateral motion thereof, is considered as a conductive discharge point, or edge, which accordingly is directed at the lightning source and made suitably conductive to the cone base, or ground.

5.2 Examples of objects which require bonding:

	Object	Requirement	Reason
(a)	Ailerons	Bonding jumper across each hinge.	For lightning protection (paragraph 3.3.1.4).
(b)	Engine mounts	Bonding connectors shall be adequate to carry the power current return.	To provide a power current path (paragraph 3.3.2.1).
(c)	Sleeve antennas	Circumferential metal-to metal contact between base of sleeve and airplane skin.	To provide counterpoise and r-f current return path (paragraph 3.3.3.2).
(d)	Radio shelves	Bonding by direct contact without jumpers.	To provide low impedance path (paragraph 3.3.4).
(e)	Transformer (electrical)	Bond frame to structure.	To prevent shock hazard in case fault occurs in the equipment. (paragraph 3.3.5.2).
(f)	Fuel lines & fittings	Need not be bonded if the combination is less than 3 inches in longest dimension; neither need they be bonded if their resistance to structure is less than one-half megohm.	To prevent accumulation of static charge (paragraph 3.3.6).
(g)	Doors	Add bonding connection to structure if doors exceed 3 inches in any dimension and if resistance to structure exceeds one-half megohn.	To prevent accumulation of static charge (paragraph 3.3.6).

5.3 Lightning protection for external antennas (design objective).- It is desired that external antennas be designed to avoid lightning currents entering the aircraft and damaging radio equipment or causing fires. Such design may consist basically of a shunt spark-gap and series capacitor in a suitable housing.

5.4 Protection or projections housing antennas (design objective).- The protection of structures housing antennas imposes the additional requirements that the antenna operation not be adversely affected. The graded high resistance path is indicated as one suitable means. A surface conductor path may be broken by gaps to avoid effect on the antenna pattern. No such gap should exceed 1/16 inch in length.

5.5 Protection of nonconducting projections.-

5.5.1 Canopies may be considered as inherently protected if the flashover voltage from any point on the canopy along the surface to the aircraft skin is less than the puncture voltage through the canopy.

5.5.2 On movable canopies the lightning conductive path need not be physically continuous but may terminate in not over a 1/4-inch gap to the skin of the aircraft. In order to avoid precipitation static effects, a spring contact providing a continuous path in the closed position is desirable.

5.5.3 The design of the conductive path shall be such as to contribute a minimum to prebipitation static effects. This may be accomplished by bridging the conductor gaps or shielding the conductive path with semiconductive material.

5.5.4 If visibility requirements dictate otherwise, the lightning conductor path need not continue longitudinally to structure if a good connection can be made to a spanwise grounded member.

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