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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 stated in inch-pound units are to be regarded as 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 Aircraft Electrical Wiring Systems

2.2 *ICAO Standard:*[3]

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

2.3 *JEDEC Standard:*[4]

EIA 471 Symbol and Label for Electrostatic Sensitive Devices

2.4 *NEMA Standard:*[5]

WC 27500 Standards for Aerospace and Industrial Electric Cable

2.5 *RTCA Standard:*[6]

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

2.6 *SAE Standards:*[7]

AS4372 Performance Requirements for Wire, Electric, Insulated Copper or Copper Alloy

AS4373 Test Methods for Insulated Electric Wire

AS21919 Clamp, Loop Type, Cushioned Support

AS22759 Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy

AS50881 Wiring Aerospace Vehicle

[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, Alteration, 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 International Civil Aviation Organization (ICAO), Customer Services Unit, 999 Robert-Bourassa Boulevard, Montréal, Québec, H3C 5H7, Canada, https://www.icao.int.

[4] Available from the JEDEC Solid State Technology Association, 3103 N. 10th St., Suite 240-S, Arlington, VA 22201-2107, https://www.jedec.org/.

[5] Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 900, Arlington, VA 22209, http://www.nema.org.

[6] Available from RTCA, Inc., 1150 18th NW, Suite 910, Washington, DC 20036, https://www.rtca.org.

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

ARP1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP1928 Torque Recommendations for Attaching Electrical Wiring Devices to Terminal Boards or Blocks, Studs, Posts, etc.

2.7 *Federal Standards:*[8]

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

[8] Available from U.S. Government Publishing Office, 732 N. Capitol St., NW, Washington, DC 20401, http://www.gpo.gov.

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
MIL-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 AS22759.
[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 AS22759.

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.

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 Guide 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

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

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 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.

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

8.1.10 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.

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.

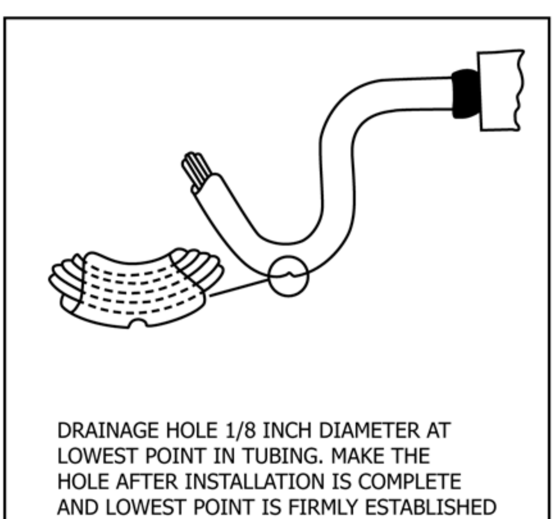

FIG. 1 Drainage Hole in Low Point of Tubing

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.

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.

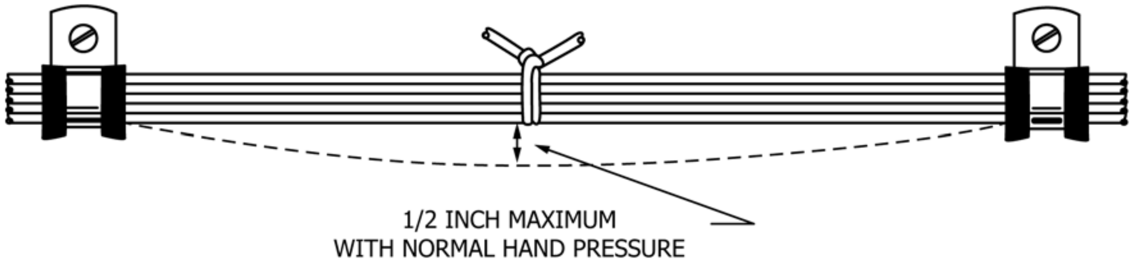

FIG. 2 Slack between Supports

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 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.

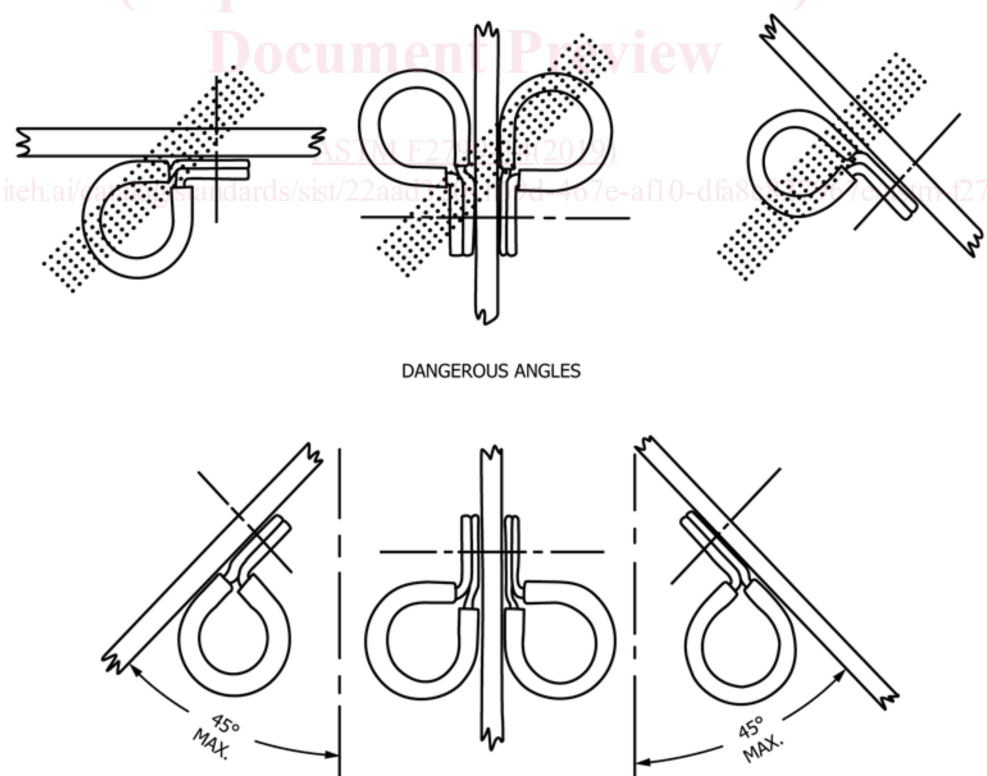

FIG. 3 Safe Angle for Cable Clamps