Designation: F2799 – 14

Standard Practice for Maintenance of Aircraft Electrical Wiring Systems[1]

This standard is issued under the fixed designation F2799; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Definition*—This practice defines acceptable practices and processes for the maintenance, preventative maintenance, and repair of electric systems in general aviation aircraft. This practice does not change or create any additional regulatory requirements nor does it authorize changes in or permit deviations from existing regulatory requirements.

1.2 *Applicability*—The guidance provided in this practice is directed to air carriers, air operators, maintenance providers, repair stations, and anyone performing maintenance or repairs.

1.3 *Protections and Warnings*—This practice provides guidance to minimize contamination and accidental damage to electrical wiring interconnection systems (EWIS) while working on aircraft.

1.4 *"Protect and Clean As You Go" Philosophy*—This philosophy is applied to aircraft wiring through inclusion in operators' maintenance and training programs. This philosophy stresses the importance of protective measures when working on or around wire bundles and connectors. It stresses how important it is to protect EWIS during structural repairs, (STC) installations, or other alterations by ensuring that metal shavings, debris, and contamination resulting from such work are removed.

1.5 *Units*—The values given in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

NOTE 1—When SI units are required, refer to Annex 5 of ICAO.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2490 Guide for Aircraft Electrical Load and Power Source Capacity Analysis

F2639 Practice for Design, Alteration, and Certification of Airplane Electrical Wiring Systems

2.2 *ICAO Standard:*

ICAO Annex 5 Units of Measurement to Be Used in Air and Ground Operations[3]

2.3 *JEDEC Standard:*

EIA 471 Symbol and Label for Electrostatic Sensitive Devices[4]

2.4 *NEMA Standard:*

WC 27500 Standards for Aerospace and Industrial Electric Cable[5]

2.5 *RTCA Standard:*

DO-160C Environmental Conditions and Test Procedures for Airborne Equipment[6]

2.6 *SAE Standards:*

AS 4372 Performance Requirements for Wire, Electric, Insulated Copper or Copper Alloy[7]

AS 4373 Test Methods for Insulated Electric Wire[7]

AS 21919 Clamp, Loop Type, Cushioned Support[7]

AS 50881 Wiring Aerospace Vehicle[7]

ARP 1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety[7]

ARP 1928 Torque Recommendations for Attaching Electrical Wiring Devices to Terminal Boards or Blocks, Studs, Posts, Etc.[7]

2.7 *Federal Standards:*

Advisory Circular 20-53A Protection of Aircraft Fuel Systems against Fuel Vapor Ignition due to Lightning

[1] This practice is under the jurisdiction of ASTM Committee F39 on Aircraft Systems and is the direct responsibility of Subcommittee F39.02 on Inspection, Maintenance, and Repair.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from ICAO, Customer Services Unit, 999 University St., Montreal, Quebec, H3C 5H7, Canada.

[4] Available from the JEDEC Solid State Technology Association, 3103 N. 10th St., Suite 240-S, Arlington, VA 22201.

[5] Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 1752, Rosslyn, VA 22209, http://www.nema.org.

[6] Available from RTCA, Inc., 1828 L St., NW, Suite 805, Washington, DC 20036.

[7] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

MIL-C-22520/2C Crimping Tools, Terminal, Hand, Wire Termination
MIL-S-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion
MIL-T-7928 Terminal, Lug Splices, Conductors, Crimp Style, Copper
MIL-T-43435 Tape, Lacing and Tying
MS17821 Specification for Cable and Marker Color Code Numbers
MS17822 Specification for Cable and Marker Color Code Numbers
NAVAIR 01-1A-505 Installation Practices—Aircraft Electric and Electronic Wiring

3. Terminology

3.1 *Definitions:*

3.1.1 *maintenance, n*—inspection, overhaul, repair, preservation, and the replacement of parts but excludes preventive maintenance.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *electrical wiring interconnection system (EWIS), n*—as used in this practice, any wire, wiring device, or combination of these, including termination devices, installed in any area of the aircraft for the purpose of transmitting electrical energy between two or more intended termination points.

3.3 *Acronyms:*

3.3.1 *AC*—alternating current

3.3.2 *CFC*—carbon fiber composite

3.3.3 *DC*—direct current

3.3.4 *EDS*—electronic data system

3.3.5 *EMI*—electromagnetic interference

3.3.6 *ESD*—electrostatic discharge

3.3.7 *EWIS*—electrical wiring interconnection system

3.3.8 *ICAO*—International Civil Aviation Organization

3.3.9 *NiCad*—nickel cadmium

3.3.10 *OEM*—original equipment manufacturer

3.3.11 *PC*—personal computer

3.3.12 *PTFE*—polytetrafluoroethylene

3.3.13 *RF*—radio frequency

3.3.14 *SOC*—state of charge

3.3.15 *STC*—supplemental-type certificate

3.3.16 *SWAMP*—severe wind and moisture problem

3.3.17 *UV*—ultraviolet

4. Significance and Use

4.1 This practice is intended to be used as a standard wiring practice for aircraft when not contrary to standards published by the aircraft original equipment manufacturer (OEM) or regulations. This practice is intended to be used for maintenance and preventive maintenance of electrical wiring interconnection systems (EWIS).

4.2 This practice is not intended to supersede or replace any government specification or specific manufacturer's instructions regarding EWIS maintenance or repair.

5. Maintenance

5.1 *Electrical Systems:*

5.1.1 *Maintenance:*

5.1.1.1 Scheduled and unscheduled maintenance activities, if done improperly, may contribute to long-term problems and degradation of wiring. Certain repairs may have limited durability and shall be evaluated to ascertain if rework is necessary. Repairs that conform to manufacturers' recommended maintenance practices are generally considered permanent and should not require rework. Care shall be taken to prevent undue collateral damage to EWIS while performing maintenance on other systems. Metal shavings and debris have been discovered on wire bundles after maintenance, repairs, or modifications have been performed. Care shall be taken to protect wire bundles and connectors during maintenance and repair. Work areas should be cleaned while the work progresses to ensure that all shavings and debris are removed. The work area should be thoroughly cleaned after work is complete, and the area shall be inspected after the final cleaning. Maintenance, repairs, and alterations should be performed using the most effective methods available to protect the surrounding EWIS. Since wire splices are more susceptible to degradation, arcing, and overheating, the recommended method of repairing a wire is with an environmentally sealed splice. (**Warning—**For personal safety and to avoid the possibility of fire, turn off all electrical power before starting an inspection of the aircraft electrical system or performing maintenance.)

5.1.1.2 Repair of any system component that fails an electrical measurement test shall conform to manufacturer's instructions and, in lieu of manufacturer's manuals, Practice F2639 or appropriate regulatory guidance materials.

5.1.1.3 Wire bundles should be routed in accessible areas that are protected from damage from personnel, cargo, and maintenance activity. They should not be routed in areas where they are likely to be used as handholds or as support for personal equipment or where they could become damaged during removal of aircraft equipment.

5.1.1.4 Replacement wires (see Tables 1 and 2) should be clamped so that contact with equipment and structure is avoided. Where this cannot be accomplished, extra protection in the form of grommets, chafe strips, and so forth, should be provided. Protective grommets shall be used wherever wires cannot be clamped in a way that ensures at least a ⅜-in. (9.5-mm) clearance from structure at penetrations.

5.1.1.5 Wire should not have a preload against the corners or edges of chafing strips or grommets. Wiring shall be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Protective flexible conduits should be made of a material and design that eliminates the potential of chafing between their internal wiring and the conduit internal walls.

5.1.1.6 Replacement wires that shall be routed across hinged panels should be routed and clamped so that the bundle will twist, rather than bend, when the panel is moved.

TABLE 1 Open Wiring

Document	Voltage Rating (Maximum)	Rated Wire Temperature, °C	Insulation Type	Conductor Type
MIL-W-22759/1[A]	600	200	Fluoropolymer-insulated TFE and TFE coated glass	Silver-coated copper
MIL-W-22759/2[A]	600	260	Fluoropolymer-insulated TFE and TFE coated glass	Nickel-coated copper
MIL-W-22759/3[A]	600	260	Fluoropolymer-insulated TFE-glass-TFE	Nickel-coated copper
MIL-W-22759/4[A]	600	200	Fluoropolymer-insulated TFE-glass-FEP	Silver-coated copper
MIL-W-22759/5[A]	600	200	Fluoropolymer-insulated extruded TFE	Silver-coated copper
MIL-W-22759/6[A]	600	260	Fluoropolymer-insulated extruded TFE	Nickel-coated copper
MIL-W-22759/7[A]	600	200	Fluoropolymer-insulated extruded TFE	Silver-coated copper
MIL-W-22759/8[A]	600	260	Fluoropolymer-insulated extruded TFE	Nickel-coated copper
MIL-W-22759/9[A]	1000	200	Fluoropolymer-insulated extruded TFE	Silver-coated copper
MIL-W-22759/10[A]	1000	260	Fluoropolymer-insulated	Nickel-coated copper
MIL-W-22759/13[A]	600	135	Fluoropolymer-insulated FEP PVF2	Tin-coated copper,
MIL-W-22759/16[A]	600	150	Fluoropolymer-insulated extruded ETFE	Tin-coated copper,
MIL-W-22759/17[A]	600	150	Fluoropolymer-insulated extruded ETFE	Silver-coated high-strength copper alloy
MIL-W-22759/20[A]	1000	200	Fluoropolymer-insulated extruded TFE	Silver-coated high-strength copper alloy
MIL-W-22759/21[A]	1000	260	Fluoropolymer-insulated extruded TFE	Nickel-coated high-strength copper alloy
MIL-W-22759/34[A]	600	150	Fluoropolymer-insulated cross-linked modified ETFE	Tin-coated copper
MIL-W-22759/35[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Silver-coated high-strength copper alloy
MIL-W-22759/41[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Nickel-coated copper
MIL-W-22759/42[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Nickel-coated high-strength copper alloy
MIL-W-22759/43[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Silver-coated copper
M1L-W-25038/3/2/	600	260	See specification sheet[B]	See specification sheet[B]
MIL-W-81044/6	600	150	Cross-linked polyalkene	Tin-coated copper
MIL-W-81044/7	600	150	Cross-linked polyalkene	Silver-coated high-strength copper alloy
MIL-W-81044/9	600	150	Cross-linked polyalkene	Tin-coated copper
MIL-W-81044/10	600	150	Cross-linked polyalkene	Silver-coated high-strength copper alloy
MIL-W-81044/12	600	150	Cross-linked polyalkene	Tin-coated copper

[A] MIL-W-22759 has been replaced by SAE AS 22759.
[B] Inorganic fibers—glass—TFE.

TABLE 2 Protected Wiring

Document	Voltage Rating (Maximum)	Rated Wire Temperature, °C	Insulation Type	Conductor Type
MIL-W-22759/11[A]	600	200	Fluoropolymer-insulated extruded TFE	Silver-coated copper
MIL-W-22759/12[A]	600	260	Fluoropolymer-insulated extruded TFE	Nickel-coated copper
MIL-W-22759/14[A]	600	135	Fluoropolymer-insulated FEP-PVF2	Tin-coated copper
MIL-W-22759/15[A]	600	135	Fluoropolymer-insulated FEP-PVF2	Silver-plated high-strength copper alloy
MIL-W-22759/18[A]	600	150	Fluoropolymer-insulated extruded ETFE	Tin-coated copper
MIL-W-22759/19[A]	600	150	Fluoropolymer-insulated extruded ETFE	Silver-coated high-strength copper alloy
MIL-W-22759/22[A]	600	200	Fluoropolymer-insulated extruded TFE	Silver-coated high-strength copper alloy
MIL-W-22759/23[A]	600	260	Fluoropolymer-insulated extruded TFE	Nickel-coated high-strength copper alloy
MIL-W-22759/32[A]	600	150	Fluoropolymer-insulated cross-linked modified ETFE	Tin-coated copper
MIL-W-22759/33[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Silver-coated high-strength copper alloy
MIL-W-22759/44[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Silver-coated copper
MIL-W-22759/45[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Nickel-coated copper
MIL-W-22759/46[A]	600	200	Fluoropolymer-insulated cross-linked modified ETFE	Nickel-coated high-strength copper alloy
MIL-W-81044/13	600	150	Cross-linked polyalkene – PVF2	Silver-coated high-strength copper alloy
MIL-W-81381/17	600	200	Fluorocarbon polyamide	Silver-coated copper
MIL-W-81381/18	600	200	Fluorocarbon polyamide	Nickel-coated copper
MIL-W-81381/19	600	200	Fluorocarbon polyamide	Silver-coated high-strength copper alloy
MIL-W-81381/20	600	200	Fluorocarbon polyamide	Nickel-coated high-strength copper alloy
MIL-W-81381/21	600	150	Fluorocarbon polyamide	Tin-coated copper

[A] MIL-W-22759 has been replaced by SAE AS 22759.

5.1.2 *General:*

5.1.2.1 The term "electrical wiring interconnection system (EWIS)" as used in this practice means any wire, wiring device, or combination of these, including termination devices, installed in any area of the aircraft for the purpose of transmitting electrical energy between two or more intended termination points.

5.1.2.2 The satisfactory performance of an aircraft is dependent upon the continued reliability of the electrical system. Damaged wiring or equipment in an aircraft, regardless of how minor it may appear to be, cannot be tolerated. Reliability of the system is proportional to the amount of maintenance received and the knowledge of those who perform such maintenance. It is, therefore, important that maintenance be accomplished using the best techniques and practices to minimize the possibility of failure.

5.1.3 *Cleaning and Preservation:*

5.1.3.1 Annual cleaning of electrical equipment to remove dust, dirt, and grime is recommended.

5.1.3.2 If terminals and mating surfaces are corroded or dirty, suitable solvents or fine abrasives that will not score the surface or remove the plating may be used to clean them. Only cleaning agents that do not leave any type of residue shall be used. Avoid using emery cloth to polish commutators or slip rings because particles may cause shorting and burning. Be sure that protective finishes are not scored or damaged when cleaning. Ensure that metal-to-metal electrically bonded surfaces are treated at the interface with a suitable anticorrosive conductive coating and that the joint is sealed around the edges by restoring the original primer and paint finish. Connections that shall withstand a highly corrosive environment may be encapsulated with an approved sealant to prevent corrosion. (**Warning—**Turn power off before cleaning.)

5.1.3.3 *"Protect and Clean As You Go" Philosophy*—It is imperative that the technician performing maintenance and repairs to the aircraft takes protective measures when working on or around wire bundles and connectors to protect the EWIS from damage. It is important to protect EWIS during airframe repairs, alterations, or other aircraft maintenance by ensuring that metal shavings, debris, and contamination resulting from such work are removed.

5.1.4 *Battery Electrolyte Corrosion*—Corrosion found on or near lead-acid batteries can be removed mechanically with a stiff bristle brush and then chemically neutralized. For lead-acid batteries, a 10 % sodium bicarbonate and water solution can be used to neutralize the electrolyte. For nickel cadmium (NiCad) batteries, a 3 % solution of acetic acid can be used to neutralize the electrolyte. After neutralizing, the battery should be washed with clean water and thoroughly dried.

5.1.5 *Adjustment and Repair:*

5.1.5.1 Accomplish adjustments to items of equipment such as regulators, alternators, generators, contactors, control devices, inverters, and relays at a location outside the aircraft and on a test stand or test bench where all necessary instruments and test equipment are at hand. Follow the adjustment and repair procedures outlined by the equipment or aircraft manufacturer. Replacement or repair shall be accomplished as a part of routine maintenance.

5.1.5.2 Adjustment of a replacement voltage regulator is likely since there will always be a difference in impedance between the manufacturer's test equipment and the aircraft's electrical system.

5.1.6 *Bus Bars*—Bus bars that exhibit corrosion, even in limited amounts, should be disassembled, cleaned, and reinstalled Grease, corrosion, or dirt on any electrical junction may cause the connections to overheat and eventually fail.

5.2 *Equipment Installation:*

5.2.1 *Alternator Diodes*—Alternators use diodes for the purpose of converting the alternating current (AC to direct current (DC)). These diodes are solid-state electronic devices and are easily damaged by rough handling, abuse, overheating, or reversing the battery connections. The battery shall never be connected with reversed polarity as this may subject the diodes to a forward bias condition allowing very high-current conduction that will generally destroy them instantly.

5.2.2 *Acceptable Means of Controlling or Monitoring the Electrical Load*—For detailed guidance for analyzing electrical loads, refer to Practice F2490.

5.3 *Circuit Protection Devices:*

5.3.1 *Circuit Breaker Maintenance:*

5.3.1.1 Resettable circuit breakers should be cycled with no load to enhance contact performance by cleaning contaminants from the contact surfaces. Unless specified in the aircraft or component maintenance instructions, it is recommended that each resettable circuit breaker be pulled and reset as part of the aircraft annual inspection.

5.3.1.2 Breakers with broken or missing parts shall be replaced.

5.3.1.3 Before considering replacement of circuit breakers that have a tendency to open circuits frequently, require resetting more than normal, or are subject to nuisance tripping, investigate and correct the reason.

5.3.2 *Relays*—A relay is an electrically controlled device that opens and closes electrical contacts to effect the operation of other devices in the same or in another electrical circuit. The relay converts electrical energy into mechanical energy through various means and, through mechanical linkages, actuates electrical conductors (contacts) that control electrical circuits. Solid- state relays may also be used in electrical switching applications.

5.3.2.1 *Relay Installation and Maintenance*—For installation and maintenance, care should be taken to ensure proper placement of hardware, especially at electrical connections. The use of properly calibrated torque wrenches and following the manufacturer's installation procedures is strongly recommended. This is especially important with hermetically sealed relays, since the glass-to-metal seal (used for insulation of the electrically "live" components) is especially vulnerable to catastrophic failure as a result of overtorquing.

(1) When replacing relays in AC applications, it is essential to maintain proper phase sequencing. For any application involving plug-in relays, proper engagement of their retaining mechanism is vital.

(2) The proximity of certain magnetically permanent, magnet-assisted, coil-operated relays may cause them to have an impact on each other. Any manufacturer's recommendations or precautions shall be followed.

5.3.2.2 *Switches*—When a switch is activated, it should have a noticeable detent feel when switched. If a switch does not have a detent feel when switching, it is suspect and further inspection shall be done before considering it airworthy. Any switch with a soft or spongy feel when switched shall be replaced.

6. Storage Batteries

6.1 *Battery Charging*—Charging of storage batteries beyond their charging voltage limits can result in excessive cell temperatures leading to electrolyte boiling, rapid deterioration of the cells, and battery failure. The relationship between maximum charging voltage and the number of cells in the battery is also significant. This will determine (for a given ambient temperature and state of charge) the rate at which energy is absorbed as heat within the battery. For lead-acid batteries, the voltage per cell shall not exceed 2.35 V. In the case of NiCad batteries, the charging voltage limit varies with design and construction. Values of 1.4 and 1.5 V per cell are generally used. In all cases, follow the recommendations of the battery manufacturer.

6.1.1 *Battery and Charger Characteristics*—The following information is provided to acquaint the user with characteristics of the more common aircraft battery and battery charger types. Products may vary from these descriptions because of different applications of available technology. Consult the manufacturer for specific performance data. (**Warning—**Under no circumstances connect a lead-acid battery to a charger unless the battery is properly serviced.)

6.1.1.1 Lead-acid vented batteries have a 2-V nominal cell voltage. Batteries are constructed so that individual cells cannot be removed. Occasional addition of water is required to replace water loss caused by overcharging in normal service. Batteries that become fully discharged may not accept recharge.

6.1.1.2 Lead-acid sealed batteries are similar in most respects to lead-acid vented batteries but do not require the addition of water.

6.1.1.3 The lead-acid battery is economical and has extensive application but is heavier than an equivalent performance battery of another type. The battery is capable of a high rate of discharge and low-temperature performance. However, maintaining a high rate of discharge for a period of time usually warps the cell plates, shorting out the battery. Its electrolyte has a moderate specific gravity, and state of charge can be checked with a hydrometer.

6.1.1.4 Do not use high-amperage automotive battery chargers to charge aircraft batteries.

6.1.1.5 NiCad vented batteries have a 1.2-V nominal cell voltage. Occasional addition of distilled water is required to replace water loss caused by overcharging in normal service. Cause of failure is usually shorting or weakening of a cell. After replacing the bad cell with a good cell, the battery's life can be extended for five or more years. Full discharge is not harmful to this type of battery.

6.1.1.6 NiCad sealed batteries are similar in most respects to NiCad vented batteries but do not normally require the addition of water. Fully discharging the battery (to 0 V) may cause irreversible damage to one or more cells leading to eventual battery failure as a result of low capacity.

6.1.1.7 The state of charge of a NiCad battery cannot be determined by measuring the specific gravity of the potassium hydroxide electrolyte. The electrolyte specific gravity does not change with the state of charge. The only accurate way to determine the state of charge of a NiCad battery is by a measured discharge with a NiCad battery charger and following the manufacturer's instructions. After the battery has been fully charged and allowed to stand for at least 2 h, the fluid level may be adjusted, if necessary, using distilled or demineralized water. Because the fluid level varies with the state of charge, water should never be added while the battery is installed in the aircraft. Overfilling the battery will result in electrolyte spewage during charging. This will cause corrosive effects on the cell links, self-discharge of the battery, dilution of the electrolyte density, possible blockage of the cell vents, and eventual cell rupture.

6.1.1.8 Lead-acid batteries are usually charged by regulated DC voltage sources. This allows maximum accumulation of charge in the early part of recharging.

6.1.1.9 Constant-current battery chargers are usually provided for NiCad batteries because the NiCad cell voltage has a negative temperature coefficient. With a constant-voltage charging source, a NiCad battery having a shorted cell might overheat because of excessive overcharge and undergo a thermal runaway, destroying the battery and creating a possible safety hazard to the aircraft.

(1) Definition—Thermal runaway can result in a chemical fire or explosion or both of the NiCad battery under recharge by a constant-voltage source and is due to cyclical, ever-increasing temperature and charging current. One or more shorted cells or an existing high temperature and low charge can produce the cyclical sequence of events:

(a) Excessive current,

(b) Increased temperature,

(c) Decreased cell(s) resistance,

(d) Further increased current, and

(e) Further increased temperature. This will not become a self-sustaining thermal-chemical action if the constant-voltage charging source is removed before the battery temperature is in excess of 160°F (71.1°C).

6.1.1.10 Pulsed-current battery chargers are sometimes provided for NiCad batteries. (**Warning—**It is important to use the proper charging procedures for batteries under test and maintenance. These charging regimes for reconditioning and charging cycles are defined by the aircraft manufacturer and should be closely followed.)

6.2 *Battery Freezing*—Discharged lead-acid batteries exposed to cold temperatures are subject to plate damage because of freezing of the electrolyte. To prevent freezing damage, maintain each cell's specific gravity at no less than 1.275 or, for sealed lead-acid batteries, check "open" circuit voltage (see Table 3). The NiCad battery electrolyte is not as susceptible to freezing because no appreciable chemical change takes place between the charged and discharged states. However, the electrolyte will freeze at approximately minus –75°F (59.4°C).

NOTE 2—Only a load check will determine overall battery condition.

6.3 *Temperature Correction*—U.S. manufactured lead-acid batteries are considered fully charged when the specific gravity reading is between 1.275 and 1.300. A ⅓ discharged battery reads about 1.240 and a ⅔ discharged battery will show a specific gravity reading of about 1.200 when tested by a hydrometer and the electrolyte temperature is 26.7°C (80°F). However, to determine precise specific gravity readings, a temperature correction (see Table 4) should be applied to the hydrometer indication. As an example, with a hydrometer

TABLE 3 Lead-Acid Battery Electrolyte Freezing Points

Specific Gravity	Freeze Point		State of Charge (SOC) for Sealed Lead-Acid Batteries at 21.1°C (70°F)		
	°C	°F	SOC	12 V	24 V
1.300	-70	-95	100%	12.9	25.8
1.275	-62	-80	75%	12.7	25.4
1.250	-52	-62	50%	12.4	24.8
1.225	-37	-35	25%	12.0	24.0
1.200	-26	-16			
1.175	-20	-4			
1.150	-15	+5			
1.125	-10	+13			
1.100	-8	+19			

TABLE 4 Sulfuric Acid Temperature Correction

Electrolyte Temperature		Points to be Subtracted or Added to Specific Gravity Readings
°C	°F	
60	140	+24
55	130	+20
49	120	+16
43	110	+12
38	100	+8
33	90	+4
27	80	0
23	70	-4
15	60	-8
10	50	-12
5	40	-16
-2	30	-20
-7	20	-24
-13	10	-28
-18	0	-32
-23	-10	-36
-28	-20	-40
-35	-30	-44

reading of 1.260 and the temperature of the electrolyte at 40°F (4.4°C), the corrected specific gravity reading of the electrolyte is 1.244.

6.4 *Battery Maintenance*—Battery inspection and maintenance procedures vary with the type of chemical technology and physical construction. Always follow the battery manufacturer's approved procedures.

NOTE 3—Careful examination of sealed batteries and proper reconditioning of vented batteries will ensure the longest possible service life.

6.4.1 Use a hydrometer to determine the specific gravity of the battery electrolyte, which is the weight of the electrolyte compared to the weight of pure water.

6.4.2 Take care to ensure the electrolyte is returned to the cell from which it was extracted. When a specific gravity difference of 0.050 or more exists between cells of a battery, the battery is approaching the end of its useful life and replacement should be considered. Electrolyte level may be adjusted by the addition of distilled water.

6.4.3 *Mechanical Integrity*—Proper mechanical integrity involves the absence of any physical damage as well as an assurance that the hardware is correctly installed and the battery is properly connected. A battery and battery compartment venting system prevent the buildup of explosive gases and should be checked periodically to ensure that they are securely connected and oriented in accordance with the maintenance manual's installation procedures. Always follow procedures approved for the specific aircraft and battery system to ensure that the battery system is capable of delivering specified performance.

6.5 *Noxious Fumes*—When charging rates are excessive, the electrolyte may boil to the extent that fumes containing droplets of the electrolyte are emitted through the cell vents. These fumes from lead-acid batteries may become noxious to the crew members and passengers; therefore, thoroughly check the venting system. NiCad batteries will emit gas near the end of the charging process and during overcharge. The battery vent system in the aircraft should have sufficient air flow to prevent this explosive mixture from accumulating. It is often advantageous to install a jar in the battery vent discharge system serviced with an agent to neutralize the corrosive effect of battery vapors.

6.6 *Installation Practices:*

6.6.1 *External Surface*—Clean the external surface of the battery before installation in the aircraft.

6.6.2 *Battery Venting*—Battery fumes and gases may cause an explosive mixture or contaminated compartments and should be dispersed by adequate ventilation. The technician should ensure that the battery venting system is reinstalled and verified following battery installation.

6.6.3 *Battery Sump Jars*—A battery sump jar installation may be incorporated in the venting system to dispose of battery electrolyte overflow. The technician should ensure that the battery sump jar is serviced following installation of a battery.

6.6.4 *Installing Batteries*—When installing batteries in an aircraft, exercise care to prevent inadvertent shorting of the battery terminals. Serious damage to the aircraft structure (frame, skin and other subsystems, avionics, wire, fuel, and so forth) can be sustained by the resultant high discharge of electrical energy. This condition may normally be avoided by insulating the terminal posts during the installation process. During battery removal, remove the grounding lead first, then the positive lead. For installation of a battery, connect the grounding lead of the battery last to minimize the risk of shorting the "hot terminal" of the battery.

6.6.5 *Battery Hold-Down Devices*—Ensure that the battery hold-down devices are secure but not so tight as to exert excessive pressure that may cause the battery to buckle resulting in internal shorting of the battery.

6.6.6 *Quick-Disconnect-Type Battery*—If a quick-disconnect-type of battery connector that prohibits crossing the battery lead is not used, ensure that the aircraft wiring is connected to the proper battery terminal. Reverse polarity in an electrical system can seriously damage a battery and other electrical components. Ensure that the battery cable connections are tight to prevent arcing or a high-resistance connection.

7. Aircraft Electrical Wire Selection

7.1 The following are considered principal causes of wiring degradation and should be used to help focus maintenance programs:

7.1.1 *Vibration*—High-vibration areas tend to accelerate degradation over time resulting in "chattering" contacts and intermittent symptoms. High vibration of tie-wraps or string ties can cause damage to insulation. In addition, high vibration will worsen any existing wire insulation cracking.

7.1.2 *Moisture*—High-moisture areas generally accelerate corrosion of terminals, pins, sockets, and conductors. Note that wiring installed in clean, dry areas with moderate temperatures appears to hold up well.

7.1.3 *Maintenance*—Scheduled and unscheduled maintenance activities, if done improperly, may contribute to long-term problems and degradation of wiring.

7.1.4 *Repairs*—Certain repairs may have limited durability and shall be evaluated to ascertain if rework is necessary.

Repairs that conform to manufacturers' recommended maintenance practices are generally considered permanent and should not require rework. Repairs should be performed using the most effective methods available. Since wire splices are more susceptible to degradation, arcing, and overheating, the recommended method of repairing a wire is with an environmentally sealed splice.

7.1.5 *Clean as You Go*—Care shall be taken to prevent undue collateral damage to EWIS while performing maintenance on other systems. Metal shavings and debris have been discovered on wire bundles after maintenance, repairs, or modifications have been performed. Care shall be taken to protect wire bundles and connectors during modification work. Work areas should be cleaned while the work progresses to ensure that all shavings and debris are removed. The work area should be thoroughly cleaned after work is complete, and the area shall be inspected after the final cleaning.

7.2 *Substitutions:*

7.2.1 In the repair and modification of existing aircraft, when a replacement wire is required, the maintenance manual for that aircraft shall first be reviewed to determine if the original aircraft manufacturer has approved any substitution.

7.2.2 If the original aircraft manufacturer has not approved a substitute wire, the technician should use standard wire as specified in Table 1, Table 2 and Table 5 (reference Practice F2639) or other applicable regulatory guidance.

7.2.3 Areas designated as severe wind and moisture problem (SWAMP) areas differ from aircraft to aircraft but generally are considered to be areas such as wheel wells, near wing flaps, wing folds, pylons, and other exterior areas that may have a harsh environment. Wires for these applications often have design features incorporated into their construction that may make the wire unique; therefore, an acceptable substitution may be difficult, if not impossible, to find. It is very important to use the wire type recommended in the aircraft manufacturer's maintenance handbook.

7.2.4 The use of current military specification, multiconductor cables in place of OEM-installed constructions may create problems such as color sequence. Some civilian aircraft are wired with the older color sequence using "red-blue-yellow" as the first three colors. Current military specification, multiconductor cables, in accordance with MIL-C-27500, use "white-blue-orange" for the initial three colors. During the repair of EWIS, the technicians should follow whichever color sequence that is currently used in the aircraft. Deviating from the existing color sequence is considered an alteration and Practice F2639 should be consulted.

8. Wiring Installation Requirements

8.1 *General*—Repairs to wires and cables should be installed with adequacy of support and protection. Accordingly, aircraft wiring shall be maintained to the following requirements:

8.1.1 Wires and cables should be supported by suitable clamps, grommets, or other devices at intervals of not more than 24 in. (61 cm), except when contained in troughs, ducts, or conduits. The supporting devices should be of a suitable size and type with the wires and cables held securely in place without damage to the insulation. "Fill" materials should not be used in lieu of a suitable sized clamp.

8.1.2 Standoffs should be used to maintain clearance between wires and structure. Using tape or tubing is not acceptable as an alternative to standoffs for maintaining clearance.

8.1.3 Phenolic blocks, plastic liners, or rubber grommets should be installed in holes, bulkheads, floors, or structural members where it is impossible to install off-angle clamps to maintain wiring separation. In such cases, additional protection in the form of plastic or insulating tape may be used.

8.1.4 Wires and cables in junction boxes, panels, and bundles should be properly supported and laced to provide proper grouping and routing.

8.1.5 Clamp-retaining screws should be properly secured so that the movement of wires and cables is restricted to the span between the points of support and not on soldered or mechanical connections at terminal posts or connectors.

8.1.6 Wire and cables should be properly supported and bound so that there is no interference with other wires, cables, and equipment.

8.1.7 Wires and cables should be adequately supported to prevent excessive movement in areas of high vibration.

8.1.8 Insulating tubing should be secured by tying, tie straps, or with clamps.

8.1.9 Continuous lacing (spaced 6 in. (15 cm) apart) should not be used except in panels and junction boxes.

8.1.10 Do not use tapes (such as friction or plastic tape) that will dry out in service, produce chemical reactions with wire or cable insulation, or absorb moisture.

8.1.11 Insulating tubing should be kept at a minimum and shall be used to protect wire and cable from abrasion, chafing, exposure to fluid, and other conditions that could affect the cable insulation. However, insulating tubing should not be used to support wires and cable in lieu of standoffs.

8.1.12 Do not tie or fasten wires and cables together in conduit or insulating tubing.

TABLE 5 Coaxial Cable Selection

Document	Part Number	Impedance (Ω)	Rated Cable Temperature (°C)	Outer Diameter, Nominal (in.)	Jacket Type/ Dielectric Type
MIL-C-17/060	M17/060-RG142	50	200	0.195	FEP/PTFE
MIL-C-17/93	M17/93-RG178	50	200	0.071	FEP/PTFE
MIL-C-17/94	M17/94-RG179	75	200	0.100	FEP/PTFE
MIL-C-17/113	M17/113-RG316	50	200	0.098	FEP/PTFE
MIL-C-17/127	M17/127-RG393	50	200	0.390	FEP/PTFE
MIL-C-17/128	M17/128-RG400	50	200	0.195	FEP/PTFE

8.1.13 Ensure cable supports do not restrict the wires or cables in such a manner as to interfere with operation of equipment shock mounts.

8.1.14 Do not use tape or cord for primary support.

8.1.14.1 Only aviation-grade tie straps should be used on aircraft and should only be used for their intended function.

8.1.15 Make sure that drain holes are present in drip loops or in the lowest portion of tubing placed over the wiring. See Fig. 1.

8.1.16 Ensure that wires and cables are routed in such a manner that chafing will not occur against the airframe or other components.

8.1.17 Ensure that replacement wires and cables in wheel wells and other areas where they may be exposed to damage from impact of rocks, ice, mud, and so forth are adequately protected.

8.1.17.1 Replacement wire closer than 2 in. (5 cm) from any flammable liquid, fuel, oxygen line, or fuel tank wall should be closely clamped and rigidly supported and tied at intervals such that contact between such lines, related equipment, fuel tank walls, or other wires will not occur, assuming a broken wire and a missing wire tie or clamp.

8.1.18 Ensure that a trap or drip loop is provided to prevent fluids or condensed moisture from running into wires and cables dressed downward to a connector, terminal block, panel, or junction box.

8.1.19 Route replacement wires and cables installed in bilges and other locations where fluids may be trapped as far as possible from the lowest point or otherwise provide with a moisture-proof covering.

8.1.20 Separate wires from high-temperature equipment such as resistors, exhaust stacks, heating ducts, and so forth to prevent insulation breakdown. Insulate wires that must run through hot areas with a high-temperature insulation material such as fiberglass or polytetrafluoroethylene (PTFE).

NOTE 4—The minimum radius of bends in wire groups or bundles shall not be less than ten times the outside diameter of the largest wire or cable, except that at the terminal strips where wires break out at terminations or reverse direction in a bundle. Where the wire is suitably supported, the radius may be three times the diameter of the wire or cable. Where it is not practical to install wiring or cables within the radius requirements, the bend should be enclosed in insulating tubing. The radius for thermocouple wire should be determined in accordance with the manufacturer's recommendation and shall be sufficient to avoid excess losses or damage to the cable. The bend radius of RF cables, for example, coaxial and triaxial, should be no less than six times the outside diameter of the cable.

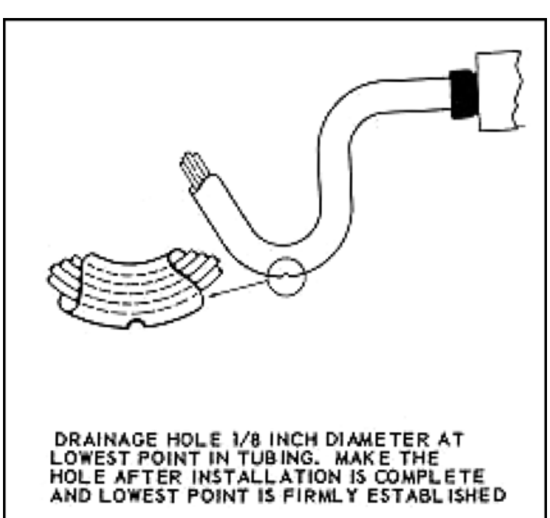


FIG. 1 Drainage Hole in Low Point of Tubing

8.1.21 Ensure that replacement wires and cables that are attached to assemblies where relative movement occurs (such as at hinges and rotating pieces, particularly doors, control sticks, control wheels, columns, and flight control surfaces) are installed or protected in such a manner as to prevent deterioration of the wires and cables caused by the relative movement of the assembled parts.

8.1.22 Ensure that replacement wires and electrical cables are separated from mechanical control cables. In no instance should wire be able to come closer than ½ in. (1.3 cm) to such controls when light hand pressure is applied to wires or controls. In cases in which clearance is less than this, adequate support shall be provided to prevent chafing.

8.1.23 Ensure that replacement wires and cables are provided with enough slack (see Fig. 2) to meet the following requirements:

8.1.23.1 Permit ease of maintenance;

8.1.23.2 Prevent mechanical strain on the wires, cables, junctions, and supports;

8.1.23.3 Permit free movement of shock and vibration mounted equipment; and

8.1.23.4 Allow shifting of equipment, as necessary, to perform alignment, servicing, tuning, removal of dust covers, and changing of internal components while installed in aircraft.

8.1.24 Ensure that unused wires are individually dead ended, tied into a bundle, and secured to a permanent structure. Each wire should have strands cut even with the insulation and a pre-insulated closed end connector or a 1-in. (2.5-cm) piece of insulating tubing placed over the wire with its end folded back and tied.

8.1.25 Ensure that all replacement wires and cables are identified properly (if the data are available in the aircraft maintenance manuals) at intervals of not more than 15 in. (38 cm). Coaxial cables are identified at both equipment ends.

8.1.25.1 Replace corroded connections and overheated connectors.

8.1.25.2 Wire bundles may consist of two or more groups of wires. Replacement wires should be placed within the wiring bundle or group to which the original wire was attached. Replacement wires shall not be attached to the outside of the tape, tie strap, or cord securing the wiring bundle.

8.1.25.3 Power feeder wires should be routed so that they can be easily inspected or replaced. They shall be given special protection to prevent potential chafing against other wiring, aircraft structure, or components. Special consideration should be given to ensure that a power feeder wire cannot chafe and short to a low-voltage wire. A short to low-voltage wires could cause failure of avionics and electronics systems as well as introduce an ignition source into the fuel system.

8.2 *Radio Frequency (RF) Cable*—All wiring needs to be protected from damage. However, coaxial and triaxial cables

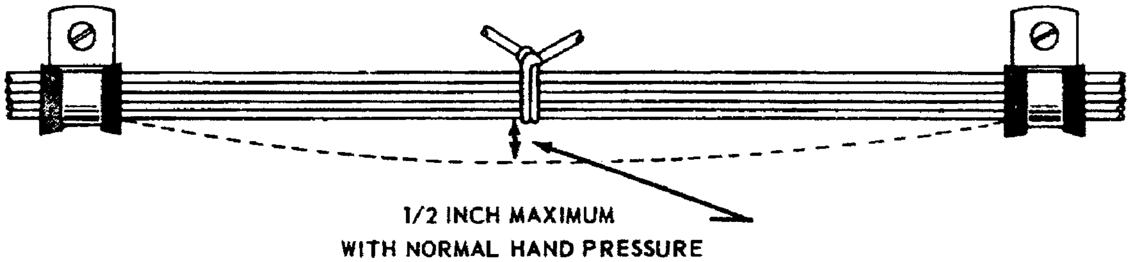


FIG. 2 Slack between Supports

are particularly vulnerable to certain types of damage. Personnel should exercise care while handling or working around RF cables. RF cable damage can occur when clamped too tightly or when they are bent sharply (normally, at or near connectors). Damage can also be incurred during unrelated maintenance actions around the coaxial cable. Coaxial can be severely damaged on the inside without any evidence of damage on the outside. Coaxial cables with solid center conductors should not be used (see Table 5). Stranded center coaxial cables can be used as a direct replacement for solid center coaxial.

8.3 *Precautions:*

8.3.1 Never kink coaxial cable.

8.3.2 Never drop anything on coaxial cable.

8.3.3 Never step on coaxial cable.

8.3.4 Never bend coaxial cable sharply.

8.3.5 Never loop coaxial cable tighter than the allowable bend radius.

8.3.6 Never pull on coaxial cable except in a straight line.

8.3.7 Never use coaxial cable for a handle, lean on it, or hang things on it (or any other wire).

9. Service Loop Harnesses (Plastic Tie Strips)

9.1 *General:*

9.1.1 The primary function of a service loop harness is to provide ease of maintenance. The components mounted in the instrument panel and on the lower console and other equipment that shall be moved to access electrical connectors are connected to aircraft wiring through service loops. Replacing wires in a service loop should maintain the design, spacing, and support of the service loop.

9.1.2 Chafing in service loop harnesses is controlled using the following techniques:

9.1.2.1 Only string ties or plastic cable straps in accordance with 11.4 should be used on service loop harnesses. A 90° or "Y"-type spot tie should be installed at the harness breakout point on the harness bundle. Ties should be installed on service loop harnesses at 4- to 6-in. (10- to 15-cm) intervals.

9.1.2.2 When service loops are likely to be in contact with each other, expandable sleeving or equivalent chafe protection jacket material shall be installed over service loop harnesses to prevent harness-to-harness chafing. The sleeve should be held in place with string ties at 6- to 8-in. (15- to 20-cm) intervals. Harness identification labels should be installed, with string tie, within 3 in. (7.6 cm) of the service loop harness installation.

9.1.2.3 The strain relief components may be installed to control routing where close clearance exists between termination and other components or bulkheads. Strain relief components provide support of the service loop harness at the termination point. Connector strain relief adapters, a heat-shrinkable boot, or a length of heat-shrinkable tubing should be installed. The heat-shrinkable boots will provide preselected angles of wire harness termination when heat is applied. Heat-shrinkable tubing should be held at the desired angle until cool.

9.2 *Service Loop*—Primary support for service loop harness(es) should be a cushion clamp and a connector at the harness termination. Service loop harnesses should be inspected for the following:

9.2.1 *Adequate Length*—Components should extend out from their mounting position at a distance that permits rotating and unlocking (or locking) the electrical connector. Usually, a distance of 3 to 6 in. (7.6 to 15 cm), with all other components installed, should be sufficient.

9.2.2 *Bundle Breakout Point:*

9.2.2.1 Bundle breakout point should be adequately supported with string tie.

9.2.2.2 Service loop shall maintain a minimum bend radius of three times the harness diameter.

9.2.2.3 The breakout point should be located directly behind, beside, below, or above the component so that the service loop harness does not bind other components.

9.2.2.4 Plastic ties should not be used between the service loop breakout and the electrical connector when they are likely to chafe against adjacent wire.

9.2.3 *Service Loop Routing*—The service loop harness should be routed directly from the breakout point to the component. The harness should not contact moving mechanical components or linkage and should not be wrapped or tangled with other service loop harnesses.

9.2.4 *Service Loop Harness Termination*—Strain relief should be provided at the service loop harness termination and is normally provided by the connector manufacturer's backshell, heat-shrinkable boot, or tubing.

10. Clamping

10.1 *General*—Wires and wire bundles shall be supported by using clamps meeting Specification AS21919 or plastic cable straps in accessible areas if correctly applied within the restrictions of 11.4. Clamps and other primary support devices shall be constructed of materials that are compatible with their installation and environment in terms of temperature, fluid resistance, exposure to ultraviolet (UV) light, and wire bundle mechanical loads. They should be spaced at intervals not exceeding 24 in. (61 cm). Clamps on wire bundles should be selected so that they have a snug fit without pinching wires as shown in Figs. 3-5. (**Warning—**The use of metal clamps on coaxial RF cables may cause problems if the clamp fit is such that the RF cable's original cross section is distorted.)

10.1.1 Clamps on wire bundles should not allow the bundle to move through the clamp when a slight axial pull is applied. Clamps on RF cables shall fit without crushing and shall be snug enough to prevent the cable from moving freely through the clamp but may allow the cable to slide through the clamp when a light axial pull is applied. The cable or wire bundle may be wrapped with one or more turns of electrical tape when required to achieve this fit. Plastic clamps or cable ties shall not be used when their failure could result in interference with movable controls, wire bundle contact with movable equipment, or chafing damage to essential or unprotected wiring. They shall not be used on vertical runs where inadvertent slack migration could result in chafing or other damage. Clamps shall be installed with their attachment hardware positioned above them, wherever practicable, so that they are unlikely to rotate as the result of wire bundle weight or wire bundle chafing (see Fig. 3).

10.1.2 Clamps lined with nonmetallic material should be used to support the wire bundle along the run. Tying may be used between clamps, but it should not be considered as a substitute for adequate clamping. Adhesive tapes are subject to age deterioration and, therefore, are not acceptable as a clamping means.

10.1.3 The back of the clamp, whenever practical, should be rested against a structural member. Standoffs should be used to maintain clearance between the wires and the structure. Clamps shall be installed in such a manner that the electrical wires do not come in contact with other parts of the aircraft when subjected to vibration. Sufficient slack should be left between the last clamp and the electrical equipment to prevent strain at the terminal and minimize adverse effects on shock-mounted equipment. Where wires or wire bundles pass through bulkheads or other structural members, a grommet or suitable clamp should be provided to prevent abrasion.

10.1.4 When wire bundle is clamped into position, if there is less than ⅜-in. (9.5-mm) clearance between the bulkhead cutout and the wire bundle, a suitable grommet should be installed as indicated in Fig. 6. The grommet may be cut at a 45° angle to facilitate installation provided it is cemented in place and the slot is located at the top of the cutout.

11. Wire Insulation and Lacing String Tie

11.1 Insulation of wires should be appropriately chosen in accordance with the environmental characteristics of wire-routing areas. Routing of wires with dissimilar insulation, within the same bundle, is not recommended, particularly when relative motion and abrasion between wires having dissimilar insulation can occur. Soft insulating tubing (spaghetti) cannot be considered as mechanical protection against external abrasion of wire since, at best, it provides only a delaying action. Conduit or ducting should be used when mechanical protection is needed.

11.2 *Insulation Materials*—Insulating materials should be selected for the best combination of characteristics in the following categories:

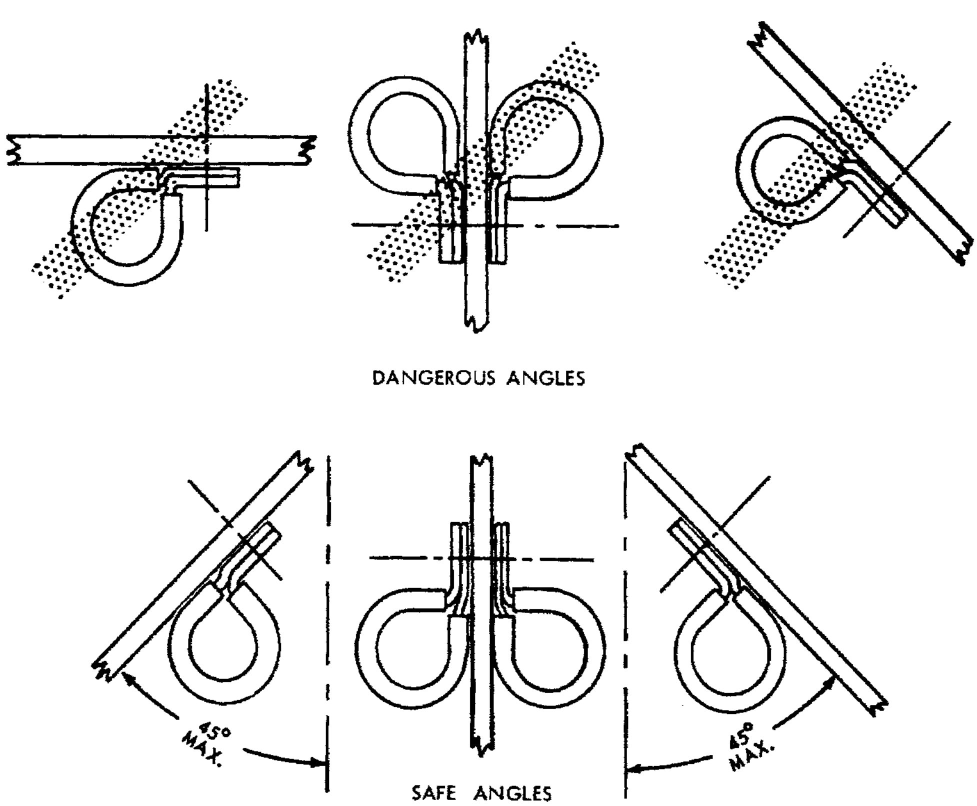


FIG. 3 Safe Angle for Cable Clamps

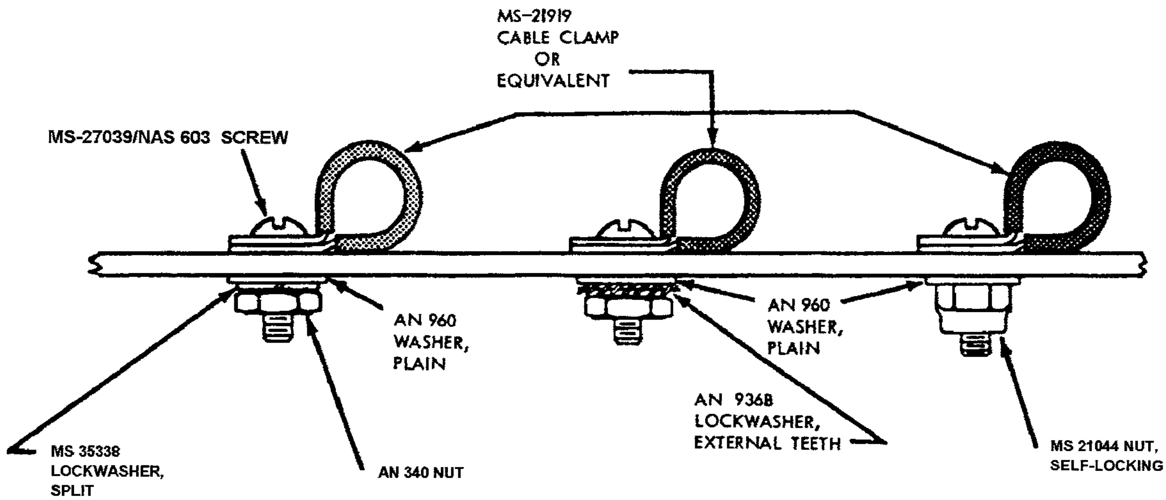


FIG. 4 Typical Mounting Hardware for MS-21919 Cable Clamps

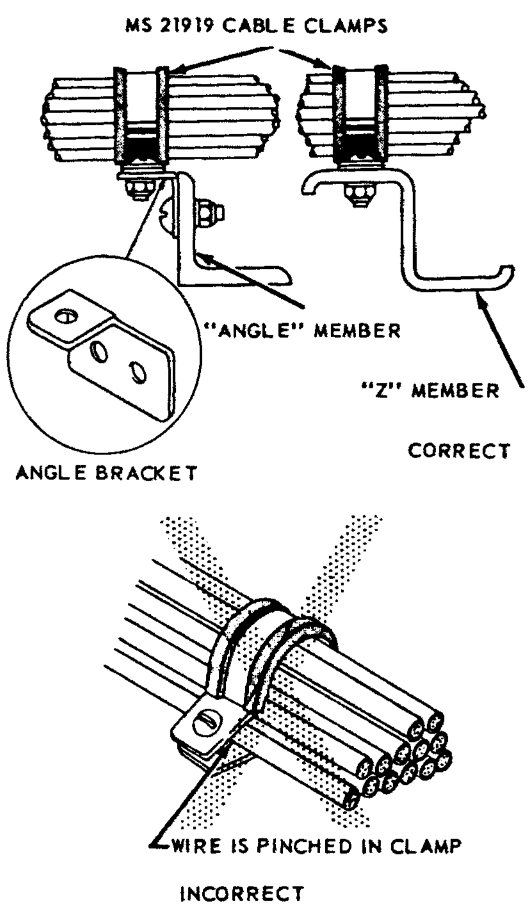


FIG. 5 Installing Cable Clamp to Structure

11.2.1 Abrasion resistance,
11.2.2 Arc resistance (noncarbon tracking),
11.2.3 Corrosion resistance,
11.2.4 Cut-through strength,
11.2.5 Dielectric strength,
11.2.6 Flame resistance,
11.2.7 Heat distortion temperature,
11.2.8 Impact strength,
11.2.9 Mechanical strength,
11.2.10 Resistance to fluids,
11.2.11 Resistance to notch propagation,
11.2.12 Smoke emission, and
11.2.13 Special properties unique to the aircraft.
11.2.14 For a more complete selection of insulated wires, refer to SAE AS 4372 and SAE AS 4373.

11.3 *Stripping Insulation*—Attachment of wire, to connectors or terminals, requires the removal of insulation to expose the conductors. This practice is commonly known as stripping. Stripping may be accomplished in many ways; however, the following basic principles should be practiced:

11.3.1 Make sure all cutting tools used for stripping are sharp;

11.3.2 When using special wire-stripping tools, adjust the tool to avoid nicking, cutting, or otherwise damaging the strands;

11.3.3 Damage to wires should not exceed the limits specified in Table 6; and

11.3.4 When performing the stripping operation, remove no more insulation than is necessary.

11.4 *Lacing and Ties:*

11.4.1 Ties, lacing, and straps are used to secure wire groups or bundles to provide ease of maintenance, inspection, and installation. Braided lacing tape per MIL-T-43435 is suitable for lacing and tying wires. In lieu of applying ties, straps meeting Specifications MS17821 or MS17822 may be used in areas in which the temperature does not exceed 248°F (120°C). Straps may not be used in areas of SWAMP such as wheel wells, near wing flaps, or wing folds. They may not be used in high-vibration areas where failure of the strap would permit wiring to move against parts that could damage the insulation and foul mechanical linkages or other moving mechanical parts. They also may not be used where they could be exposed to UV light unless the straps are resistant to such exposure.

11.4.2 *Lacing*—Lace wire groups or bundles inside junction boxes or other enclosures. The single-cord lacing method, shown in Fig. 7, and tying tape, meeting specification MIL-T-43435, may be used for wire groups of bundles 1 in. (2.5 cm)

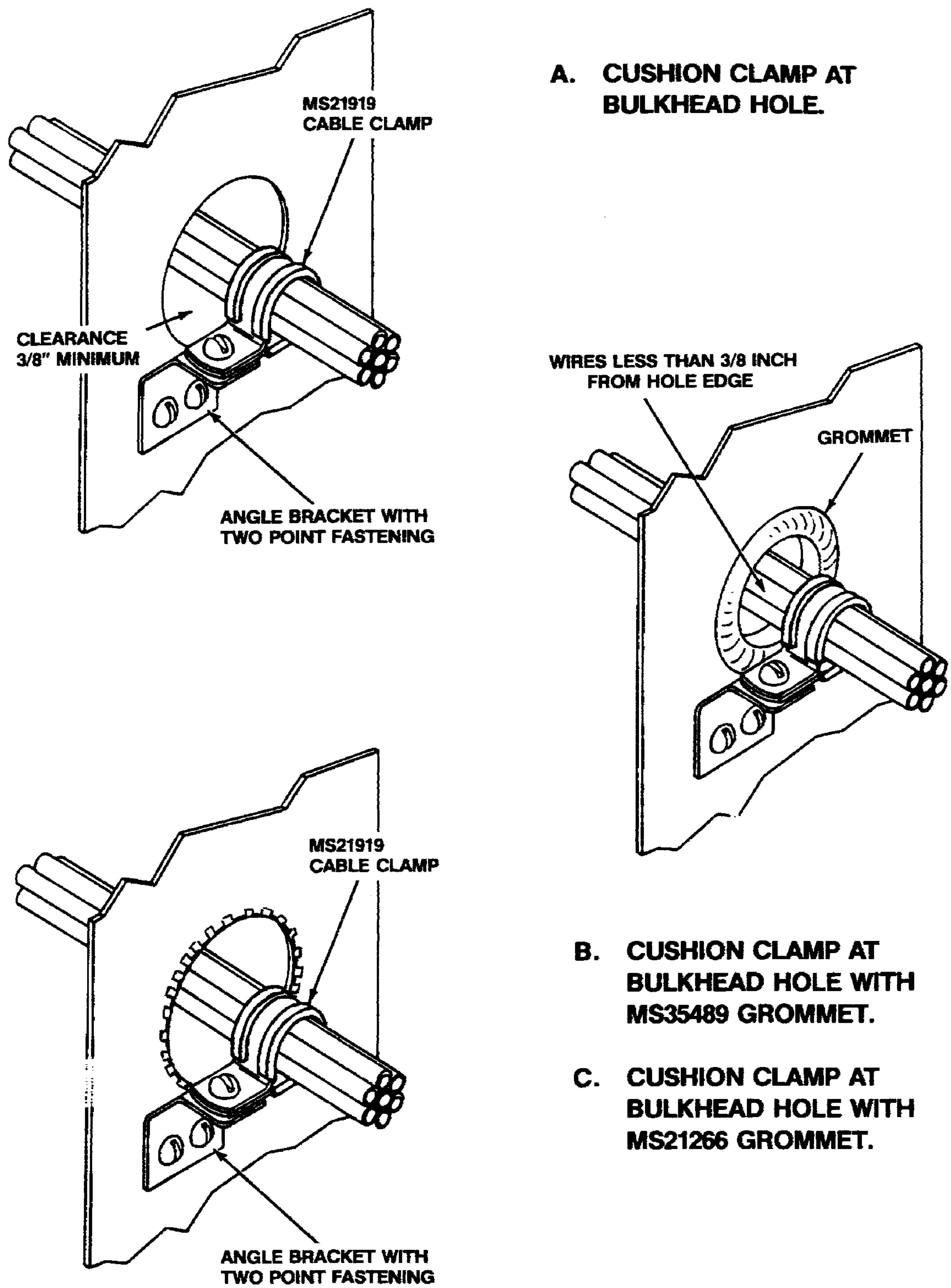


FIG. 6 Clamping at a Bulkhead Hole

in diameter or less. The recommended knot for starting the single-cord lacing method is a clove hitch secured by a double-looped overhand knot as shown in Fig. 7, Step a. Use the double-cord lacing method on wire bundles 1 in. (2.5 cm) in diameter or larger as shown in Fig. 8. When using the double-cord lacing method, use a bowline on a bight as the starting knot.

TABLE 6 Allowable Nicked or Broken Strands

Maximum Allowable Nickel and Broken Strands			
Wire Size	Conductor Material	Number of Strands per Conductor	Total Allowable Nickel and Broken Strands
24-14		19	2 nickel, none broken
12-10		37	4 nickel, none broken
8-4	Copper	133	6 nickel, 6 broken
2-1	or	665-817	6 nickel, 6 broken
0-00	Copper Alloy	1045-1330	6 nickel, 6 broken
000		1665	6 nickel, 6 broken
0000		2109	6 nickel, 6 broken
8-000	Aluminum	All numbers of strands	None, none

11.4.3 *Tying*—Use wire group or bundle ties where the supports for the wire are more than 12 in. (30.5 cm) apart. A tie consists of a clove hitch around the wire group or bundle secured by a square knot as shown in Fig. 9.

11.4.4 *Plastic Ties*—Refer to Table 7.

11.5 *Insulation Tape*—Insulation tape should be of a type suitable for the application or as specified for that particular use. Insulation tape should be used primarily as filler under clamps and as secondary support. Nonadhesive tape may be used to wrap around wiring for additional protection such as in wheel wells. All tape should have the ends tied or otherwise suitably secured to prevent unwinding. Tape used for protection should be applied so that overlapping layers shed liquids. Drainage holes should be provided at all trap points and at each low point between clamps. Plastic tapes that absorb moisture or have volatile plasticizers that produce chemical reactions with other wiring should not be used (reference AS 50881A).

12. Splicing

12.1 *General*—Splicing is permitted on wiring as long as it does not affect the reliability and the electromechanical characteristics of the wiring. Splicing of wires larger than 12 gauge, RF cables, and multiplex bus wire shall have engineering approved data.

12.1.1 Splicing of electrical wire should be kept to a minimum and avoided entirely in locations subject to extreme vibrations.

12.1.1.1 Any splicing of critical safety-of-flight systems shall have engineering approval.

12.1.1.2 All splice(s) should be located to allow periodic inspection.

12.1.2 Many types of aircraft splice connectors are available for use when splicing individual wires. Use of a self-insulated splice connector is preferred; however, a noninsulated splice connector may be used provided the splice is covered with plastic sleeving that is secured at both ends. Environmentally sealed splices that conform to MIL-T-7928 provide a reliable means of splicing in SWAMP areas. However, a noninsulated splice connector may be used, provided the splice is covered with dual wall shrink sleeving of a suitable material.

12.1.3 There should not be more than one splice in any one wire segment between any two connectors or other disconnect points except when: attaching to the spare pigtail lead of a potted connector, splicing multiple wires to a single wire, adjusting wire size to fit connector contact crimp barrel size, and making an approved repair (reference AS 50881A).

12.1.4 Splices in bundles shall be staggered so as to minimize any increase in the size of the bundle, prevent the bundle from fitting into its designated space, or cause congestion that will adversely affect maintenance (see Fig. 10). Splicing of individual wires in a group or bundle should be positioned so that no two splices are located within 2 in. (5 cm) of each other.

12.1.5 Splices should not be used within 12 in. (30.5 cm) of a termination device except for 12.1.6.

12.1.6 Splices may be used within 12 in. (30.5 cm) of a termination device when attaching to the pigtail spare lead of a potted termination device, splicing multiple wires to a single wire, or adjusting the wire sizes so that they are compatible with the contact crimp barrel sizes.

12.1.7 For the selection of a proper crimping tool, refer to 13.5.

12.1.7.1 Each person performing maintenance, alteration, or preventive maintenance on an aircraft, engine, propeller, or appliance shall use the tools, equipment, and test apparatus necessary to assure completion of the work in accordance with accepted industry practices.

12.1.7.2 For performing electrical work on aviation articles, the individual will need a full range of wire cutters, strippers, and crimpers.

12.1.7.3 Crimpers come in a variety of sizes, shapes, and functions, but all need to be calibrated regularly. For most general use crimpers, an annual calibration should be adequate with a go-no-go gauge designed for and provided by the equipment manufacturer.

13. Terminal Repairs

13.1 *General*—Terminals are attached to the ends of electrical wires to facilitate connection of the wires to terminal strips or items of equipment. The tensile strength of the wire-to-terminal joint should be equivalent to the tensile strength of the wire itself, and its resistance negligible relative to the normal resistance of the wire.

13.1.1 *Terminations*—Terminations shall be made using terminals of the proper size and the appropriate terminal crimping tools.

13.1.1.1 *Selection of Wire Terminals*—The following should be considered in the selection of wire terminals:

(1) Current rating;
(2) Wire size (gauge) and insulation diameter;
(3) Conductor material compatibility;
(4) Stud size;
(5) Insulation material compatibility;
(6) Application environment;
(7) Solder/solderless; and
(8) Preinsulated crimp-type ring-tongue terminals are preferred. The strength, size, and supporting means of studs and binding posts, as well as the wire size, should be considered when determining the number of terminals to be attached to any one post. In high-temperature applications, the terminal temperature rating shall be greater than the ambient temperature plus current related temperature rise. Use of nickel-plated

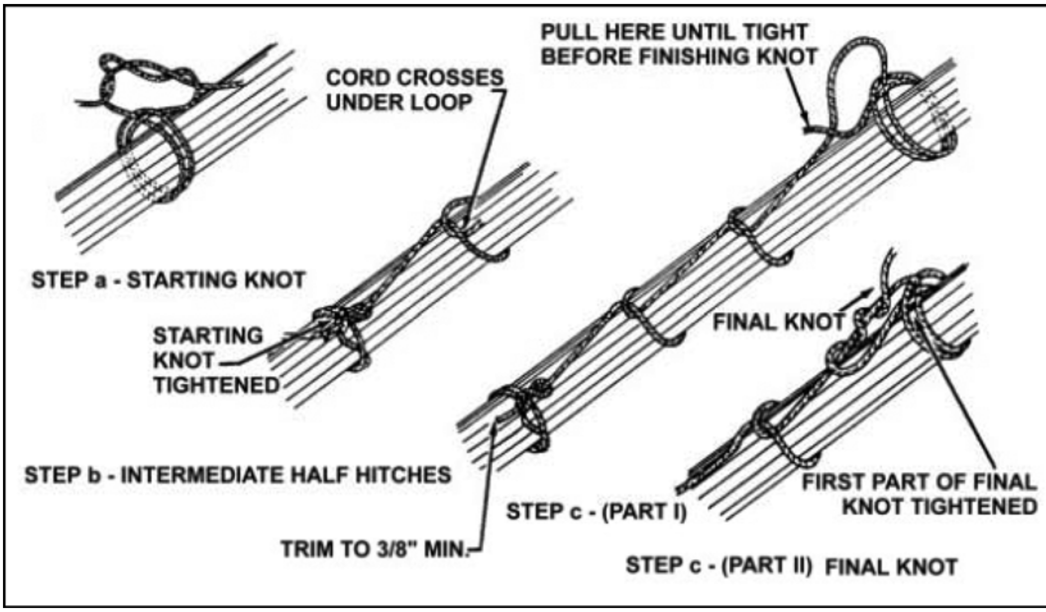


FIG. 7 Single Cord Lacing

terminals and uninsulated terminals with high-temperature insulating sleeves should be considered. Terminal blocks should be provided with adequate electrical clearance or insulation strips between mounting hardware and conductive parts.

13.1.1.2 *Terminal Strips*—Wires are usually joined at terminal strips. A terminal strip fitted with barriers should be used to prevent the terminals on adjacent studs from contacting each other. Studs should be anchored against rotation.

(1) When more than four terminals are to be connected together, a small metal bus should be mounted across two or more adjacent studs. In all cases, the current should be carried by the terminal contact surfaces and not by the stud itself.

(2) Defective studs should be replaced with studs of the same size and material since terminal strip studs of the smaller sizes may shear as a result of overtightening the nut. The replacement stud should be securely mounted in the terminal strip and the terminal securing nut should be tight. Terminal strips should be mounted in such a manner that loose metallic objects cannot fall across the terminals or studs. It is good practice to provide at least one spare stud for future circuit expansion or in case a stud is broken.

(3) Terminal strips that provide connection of radio and electronic systems to the aircraft electrical system should be inspected for loose connections, metallic objects that may have fallen across the terminal strip, dirt and grease accumulation, and so forth. These type conditions can cause arcing, which may result in a fire or system failures.

13.1.1.3 *Terminal Lugs*—Wire terminal lugs should be used to connect wiring to terminal block studs or equipment terminal studs.

(1) No more than four terminal lugs or three terminal lugs and a bus bar should be connected to any one stud. Total number of terminal lugs per stud includes a common bus bar joining adjacent studs. Four terminal lugs plus a common bus bar thus are not permitted on one stud.

(2) Terminal lugs should be selected with a stud hole diameter that matches the diameter of the stud. However, when the terminal lugs attached to a stud vary in diameter, the greatest diameter should be placed on the bottom and the smallest diameter on top.

(3) Tightening terminal connections should not deform the terminal lugs or the studs. Terminal lugs should be so positioned that bending of the terminal lug is not required to remove the fastening screw or nut and movement of the terminal lugs will tend to tighten the connection.

(4) Spacers or washers should not be used between the tongues of terminal lugs.

13.1.1.4 *Copper Terminal Lugs*—Solderless crimp style, copper wire, terminal lugs should be used and conform to MIL-T-7928.

NOTE 5—Use appropriate washers when bonding aluminum or copper to dissimilar metallic structures so that any corrosion that may occur will be on the washer.

13.1.1.5 *Aluminum Terminal Lugs*—The aluminum terminal lugs conforming to MIL-T-7099 (MS-25435, MS-25436, MS-25437, and MS-25438) should be crimped to aluminum wire only.

(1) The tongue of the aluminum terminal lugs or the total number of tongues of aluminum terminal lugs when stacked should be sandwiched between two MS-25440 flat washers when terminated on terminal studs.

(2) Special attention should be given to aluminum wire and cable installations to guard against conditions that would result in excessive voltage drop and high resistance at junctions that may ultimately lead to failure of the junction. Examples of such conditions are improper installation of terminals and washers, improper torsion ("torquing" of nuts), and inadequate terminal contact areas.

13.1.1.6 *Class 2 Terminal Lugs*—The Class 2 terminal lugs conforming to MIL-T-7928 may be used for installation

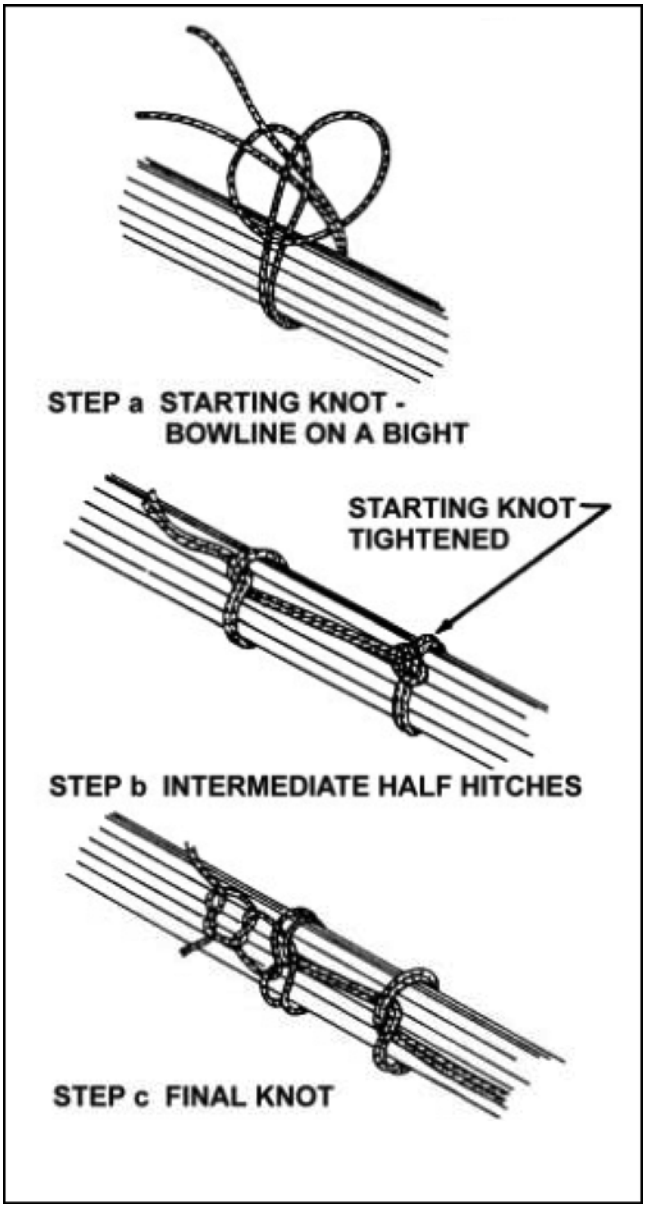


FIG. 8 Double Cord Lacing

provided that, in such installations, Class 1 terminal lugs are adequate for replacement without rework of installation or terminal lugs. Class 2 terminal lugs should be the insulated type, unless the conductor temperature exceeds 221°F (105°C). In that case, uninsulated terminal lugs should be used. Parts lists should indicate the appropriate Class 1 terminal lugs to be used for service replacement of any Class 2 terminal lugs installed.

13.1.1.7 *Termination of Shielded Wire*—For termination of shielded wire, refer to NEMA WC 27500.

13.2 *Attachment of Terminals to Studs:*

13.2.1 Connectors and terminals in aircraft require special attention to ensure a safe and satisfactory installation. Every possibility of short circuits as a result of misinstallation, poor maintenance, and service life should be addressed in the design.

13.2.2 Electrical equipment malfunction has frequently been traced to poor terminal connections at terminal boards. (**Warning—**Loose, dirty, or corroded contact surfaces can produce localized heating that may ignite nearby combustible materials or overheat adjacent wire insulation (see 13.5)).

13.3 *Studs and Insulators*—The following recommendations concerning studs also apply to other feed-through conductors.

13.3.1 *Current-Carrying Stud Resistance*—Because of heat loss arising from wire-to-lug and lug-to-stud voltage drop, the resistance per unit length of a current-carrying stud should not be greater than that of the wire.

13.3.2 *Size of Studs*—In designing the stud for a feed-through connection, attention should be given to the higher resistance of brass as compared to copper. A suggested method of determining the size is to use a current density in the stud equivalent to that of the wire compensating for the difference of resistance of the metals. Consideration should also be given to mechanical strength.

13.3.3 *Support for Studs*—The main stud support in the feed-through insulation should be independent of the attachment of the lugs to the stud. Therefore, loosening of the insulation support of the stud will not affect the electric contact efficiency. In other words, the contact pressure on the wire lugs should not in any way be affected by the loosening of the stud in the insulator.

13.3.4 *Support of Wire at Studs*—Unless some other positive locking action is provided, the lug or wire should be supported next to the stud to prevent loosening the connection with a side pull on the wire. Torque recommendations for attaching electrical wiring devices to terminal boards or blocks, studs, posts, and so forth are normally found in the manufacturer's maintenance instruction manual.

13.3.5 *Feed-Through Insulator and Stud Design*—Feed-through insulator design should be such as to prevent a loose insulator from failing to provide circuit isolation. It should not be able to move from between the stud and the structure, thus allowing the two to come into contact. The assembly should be so designed that it is impossible to misassemble the parts inadvertently so that faults will result. Also, it is desirable to provide means to prevent the feed-through stud from turning while tightening the connection.

13.4 *Wire Terminals and Binding Posts:*

13.4.1 All wire terminals in or on electrical equipment, except case ground, shall be firmly held together with two nuts or suitable locking provisions or should be secured in a positive manner to equipment in such a way that no insulation material is involved in maintaining physical pressure between the various current-carrying members of an electrical connection.

13.4.2 Terminal studs or binding posts should be of a size that is entirely adequate for the current requirements of the equipment and have sufficient mechanical strength to withstand the torque required to attach the cable to the equipment. All terminals on equipment that have barriers and covers provided by equipment manufacturers should have the barriers and covers installed.

13.5 *Crimp on Terminal Lugs and Splices (Pre-Insulated Crimp Type)*—The crimp on terminal lugs and splices shall be

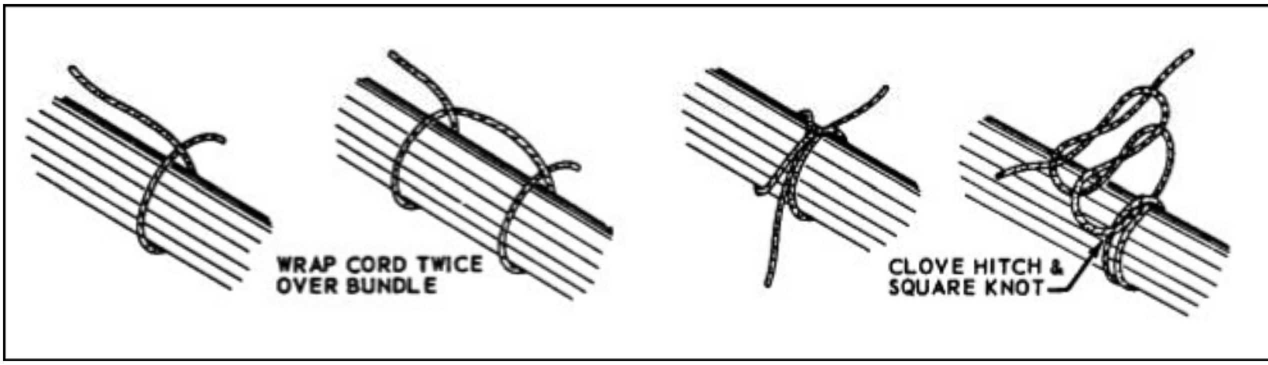


FIG. 9 Making Ties

TABLE 7 Plastic Tie-Down Straps (MS3367, Type I, Class 1)

NOTE 1—See 11.4.1 for strap selection and installation.

Cable Diameter (in.)^A		Tie-down Strap MS3367-	Strap Identification	Length (in.)	Installation Tool MS90387-	Tension Setting
Min	Max					
1⁄16	1¾	-1-0	Standard (STD), Black, UV Resistant	6.30	-1	6 to 8
1⁄16	1¾	-1-9	Standard (STD), Natural	6.30	-1	6 to 8
1⁄16	4	-2-0	Standard (STD), Black, UV Resistant	13.35	-1	6 to 8
1⁄16	4	-2-9	Standard (STD), Natural	13.35	-1	6 to 8
3⁄16	3½	-3-0	Heavy (HVY), Black, UV Resistant	12.00	-2	5 to 8
3⁄16	3½	-3-9	Heavy (HVY), Natural	12.00	-2	5 to 8
3⁄16	5⁄8	-4-0	Miniature (MIN), Black, UV Resistant	2.72	-1	1 to 3
3⁄16	5⁄8	-4-9	Miniature (MIN), Natural	2.72	-1	1 to 3
3⁄16	1¼	-5-0	Intermediate (INT), Black, UV Resistant	4.68	-1	3 to 5
3⁄16	1¼	-5-9	Intermediate (INT), Natural	4.68	-1	3 to 5
3⁄16	8	-6-0	Heavy (HVY), Black, UV Resistant	26.25	-2	5 to 8
3⁄16	8	-6-9	Heavy (HVY), Natural	26.25	-2	5 to 8
1⁄16	3	-7-0	Standard (STD), Black, UV Resistant	10.20	-1	6 to 8
1⁄16	3	-7-9	Standard (STD), Natural	10.20	-1	6 to 8

^{A} 1 in. = 2.54 cm.

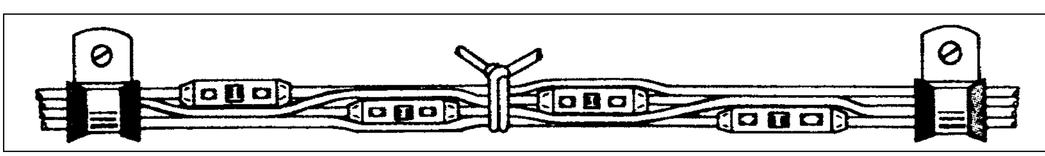


FIG. 10 Staggered Splices in Wire Bundle

installed using a high-quality ratchet-type, crimping tool. The use of the proper calibrated tool is recommended. Aircraft quality crimp tools are manufactured to standards. Such tools are provided with positioners for the wire size and are adjusted for each wire size. It is essential that the crimp depth be appropriate for each wire size. If the crimp is too deep or not deep enough, it may break or cut individual strands or it may not be tight enough to retain the wire in the terminal or connector. Crimps that are not tight enough are also susceptible to high resistance caused by corrosion buildup between the crimped terminal and the wire. Specification Mil-C-22520/2C covers in detail the general requirement for crimp tools, inspection gages, and tool kits.

13.5.1 Hand, portable, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel to the conductor and simultaneously form the insulation support to the wire insulation.

13.5.2 Crimp tools shall be carefully inspected:

13.5.2.1 Insure that the full cycle ratchet mechanism is tamper-proof so that it cannot be disengaged before or during the crimp cycle.

13.5.2.2 If the tool does not function or faults are found, reject the tool and send the tool to be repaired.

13.5.3 *Crimper Calibration Standards:*

NOTE 6—Crimper should be checked at least once a year.

13.5.3.1 The crimper calibration standards shall be derived from and traceable to one of the following:

(1) Standards established by the crimper manufacturer,

(2) The National Institute of Standards and Technology, or

(3) If foreign-manufactured test equipment, the standards of the country where it was manufactured if approved by the administrator.

13.5.3.2 The technician shall make sure that the crimper used for such maintenance is the correct equipment called for by the hardware manufacturer.

13.5.3.3 *Inspection of the Go-No-Go Gauge*—Go-no-go gauges seldom wear out and normally will not require calibration themselves. However, before calibrating the crimper, the go-no-go gauge should be inspected for obvious damage such as bending, unusual wear, corrosion, or alterations. Any gauge with these types of wear should be preplaced before calibration of the crimper.

13.6 *Lock Washers for Terminals on Equipment*—Where locknuts are used to ensure binding and locking of electrical terminals, they should be of the all-metal type. In addition, a spring lock washer of suitable thickness may be installed under the nut to ensure good contact pressure. A plain washer should be used between the spring washer and the terminal to prevent galling. A plain nut with a spring lock washer and a plain washer may be used to provide binding and contact pressure.

13.6.1 *Electrostatic Discharge (ESD) Considerations*—Many components used in personal computer (PC) board assemblies can be damaged by ESD. The damage may not manifest itself immediately but may result in system failure at a later time. PC board assemblies susceptible to ESD shall be labeled to ensure proper handling. Enclosures containing ESD-sensitive assemblies shall be labeled in accordance with EIA 471.

14. Grounding and Bonding

14.1 *General*—Two of the more important factors in the maintenance of aircraft electrical systems are proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, for example, electromagnetic interference (EMI), ESD 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 far more complete detailed information on grounding and bonding and the application of related hardware.

14.2 *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.

14.2.1 *Types of Grounding:*

14.2.1.1 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.

14.2.1.2 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."

14.2.2 *Current Return Paths:*

14.2.2.1 A 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 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 (for example, 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.

14.2.2.2 Direct connections to a magnesium (which may create a fire hazard) structure shall not be used for ground return.

14.2.3 *Heavy-Current Grounds*—Power ground connections for generators, transformer rectifiers, batteries, external power receptacles, and other heavy-current loads shall be attached to individual grounding brackets that are attached to an aircraft structure with a proper metal-to-metal bonding attachment. This attachment and the surrounding structure shall 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, shall be used to secure such brackets 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.

14.2.4 *Current Return Paths for Internally Grounded Equipment*—Power return or fault current ground connections within flammable vapor areas shall be avoided. If they must be made, ensure 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 shall 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.

14.2.5 *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.

14.2.5.1 Redundant systems are normally provided with the objective of assuring continued safe operation in the event of failure of a single channel and shall, 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.

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

14.2.5.3 Electrical power sources shall 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 avoid single ground return to the primary structure.

14.2.5.4 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 using terminal junction grounding modules or other types of gang grounds that have a single attachment point.

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

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

14.2.6.2 Running power wires too close will cause signal interference.

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

14.2.6.4 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.

14.3 *Bonding*—The following bonding requirements shall be considered:

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

14.3.2 *Metallic Surface Bonding*—All conducting objects on the exterior of the airframe shall 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 or lightning currents or both, as appropriate.

14.3.3 *Static Bonds*—All isolated conducting parts inside and outside the aircraft, having an area greater than 3 in.^{2} (19 cm^2) and a linear dimension over 3 in. (7.6 cm), that are subjected to appreciable electrostatic charging as a result of 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 Ω when clean and dry will generally ensure such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.

14.4 *Bonding:*

14.4.1 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.

14.4.2 Bond connections should be secure and free from corrosion.

14.4.3 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.

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

14.4.5 Exposed conducting frames or parts of electrical or electronic equipment should have a low-resistance bond of less than 2.5 mΩ to structure. If the equipment design includes a ground terminal or pin that is internally connected to such exposed parts, a ground wire connection to such terminal will satisfy this requirement. Refer to manufacturer's instructions.

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

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

14.4.8 Use of bonding testers is strongly recommended.

14.4.9 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 is required to measure accurately the very low-resistance values specified in this practice. Another method of measurement is the millivolt drop test as shown in Fig. 11.

NOTE 7—A high-quality test instrument is required.

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

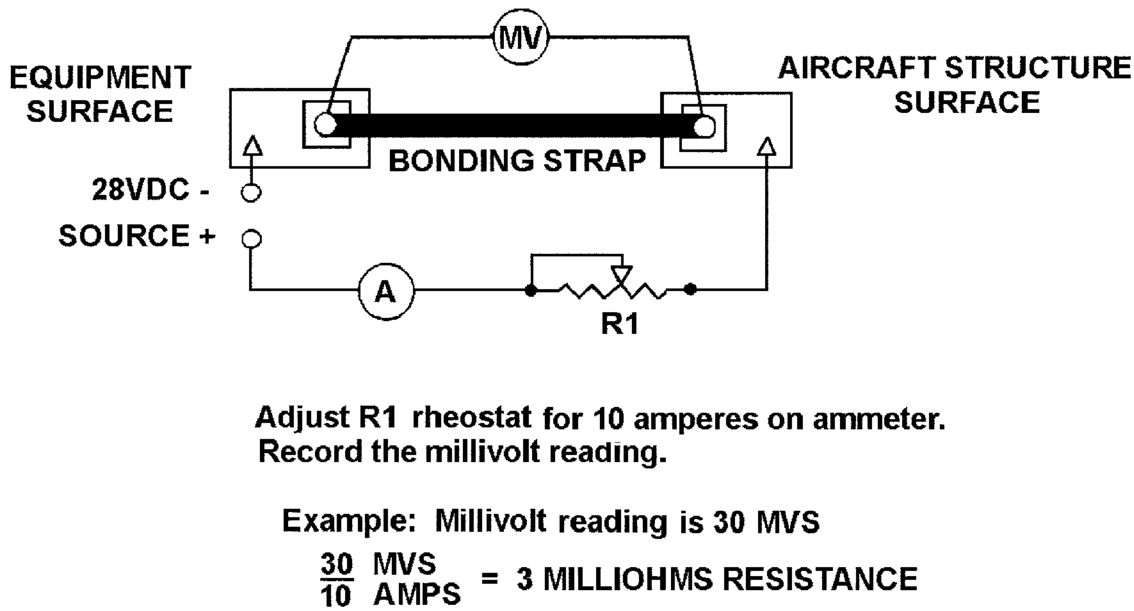


FIG. 11 Millivolt Drop Test

14.5 *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 0.003 Ω. 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.

14.5.1 *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 h 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.

14.5.2 *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 postfinished in accordance with the original finish requirements or some other suitable protective finish within 24 h of the cleaning process. In applications exposed to a 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.

14.5.3 *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 8-10 and Figs. 12-14 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.

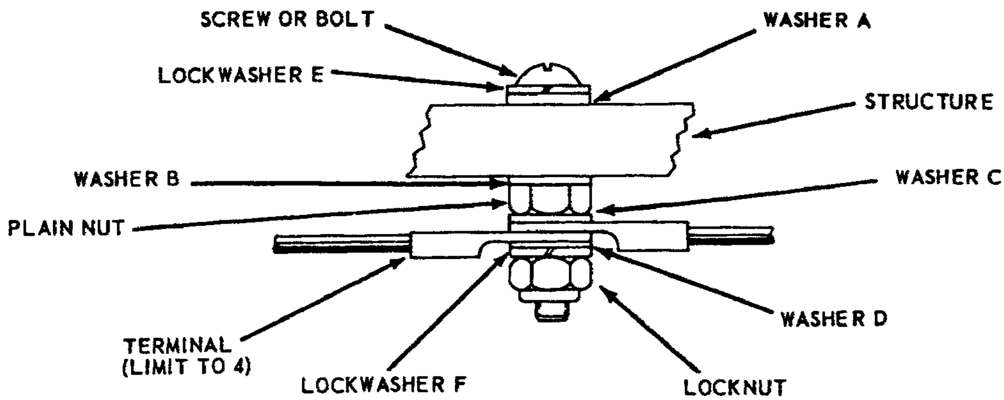
14.5.4 *Bonding Jumper Attachment*—The use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. The proper choice of clamp material should minimize the probability of corrosion.

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

14.6 *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.

14.7 *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 Ω 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

TABLE 8 Stud Bonding or Grounding to Flat Surface



Structure	Screw or Bolt and Lock Nut	Plain Nut	Washer A	Washer B	Washers C and 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 resisting steel	Cadmium plated steel	None	None	Cadmium plated steel or aluminum	Corrosion resisting steel	Cadmium plated steel
Tinned Copper Terminal and Jumper							
Aluminum alloys Magnesium alloys[A]	Cadmium plated steel	Cadmium plated steel	Aluminum alloy	Aluminum alloy	Cadmium plated steel	Cadmium plated steel	Cadmium plated steel or aluminum
Steel, cadmium plated	Cadmium plated steel	Cadmium plated steel	None	None	Cadmium plated steel	Cadmium plated steel	Cadmium plated steel
Steel, corrosion resisting	Corrosion resisting steel	Corrosion resisting steel	None	None	Cadmium plated steel	Corrosion resisting steel	Corrosion resisting steel

[A] Avoid connecting copper to magnesium.

doors, fuel line supports, structural parts, fuel outlets, or brackets should have an electromechanical (bonding strap) secure connector that ensures 1 Ω or less resistance to the structure. Advisory Circular 20-53A and DOT/FAA/CT-83/3 provide detailed information on necessary precautions.[8]

14.8 *Electric Shock Prevention Bonding*—Electric shock to personnel should be prevented by providing a low-resistance path of 1⁄100 Ω or less between the 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.

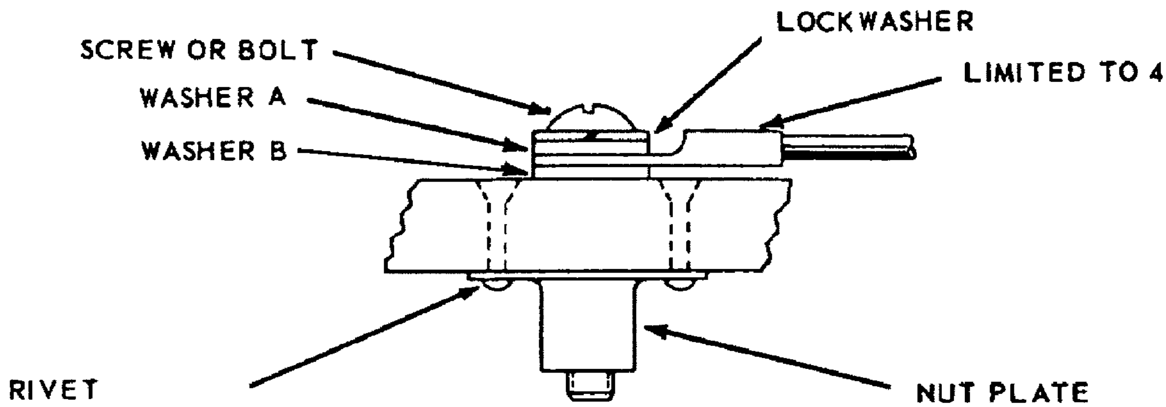
14.9 *Lightning Protection Bonding*—Electrical bonding is frequently required for lightning protection of aircraft and systems, especially to facilitate safe conduction of lightning currents through the airframe. Most of this bonding is achieved through normal airframe riveted or bolted joints, but some 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 shall 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.[9] Report DOT/FAA/CT 86/8 may provide additional information for composite materials.[10]

[8] DOT/FAA/CT-83/3, *Users Manual for AC 20-53A Protection of Aircraft Fuel Systems against Fuel Vapor Ignition due to Lightning*, National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

[9] DOT/FAA/CT-89/22, *Aircraft Lightning Protection Handbook*, National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

[10] Report DOT/FAA/CT 86/8, Determination of Electrical Properties of Bonding and Fastening Techniques, April 1987, National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

TABLE 9 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 Magnesium alloys[A]	Cadmium plated steel	Aluminum alloy	Cadmium plated steel	Cadmium plated steel	Aluminum alloy[B]
Steel,cadmium plated	Cadmium plated steel	Corrosion resisting steel	Cadmium plated steel	Cadmium plated steel	None
Steel,corrosionresisting	Corrosion resisting steel	Corrosion resisting steel	Cadmium plated steel	Cadmium plated steel	None

[A] Avoid connecting copper to magnesium.
[B] Use washers having a conductive finish treated to prevent corrosion, suggest AN980JD10L.

14.10 *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 (165 circular mm) area copper (for example, 7 by 37 AWG Size 36 strands) jumper across each hinge. In any case, not less than two 6500 circular mil (165 circular mm) 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 (1016 circular mm) 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.

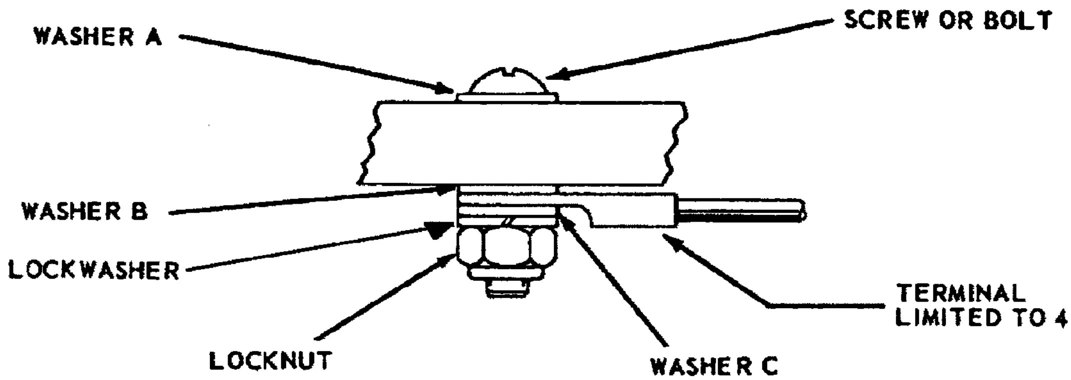
14.11 *Control Cable Lightning Protection Bonding*—To prevent damage to the control system or injury to flight personnel as a result of lightning strike, cables and levers coming from each control surface should be protected by one or more bonding jumpers located as close to the control surface as possible.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

14.12 *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 transfer lightning currents safely to the airframe and 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.

14.13 *Static-Discharge Device*—Means should be provided to bleed accumulated static charges from aircraft before ground personnel come 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.

14.14 *Cleaning*—To ensure proper ground connection conductivity, all paint, primer, anodize coating, grease, and other foreign material shall be carefully removed from areas

TABLE 10 Bolt and Nut Bonding or Grounding to Flat Surface



Structure	Screw or Bolt and Nut Plate	Locknut	Washer A	Washer B	Washer C
Aluminum Terminal and Jumper					
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 resisting	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					
Aluminum alloys Magnesium alloys[A]	Cadmium plated steel	Cadmium plated steel	Cadmium plated steel	Aluminum alloy[B]	Cadmium plated steel
Steel, cadmium plated	Cadmium plated steel	Cadmium plated steel	Cadmium plated steel	None	Cadmium plated steel
Steel, corrosion resisting	Corrosion resisting steel or cadmium plated steel	Cadmium plated steel	Corrosion resisting steel	None	Cadmium plated steel

[A] Avoid connecting copper to magnesium.
[B] Use washers having a conductive finish treated to prevent corrosion, suggest AN980JD10L.

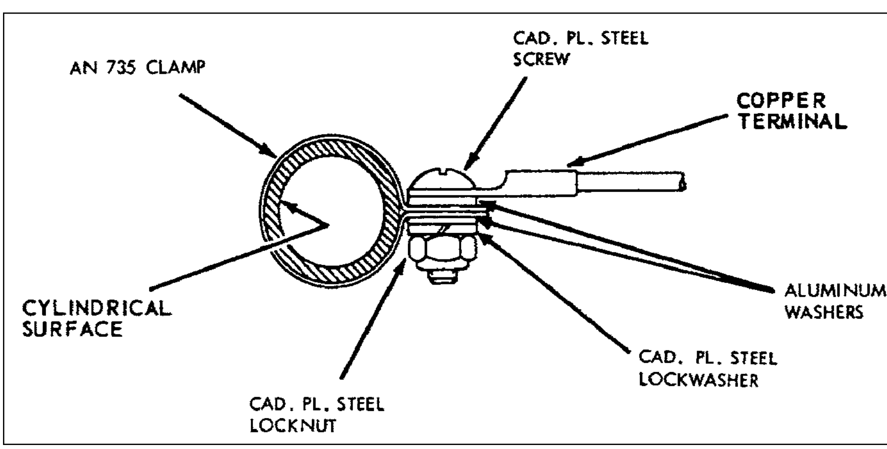


FIG. 12 Copper Jumper Connector to Tubular Structure

that conduct electricity. On aluminum surfaces, apply a chemical surface treatment to the cleaned bare metal surface in accordance with the manufacturer's instructions within 4 to 8 h depending on ambient moisture/contaminate content.

14.15 *Hardware Assembly*—Details of bonding connections shall be described in maintenance manuals and adhered to carefully when connections are removed or replaced during maintenance operations. To avoid corrosion problems and ensure long-term integrity of the electrical connection, hardware used for this purpose shall be as defined in this practice 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 shall be torqued to the level required by SAE ARP 1928.

15. Keywords

15.1 aircraft; aircraft electrical wiring system; aviation; electrical wiring interconnection system; EWIS; maintenance; repair

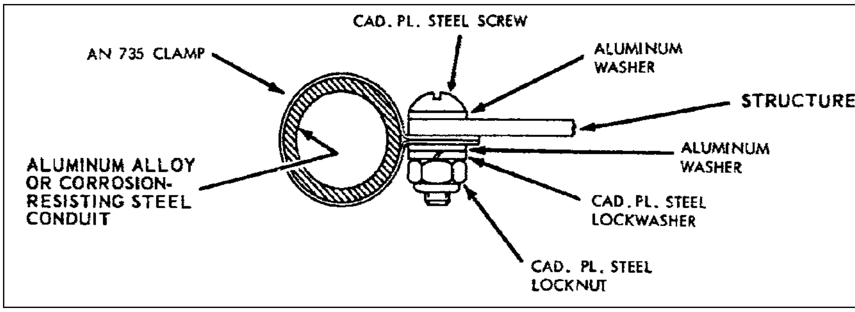


FIG. 13 Bonding Conduit to Structure

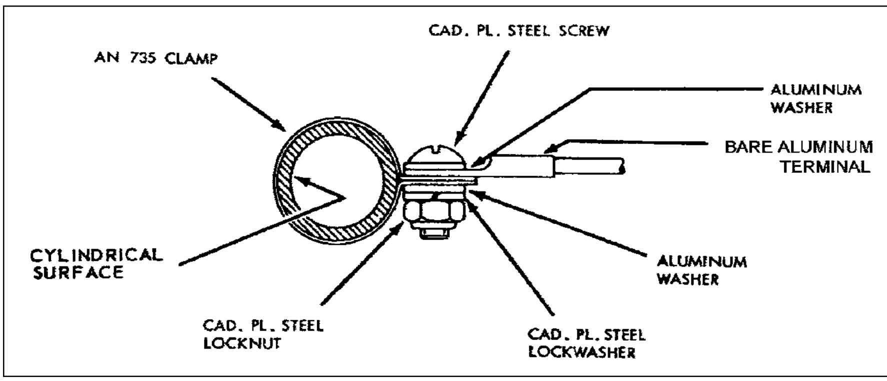


FIG. 14 Aluminum Jumper Connection to Tubular Structure