SECTION 15. GROUNDING AND BONDING

11-185. GENERAL. One of the more important factors in the design and maintenance of aircraft electrical systems is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, e.g., EMI, electrostatic discharge damage to sensitive electronics, personnel shock hazard, or damage from lightning strike. This section provides an overview of the principles involved in the design and maintenance of electrical bonding and grounding. SAE ARP-1870 provides for more complete detailed information on grounding and bonding, and the application of related hardware.

11-186. GROUNDING. Grounding is the process of electrically connecting conductive objects to either a conductive structure or some other conductive return path for the purpose of safely completing either a normal or fault circuit.

a. Types of Grounding. If wires carrying return currents from different types of sources, such as signals of DC and AC generators, are connected to the same ground point or have a common connection in the return paths, an interaction of the currents will occur. Mixing return currents from various sources should be avoided because noise will be coupled from one source to another and can be a major problem for digital systems. To minimize the interaction between various return currents, different types of grounds should be identified and used. As a minimum, the design should use three ground types: (1) ac returns, (2) dc returns, and (3) all others. For distributed power systems, the power return point for an alternative power source would be separated. For example, in a two-ac generator (one on the right side and the other on the left side) system, if the right ac generator were supplying backup power to equipment located in the left side, (left equipment rack) the backup ac ground return should be labeled "ac Right". The return currents for the left generator should be connected to a ground point labeled "ac Left"

b. Current Return Paths. The design of the ground return circuit should be given as much attention as the other leads of a circuit. A requirement for proper ground connections is that they maintain an impedance that is essentially constant. Ground return circuits should have a current rating and voltage drop adequate for satisfactory operation of the connected electrical and electronic equipment. EMI problems, that can be caused by a system's power wire, can be reduced substantially by locating the associated ground return near the origin of the power wiring (e.g. circuit breaker panel) and routing the power wire and its ground return in a twisted pair. Special care should be exercised to ensure replacement on ground return leads. The use of numbered insulated wire leads instead of bare grounding jumpers may aid in this respect. In general, equipment items should have an external ground connection, even when internally grounded. Direct connections to a magnesium (which may create a fire hazard) structure must not be used for ground return.

c. Heavy-Current Grounds. Power ground connections, for generators, transformer rectifiers, batteries, external power receptacles, and other heavy-current, loads must be attached to individual grounding brackets that are attached to aircraft structure with a proper metal-to-metal bonding attachment. This attachment and the surrounding structure must provide adequate conductivity to accommodate normal and fault currents of the system without creating excessive voltage drop or damage to the structure. At least three fasteners, located in a triangular or rectangular pattern, must be used to secure such brackets in order to minimize susceptibility to loosening under vibration. If the structure is fabricated of a material such as carbon fiber composite (CFC), which has a higher resistivity than aluminum or copper, it will be necessary to provide an alternative ground path(s) for power return current. Special attention should be considered for composite aircraft.

d. Current Return Paths for Internally Grounded Equipment. Power return or fault current ground connections within flammable vapor areas must be avoided. If they must be made, make sure these connections will not arc, spark, or overheat under all possible current flow or mechanical failure conditions, including induced lightning currents. Criteria for inspection and maintenance to ensure continued airworthiness throughout the expected life of the aircraft should be established. Power return fault currents are normally the highest currents flowing in a structure. These can be the full generator current capacity. If full generator fault current flows through a localized region of the carbon fiber structure, major heating and failure can occur. CFC and other similar low-resistive materials must not be used in power return paths. Additional voltage drops in the return path can cause voltage regulation problems. Likewise, repeated localized material heating by current surges can cause material degradation. Both problems may occur without warning and cause nonrepeatable failures or anomalies.

e. Common Ground Connections. The use of common ground connections for more than one circuit or function should be avoided except where it can be shown that related malfunctions that could affect more than one circuit will not result in a hazardous condition. Even when the loss of multiple systems does not, in itself, create a hazard, the effect of such failure can be quite distracting to the crew.

(1) Redundant systems are normally provided with the objective of assuring continued safe operation in the event of failure of a single channel and must therefore be grounded at well separated points. To avoid construction or maintenance errors that result in connecting such ground at a single point, wires that ground one channel of a redundant system should be incapable of reaching the ground attachment of the other channel.

(2) The use of loop type grounding systems (several ground leads connected in series with a ground to structure at each end) must be avoided on redundant systems, because the loss of either ground path will remain undetected, leaving both systems, with a potential single-point failure.

(3) Electrical power sources must be grounded at separate locations on the aircraft structure. The loss of multiple sources of electrical power, as the result of corrosion of a ground connection or failure of the related fasteners, may result in the loss of multiple systems and should be avoided by making the ground attachments at separate locations.

(4) Bonds to thermally or vibration-isolated structure require special consideration to avoid single ground return to primary structure.

(5) The effect of the interconnection of the circuits when ungrounded should be considered whenever a common ground connection is used. This is particularly important when employing terminal junction grounding modules or other types of gang grounds that have a single attachment point.

f. Grounds for Sensitive Circuits. Special consideration should be given to grounds for sensitive circuits. For example:

(1) Grounding of a signal circuit through a power current lead introduces power current return voltage drop into the signal circuit.

(2) Running power wires too close will cause signal interference.

(3) Separately grounding two components of a transducer system may introduce ground plane voltage variations into the system.

(4) Single point grounds for signal circuits, with such grounds being at the signal source, are often a good way to minimize the effects of EMI, lightning, and other sources of interference.

11-187. BONDING. The following bonding requirements must be considered:

a. Equipment Bonding. Low-impedance paths to aircraft structure are normally required for electronic equipment to provide radio frequency return circuits and for most electrical equipment to facilitate reduction in EMI. The cases of components which produce electromagnetic energy should be grounded to structure. To ensure proper operation of electronic equipment, it is particularly important to conform the system's installation specification when interconnections, bonding, and grounding are being accomplished.

b. Metallic Surface Bonding. All conducting objects on the exterior of the airframe must be electrically connected to the airframe through mechanical joints, conductive hinges, or bond straps capable of conducting static charges and lightning strikes. Exceptions may be necessary for some objects such as antenna elements, whose function requires them to be electrically isolated from the airframe. Such items should be provided with an alternative means to conduct static charges and/or lightning currents, as appropriate.

c. Static Bonds. All isolated conducting parts inside and outside the aircraft, having an area greater than 3 in^2 and a linear dimension over 3 inches, that are subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion, should have a mechanically secure electrical connection to the aircraft structure of sufficient conductivity to dissipate possible static charges. A resistance of less than 1 ohm when clean and dry will generally ensure such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.

11-188. BONDING INSPECTION. Inspect for the following:

a. If there is evidence of electrical arcing, check for intermittent electrical contact between conducting surfaces, that may become a part of a ground plane or a current path. Arcing can be prevented either by bonding, or by insulation if bonding is not necessary.

b. The metallic conduit should be bonded to the aircraft structure at each terminating and break point. The conduit bonding strap should be located ahead of the piece of equipment that is connected to the cable wire inside the conduit.

c. Bond connections should be secure and free from corrosion.

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

e. Self-tapping screws should not be used for bonding purposes. Only standard threaded screws or bolts of appropriate size should be used.

f. Exposed conducting frames or parts of electrical or electronic equipment should have a low resistance bond of less than 2.5 millohms 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. Refer to manufacturer's instructions.

g. Bonds should be attached directly to the basic aircraft structure rather than through other bonded parts.

h. Bonds must be installed to ensure that the structure and equipment are electrically stable and free from the hazards of lightning, static discharge, electrical shock, etc. To ensure proper operation and suppression of radio interference from hazards, electrical bonding of equipment must conform to the manufacturer's specifications.

i. Use of bonding testers is strongly recommended.

j. Measurements should be performed after the grounding and bonding mechanical connections are complete to determine if the measured resistance values meet the basic requirements. A high quality test instrument (AN AN/USM-21A or equivalent) is required to accurately measure the very low resistance values specified in this document. Another method of measurement is the millivolt drop test as shown in figure 11-19.

k. Use appropriate washers when bonding aluminum or copper to dissimilar metallic structures so that any corrosion that may occur will be on the washer.

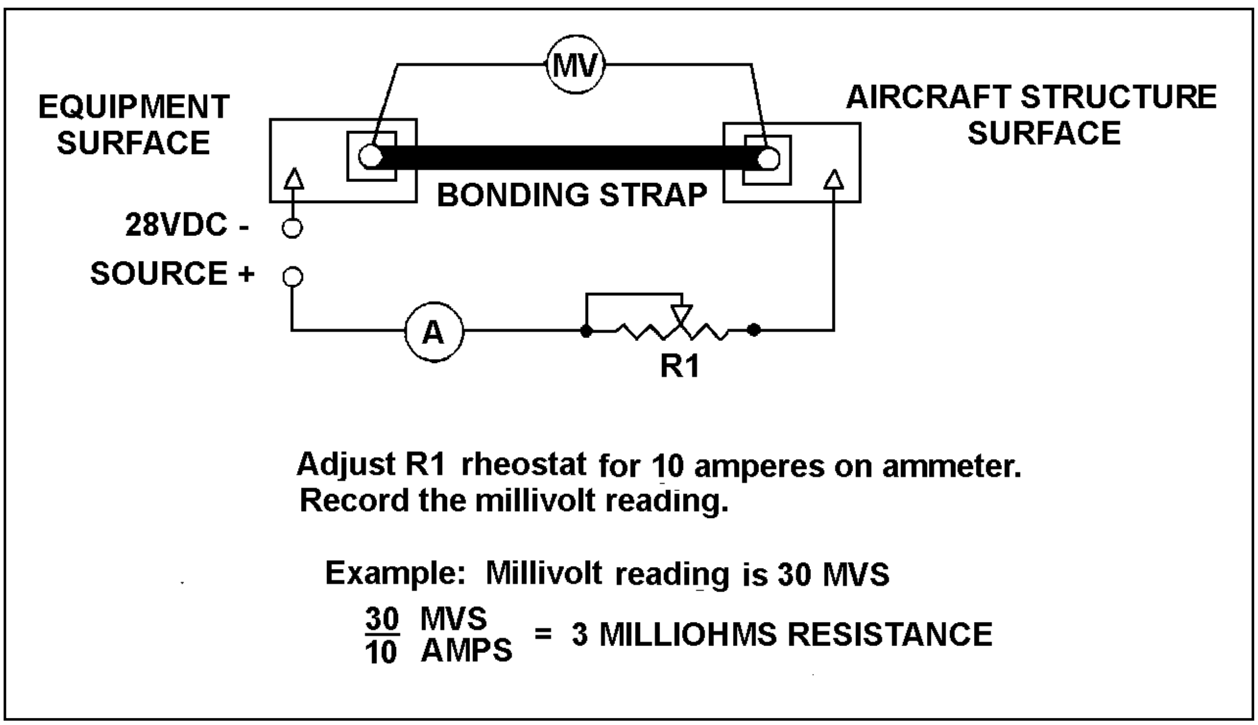


Figure 11-19. Millivolt drop test.

11-189. BONDING JUMPER INSTALLATIONS. Bonding jumpers should be made as short as practicable, and installed in such a manner that the resistance of each connection does not exceed .003 ohm. The jumper should not interfere with the operation of movable aircraft elements, such as surface controls, nor should normal movement of these elements result in damage to the bonding jumper.

a. Bonding Connections. To ensure a low-resistance connection, nonconducting finishes, such as paint and anodizing films, should be removed from the attachment surface to be contacted by the bonding terminal. On aluminum surfaces, a suitable conductive chemical surface treatment, such as Alodine, should be applied to the surfaces within 24 hours of the removal of the original finish. Refer to SAE, ARP 1870 for detailed instructions. Electric wiring should not be grounded directly to magnesium parts.

b. Corrosion Protection. One of the more frequent causes of failures in electrical system bonding and grounding is corrosion. Aircraft operating near salt water are particularly vulnerable to this failure mode. Because bonding and grounding connections may involve a variety of materials and finishes, it is important to protect completely against dissimilar metal corrosion. The areas around completed connections should be post-finished in accordance with the original finish requirements or with some other suitable protective finish within 24 hours of the cleaning process. In applications exposed to salt spray environment, a suitable noncorrosive sealant, such as one conforming to MIL-S-8802, should be used to seal dissimilar metals for protection from exposure to the atmosphere.

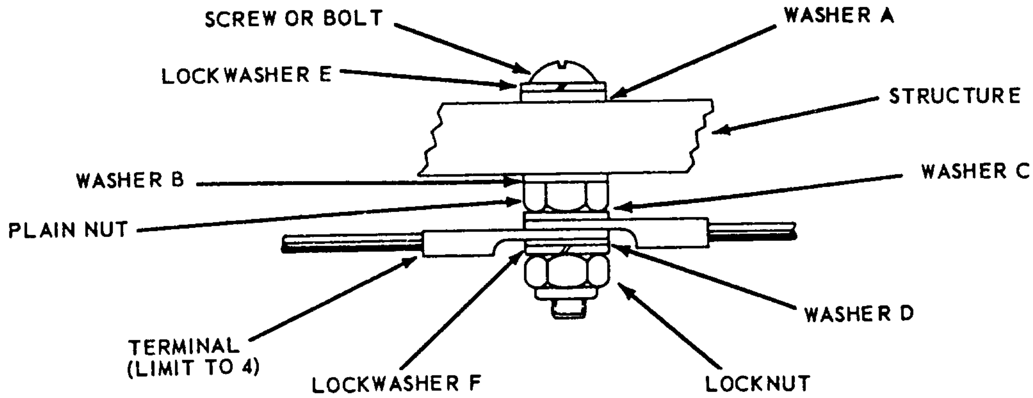
c. Corrosion Prevention. Electrolytic action may rapidly corrode a bonding connection if suitable precautions are not taken. Aluminum alloy jumpers are recommended for most cases; however, copper jumpers should be used to bond together parts made of stainless steel, cadmium plated steel, copper, brass, or bronze. Where contact between dissimilar metals cannot be avoided, the choice of jumper and hardware should be such that corrosion is minimized, and the part likely to corrode would be the jumper or associated hardware. Tables 11-14 through 11-16 and figures 11-20 through 11-22 show the proper hardware combinations for making a bond connection. At locations where finishes are removed, a protective finish should be applied to the completed connection to prevent subsequent corrosion.

d. Bonding Jumper Attachment. The use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. Proper choice of clamp material should minimize the probability of corrosion.

e. Ground Return Connection. When bonding jumpers carry substantial ground return current, the current rating of the jumper should be determined to be adequate and that a negligible voltage drop is produced.

11-190. CREEPAGE DISTANCE. Care should be used in the selection of electrical components to ensure that electrical clearance and creepage distance along surfaces between adjacent terminals, at different potentials, and between these terminals and adjacent ground surfaces are adequate for the voltages involved.

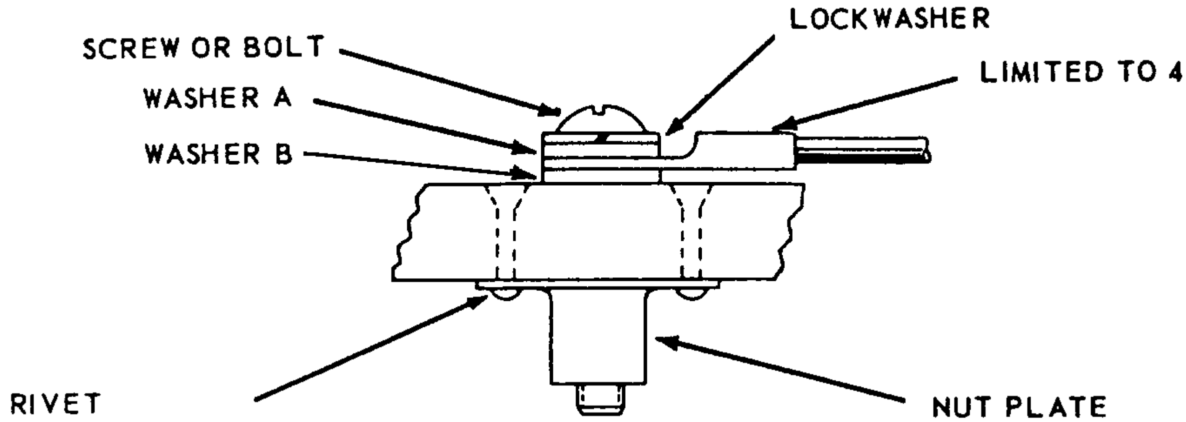
TABLE 11-14. Stud bonding or grounding to flat surface.



Structure	Screw or Bolt and Lock nut	Plain nut	Washer A	Washer B	Washer C & D	Lock washer E	Lock washer F
Aluminum Terminal and Jumper							
Aluminum Alloys	Cadmium Plated steel	Cadmium Plated Steel	Aluminum Alloy	Aluminum Alloy	Cadmium Plated Steel or Aluminum	Cadmium Plated Steel	Cadmium Plated Steel
Magnesium Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Magnesium Alloy	Magnesium Alloy	Cadmium Plated Steel or Aluminum	Cadmium Plated Steel	Cadmium Plated Steel
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	None	None	Cadmium Plated Steel or Aluminum	Cadmium Plated Steel	Cadmium Plated Steel
Steel, Corrosion Resisting	Corrosion Re-sisting Steel	Cadmium Plated Steel	None	None	Cadmium Plated Steel or Aluminum	Corrosion Resist Steel	Cadmium Plated Steel
Tinned Copper Terminal and Jumper							
Aluminum Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Aluminum Alloy	Aluminum Alloy	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum
Magnesium Alloys[1]							
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	None	None	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel
Steel, Corrosion Resisting	Corrosion Re-sisting Steel	Corrosion Resisting Steel	None	None	Cadmium Plated Steel	Corrosion Resisting Steel	Corrosion Resisting Steel

[1] Avoid connecting copper to magnesium.

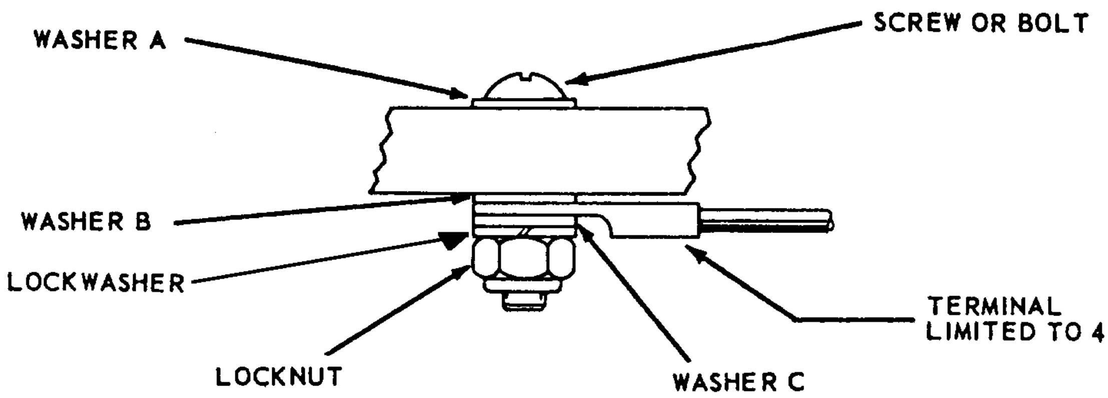
TABLE 11-15. Plate nut bonding or grounding to flat surface.



Structure	Screw or bolt and nut plate	Rivet	Lockwasher	Washer A	Washer B
Aluminum Terminal and Jumper					
Aluminum Alloys	Cadmium Plated Steel	Aluminum Alloy	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	None
Magnesium Alloys	Cadmium Plated Steel	Aluminum Alloy	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	None or Magnesium Alloy
Steel, Cadmium Plated	Cadmium Plated Steel	Corrosion Resisting Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	None
Steel, Corrosion Resisting	Corrosion Resisting Steel or Cadmium Plated Steel	Corrosion Resisting Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	Cadmium Plated Steel
Tinned Copper Terminal and Jumper					
Aluminum Alloys	Cadmium Plated Steel	Aluminum Alloy	Cadmium Plated Steel	Cadmium Plated Steel	Aluminum[2] Alloy
Magnesium Alloys[1]					
Steel, Cadmium Plated	Cadmium Plated Steel	Corrosion Resisting Steel	Cadmium Plated Steel	Cadmium Plated Steel	None
Steel, Corrosion Resisting	Corrosion Resisting Steel	Corrosion Resisting Steel	Cadmium Plated Steel	Cadmium Plated Steel	None

[1] Avoid connecting copper to magnesium.
[2] Use washers having a conductive finished treated to prevent corrosion, suggest AN960JD10L

TABLE 11-16. Bolt and nut bonding or grounding to flat surface.



Aluminum Terminal and Jumper

Structure	Screw or bolt and nut plate	Lock-nut	Washer A	Washer B	Washer C
Aluminum Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	None	Cadmium Plated Steel or Aluminum
Magnesium Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Magnesium Alloy	None or Magnesium alloy	Cadmium Plated Steel or Aluminum
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum
Steel, Corrosion Re-sisting	Corrosion Resisting Steel or Cadmium Plated Steel	Cadmium Plated Steel	Corrosion Resisting Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum

Tinned Copper Terminal and Jumper

Structure	Screw or bolt and nut plate	Lock-nut	Washer A	Washer B	Washer C
Aluminum Alloy Magnesium Alloy[1]	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Aluminum[2] Alloy	Cadmium Plated Steel
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	None	Cadmium Plated Steel
Steel, Corrosion Re-sisting	Corrosion Resisting Steel or Cadmium Plated Steel	Cadmium Plated Steel	Corrosion Resisting Steel	None	Cadmium Plated Steel

[1] Avoid connecting copper to magnesium.
[2] Use washers having a conductive finished treated to prevent corrosion, suggest AN960JD10L

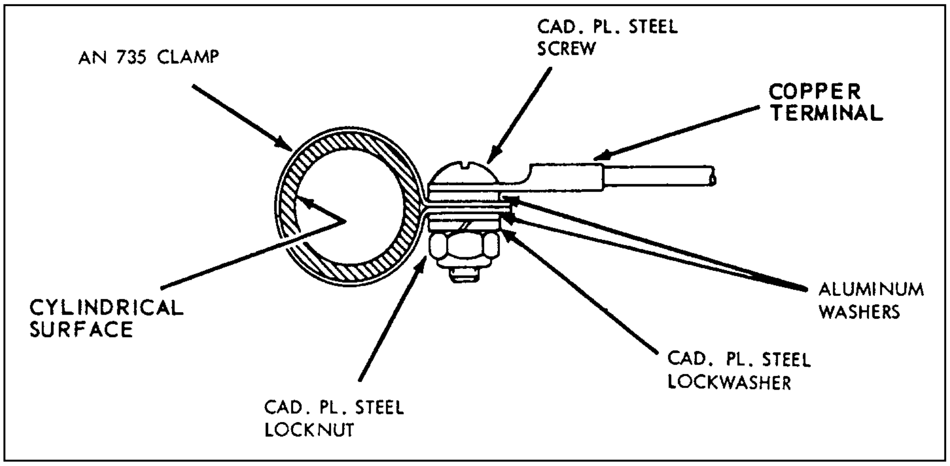


FIGURE 11-20. Copper jumper connector to tubular structure.

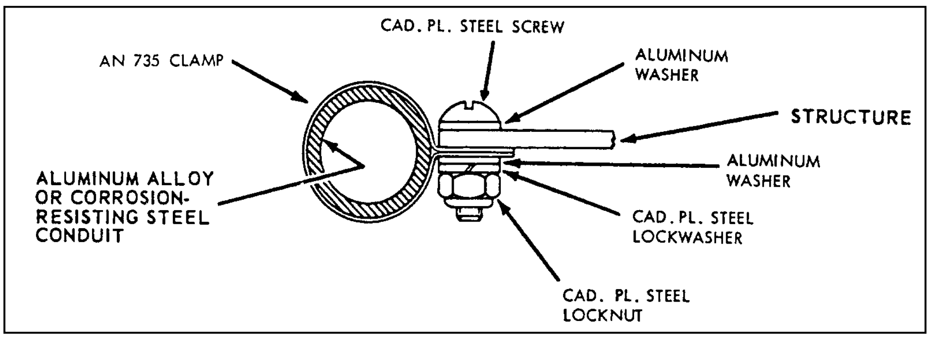


FIGURE 11-21. Bonding conduit to structure.

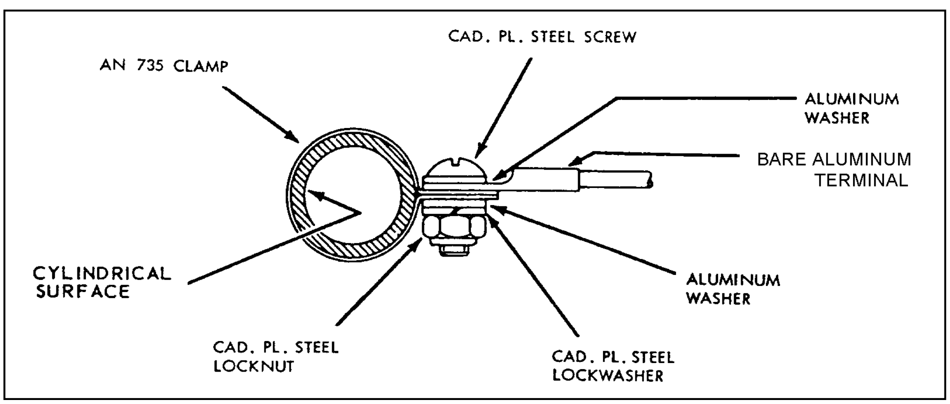


FIGURE 11-22. Aluminum jumper connection to tubular structure.

11-191. FUEL SYSTEMS. Small metallic objects within an aircraft fuel tank, that are not part of the tank structure, should be electrically bonded to the structure so as to dissipate static charges that may otherwise accumulate on these objects. A practical bonding design would use a flexible braided jumper wire or riveted bracket. In such situations, a DC resistance of 1 ohm or less should indicate an adequate connection. Care should be taken, in designing such connections, to avoid creating continuous current paths that could allow lightning or power fault currents to pass through connections not designed to tolerate these higher amplitude currents without arcing. Simulated static charge, lightning, or fault current tests may be necessary to establish or verify specific designs. All other fuel system components, such as fuel line (line to line) access doors, fuel line supports, structural parts, fuel outlets, or brackets should have an electromechanical (bonding strap) secure connector that ensures 1 ohm or less resistance to the structure. Advisory Circular 20-53A Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning, and associate manual DOT/FAA/ CT-83/3, provide detailed information on necessary precautions.

11-192. ELECTRIC SHOCK PREVENTION BONDING. Electric shock to personnel should be prevented by providing a low resistance path of 1/100 ohm or less between structure and metallic conduits or equipment. The allowable ground resistance should be such that the electric potential of the conduit or equipment housing does not reach a dangerous value under probable fault conditions. The current carrying capacity of all elements of the ground circuit should be such that, under the fault condition, no sparking, fusion, or dangerous heating will occur. Metallic supports usually provide adequate bonding if metal-to-metal contact is maintained.

11-193. LIGHTNING PROTECTION BONDING. Electrical bonding is frequently required for lightning protection of aircraft and systems, especially to facilitate safe conduction of lightning currents through the airframe. Most of this bonding is achieved through normal airframe riveted or bolted joints but some externally mounted parts, such as control surfaces, engine nacelles, and antennas, may require additional bonding provisions. Generally, the adequacy of lightning current bonds depends on materials, cross-sections, physical configurations, tightness, and surface finishes. Care should be taken to minimize structural resistance, so as to control structural voltage rises to levels compatible with system protection design. This may require that metal surfaces be added to composite structures, or that tinned copper overbraid, conduits, or cable trays be provided for interconnecting wire harnesses within composite airframes. Also care must be taken to prevent hazardous lightning currents from entering the airframe via flight control cables, push rods, or other conducting objects that extend to airframe extremities. This may require that these conductors be electrically bonded to the airframe, or that electrical insulators be used to interrupt lightning currents. For additional information on lightning protection measures, refer to DOT/FAA/CT-89-22. Report DOT/FAA/ CT 86/8, April 1987, Determination of Electrical Properties of Bonding and Fastening Techniques may provide additional information for composite materials.

a. Control Surface Lightning Protection Bonding. Control surface bonding is intended to prevent the burning of hinges on a surface that receives a lightning strike; thus causing possible loss of control. To accomplish this bonding, control surfaces and flaps should have at least one 6500 circular mil area copper (e.g. 7 by 37 AWG size 36 strands) jumper across each hinge. In any case, not less than two 6500 circular mil jumpers should be used on each control surface. The installation location of these jumpers should be carefully chosen to provide a low-impedance shunt for lightning current across the hinge to the structure. When jumpers may be subjected to arcing, substantially larger wire sizes of 40,000 circular mils or a larger cross section are required to provide protection against multiple strikes. Sharp bends and loops in such jumpers can create susceptibility to breakage when subjected to the inductive forces created by lightning current, and should be avoided.

b. Control Cable Lightning Protection Bonding. To prevent damage to the control system or injury to flight personnel due to lightning strike, cables and levers coming from each control surface should be protected by one or more bonding jumpers located as close to the control surface as possible. Metal pulleys are considered a satisfactory ground for control cables.

11-194. LIGHTNING PROTECTION FOR ANTENNAS AND AIR DATA PROBES. Antenna and air data probes that are mounted on exterior surfaces within lightning strike zones should be provided with a means to safely transfer lightning currents to the airframe, and to prevent hazardous surges from being conducted into the airframe via antenna cables or wire harnesses. Usually, the antenna mounting bolts provide adequate lightning current paths. Surge protectors built into antennas or installed in coaxial antenna cables or probe wire harnesses will fulfill these requirements. Candidate designs should be verified by simulated lightning tests in accordance with RTCA DO-160C, Section 23.

11-195. STATIC-DISCHARGE DEVICE. Means should be provided to bleed accumulated static charges from aircraft prior to ground personnel coming in contact with an aircraft after landing. Normally, there is adequate conductivity in the tires for this, but if not, a static ground should be applied before personnel come into contact with the aircraft. Fuel nozzle grounding receptacles should be installed in accordance with the manufacturer's specifications. Grounding receptacles should provide a means to eliminate the static-induced voltage that might otherwise cause a spark between a fuel nozzle and fuel tank access covers and inlets. In addition, static discharging wicks are installed on wings and tail surfaces to discharge static changes while in flight.

11-196. CLEANING. In order to ensure proper ground connection conductivity, all paint, primer, anodize coating, grease, and other foreign material must be carefully removed from areas that conduct electricity. On aluminum surfaces, apply chemical surface treatment to the cleaned bare metal surface in accordance with the manufacturer's instructions within 4-8 hours, depending on ambient moisture/contaminate content.

11-197. HARDWARE ASSEMBLY. Details of bonding connections must be described in maintenance manuals and adhered to carefully when connections are removed or replaced during maintenance operations. In order to avoid corrosion problems and ensure long-term integrity of the electrical connection, hardware used for this purpose must be as defined in these documents or at least be equivalent in material and surface. Installation of fasteners used in bonded or grounded connections should be made in accordance with SAE ARP-1870. Threaded fasteners must be torqued to the level required by SAE ARP-1928.

11-198.—11-204. [RESERVED.]