Designation: F2639 – 15

Standard Practice for Design, Alteration, and Certification of Aircraft Electrical Wiring Systems[1]

This standard is issued under the fixed designation F2639; 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 design, alteration, and certification of electric systems and installations 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, design approval holders, Supplemental Type Certificate (STC) holders, maintenance providers, repair stations, and anyone performing field approval modifications or repairs.

1.3 *Protections and Cautions*—This practice provides guidance for developing actions and cautionary statements to be added to maintenance instructions for the protection of wire and wire configurations. Maintenance personnel will use these enhanced procedures to minimize contamination and accidental damage to electrical wiring interconnection system (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 making sure that metal shavings, debris, and contamination resulting from such work are removed.

1.5 This practice includes the following sections:

[1] This practice is under the jurisdiction of ASTM Committee F39 on Aircraft Systems and is the direct responsibility of Subcommittee F39.01 on Design, Alteration, and Certification of Electrical Systems.

Current edition approved Aug. 1, 2015. Published September 2015. Originally approved in 2007. Last previous edition approved in 2007 as F2639 – 07$^{\varepsilon 1}$. DOI: 10.1520/F2639-15.

1.6 *Values*—The values given in inch-pound units are to be regarded as the standard. The values in parentheses are for information only. See Appendix X2 for SI-based prefixes and powers of 10.

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

1.7 *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 Unless approved by the administrator, the latest revision of the listed documents shall be used for reference.

2.2 *ASTM Standards:*[2]

F2490 Guide for Aircraft Electrical Load and Power Source Capacity Analysis

2.3 *ANSI Standards:*[3]

ANSI/EIA-5200000 Generic Specification for Special-Use Electromechanical Switches of Certified Quality

ANSI EIA/TIA-568-B Commercial Building Telecommunications Cabling Standard

ANSI J-STD-004 Requirements for Soldering Fluxes

2.4 *FAA Standards:*[4]

Advisory Circular 20-53A Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due To Lightning

AC 20-136 Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning

AC 21-160E RTCA Document DO-160E

AC 23.1309-1C Equipment, Systems, and Installations in Part 23 Airplanes

AC 25-16 Electrical Fault and Fire Prevention and Protection

AC 25.869-1 Electrical System Fire and Smoke Protection

AC 25.981-1B Fuel Tank Ignition Source Prevention Guidelines

AC 25.1353-1 Electrical Equipment and Installations

AC 25.1357-1 Circuit Protective Device Accessibility

DOT/FAA/CT 86/8 Determination of Electrical Properties of Bonding and Fastening Techniques

DOT/FAA/CT-83/3 Users Manual for FAA Advisory Circular 20-53a

DOT/FAA/CT-89-22 Aircraft Lightning Protection Handbook

Title14 Code of Federal Regulations Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

Title14 Code of Federal Regulations Part 25 Airworthiness Standards: Transport Category Airplanes

Title14 Code of Federal Regulations Part 27 Airworthiness Standards: Normal Category Rotorcraft

Title14 Code of Federal Regulations Part 29 Airworthiness Standards: Transport Category Rotorcraft

Title14 Code of Federal Regulations Part 31 Airworthiness Standards: Manned Free Balloons

Title14 Code of Federal Regulations Part 33 Airworthiness Standards: Aircraft Engines

Title14 Code of Federal Regulations Part 34 Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes

Title14 Code of Federal Regulations Part 35 Airworthiness Standards: Propellers

Title14 Code of Federal Regulations Part 36 Noise Standards: Aircraft Type and Airworthiness Certification

2.5 *SAE Standards:*[5]

AMS-S-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion (Replaces MIL-S-8802)

ARP 1199 Selection, Application, and Inspection of Electric Overcurrent Protective Devices

ARP 1308 Preferred Electrical Connectors for Aerospace Vehicles and Associated Equipment

[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

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

ARP 1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP 1928 Torque Recommendations for Attaching Electrical Wiring Devices to Terminal Boards or Blocks, Studs, Posts, Etc
ARP 4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP 5369 Guidelines for Wire Identification Marking Using the Hot Stamp Process
ARP 5414 Aircraft Lightning Zoning
ARP 5583 Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment
AS 4372 Performance Requirements for Wire, Electric, Insulated Copper or Copper Alloy
AS 4373 Test Methods for Insulated Electric Wire
AS 4461 Assembly and Soldering Criteria for High Quality/High Reliability
AS 6136 Conduit, Electrical, Flexible, Shielded, Aluminum Alloy for Aircraft Installations. (Replaces MIL-C-6136)
AS 7351 Clamp, Loop Type Bonding-FSC 5340 (replaces AN735)
AS 7431 Bracket, Support Clamp-FSC 5340 (replaces AN743)
AS 7928 Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification for (Replaces MIL-T-7928)
AS 22759 Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy. (Replaces MIL-W-22759)
AS 23190 Straps, Clamps, Plastic and Metal, and Mounting Hardware, Plastic for Cable Harness Tying and Support Clamp, Loop, Metal, Cushioned, Adjustable, Wire Support, Type V, Class 1-FSC (replaces MIL-S-23190)
AS 25064 Conduit, Flexible, Radio Frequency Shielding [use in place of MIL-C-7931?]
AS 25281 Clamp, Loop, Plastic, Wire Support-FSC 5340 (replaces MS25281)
AS 25435 Terminal-Lug, Crimp Style, Straight Type, for Aluminum Aircraft Wire, Class 1 (Replaces MS254350)
AS 25436 Terminal-Lug, Crimp Style, 90° Upright Type, for Aluminum Aircraft Wire, Class 1 (Replaces MS25436)
AS 25438 Terminal-Lug, Crimp Style Right Angle Type, for Aluminum Aircraft Wire, Class 1 (Replaces MS25438)
AS 33671 Strap, Tie Down, Electrical Components, Adjustable, Self Clinching, Plastic, Type I, Class 1 (Replaces MS3367)
AS 50881A Wiring Aerospace Vehicle (Replaces MIL-W-5088)
AS 70991 Terminal, Lug and Splice, Crimp Style Aluminum, for Aluminum Aircraft Wire. (Replaces MIL-T-7099E)

2.6 *Military Standards:*[4]
A-A-52080 Nylon Lacing Tape (replaces MIL-T-43435)
A-A-52081 Polyester Lacing Tape (replaces MIL-T-43435)
A-A-52082 Tape, Lacing and Tying, TFE Fluorocarbon (tetra fluorocarbon) (replaces MIL-T-43435)
A-A-52083 Tape, Lacing and Tying, Glass (replaces MIL-T-43435)
A-A-52084 Tape, Lacing and Tying, Aramid (replaces MIL-T-43435)
A-A-59163 Insulation Tape, Electrical, Self Adhering, Unsupported Silicone Rubber
AN735 Clamp
AN960JD10L Conductive Washer
MIL-C-22520 Wire Termination Crimp Tools
MIL-C-26482 Connectors, Electrical, (Circular, Miniature, Quick Disconnect, Environment Resisting), Receptacles and Plugs, General Specification for
MIL-C-39029 Contacts, Electrical Connector, General Specification for
MIL-PRF-81309 Corrosion Preventative Compounds, Water Displacing, Ultra-Thin Film
MIL-DTL-22520 Crimping Tools, Wire Termination, General Specification for (replaces MIL-C-22520/2)
MIL-DTL-27500 Cable, Power, Electrical and Cable Special Purpose, Electrical Shielded and Unshielded, General Specification for
MIL-DTL-5015 Connectors, Electrical, Circular Threaded, AN Type, General Specification for
MIL-DTL-83723 Connectors, Electrical, (Circular, Environment Resisting), Receptacles and Plugs, General Specification for
MIL-F-14256F Flux, Soldering, Liquid, Paste Flux, Solder Paste and Solder-Paste Flux (for Electronic/Electrical use), General Specification for
MIL-M-81531 Marking of Electrical Insulating Materials
MIL-PRF-39016 Relays Electromagnetic, Established Reliability, General Specification for
MIL-PRF-5757 Relays, Hermetically Sealed
MIL-PRF-6106 Relays, Electromagnetic, General Specification for
MIL-PRF-83536 Relays, Electromagnetic, Established Reliability, 25 Amperes and Below, General Specification for
MIL-S-8516 Sealing Compound, Polysulfide Rubber, Electric Connectors and Electric Systems, Chemically Cured
MIL-STD-704 Aircraft, Electrical Power Characteristics
MIL-T-8191 Test and Checkout Equipment, Guided Missile Weapons Systems, General Specification for [should this be SAE AMS-T-81914 replaces MIL-T-81914?]
MIL-W-25038 Wire, Electrical, High-Temperature, Fire Resistant, and Flight Critical
MIL-W-81044 Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkine-Imide, or Polyarylene Insulated, Copper or Copper Alloy
MIL-W-81381 Wire, Electric, Fluorocarbon/Polyimide Insulated
MS21919 Cable Clamps
MS25440 Flat Washer
MS3057 Cable Clamp Adapters
MS3109 Boots, Heat-Shrinkable, Strain-Relief, Right Angle
MS3115 Connectors, Receptacle, Electrical, Dummy Stowage, Bayonet Coupling, for MIL-C-26482 Connectors, Series 1 and 2
MS3117 Boots, Heat-Shrinkable, Strain-Relief, Right Angle

MS3142 Connector, Receptacle, Electrical, Box Mounting, Solder Contact Hermetic, AN Type
MS3143 Connector, Receptacle, Electrical, Solder Mounting, Solder Contact Hermetic, AN Type
MS3158 Backshells Shrinkable Boot, for Electric Connector
MS3180 Cover, Protective, Electrical Connector Plug, Bayonet Coupling for MIL-C-26482 Connectors
MS3181 Cover, Protective, Electrical Connector Receptacle, Bayonet Coupling for MIL-C-26482 Connectors
MS3416 Backshells, Straight, for Electrical Connectors
MS3440 Connectors, Receptacle, Electric Series 2, Narrow Flange Mount, Bayonet Coupling, Solder Pin Contact Class H
MS3443 Connectors, Receptacle, Electric, Series 2, Solder Flange Mount, Bayonet Coupling, Solder Pin Contact Class H
MS3450 Connectors, Receptacle, Electrical, Wall Mounting, Rear Release, Crimp Contact, AN Type
MS3451 Connectors Receptacle, Electrical, Cable Connecting, Rear Release, Crimp Contact, AN Type
MS3452 Connector, Receptacle, Electric, Box Mounting, Rear Release, Crimp Contact, AN Type
MS3456 Connectors, Plug, Electrical, Rear Release, Crimp Contact, AN Type
MS3459 Connector, Plug, Electrical, Self-Locking, Coupling Nut, Rear Release, Crimp Contact, AN Type
MS3470 Connectors, Receptacle, Electric, Series 2, Single Hole Mount, Bayonet Coupling, Solder Pin Contact, Class H
MS3471 Connector, Receptacle, Electric, Series 2, Crimp Type, Cable Connecting, Bayonet Coupling, Classes A, L, S, and W
MS3472 Connector, Receptacle, Electric, Series 2, Crimp Type, Wide Flange Mounting, Bayonet Coupling, Classes A, L, S, and W
MS3475 Connector, Plug Electric, RFI Shielded, Series 2, Crimp Type, Bayonet Coupling, Classes L, S, and W
MS3476 Connector, Plug Electric, Series 2, Crimp Type, Bayonet Coupling, Classes A, L, S, and W
MS25437 Terminal-Lug
MS35489 Grommet
MS90387 Tool, Hand, Adjustable for Plastic and Metal Tie Down Straps
QQ-S-571 Solder, Electronic (96 to 485 Deg C)

2.7 *Other Standards:*

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment[6]
EIA 471 Symbol & Label for Electrostatic Sensitive Devices[7]
National Electrical Manufacturers Association (NEMA) WC 27500 Standards for Aerospace and Industrial Electric Cable (replaces MIL-DTL-27500H)[8]
ICAO Annex 5 Units of Measurement to be used in Air and Ground Operations[9]

3. Terminology

3.1 *Definitions:*

3.1.1 *abrasion resistance, n*—ability of a material to resist intrinsic property deterioration as a result of physical abrasion.

3.1.2 *adhesive, n*—compound that adheres or bonds two items together.

3.1.2.1 *Discussion*—Adhesives may come from either natural or synthetic sources.

3.1.3 *Airworthiness Directive (AD), n*—regulation issued by the Federal Aviation Administration (FAA) that applies to aircraft, aircraft engines, propellers, or appliances when an unsafe condition exists and that condition is likely to exist or develop in other products of the same type design.

3.1.4 *ampere (A), n*—basic unit of current flow; 1 A is the amount of current that flows when a difference of potential of 1 V is applied to a circuit with a resistance of one; 1 coulomb/s.

3.1.5 *antenna, n*—device designed to radiate or intercept electromagnetic waves.

3.1.6 *appliance, n*—any instrument, mechanism, equipment, part, apparatus, appurtenance, or accessory, including communications equipment, that is used or intended to be used in operating or controlling an aircraft in flight; is installed in or attached to the aircraft; and is not part of an airframe, engine, or propeller.

3.1.7 *arc fault circuit breaker (AFCB), n*—contains circuitry to cause circuit breaker to open when arcing faults are detected.

3.1.8 *arc resistance (noncarbon tracking), n*—measure of the ability of a material to resist physical penetration by an electrical arc.

3.1.9 *avionics, n*—science and technology of electronics as applied to aviation.

3.1.10 *bond, n*—adhesion of one surface to another with or without the use of an adhesive as a bonding agent.

3.1.11 *bonding, v*—general term applied to the process of electrically connecting two or more conductive objects.

3.1.11.1 *Discussion*—In aircraft, the purpose of bonding (except as applied to individual connections in the wiring and grounding systems) is to provide conductive paths for electric currents. This is accomplished by providing suitable low-impedance connections joining conductive aircraft components and the aircraft structure. Another purpose of bonding is to ensure the safe passage of current caused by lightning or static electricity through the aircraft structure.

3.1.12 *bundle, n*—wire bundle consists of a quantity of wires fastened or secured together and all traveling in the same direction.

3.1.13 *bus or bus bar, n*—solid copper strips to carry current between primary and secondary circuits; also used as jumpers.

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

[7] Available from Electronic Industries Alliance (EIA), 2500 Wilson Blvd., Arlington, VA 22201, http://www.eia.org

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

[9] Available from ICAO, Document Sales Unit, 999 University St., Montreal, Quebec H3C 5H7, Canada.

3.1.14 *cable (electrical), n*—assembly of one or more conductors within an enveloping protective sheath so constructed as to permit use of conductors separately or in a group.

3.1.15 *calibration, n*—set of operations, performed in accordance with a definite document procedure, that compares the measurements performed by an instrument or standard, for the purpose of detecting and reporting, or eliminating by adjustment, errors in the instrument tested.

3.1.16 *certification, n*—implies that a certificate is in existence that certifies or states a qualification.

3.1.17 *circuit, n*—closed path or mesh of closed paths usually including a source of electromotive force (EMF).

3.1.18 *circuit breaker, n*—protective device for opening a circuit automatically when excessive current is flowing through it.

3.1.19 *conductor, n*—wire or other material suitable for conducting electricity.

3.1.20 *conduit, n*—rigid metallic or nonmetallic casing or a flexible metallic casing covered with a woven braid or synthetic rubber used to encase electrical cables.

3.1.21 *contact, n*—electrical connectors in a switch, solenoid, or relay that controls the flow of current.

3.1.22 *corrosion resistance, n*—ability of a material to resist intrinsic property deterioration as a result of environment.

3.1.23 *crack, n*—partial separation of material caused by vibration, overloading, internal stresses, nicks, defective assemblies, fatigue, or rapid changes in temperature.

3.1.24 *creepage, n*—conduction of electrical current along a surface between two points at different potentials.

3.1.24.1 *Discussion*—The current's ability to pass between two points increases with higher voltage and when deposits of moisture or other conductive materials exist on the surfaces.

3.1.25 *curing temperature, n*—temperature at which a resin or an assembly is subjected to cure the resin.

3.1.26 *cut-through strength, n*—measure of the effort required to sever a material.

3.1.27 *data, n*—information that supports or describes, or both, the original aircraft design, alteration, or repair including the following: *(1)* drawings, sketches, and/or photographs; *(2)* engineering analysis; *(3)* engineering orders; and *(4)* operating limitations.

3.1.28 *derating, n*—technique whereby a part is stressed in actual usage at values well below the manufacturer's rating for the part.

3.1.28.1 *Discussion*—By decreasing mechanical, thermal, and electrical stresses, the probability of degradation or catastrophic failure is lessened.

3.1.29 *dielectric strength, n*—maximum electric field that a material can withstand without failure of its electrical insulation properties.

3.1.30 *discontinuity, n*—interruption in the normal physical structure or configuration of a part such as a crack, lap, seam, inclusion, or porosity.

3.1.31 *drip loop, n*—bundle installation method used to prevent water or other fluid contaminants from running down the wiring into a connector.

3.1.32 *electrical wiring interconnection system (EWIS), n*—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.

3.1.33 *electricity, n*—one of the fundamental quantities in nature consisting of elementary particles, electrons, and protons that are manifested as a force of attraction or repulsion and also in work that can be performed when electrons are caused to move; a material agency that, when in motion, exhibits magnetic, chemical, and thermal effects and when at rest is accompanied by an interplay of forces between associated localities in which it is present.

3.1.34 *electromagnet, n*—temporary magnet that is magnetized by sending current through a coil of wire wound around an iron core.

3.1.35 *electromagnetic/radio frequency interference (EMI/RFI), n*—frequency spectrum of electromagnetic radiation extending from subsonic frequency to X-rays.

3.1.35.1 *Discussion*—This term shall not be used in place of the term radio frequency interference (RFI). (See *radio frequency interference*.) Shielding materials for the entire EMI spectrum are not readily available.

3.1.36 *electron, n*—negative charge that revolves around the nucleus of an atom; a unit of a negative electrical charge.

3.1.37 *electronics, n*—general term that describes the branch of electrical science and technology that treats the behavior and effects of electron emission and transmission.

3.1.38 *expandable sleeving, n*—open-weave braided sleeving used to protect wire and cables from abrasion and other hazards (commonly called "Expando").

3.1.39 *fill, n*—threads in a fabric that run crosswise of the woven material.

3.1.40 *flame resistance, n*—ability of a material to resist intrinsic property deterioration because of immersion in flame.

3.1.41 *fluorinated ethylene propylene (FEP), n*—melt-extrudable fluorocarbon resin, very similar in appearance and performance to polytetrafluoroethylene (PTFE), but with a maximum temperature rating of 200°C.

3.1.42 *flux, n*—materials used to prevent, dissolve, or facilitate removal of oxides and other undesirable surface substances.

3.1.42.1 *Discussion*—Also, the name for magnetic fields.

3.1.43 *fuse, n*—protective device containing a special wire that melts when current exceeds the rated value for a definite period.

3.1.44 *generator, n*—device for converting mechanical energy into electrical energy.

3.1.45 *grommet, n*—insulating washer that protects the sides of holes through which wires shall pass or a metal or plastic drain attached to fabric on aircraft.

3.1.46 *grounding, v*—term usually applied to a particular form of bonding that is the process of electrically connecting conductive objects to either conductive structure or some other conductive return path for the purpose of safely completing either a normal or fault circuit.

3.1.47 *harness, n*—group of cables or wires securely tied as a unit.

3.1.48 *heat distortion temperature, n*—temperature at which a material begins to alter its intrinsic properties.

3.1.49 *impact strength, n*—ability of a material to resist intrinsic property deterioration as a result of physical impact.

3.1.50 *insulator, n*—material that will not conduct current to an appreciable degree.

3.1.51 *integrated circuit, n*—small, complete circuit built up by vacuum deposition and other techniques, usually on a silicon chip, and mounted in a suitable package.

3.1.52 *inverter, n*—device for converting direct current (DC) to alternating current (AC).

3.1.53 *magnetic field, n*—space around a source of magnetic flux in which the effects of magnetism can be determined.

3.1.54 *mechanical strength, n*—ability of a material to resist intrinsic property deterioration as a result of physical forces.

3.1.55 *multiconductor cable, n*—consists of two or more cables or wires, all of which are encased in an outer covering composed of synthetic rubber, fabric, or other material.

3.1.56 *open circuit, n*—incomplete or broken electrical circuit.

3.1.57 *plastic, n*—organic substance of large molecular weight that is solid in its finished state and, at some stage during its manufacture or its processing into a finished article, can be shaped by flow.

3.1.58 *polytetrafluoroethylene (PTFE) tape (insulation), n*—wrapped around a conductor and layered into a virtually homogeneous mass.

3.1.58.1 *Discussion*—It is used both as a primary insulation against the conductor and as an outer layer or jacket over a shield. Maximum temperature rating is 260°C.

3.1.59 *polyvinylidine fluoride (PVF2), n*—fluorocarbon plastic that, when used in aircraft wire, is invariably radiation cross-linked and used as the outer layer.

3.1.60 *radar (radio detecting and ranging), n*—radio equipment that uses reflected pulse signals to locate and determine the distance to any reflecting object within its range.

3.1.61 *rectifier, n*—device for converting AC to DC.

3.1.62 *relay, n*—electrically operated remote control switch.

3.1.63 *resin, n*—vast profusion of natural and increasingly synthetic materials used as adhesives, fillers, binders, and insulation.

3.1.64 *resistance, n*—opposition a device or material offers to the flow or current.

3.1.65 *resistance to fluids, n*—ability of a material to resist intrinsic property deterioration as a result of fluids.

3.1.66 *resistance to notch propagation, n*—ability of a material to resist propagation of breeches.

3.1.67 *severe wind and moisture problem (SWAMP) areas, n*—areas such as wheel wells, wing folds, and near wing flaps and areas directly exposed to extended weather conditions are considered SWAMP areas on aircraft.

3.1.68 *silicone rubber, n*—high-temperature (200°C) plastic insulation that has a substantial silicone content.

3.1.69 *smoke emission, n*—gases or particulate emitted from a material as a result of combustion.

3.1.70 *soldering, v*—group of welding processes that produces coalescence of materials by heating them to the soldering temperature and using a filler metal having a liquidus not exceeding 450°C (840°F) and below the solidus of the base metals and the filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

3.1.71 *solenoid, n*—tubular coil for the production of a magnetic field; electromagnet with a core that is able to move in and out.

3.1.72 *special properties unique to the aircraft, n*—any characteristic of an aircraft not incorporated in other designs.

3.1.73 *swarf, n*—term used to describe the metal particles generated from drilling and machining operations.

3.1.73.1 *Discussion*—Swarf particles may collect on and between wires within a wire bundle.

3.1.74 *switch, n*—device for opening or closing an electrical circuit.

3.1.75 *tape, n*—tape or a "narrow fabric" is loosely defined as a material that ranges in width from ¼ to 12 in. (0.6 to 30 cm).

3.1.76 *thermocouple, n*—device to convert heat energy into electrical energy.

3.1.77 *transformer, n*—device for raising or lowering AC voltage.

3.1.78 *transmitter, n*—electronic system designed to produce modulated radio frequency (RF) carrier waves to be radiated by an antenna; also, an electric device used to collect quantitative information at one point and send it to a remote indicator electrically.

3.1.79 *velocity of propagation (VOP), n*—or velocity factor is a parameter that characterizes the speed at which an electrical or radio signal passes through a medium and expressed as a percentage, it is the ratio of a signal's transmission speed compared to the speed of light.

3.1.80 *volt, n*—unit of potential, potential difference, or electrical pressure.

3.1.81 *waveguide, n*—hollow, typically rectangular, metallic tube designed to carry electromagnetic energy at extremely high frequencies.

3.1.82 *wire, n*—single, electrically conductive path.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *electrical system, n—as used in this practice*, those parts of the aircraft that generate, distribute, and use electrical energy, including their support and attachments.

3.3 *Acronyms:*
3.3.1 *AC*—alternating current
3.3.2 *AFM*—aircraft flight manual
3.3.3 *CDO*—Certified Design Organization
3.3.4 *CFR*—Code of Federal Regulations
3.3.5 *COMP*—composite
3.3.6 *COTS*—commercial off the shelf
3.3.7 *DC*—direct current
3.3.8 *EMI*—electromagnetic interference
3.3.9 *ESD*—electrostatic discharge
3.3.10 *EWIS*—electrical wiring interconnection system
3.3.11 *F*—Fahrenheit
3.3.12 *FEP*—fluorinated ethylene propylene
3.3.13 *ID*—identification
3.3.14 *NiCad*—nickel cadmium
3.3.15 *NiMH*—nickel metal hydride
3.3.16 *OD*—outside diameter
3.3.17 *ODA*—optional designation authorization
3.3.18 *OEM*—original equipment manufacturer
3.3.19 *PI*—polyimide
3.3.20 *RCCB*—remote-controlled circuit breaker
3.3.21 *RFI*—radio frequency interference
3.3.22 *SOF*—safety of flight
3.3.23 *SSPC*—solid-state power controller
3.3.24 *SWAMP*—severe wind and moisture problems
3.3.25 *TFE*—tetrafluoroethylene

4. Significance and Use

4.1 *Design*—The design procedures defined in this practice are intended to provide acceptable guidance in the original design of electrical systems.

4.2 *Alteration*—The alteration procedures defined in this practice are intended to provide acceptable guidance for modification of general aviation aircraft. Design of any modification shall follow the practices and processes defined in the design sections of this practice.

4.3 *Certification*—Certification guidance provided in this practice is intended to provide generally accepted procedures and processes for certification of original and modified electrical systems and equipment. Requirements for certification shall be coordinated with the applicable National Aeronautics Association/Civil Aeronautics Administration (NAA/CAA) regulatory agency.

5. Wire Selection

5.1 *General:*

5.1.1 Wires shall be sized to carry continuous current in excess of the circuit-protective device rating, including its time current characteristics, and to avoid excessive voltage drop. Refer to 8.2 for wire-rating methods.

5.1.2 *Electrical Wire Rating:*

5.1.2.1 Wires shall be sized so that they: have sufficient mechanical strength to allow for service conditions, do not exceed allowable voltage drop levels, are protected by system circuit protection devices, and meet circuit current carrying requirements.

5.1.2.2 *Mechanical Strength of Wires*—If it is desirable to use wire sizes smaller than #20, particular attention shall be given to the mechanical strength and installation handling of these wires, for example, vibration, flexing, and termination. Consideration shall be given to the use of high-strength alloy conductors in small gage wires to increase mechanical strength. As a general practice, wires smaller than size #20 shall be provided with additional clamps and be grouped with at least three other wires. They shall also have additional support at terminations, such as connector grommets, strain relief clamps, shrinkable sleeving, or telescoping bushings. They shall not be used in applications in which they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw termination.

5.1.2.3 *Voltage Drop in Wires*—The voltage drop in the main power wires from the generation source or the battery to the bus shall not exceed 2 % of the regulated voltage when the generator is carrying rated current or the battery is being discharged at the 5-min rate. The tabulation shown in Table 1 defines the maximum acceptable voltage drop in the load circuits between the bus and the utilization equipment ground.

5.1.2.4 *Resistance*—The resistance of the current return path through the aircraft structure is generally considered negligible. However, this is based on the assumption that adequate bonding to the structure or a special electric current return path has been provided that is capable of carrying the required electric current with a negligible voltage drop. To determine circuit resistance, check the voltage drop across the circuit. If the voltage drop does not exceed the limit established by the aircraft or product manufacturer, the resistance value for the circuit may be considered satisfactory. When checking a circuit, the input voltage shall be maintained at a constant value. Tables 2 and 3 show formulas that may be used to determine electrical resistance in wires and some typical examples.

5.1.2.5 *Resistance Calculation Methods*—Figs. 1 and 2 provide a convenient means of calculating maximum wire length for the given circuit current. Values in Tables 2 and 3 are for tin-plated copper conductor wires. Because the resistance of tin-plated wire is slightly higher than that of nickel or silver plated wire, maximum run lengths determined from these charts will be slightly less than the allowable limits for nickel or silver-plated copper wire and are therefore safe to use. Figs. 1 and 2 can be used to derive slightly longer maximum run

TABLE 1 Tabulation Chart (Allowable Voltage Drop Between Bus and Utilization Equipment Ground)

Nominal System Voltage	Allowable Voltage Drop Continuous Operation	Intermittent Operation
14	0.5	1
28	1	2
115	4	8
200	7	14

TABLE 2 Examples of Determining Required Tin-Plated Copper Wire Size and Checking Voltage Drop Using Fig. 1

Voltage Drop	Run Lengths, ft	Circuit Current, amps	Wire Size from Chart	Check Calculated Voltage Drop (VD) = (Resistance/ft) (Length) (Current)
1	107	20	No. 6	VD = (0.000 44 Ω/ft) (107)(20) = 0.942
0.5	90	20	No. 4	VD = (0.000 28 Ω/ft) (90)(20) = 0.504
4	88	20	No. 12	VD = (0.002 02 Ω/ft) (88)(20) = 3.60
7	100	20	No. 14	VD = (0.003 06 Ω/ft) (100)(20) = 6.12

TABLE 3 Examples of Determining Maximum Tin-Plated Copper Wire Length and Checking Voltage Drop Using Fig. 1

Maximum Voltage Drop	Wire Size	Circuit Current, amps	Maximum Wire Run Length, ft	Check Calculated Voltage Drop (VD) = (Resistance/ft) (Length) (Current)
1	No. 10	20	39	VD = (0.001 26 Ω/ft) (39)(20)= 0.98
0.5	—		19.5	VD = (0.001 26 Ω/ft) (19.5)(20) = 0.366
4	—		156	VD = (0.001 26 Ω/ft) (156)(20) = 3.93
7	—		273	VD = (0.001 26 Ω/ft) (273)(20) = 6.88

lengths for silver or nickel-plated wires by multiplying the maximum run length by the ratio of resistance of tin-plated wire divided by the resistance of silver or nickel-plated wire.

5.1.2.6 As an alternative method or a means of checking results from Fig. 1, continuous flow resistance for a given wire size can be read from Table 4 and multiplied by the wire run length and the circuit current. For intermittent flow, use Fig. 2.

5.1.2.7 When the estimated or measured conductor temperature (T_2) exceeds 20°C, such as in areas having elevated ambient temperatures or in fully loaded power-feed wires, the maximum allowable run length (L_2), must be shortened from L_1 (the 20°C value) using the following formula for copper conductor wire:

$$L_2 = \frac{(254.5°C)(L_1)}{(234.5°C)(T_2)} \quad (1)$$

(1) For aluminum conductor wire, the formula is:

$$L_2 = \frac{(258.1°C)(L_1)}{(238.1°C)(T_2)} \quad (2)$$

(2) These formulas use the reciprocal of each material's resistive temperature coefficient to take into account increased conductor resistance resulting from operation at elevated temperatures.

5.1.2.8 To determine T_2 for wires carrying a high percentage of their current-carrying capability at elevated temperatures, laboratory testing using a load bank and a high-temperature chamber is recommended. Such tests shall be run at anticipated worst-case ambient temperature and maximum current-loading combinations.

5.1.2.9 Approximate T_2 can be estimated using the following formula:

$$T_2 = T_1 + (T_R - T_1)\sqrt{(I_2/I_{max})} \quad (3)$$

where:

T_1 = ambient temperature,
T_2 = estimated conductor temperature,
T_R = conductor temperature rating,
I_2 = circuit current (A = amps), and
I_{max} = maximum allowable current (A = amps) at T_R.

(1) This formula is quite conservative and will typically yield somewhat higher estimated temperatures than are likely to be encountered under actual operating conditions.

5.1.2.10 *Effects of Heat Aging on Wire Insulation*—Since electrical wire may be installed in areas where inspection is infrequent over extended periods of time, it is necessary to give special consideration to heat-aging characteristics in the selection of wire. Resistance to heat is of primary importance in the selection of wire for aircraft use, as it is the basic factor in wire rating. Where wire may be required to operate at higher temperatures because of either high ambient temperature, high-current loading, or a combination of the two, selection shall be made on the basis of satisfactory performance under the most severe operating conditions.

5.1.2.11 *Maximum Operating Temperature*—The current that causes a temperature steady state condition equal to the rated temperature of the wire shall not be exceeded. Rated temperature of the wire may be based upon the ability of either the conductor or the insulation to withstand continuous operation without degradation.

5.1.2.12 *Single Wire in Free Air*—Determining a wiring system's current-carrying capacity begins with determining the maximum current that a given-sized wire can carry without exceeding the allowable temperature difference (wire rating minus ambient °C). The curves are based upon a single copper wire in free air. (See Figs. 3 and 4.)

5.1.3 Aircraft service imposes severe environmental condition on electrical wire. To ensure satisfactory service, schedule wire inspections annually for abrasions, defective insulation, condition of terminations, and potential corrosion. Grounding connections for power, distribution equipment, and electromagnetic shielding shall be given particular attention to ensure that electrical bonding resistance will not be significantly increased by the loosening of connections or by corrosion during service.

5.1.4 *Insulation* of wires shall 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 cannot be considered as mechanical protection against external abrasion of wire since, at best, it provides only a delaying action. Conduit or ducting shall be used when mechanical protection is needed. Refer to 9.8 and 10.7 for conduit selection and installation.

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

5.1.5.1 Abrasion resistance,

5.1.5.2 Arc resistance (non-carbon tracking),

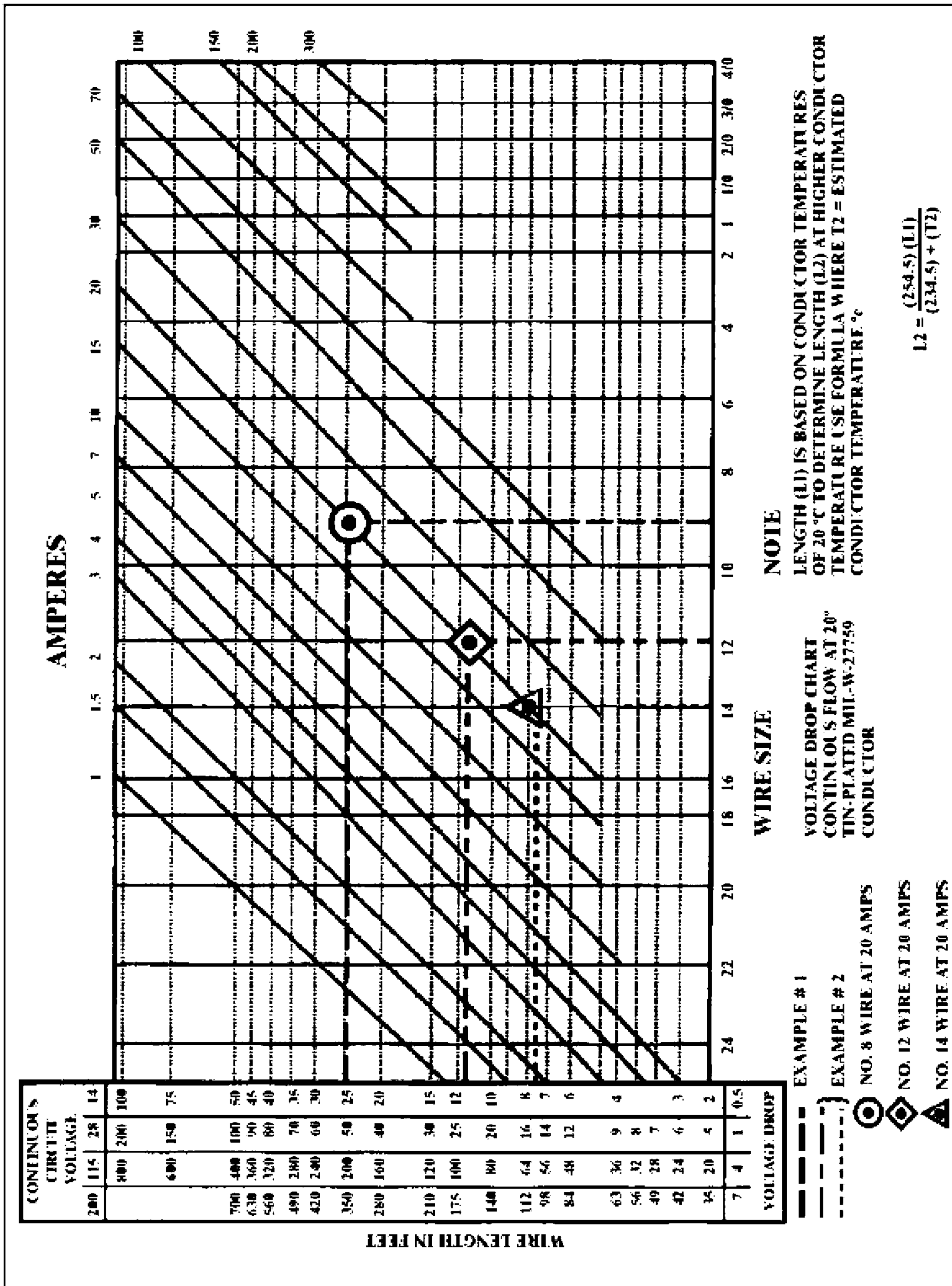


FIG. 1 Conductor Chart, Continuous Flow

5.1.5.3 Corrosion resistance,

5.1.5.4 Cut-through strength,

5.1.5.5 Dielectric strength,

5.1.5.6 Flame resistance,

5.1.5.7 Heat distortion temperature,

5.1.5.8 Impact strength,

5.1.5.9 Mechanical strength,

5.1.5.10 Resistance to fluids,

5.1.5.11 Resistance to notch propagation,

5.1.5.12 Smoke emission, and

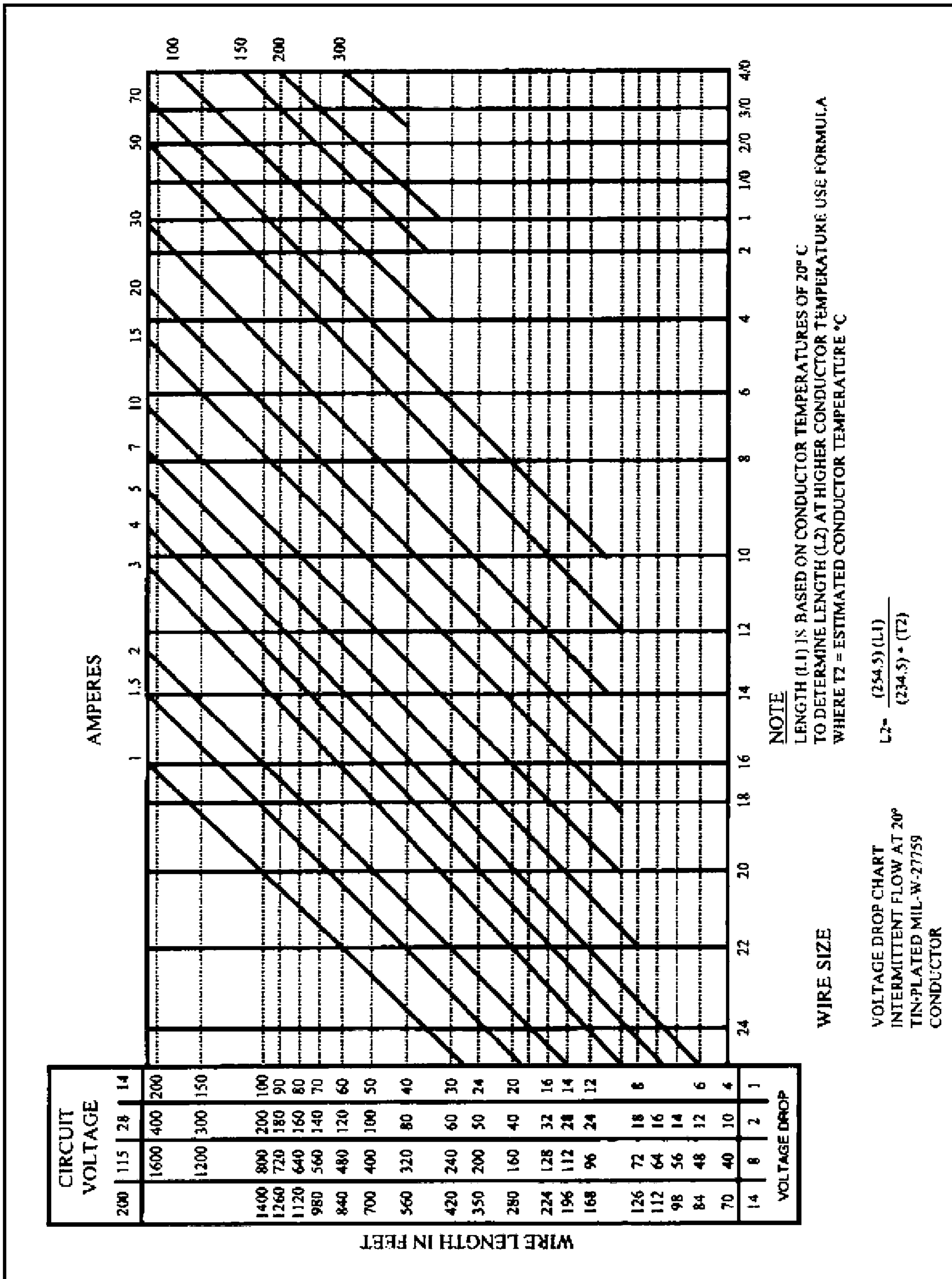


FIG. 2 Conductor Chart, Intermittent Flow

5.1.5.13 Special properties unique to the aircraft.

NOTE 2—See 5.2.10 for additional insulation properties.

5.1.6 For a more complete selection of insulated wires, refer to SAE AS 4372 and SAE AS 4373.

5.1.7 Wires are typically categorized as being suitable for either “open wiring” or “protected wiring” application.

5.2 *Aircraft Wire Materials:*

5.2.1 *Open Airframe Interconnecting Wire:*

TABLE 4 Current-Carrying Capacity and Resistance of Copper Wire

Wire Size	Continuous Duty Current (amps)—Wires in Bundles, Groups, Harnesses, or Conduits[A] — Wire Conductor Temperature Rating 105°C	150°C	200°C	Max. Resistance Ω/1000 ft at 20°C Tin-Plated Conductor[B]	Nominal Conductor Area circ.mils
24	2.5	4	5	28.40	475
22	3	5	6	16.20	755
20	4	7	9	9.88	1 216
18	6	9	12	6.23	1 900
16	7	11	14	4.81	2 426
14	10	14	18	3.06	3 831
12	13	19	25	2.02	5 874
10	17	26	32	1.26	9 354
8	38	57	71	0.70	16 983
6	50	76	97	0.44	26 818
4	68	103	133	0.28	42 615
2	95	141	179	0.18	66 500
1	113	166	210	0.15	81 700
0	128	192	243	0.12	104 500
00	147	222	285	0.09	133 000
000	172	262	335	0.07	166 500
0000	204	310	395	0.06	210 900

[A] Rating is for 70°C ambient, 33 or more wires in the bundle for sizes 24 through 10, and 9 wires for size 8 and larger, with no more than 20 % of harness current-carrying capacity being used at an operating altitude of 60 000 ft (18 288 m). For rating of wires under other conditions or configurations, see 8.2.
[B] For resistance of silver- or nickel-plated conductors, see wire specifications.

5.2.1.1 *Aircraft Wire Materials*—Only wire that meets the performance and environmental standards for airborne use shall be installed in aircraft.

5.2.1.2 *Open Airframe Interconnecting Wire*—Interconnecting wire is used in point-to-point open harnesses, normally in the interior or pressurized fuselage, with each wire providing enough insulation to resist damage from handling and service exposure. (See Table 5.) Electrical wiring is often installed in aircraft without special enclosing means. This practice is known as open wiring and offers the advantages of ease of maintenance and reduced weight.

5.2.2 *Protected Wiring:*

5.2.2.1 *Protected Wire*—Airborne wire that is used within equipment boxes, or has additional protection, such as an exterior jacket, conduit, tray, or other covering is known as protected wire. (See Table 6.)

5.2.3 *Coaxial Cables*—Table 7 lists coaxial cables acceptable for use in aircraft. Use in aircraft of cables not listed in Table 7 requires demonstration of their acceptability for the application.

5.2.3.1 *Low Temperature Coaxial and Triaxial Cables*—Coaxial and Triaxial cables with low temperature dielectrics and jackets such as Polyethylene (–40ºC to +80ºC) shall not be used. The minimum high temperature tolerance of a cable material shall be +150ºC. Use of low temperature cables near a heat source, or in a high heat area, such as behind an instrument panel, can cause the dielectric to soften and permit the center conductor to migrate. This will result in a change of impedance and will cause high signal reflections. The resultant cable heating can damage connected equipment. The center conductor may also migrate sufficiently to short circuit the cable shielding. An acceptable cable, commonly specified in aerospace applications, is RG142. This –55ºC to +200ºC rated cable has a PTFE dielectric and an FEP jacket.

5.2.4 *Plating*—Bare copper develops a surface oxide coating at a rate dependent on temperature. This oxide film is a poor conductor of electricity and inhibits determination of wire. Therefore, all aircraft wiring has a coating of tin, silver, or nickel, which has far slower oxidation rates.

5.2.5 Tin-coated copper is a very common plating material. Its ability to be successfully soldered without highly active fluxes diminishes rapidly with time after manufacture. It can be used up to the limiting temperature of 150°C.

5.2.6 *Silver-Coated Wire* is used where temperatures do not exceed 200°C (392°F).

5.2.7 *Nickel-Coated Wire* retains its properties beyond 260°C, but most aircraft wire using such coated strands have insulation systems that cannot exceed that temperature on long-term exposure. Soldered terminations of nickel-plated conductor require the use of different solder sleeves or flux than those used with tin- or silver-plated conductor.

5.2.8 *Conductor Stranding*—Due flight vibration and flexing, stranded round conductor wire shall be used to minimize fatigue breakage on smaller gauge wire. Some coaxial cables such as RG142 use a solid center conductor although, it is a copper clad steel, which has a much higher tensile strength than a tin or solid copper and therefore is acceptable for use. A coaxial cable, which is exposed to frequent or constant flexure, should always have a stranded center conductor.

5.2.9 *Wire Construction versus Application*—The most important consideration in the selection of aircraft wire is properly matching the wire's construction to the application environment. Wire construction that is suitable for the most severe environmental condition to be encountered shall be selected. AS 50881A, Appendix A, Table A-I lists wires considered to have sufficient abrasion and cut-through resistance to be suitable for open-harness construction lists wires for protected applications. These wires are not recommended for aircraft interconnection wiring unless the subject harness is covered throughout its length by a protective jacket. The wire temperature rating is typically a measure of the insulation's

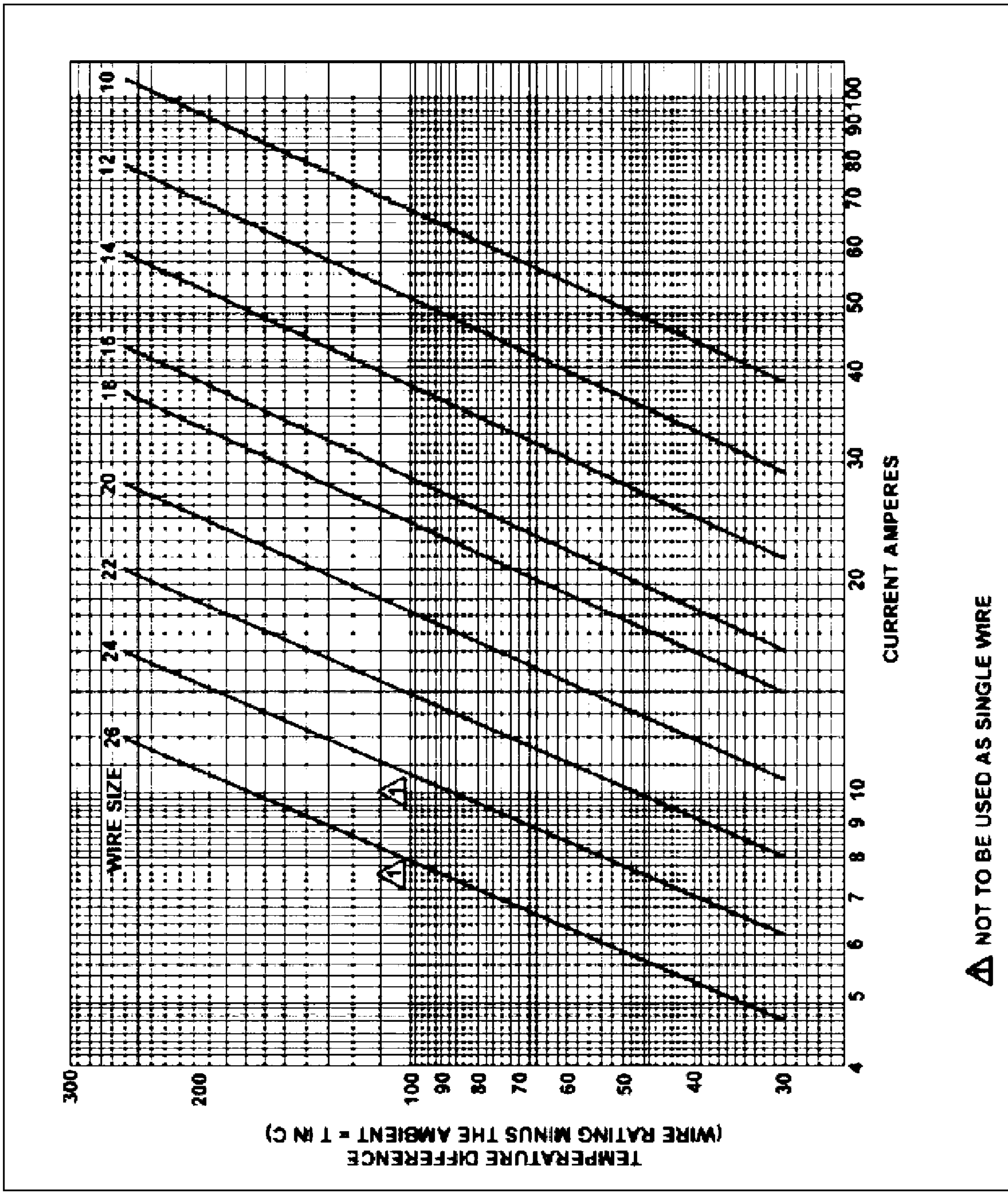


FIG. 3 Single Copper Wire in Free Air

ability to withstand the combination of ambient temperature and current related conductor temperature rise. AS 50881A, Appendix A, Table A2 lists wires for protected applications.

5.2.10 *Insulation*—There are many insulation materials and combinations used on aircraft electrical wire. Characteristics shall be chosen based on environment; such as abrasion resistance, arc resistance, corrosion resistance, cut-through strength, dielectric strength, flame resistance, mechanical strength, smoke emission, fluid resistance, and heat distortion. Table 8 ranks various wire insulation system properties in a number of categories and may be used as a guide when selecting wiring insulation for a particular application.

5.2.11 An explanation of many of the acronyms used is given in 3.3.

5.2.12 *Aluminum Wire:*

5.2.12.1 Voltage drop calculations for aluminum wires can be accomplished by multiplying the resistance for a given wire size (defined in Table 9) by the wire run length and circuit current.

5.2.12.2 For aluminum wire from Table 4 and Table 9, note that the conductor resistance of aluminum wire and that of copper wire (two numbers higher) are similar. Accordingly, the electric wire current in Table 4 can be used when it is desired to substitute aluminum wire and the proper size can be selected

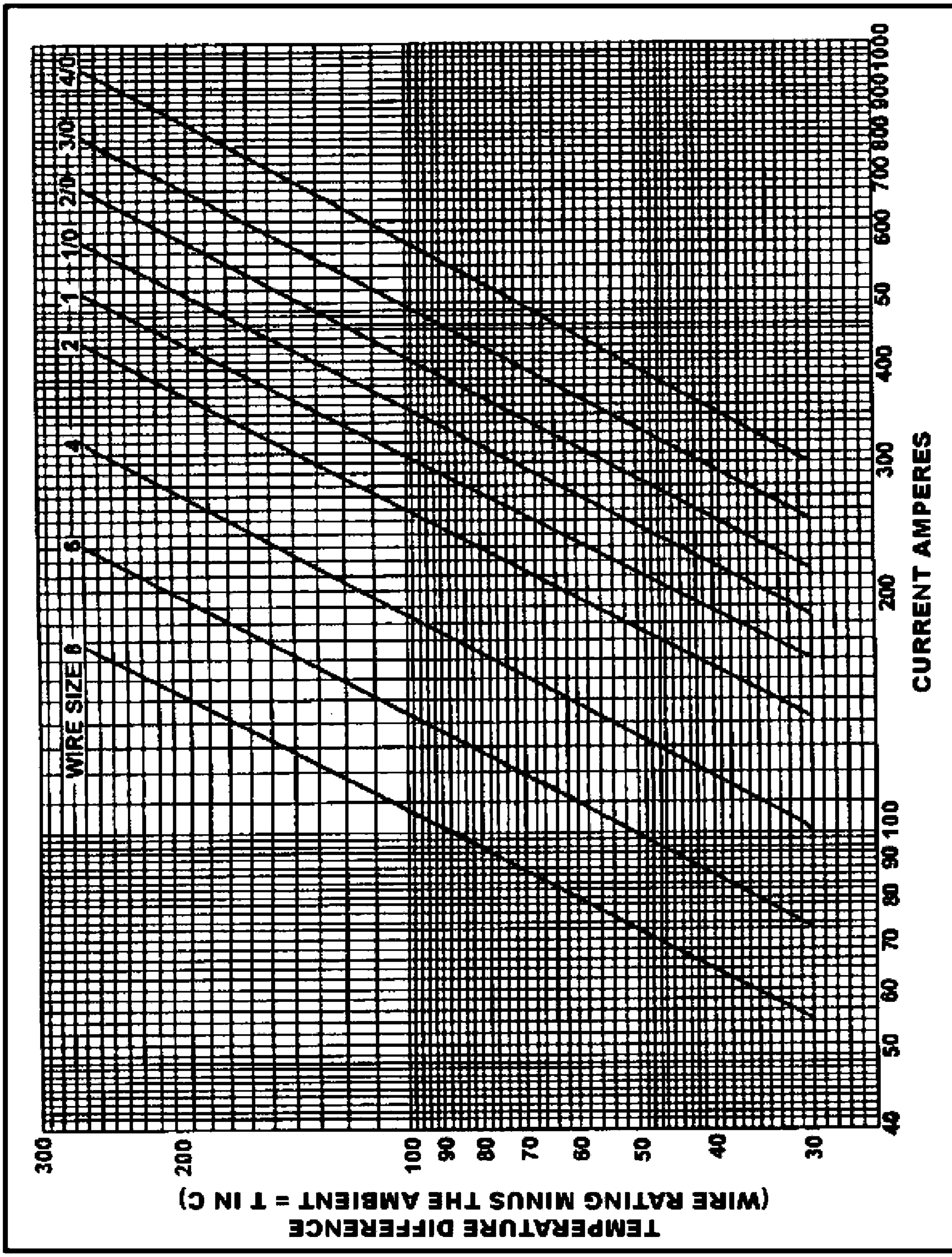


FIG. 4 Single Copper Wire in Free Air

by reducing the copper wire size by two numbers and referring to Table 4. The use of aluminum wire size smaller than No. 8 is not recommended.

5.2.12.3 *Aluminum Conductor Wire*—When aluminum conductor wire is used, sizes shall be selected on the basis of current ratings shown in Table 9. The use of sizes smaller than #8 gauge is discouraged (Refer to AS 50881A). Aluminum wire shall not be attached to engine-mounted accessories or used in areas having corrosive fumes, severe vibration, mechanical stresses, or where there is a need for frequent disconnection. Use of aluminum wire is also discouraged for runs of less than 3 ft (0.9 m) (Refer to AS 50881A). Termination hardware shall be of the type specifically designed for use with aluminum conductor wiring.

TABLE 5 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 extruded TFE	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 *	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 6 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.

5.2.13 *Shielded Wire:*

5.2.13.1 *Shielded Wire*—With the increase in number of highly sensitive electronic devices found on modern aircraft, it has become very important to ensure proper shielding for many electric circuits. Shielding is the process of applying a metallic covering to wiring and equipment to eliminate interference caused by stray electromagnetic energy. Shielded wire or cable is typically connected to the aircraft's ground at both ends of the wire or at connectors in the cable. Electromagnetic interference (EMI) is caused when electromagnetic fields (radio waves) induce high-frequency (HF) voltages in a wire or component. The induced voltage can cause system inaccuracies or even failure, therefore, putting the aircraft and passengers at risk. Shielding helps to eliminate EMI by protecting the primary conductor with an outer conductor. Refer to NEMA WC 27500, Standards for Aerospace and Industrial Electric Cable. (Replaces MIL-DTL-27500H.) Refer to 11.3 for shielding considerations related to HIRF.

5.2.13.2 *Termination of Shielded Wire*—For termination of shielded wire, refer to NEMA WC 27500 (replaces MIL-DTL-27500).

5.2.14 *Special Purpose Wire and Thermocouples:*

TABLE 7 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

TABLE 8 Comparable Properties of Wire Insulation Systems

Relative Ranking	Most Desirable → Least			
	1	2	3	4
Weight	PI	ETFE	COMP	PTFE
Temperature	PTFE	COMP	PI	ETFE
Abrasion resistance	PI	ETFE	COMP	PTFE
Cut-through resistance	PI	COMP	ETFE	PTFE
Chemical resistance	PTFE	ETFE	COMP	PI
Flammability	PTFE	COMP	PI	ETFE
Smoke generation	PI	COMP	PTFE	ETFE
Flexibility	PTFE	ETFE	COMP	PI
Creep (at temperature)	PI	COMP	PTFE	ETFE
Arc propagation resistance	PTFE	ETFE	COMP	PI

TABLE 9 Current-Carrying Capacity and Resistance of Aluminum Wire

NOTE 1—Observe design practices described in 8.2 for aluminum conductor.

Wire Size	Continuous duty current (amps) Wires in bundles, groups, harnesses, or conduits (see Table 4, footnote A)		Maximum Resistance Ω/1000 ft at 20°C
	Wire Conductor Temperature Rating		
	105°C	150°C	
8	30	45	1.093
6	40	61	0.641
4	54	82	0.427
2	76	113	0.268
1	90	133	0.214
0	102	153	0.169
00	117	178	0.133
000	138	209	0.109
0000	163	248	0.085

5.2.14.1 *Data Cables:*

(1) 100 ohm Unshielded Twisted Pair (UTP) cabling is commonly used in commercial buildings for network cabling. This category of cables is commonly referred to as Ethernet cables or “Cat” 5, “Cat” 5e or “Cat” 6. See EIA/TIA-568-B for requirements and electrical properties of these cables.

(2) Cat 5 and Cat 5e cables are used for applications up to 100 MHz. Cat 6 cables are used for applications up to 250 MHz. The maximum length of a Cat 5, 5e or 6 cable assembly from the source to a jack, called the “permanent link” is 295 ft (90 m). The maximum length of the “patch” cable which runs from the jack to the connected device is 33 ft (10 m).

(a) RJ-45 electrical connectors are nearly always used for connecting category 5 cable. Generally solid core cable is used for connecting between the wall socket and the socket in the patch panel whilst stranded cable is used for the patch leads between hub/switch and patch panel socket and between wall port and computer. However, it is possible to put plugs onto solid core cable and some installations save on the cost of patch panels or wall ports or both by putting plugs directly onto the fixed Cat 5 wiring and plugging them straight into the computers or hub/switches or both.

(3) Category 5e cable is commonly installed in commercial networking systems. Table 10 is a breakdown of the different category cables that are or have been used.

(4) ARINC 646 and ARINC 664 provide guidelines for aerospace applications of ethernet cables. The conductors shall be stranded (not solid), shielded and covered with an aerospace grade material such as FEP. Typically a cable length of 380 Ft (100M) cannot be used due to cable attenuation. The supplier specification shall be checked for maximum permitted cable length without performance degradation. Poor installation techniques, such as untwisting the pairs beyond ½ in. when terminating the cable to a connector, will also degrade system performance. Installation design shall avoid any sharp bends or kinks. See Section 7 for wiring installation requirements.

5.2.14.2 *RF Cables:*

(1) RF cables are a specific type of coaxial cable, often used for low-power video and RF signal connections.

(2) RF connectors are typically used with coaxial cables and are designed to maintain the shielding that the coaxial design offers. RF connectors are an electrical connector designed to work at radio frequencies from a few megahertz up to the gigahertz range. Better models also minimize the change in transmission line impedance at the connection.

5.2.14.3 *Thermocouples:*

TABLE 10 Unshielded Twisted Pair (UTP) Cabling Standards

Category	TIA/EIA Definition	Capability	Notes
1	Unrecognized	Transmissions up to 4Mbit/s	POTS telephone communications, ISDN and doorbell wiring
2	Unrecognized	Transmissions up to 4Mbit/s	Commonly used on 4Mbit/s token ring networks
3	TIA/EIA-568-B	Transmissions up to 16 MHz	Data networks with frequencies up to 16 MHz. Popular for 10Mbit/s ethernet networks.
4	Unrecognized	Transmissions up to 20 MHz.	Frequently used on 16Mbit/s token ring networks
5	Unrecognized	Transmissions up to 100 Mbit/s	Frequently used on 100Mbit/s ethernet networks. May be unsuitable for 100 BASE-T gigabit ethernet
5e	TIA/EIA-568-B	Transmissions up to 100 Mbit/s	Frequently used for both 100 Mbit/s and 1 Gbit/s ethernet networks
6	TIA/EIA-568-B	Transmissions up to 250 MHz	Has more than double the performance of category 5 and 5e
7	ISO/IEC 11801 Class F	Transmissions up to 600 MHz	Specification for 4 individually shielded pairs inside an overall shield

(1) Thermocouples are a widely used type of temperature sensor. They are interchangeable, have standard connectors, and can measure a wide range of temperatures. The main limitation is accuracy; system errors of less than 1°C can be difficult to achieve. Thermocouples are usually selected to ensure that the measuring equipment does not limit the range of temperatures that can be measured. Note that thermocouples with low sensitivity (B, R, and S) have a correspondingly lower resolution. Thermocouple Types B, R, and S are all noble metal thermocouples and exhibit similar characteristics. They are the most stable of all thermocouples, but because of their low sensitivity, they are usually only used for high-temperature measurement (>300°C). A thermopile is a group of thermocouples connected in series. When any conductor (such as a metal) is subjected to a thermal gradient, it will generate a small voltage. Thermocouples make use of this effect.

(2) Thermocouples produce an output voltage that depends on the temperature difference between the junctions of two dissimilar metal wires. It is important to appreciate that thermocouples measure the temperature difference between two points, not absolute temperature. In most applications, one of the junctions—the "cold junction"—is maintained at a known (reference) temperature, while the other end is attached to a probe. For example, in Fig. 3, the cold junction will be at copper tracks on the circuit board. Another temperature sensor will measure the temperature at this point, so that the temperature at the probe tip can be calculated. The relationship between the temperature difference and the output voltage of a thermocouple is nonlinear and is given by a polynomial equation (which is fifth to ninth order depending on thermocouple type). To achieve accurate measurements, some type of linearization shall be carried out, either by a microprocessor or by analog means.

(3) A variety of thermocouples are available, suitable for different measuring applications.

(a) Type K Ni-Cr alloy/Ni-Al alloy—This is the "general purpose" thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. They are available in the −200 to +1200°C range. The Ni-Al alloy consists of 95 % nickel, 3 % manganese, 2 % aluminum, and 1 % silicon. This magnetic alloy is used for thermocouples and thermocouple extension wire.

(b) Type E (Ni-Cr alloy/Constantan (Cu-Ni alloy))—Type E has a high output that makes it well suited to low-temperature use. Another property is that it is nonmagnetic.

(c) Type J (iron/Constantan)—The limited range (−40 to +750°C) makes Type J less popular than Type K. The main application is with older equipment that cannot accept "modern" thermocouples. J types cannot be used above 760°C as an abrupt magnetic transformation causes permanent decalibration.

(d) Type N (Nicrosil (Ni-Cr-Si alloy) / Nisil (Ni-Si alloy))—High stability and resistance to high-temperature oxidation makes Type N suitable for high-temperature measurements without the cost of platinum (B, R, S) types. Designed to be an "improved" type K.

(e) Type B (platinum-rhodium/Pt-Rh)—Suited for high-temperature measurements up to 1800°C. Unusually, Type B thermocouples give the same output at 0 and 42°C. This makes them useless below 50°C.

(f) Type R (platinum/rhodium)—Suited for high-temperature measurements up to 1600°C. Low sensitivity and high cost makes them unsuitable for general-purpose use.

(g) Type S (platinum/rhodium)—Suited for high-temperature measurements up to 1600°C. Low sensitivity and high cost makes them unsuitable for general-purpose use. Because of its high stability, Type S is used as the standard of calibration for the melting point of gold (1064.43°C).

(h) Type T (copper/constantan)—Suited for measurements in the −200 to 0°C range. The positive conductor is made of copper, and the negative conductor is made of constantan.

5.2.14.4 *Waveguides:*

(1) A waveguide is a physical structure that guides the propagation of electromagnetic waves. Waveguides can be constructed to carry waves over a wide portion of the electromagnetic spectrum, but are especially useful in the microwave and optical frequency ranges. Depending on the frequency, they can be constructed from either conductive or dielectric materials. Waveguides are used for transferring both power and communication signals.

(2) A slotted waveguide is generally used for radar and other similar applications. The waveguide structure has the capability of confining and supporting the energy of an electromagnetic wave to a specific relatively narrow and controllable path.

(3) A closed waveguide is an electromagnetic waveguide:

(a) That is tubular, usually with a circular or rectangular cross section,

(b) That has electrically conducting walls, that may be hollow or filled with a dielectric material,

(c) That can support a large number of discrete propagating modes, though only a few may be practical,

(d) In which each discrete mode defines the propagation constant for that mode,

(e) In which the field at any point is describable in terms of the supported modes,

(f) In which there is no radiation field, and

(g) In which discontinuities and bends cause mode conversion but not radiation.

5.3 *Table of Acceptable Wires:*

5.3.1 *Using the Aircraft Wire Tables:*

5.3.1.1 *Aircraft Wire Table*—Tables 5 and 6 list wires used for the transmission of signal and power currents in aircraft. They do not include special purpose wires such as thermocouple, engine vibration monitor wire, fiber optics, data bus, and other such wire designs. Fire-resistant wire is included because it is experiencing a wider application in aircraft circuits beyond that of the fire detection systems.

5.3.1.2 All wires in Tables 5-7 have been determined to meet the flammability requirements of Title 14 of the Code of Federal Regulation (14 CFR) Part 23, 23.1359 and Part 25 Section 25.869(a)(4), including the applicable portion of Appendix F of Part 25.

5.3.1.3 The absence of any wire from Tables 5-7 is not to be construed as being unacceptable for use in aircraft. However, the listed wires have all been reviewed for such use and have been found suitable or have a successful history of such usage.

5.3.1.4 Explanations of the various insulation materials mentioned in Table 8 by acronyms can be found in 3.3.

5.4 *Severe Wind and Moisture Problems (SWAMP):*

5.4.1 Areas designated as 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.

5.4.2 *SWAMP*—Areas such as wheel wells, wing fold and pylons, flap areas, and those areas exposed to extended weather shall dictate selection and will require special consideration. Insulation or jacketing will vary according to the environment. Suitable wire types selected from SAE AS 22759 (replaces MIL-W-22759) shall be used in these applications. (See Tables 5 and 6.) Suitable wire types selected from SAE AS 22759 (replaces MIL-W-22759) are preferred for areas that require repeated bending and flexing of the wire. Consideration shall be made to areas that require frequent component removal or repair.

5.5 *Grounding and Bonding:*

5.5.1 One of the more important factors in the design and maintenance of aircraft electrical systems is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, for example, EMI, electrostatic discharge damage to sensitive electronics, personnel shock hazard, or damage from lightning strike. See 7.8 for grounding and bonding installation details.

5.6 *Electrical Wire Chart:*

5.6.1 *Instructions for Use of Electrical Wire Chart:*

5.6.1.1 *Correct Size*—To select the correct size of electrical wire, two major requirements shall be met:

(1) The wire size shall be sufficient to prevent an excessive voltage drop while carrying the required current over the required distance. (See Table 1 for allowable voltage drops.)

(2) The size shall be sufficient to prevent overheating of the wire carrying the required current. (See 8.2 for allowable current-carrying calculation methods.)

5.6.2 *Two Requirements*—To meet the two requirements (see 5.6.1) in selecting the correct wire size using Fig. 1 or Fig. 2, the following must be known:

(1) The wire length in feet,

(2) The number of amperes of current to be carried,

(3) The allowable voltage drop permitted,

(4) The required continuous or intermittent current,

(5) The estimated or measured conductor temperature,

(6) Is the wire to be installed in conduit or bundle or both, and

(7) Is the wire to be installed as a single wire in free air?

5.6.3 *Example No. 1*—Find the wire size in Fig. 1 using the following known information:

(1) The wire run is 50 ft (15 m) long, including the ground wire,

(2) Current load is 20 A,

(3) The voltage source is 28 V from bus to equipment,

(4) The circuit has continuous operation, and

(5) Estimated conductor temperature is 20°C or less.

5.6.3.1 The scale on the left of the chart represents maximum wire length in feet to prevent an excessive voltage drop for a specified voltage source system (for example, 14, 28, 115, and 200 V). This voltage is identified at the top of scale and the corresponding voltage drop limit for continuous operation at the bottom. The scale (slant lines) on top of the chart represents amperes. The scale at the bottom of the chart represents wire gage.

Step 1—From the left scale find the wire length, 50 ft (15 m) under the 28-V source column.

Step 2—Follow the corresponding horizontal line to the right until it intersects the slanted line for the 20-A load.

Step 3—At this point, drop vertically to the bottom of the chart. The value falls between Nos. 8 and 10. Select the next larger size wire to the right, in this case, No. 8. This is the smallest size wire that can be used without exceeding the voltage drop limit expressed at the bottom of the left scale. This example is plotted on the wire chart, Use Fig. 1 for continuous flow and Fig. 2 for intermittent flow.

5.6.4 Procedures in 5.6.3 can be used to find the wire size for any continuous or intermittent operation (maximum 2 min). Voltage (for example, 14, 28, 115, and 200 V) as indicated on the left scale of the wire chart in Fig. 1 for continuous flow and Fig. 2 for intermittent flow.

5.6.5 *Example No. 2*—Using Fig. 1, find the wire size required to meet the allowable voltage drop in Table 1 for a wire-carrying current at an elevated conductor temperature using the following information:

(1) The wire run is 15.5 ft (5 m) long, including the ground wire.

(2) Circuit current (I2) is 20 A, continuous.

(3) The voltage source is 28 V.

(4) The wire type used has a 200°C conductor rating and it is intended to use this thermal rating to minimize the wire gage. Assume that the method described in 5.1.2.9 was used and the minimum wire size to carry the required current is #14.

(5) Ambient temperature is 50°C under hottest operating conditions.

5.6.5.1 *Procedures in Example No. 2:*

Step 1—Assuming that the recommended load bank testing described in 5.1.2.8 is unable to be conducted, then the estimated calculation methods outlined in 5.1.2.9 may be used to determine the estimated maximum current (I_{max}). The #14 gage wire mentioned in 5.6.5 can carry the required current at 50°C ambient (allowing for altitude and bundle derating).

(1) Use Figs. 3 and 4 to calculate the I_{max} a #14 gage wire can carry where: T_2 = estimated conductor temperature, T_1 = 50°C ambient temperature, and T_R = 200°C maximum conductor rated temperature.

(2) Find the temperature differences ($T_R - T_1$) = (200 – 50°C) = 150°C.

(3) Follow the 150°C corresponding horizontal line to intersect with #14 wire size, drop vertically, and read 47 A at bottom of chart (current amperes).

(4) Use Fig. 5. Left side of chart reads 0.91 for 20 000 ft (6096 m), multiple 0.91 × 47 A = 42.77 A.

(5) Use Fig. 5. Find the derating factor for eight wires in a bundle at 60 %. First find the number of wires in the bundle (eight) at bottom of graph and intersect with the 60 % curve meet. Read derating factor (left side of graph) which is 0.6. Multiply 0.6 × 42.77 A = 26 A. I_{max} = 26 A (this is the maximum current the #14 gage wire could carry at 50°C ambient L_1 = 15.5-ft (5-m) maximum run length for size #14 wire carrying 20 A from Fig. 1.

Step 2—From 5.1.2.8 and 5.1.2.9, determine the T_2 and the resultant maximum wire length when the increased resistance of the higher temperature conductor is taken into account.

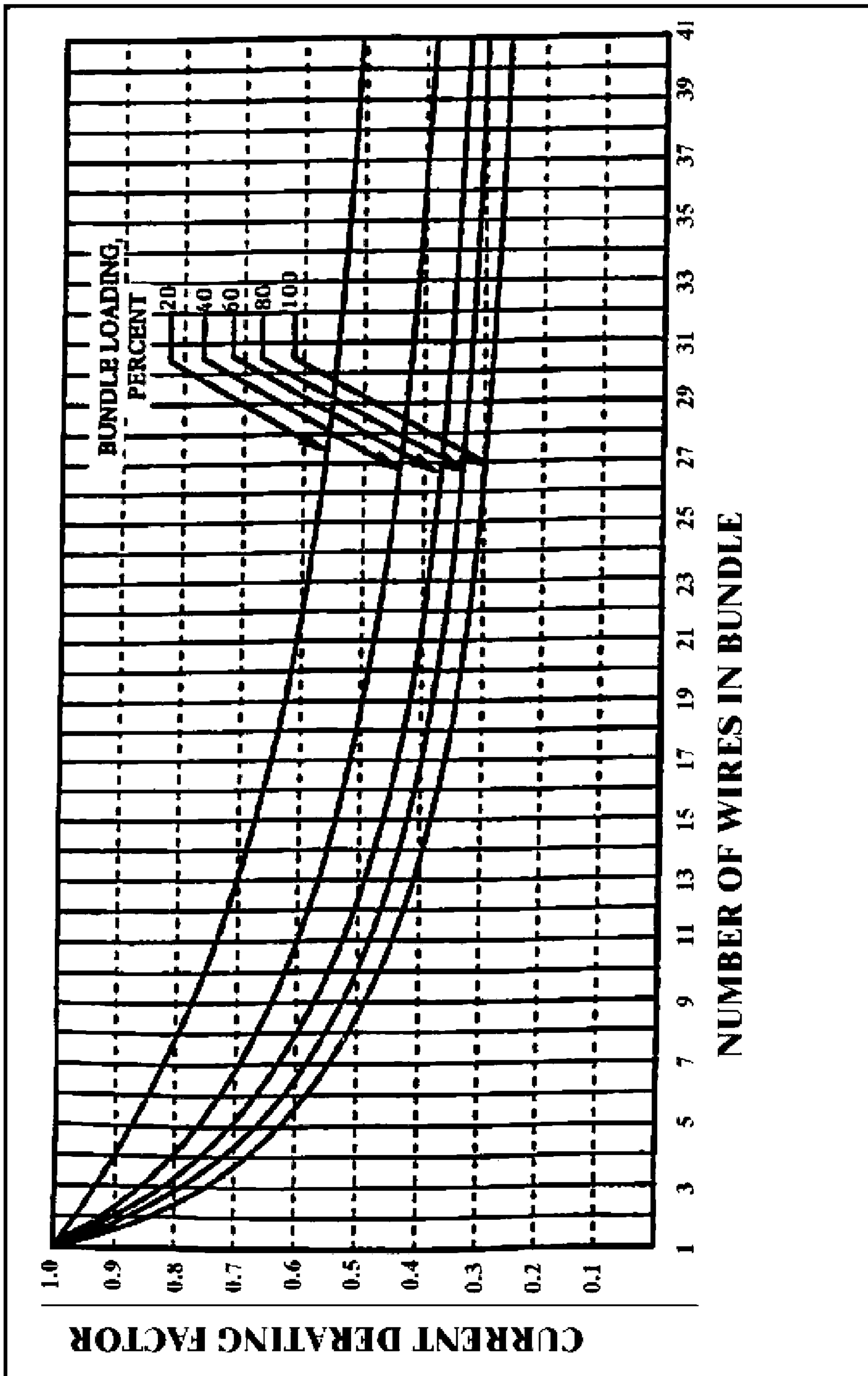


FIG. 5 Bundle Derating Curves

$$T_2 = T_1 + (T_R - T_1)\sqrt{(I_2/I_{max})}$$
$$T_2 = 50°C + (200°C - 50°C)\sqrt{(20A/26A)} = 50°C + (150°C)(0.877)$$
$$T_2 = 182°C$$
$$L_2 = (254.5°C)(L_1)/(234.5°C) + (T_2)$$
$$L_2 = (254.5°C)(15.5\ ft)/(234.5°C) + (182°C)$$
$$L_2 = 9.5\ ft$$

(1) The size #14 wire selected using the methods outlined in 5.6.5 is too small to meet the voltage drop limits from Fig. 1 for a 15.5-ft (5-m) long wire run.

Step 3—Select the next larger wire (size #12) and repeat the calculations as follows: L_1 = 24-ft (7-m) maximum run length for 12-gage wire carrying 20 A from Fig. 1. I_{max} = 37 A (this is the maximum current the size #12 wire can carry at 50°C ambient. Use calculation methods outlined in 8.2, Figs. 3 and 4.

$$T_2 = T_1 + (T_R - T_1)\sqrt{(I_2/I_{max})}$$
$$T_2 = 50°C + (200°C - 50°C)\sqrt{(20A/37A)} = 50°C + (150°C)(-540)$$
$$T_2 = 131°C$$
$$L_2 = (254.5°C)(L_1)/(234.5°C) + (T_2)$$
$$L_2 = (254.5°C)(24\ ft)/(234.5°C) + (131°C) = 6108/366$$
$$L_2 = (254.5°C)(24\ ft)/366$$
$$L_2 = 16.7\ ft$$

(1) The resultant maximum wire length, after adjusting downward for the added resistance associated with running the wire at a higher temperature, is 15.4 ft (4.7 m), which will meet the original 15.5-ft (5-m) wire run length requirement without exceeding the voltage drop limit expressed in Fig. 1.

6. Wire and Cable Identification

6.1 *General*—The proper identification of electrical wires and cables with their circuits and voltages is necessary to provide safety of operation, safety to maintenance personnel, and ease of maintenance.

6.1.1 Each wire and cable shall be marked with a unique identifier.

6.1.2 The method of identification shall not impair the characteristics of the wiring. (**Warning—**Do not use metallic bands in place of insulating sleeves. Exercise care when marking coaxial or data bus cable, as deforming the cable may change its electrical characteristics.)

6.1.3 A current method for identifying the wires and cables connected to EMI-sensitive systems consists of a suffix to the wire number that identifies the susceptibility to EMI and indicates that specific handling instructions are detailed in the aircraft wiring manual. This suffix shall remain at the end of the significant wire number regardless of the requirement for any other suffix. Fig. 6 provides an example of a wire identification number with the EMI identifier included.

6.1.4 The identification of EMI-sensitive wiring is dependent on the following:

6.1.4.1 Level of shielding or protection applied to the wire (for example, twisted pair, shielded wire, and so forth);

6.1.4.2 Electromagnetic susceptibility of the coupled victim equipment;

6.1.4.3 Physical separation between the subject wiring and potential electromagnetic sources (including other wires); and/or

6.1.4.4 The type of grounding/bonding methods used.

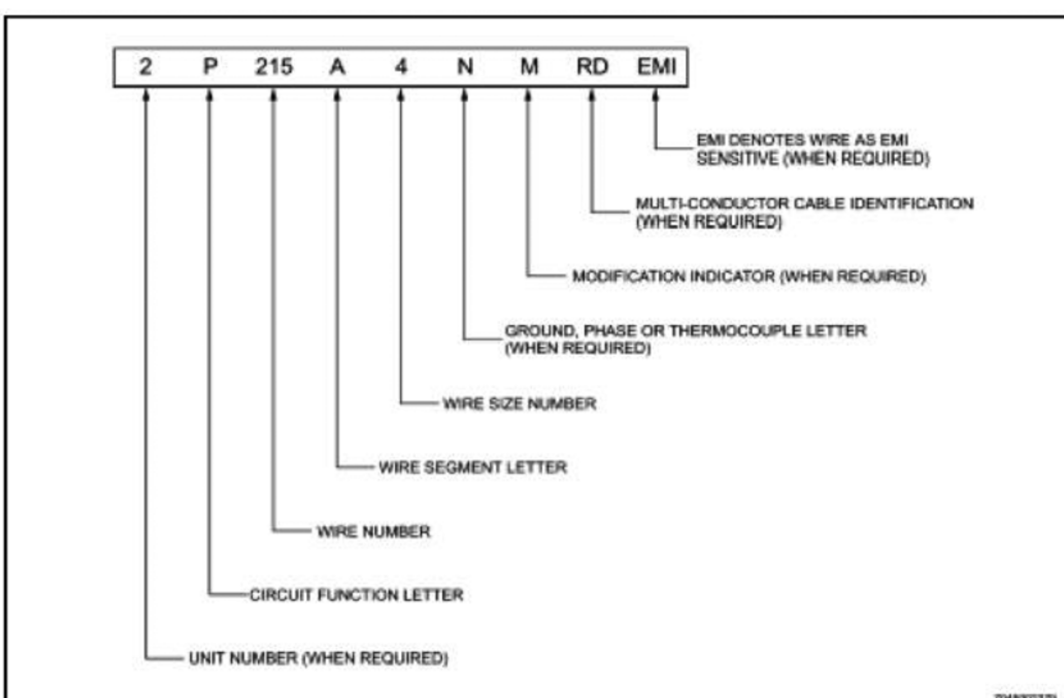


FIG. 6 Example of Wire Identification Coding

6.1.5 Audio and data signals are often the most susceptible to EMI. Other typical waveforms that are more susceptible to EMI have the following characteristics:

6.1.5.1 Low voltage,

6.1.5.2 Low current, and/or

6.1.5.3 Slow rise times.

6.1.6 SAE AS 50881 Wiring, Aerospace Vehicle, requires sensitive wiring to be routed to avoid electromagnetic interference. SAE AS 50881 Appendix B allows for, but does not mandate, the identification of EMI sensitive wires and cables with a category code added to the significant wire number. In the past, EMI-sensitive wires and cables added during modification of aircraft have been isolated in accordance with the specification, however they have not been identified as EMI sensitive and therefore their integrity may be compromised during subsequent aircraft modification. Where wires and cables are susceptible to EMI and are identified as critical to the safety of flight (SOF) of the aircraft, they shall be identified with red sleeves. (This is in addition to the EMI suffix on the wire identification code). The red sleeves (heat shrink is appropriate) shall be a minimum of 2 in. (5 cm) in length and positioned at intervals no greater than 15 in. (38 cm) along the entire length of the wire or loom, using application methods detailed in this manual. Marking of the sleeving to further highlight the EMI sensitivity is optional, but shall be consistent with existing aircraft labeling practices and clearly documented in wiring publications. (See Fig. 6.)

6.1.7 The sleeving procedure detailed above is also appropriate for non-SOF systems that are sensitive to EMI and where interference may affect the airworthiness of the aircraft.

6.2 *Wire and Cable Identification:*

6.2.1 *Wire Identification*—The wire identification marks shall consist of any combination of letters, numbers, and colors that identify the wire and relates the wire to a wiring diagram. Ensure all wires and cables are identified properly. All markings shall be legible in size, type, and color. Wires and cables for which the identification is reassigned after installation may be reidentified by an appropriate approved method of marking at each termination point and at each junction. It is not necessary to reidentify these wires and cables throughout their length. When replacing wire or cable, as part of a repair or alteration the original wire-marking identification shall be retained.

6.2.2 *Identification and Information Related to the Wire and Wiring Diagrams*—The wire identification marking shall consist of similar information to relate the wire to a wiring diagram. Each wire, cable, and bundle assembly shall be identified with the identification code and such other information as specified on the engineering drawing.

6.2.3 *Identification of Wire Bundles and Harnesses*—The identification of wire bundles and harnesses may be accomplished by the use of a marked sleeve tied in place or by the use of pressure sensitive tape as indicated in Fig. 7.

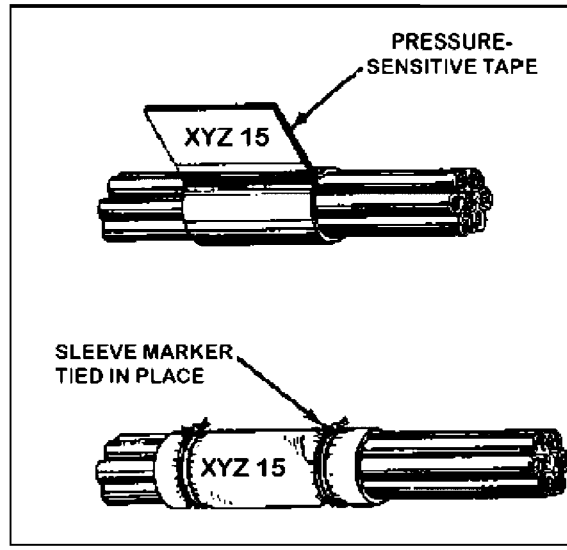


FIG. 7 Identification of Wire Bundles and Harnesses

6.3 *Types of Markings:*

6.3.1 *Direct Marking* (preferred method) is accomplished by printing the wire or cable's outer covering. If this is not practical, successful requirement qualification shall produce markings that meet the marking characteristics specified in AS 50881A (replaces MIL-W-5088) without causing insulation degradation. Appropriate processes shall be used when marking wire to avoid insulation damage during the marking process.

6.3.2 *Indirect Marking* is accomplished by placing printed identification tape, tags, sleeves, or heat-shrinkable sleeves on the wire or cables outer covering.

6.3.2.1 *Indirect Marking*—Identification tape, tags, sleeves, and heat-shrinkable sleeve.

(1) Identification Tape—Identification tape can be used in place of sleeving in most cases (for example, polyvinylfluoride).

(2) Identification Sleeves—Flexible sleeving, either clear or opaque, is satisfactory for general use. When color-coded or striped component wire is used as part of a cable, the identification sleeve shall specify which color is associated with each wire identification code. Identification sleeves are normally used for identifying the following types of wire or cable:

(a) Unjacketed Shielded Wire.

(b) Thermocouple Wire—Thermocouple wire identification is normally accomplished by means of identification sleeves. As the thermocouple wire is usually of the duplex type (two insulated wires within the same casing), each wire at the termination point bears the full name of the conductor. Thermocouple conductors are nickel-aluminum alloy, nickel-chrome alloy, iron, constantan, and copper constantan.

(c) Coaxial Cable—Coaxial cable shall not be hot stamped directly. When marking coaxial cable, care shall be taken not to deform the cable as this may change the electrical characteristics of the cable. When cables cannot be printed directly, they shall be identified by printing the identification code (and individual wire color, where applicable) on a nonmetallic material placed externally to the outer covering at the terminating end and at each junction or pressure bulkhead. Cables not enclosed in conduit or a common jacket shall be identified with printed sleeves at each end and at intervals not

longer than 3 ft (0.9 m). Individual wires within a cable shall be identified within 3 in. (8 cm) from their termination.

(d) High-Temperature Wire—High-temperature wire with insulation is difficult to mark (such as fluorinated ethylene propylene (FEP) coating and fiberglass).

(3) Operating Conditions—For sleeving exposed to high temperatures (over 400°F (204.4°C)), materials such as silicone fiberglass shall be used.

(4) Installation of Printed Sleeves—Polyolefin sleeving shall be used in areas in which resistance to solvent and synthetic hydraulic fluids is necessary. Sleeves may be secured in place with cable ties or by heat shrinking. The identification sleeving for various sizes of wire is shown in Table 11.

6.3.3 Whatever method of marking is used, the marking shall be legible and the color shall contrast with the wire insulation or sleeve. The major types of wire marking machines used today are hot stamp, ink jet, laser and dot matrix. Whichever method is used, the machine manufacturing instructions must be followed as improper machine operation may damage the wire insulation.

6.3.4 *Dot Matrix Marking:*

6.3.4.1 The dot matrix marking is imprinted onto the wire or cable in a very similar manner to that of a dot matrix computer printer. The wire shall go through a cleaning process to make sure it is clean and dry for the ink to adhere. Wires marked with dot matrix equipment require a cure consisting of an UV curing process, which is normally applied by the marking equipment. This cure should normally be complete 16 to 24 hours after marking. Dot matrix makes a legible mark without damaging the insulation. Multiconductor cable can also be marked.

6.3.5 *Ink Jet Marking:*

6.3.5.1 This is a "nonimpact" marking method wherein ink droplets are electrically charged and then directed onto the moving wire to form the characters. Two basic ink types are available: thermal cure and UV cure.

6.3.5.2 Thermal cure inks shall generally be heated in an oven for a length of time after marking to obtain their durability. UV cure inks are cured in line much like dot matrix.

TABLE 11 Recommended Size of Identification Sleeving

Wire Size		Sleeving Size	
AN	AL	No.	Nominal ID (in.)[A]
#24	#8	12	0.085
#22	#6	11	0.095
#20	#4	10	0.106
#18	#2	9	0.118
#16	#1	8	0.113
#14	#0	7	0.148
#12	#00	6	0.166
#10	#000	4	0.208
#8	#0000	2	0.263
#6		0	0.330
#4		⅜ in.	0.375
#2		½ in.	0.500
#1		½ in.	0.500
#0		⅝ in.	0.625
#00		⅝ in.	0.625
#000		¾ in.	0.750
#0000		¾ in.	0.750

[A] 1 in. = 2.54 cm.

6.3.5.3 Ink jet marks the wire on the fly and makes a reasonably durable and legible mark without damaging the insulation. Multiconductor cable can also be marked.

NOTE 3—When using dot matrix or ink jet, care should be taken on the cleaning process as the durability of the mark is dependent on the ink's adherence to the wire insulation. The marks shall pass the durability requirements of AS 50881A (replaces MIL-W-5088).

6.3.6 *Laser Marking:*

6.3.6.1 Lasers mark wire by changing the color of the titanium dioxide (TiO_2) from white to gray. This is done by theTiO_2 absorbing energy from the laser and heating to a high temperature. This heat is very localized and is for a very short period of time. Lasers have frequencies varying from UV, visible, and infrared (IR). Titanium dioxide absorbs these frequencies at different rates, making some lasers faster than others. The insulation must have sufficient TiO_2 in the formulation to create a mark before the polymer (plastics) holding the TiO_2 becomes hot enough to char.

NOTE 4—If operated improperly, the laser can burn the insulation resulting in a defective part. The manufacturer's instructions must be followed.

6.3.6.2 Lasers leave a mark from 0.0002 to 0.0015 in. (0.0005 to 0.0038 cm) deep in the insulation depending on the type and frequency of laser used. The marks are extremely durable and solvent resistant. Lasers can mark on the fly and mark multi-conductor cable.

6.3.7 *Hot Stamp Marking:*

6.3.7.1 Hot stamp process uses a heated typeface to transfer pigment from a ribbon or foil to the surface of wires or cables. The traditional method imprints hot ink marks onto the wire. Exercise caution when using this method as it has been shown to damage insulation when incorrectly applied. Typeset characters, similar to that used in printing presses but shaped to the contour of the wire, are heated to the desired temperature. Wire is pulled through a channel directly underneath the characters. Always use type face with the proper curve radius to match the radius of the wire being marked. The heat of the type set characters transfers the ink from the marking foil onto the wire. To minimize the effect of hot stamping on wiring insulation personnel shall refer to SAE ARP 5369 and MIL-M-81531 for guidance.

6.3.7.2 Proper marking is obtained only by the correct combination of temperature, pressure, and dwell time.

6.3.7.3 Before producing hot stamp wire, it shall be assured that the marking machine is properly adjusted to provide the best wire marking with the least wire insulation deterioration. The marking shall never create an indent greater than 10 % of the insulation wall. Stamping dies may cause fracture of the insulation wall and penetration to the conductor of these materials. Later in service, when various fluids have wet these openings, serious arcing and surface tracking may have damaged wire bundles. (**Warning—**The traditional hot stamp method is not recommended for use on wire with outside diameters of less than 0.035. (Reference SAE ARP 5369.))

NOTE 5—Some hot stamp machines do not have a mechanical stop and the wire will take the full force of the stamping machine. On these machines, the stamping process is extremely important. The total pressure of the machine is divided among the number of characters being marked so it varies with each set up.

6.3.7.4 *Spark Test*—This test shall be used when using a hot stamp method. This will test the wire insulation for fractures. It can be used during the hot stamp process or as a secondary operation. To ensure a good test, the manufacturer's instructions must be followed.

NOTE 6—Some wire insulations that have a high notch effect (exhibit a large reduction in tear strength after a small notch is placed in the material), that is, polyimide shall not be hot stamped even with a spark test.

6.4 *Sleeve and Cable Marker Selection:*

6.4.1 *Terminal Marking Sleeve and Tags*—Typical cable markers are flat, nonheat-shrinkable tags. Heat-shrinkable marking sleeves are available for marking wires and cables and shall be inserted over the proper wire or cable and heat shrunk using the proper manufacturer recommended heating tool. (See Figs. 8 and 9.)

6.4.2 *Sleeves and Cable Markers Selection*—Sleeves and cable markers shall be selected by cable size and operating conditions. (See Tables 12-15.)

6.4.3 Markers are printed using a typewriter with a modified roller. Blank markers on a bandolier are fed into the typewriter where they are marked in any desired combination of characters. The typed markers, still on bandoliers, are heated in an infrared heating tool that processes the markers for permanency. The typed and heat-treated markers remain on the bandolier until ready for installation.

6.4.4 Markers are normally installed using the following procedure:

6.4.4.1 Select the smallest tie-down strap that will accommodate the outside diameter of the cable. (See Table 16.)

6.4.4.2 Cut the marking plate from the bandolier. (See Fig. 10.)

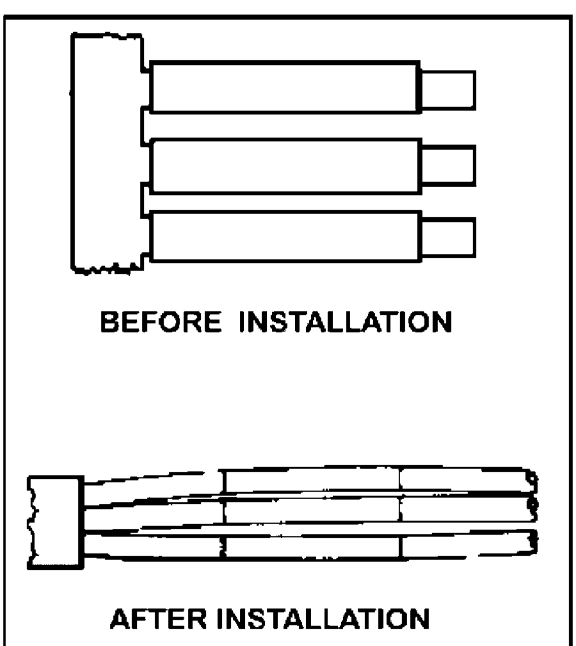


FIG. 8 Standard Sleeves (135ºC)

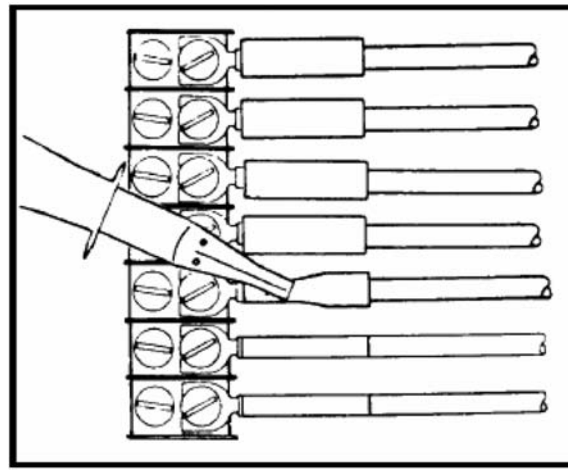


FIG. 9 Installation of Heat-Shrinkable Insulation Sleeves

6.4.4.3 Thread the tie-down straps through holes in marking plate and around cable. Thread tip of tie-down strap through slot in head. (See Fig. 11.) Pull tip until strap is snug around cable.

6.4.4.4 Select the applicable installation tool and move the tension setting to the correct position. (See Fig. 12.)

6.4.4.5 Slide tip of strap into opening in the installation tool nose piece. (See Fig. 12.)

6.4.4.6 Keeping tool against head of tiedown strap, ensure gripper engages tie-down strap and squeeze trigger of installation tool until strap installation is completed as shown in Fig. 13.

6.5 *Placement of Identification Markings*—Placement of Identification Markings Wire identification codes shall be printed to read horizontally (from left to right) or vertically (from top to bottom). Identification sleeves shall be added as required during installation and so located that ties, clamps or supporting devices need not be removed to identify a cable or wire.

6.5.1 *Direct Marking* identification markings shall be placed at each end of the wire or cable at 3 in. (8 cm) maximum intervals (measured from the end of one mark to the start of the next) on the first and last 30 in. (76 cm) of each wire or cable, and a maximum of 15 in. (38 cm) intervals in the center. (See Fig. 14*(b)*.) Wires 6 to 10 in. (16 to 25 cm) in length shall be identified approximately in the center. Wires less than 6 in. (16 cm) long need not be identified.

6.5.1.1 *Multiple Wires in Sleeve*—Individual wires extending more than 6 in. (16 cm) from a cable shall be identified as an individual wire. (See Fig. 14*(a)*.)

6.5.2 Indirect-marked wire or cable shall be identified with printed sleeves at each end and at intervals not longer than 6 ft (2 m). The individual wires extending more than 6 in. (16 cm) from a cable shall be identified as an individual wire. (See Fig. 15.)

6.5.3 *Coaxial Cables* shall be identified within 3 in. (8 cm) of both equipment ends.

6.5.4 *Temporary Marking:*

TABLE 12 Selection Table for Standard Sleeves

Wire or Cable Diameter Range (in.)		Markable Length^A (in.)	Installed Sleeve Length (nom) (in.)	Installed Wall Thickness (max in.)	As-Supplied Inside Diameter (min in.)
Min	Max				
0.050	0.080	18	1.5	0.026	0.093
0.075	0.110	18	1.5	0.026	0.125
0.100	0.150	18	1.5	0.028	0.187
0.135	0.215	18	1.5	0.028	0.250
0.200	0.300	18	1.5	0.028	0.375
0.135	0.300	18	1.5	0.028	0.375
0.260	0.450	18	1.5	0.028	0.475

^A Based on twelve characters per inch. 1 in. = 2.54 cm.

TABLE 13 Selection Table for Thin-Wall Sleeves

Wire or Cable Diameter Range (in.)		Markable Length^A (in.)	Installed Sleeve Length (nom) (in.)	Installed Wall Thickness (max in.)	As-Supplied Inside Diameter (min in.)
Min	Max				
0.035	0.080	22	1.75	0.020	0.093
0.075	0.110	22	1.75	0.020	0.125
0.100	0.150	21	1.75	0.021	0.187
0.135	0.225	21	1.75	0.021	0.250

^A Based on twelve characters per inch. 1 in. = 2.54 cm.

TABLE 14 Selection Table for High-Temperature Sleeves

Wire or Cable Diameter Range (in.)		Markable Length^A (in.)	Installed Sleeve Length (nom) (in.)	Installed Wall Thickness (max in.)	As-Supplied Inside Diameter (min in.)
Min	Max				
0.035	0.080	18	1.5	0.019	0.093
0.075	0.110	18	1.5	0.016	0.125
0.100	0.150	18	1.5	0.018	0.187
0.135	0.215	18	1.5	0.018	0.250
0.200	0.300	18	1.5	0.018	0.375
0.260	0.450	18	1.5	0.018	0.475

^A Based on twelve characters per inch. 1 in. = 2.54 cm.

TABLE 15 Selection Table for Cable Markers

Cable Diameter Range (in.)^A	Type of Cable Marker	Number of Attachment Holes	Number of Lines of Type	Marker Thickness (nom) (in.)^A
0.25-0.50	Standard, 135°C	4	2	0.025
0.25-0.50	High Temperature, 200°C	4	2	0.020
0.25-0.50	Nuclear, 135°C	4	2	0.025
0.50-up	Standard, 135°C	4	3	0.025
0.50-up	Standard, 135°C	6	3	0.025
0.50-up	High Temperature, 200°C	4	3	0.020
0.50-up	High Temperature, 200 °C	6	3	0.020
0.50-up	Nuclear, 135°C	4	3	0.025
0.50-up	Nuclear, 135°C	6	3	0.025

^A 1 in. = 2.54 cm.

6.5.4.1 *Temporary Wire and Cable-Marking Procedure*—A temporary wire-marking procedure is given in this section but shall be used only with caution and plans for future permanence. (See Fig. 16.)

6.5.4.2 With a pen or a typewriter, write wire number on good quality white split insulation sleeve. Computer-generated printed identification sleeves may also be used.

6.5.4.3 Trim excess white insulation sleeve leaving just enough for one wraparound wire to be marked with number fully visible.

6.5.4.4 Position marked white insulation sleeve on wire so that shielding, ties, clamps, or supporting devices need not be removed to read the number.

TABLE 16 Plastic Tie-Down Straps (MS3367, Type I, Class 1)

NOTE 1—See 7.2.2 for strap selection and installation.

Cable Diameter (in.)[A] Min	Cable Diameter (in.)[A] Max	Tie-down Strap MS3367-	Strap Identification	Length (in.)	Installation Tool MS90387-	Tension Setting
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.

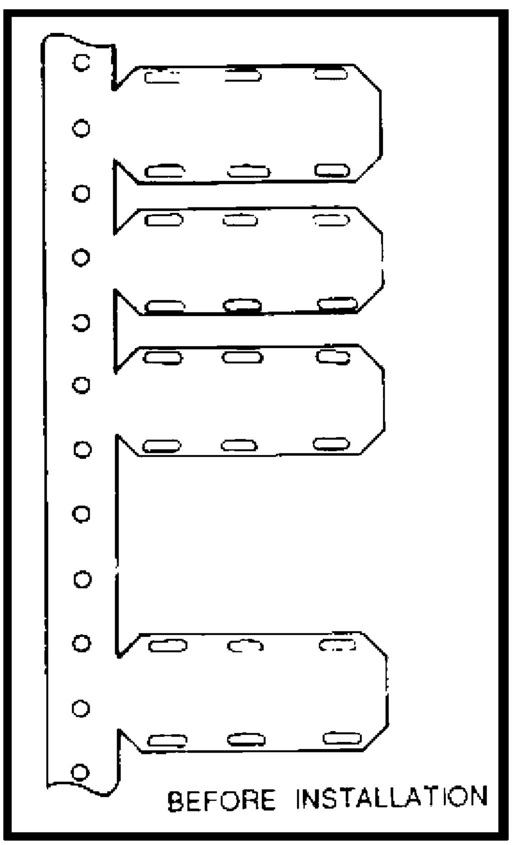


FIG. 10 Cable Markers

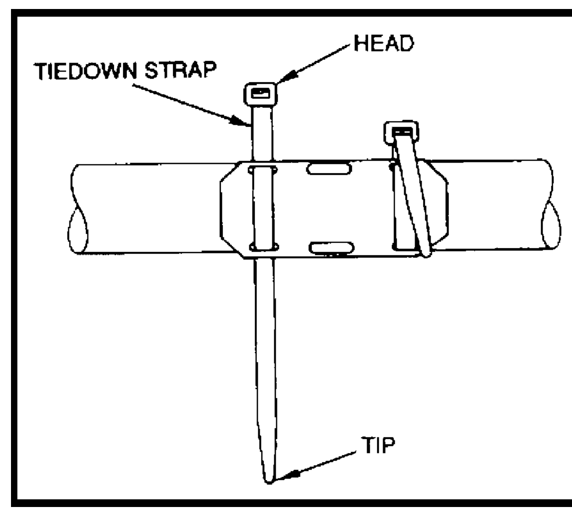


FIG. 11 Tie-Down Strap Installation

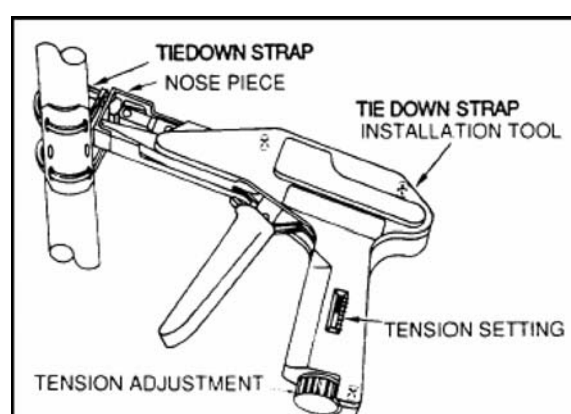


FIG. 12 Tie-Down Strap Installation Tool

6.5.4.5 Obtain clear plastic sleeve that is long enough to extend ¼ in. (0.6 cm) past white insulation sleeve marker edges and wide enough to overlap itself when wrapped around white insulation and wire.

6.5.4.6 Slit clear sleeve lengthwise and place around marker and wire.

6.5.4.7 Secure each end of clear sleeve with lacing tape spot tie to prevent loosening of sleeve.

6.5.4.8 *Marker Sleeve Installation after Printing*—The following general procedures apply:

(1) Hold marker, printed side up, and press end of wire on lip of sleeve to open sleeve. (See Fig. 17.)

(2) If wire has been stripped, use a scrap piece of unstripped wire to open the end of the marker.

(3) Push sleeve onto wire with a gentle twisting motion.

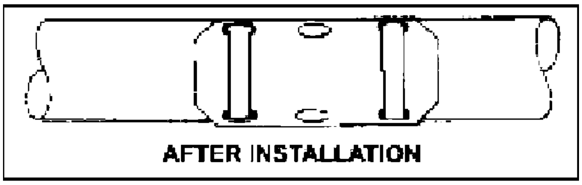


FIG. 13 Completed Installation

(4) Shrink marker sleeve using heat gun with shrink tubing attachment. (See Fig. 18.)

7. Wiring Installation

7.1 *General:*

7.1.1 The desirable and undesirable features in aircraft wiring installations are listed in this section and indicate conditions that may or may not exist.

7.1.2 Ensure that wires and cables are positioned in such a manner that they are not likely to be used as handholds or as support for personal belongings and equipment.

7.1.3 Ensure that wires and cables are routed, insofar as practicable, so that they are not exposed to damage by personnel moving within the aircraft.

7.1.4 Ensure that wires and cables are located so as not to be susceptible to damage by the storage or shifting of cargo.

7.1.5 *Wires in a Harness*—When wires are bundled into harnesses, the current derived for a single wire shall be reduced as shown in Fig. 5. The amount of current derating is a function of the number of wires in the bundle and the percentage of the total wire bundle capacity that is being used.

7.1.6 *Harness at Altitude*—Since heat loss from the bundle is reduced with increased altitude, the amount of current shall be derated. Fig. 19 gives a curve whereby the altitude-derating factor may be obtained.

7.1.7 *Wire Size*—Wires shall have sufficient mechanical strength to allow for service conditions. Do not exceed allowable voltage drop levels. (See Table 1.) Ensure that the wires are protected by system circuit protection devices and that they meet circuit current carrying requirements. If it is desirable to use wire sizes smaller than #20, particular attention shall be given to the mechanical strength and installation handling of these wires, for example, vibration, flexing, and termination. When used in interconnecting airframe application, #24 gauge wire shall be made of high-strength alloy.

7.1.8 *Installation Precautions for Small Wires*—As a general practice, wires smaller than size #20 must be provided with additional clamps, grouped with at least three other wires, and have additional support at terminations, such as connector grommets, strain-relief clamps, shrinkable sleeving, or telescoping bushings. They shall not be used in applications in which they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw terminations.

7.1.9 *Dead Ending of Wire*—Individual wires shall be dead-ended using heat-shrinkable end caps or mechanical-staked wire end caps. Heat-shrinkable end caps shall be installed per Fig. 20.

7.1.10 *Group and Bundle Ties*—A wire bundle consists of a quantity of wires fastened or secured together and all traveling in the same direction. Wire bundles may consist of two or more groups of wires. It is often advantageous to have a number of wire groups individually tied within the wire bundle for ease of identification at a later date. (See Fig. 21.)

7.1.11 *Installation Considerations*—When a wire has been damaged, a determination shall be made to repair or replace the damaged wiring. Refer to 7.9 for acceptable criteria for splicing and installing electrical wire.

7.1.12 *Moisture Protection, Wheel Wells, and Landing Gear Areas:*

7.1.12.1 Wires located on landing gear and in the wheel well area can be exposed to many hazardous conditions if not suitably protected. Where wire bundles pass flex points, there shall not be any strain on attachments or excessive slack when parts are fully extended or retracted.

7.1.12.2 Wires shall be routed so that fluids drain away from the connectors. When this is not practicable, connectors shall be potted or sealed connectors shall be installed. Wiring that must be routed in wheel wells or other external areas shall be given extra protection in the form of harness jacketing and connector strain relief. Conduits or flexible sleeving used to protect wiring shall be equipped with drain holes to prevent entrapment of moisture.

7.1.13 *Protection Against Personnel and Cargo*—Wiring shall be installed so the structure affords protection against its use as a handhold and damage from cargo. Where the structure does not afford adequate protection, conduit shall be used or a suitable mechanical guard shall be provided.

7.1.14 *Heat Precautions*—Wiring shall be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Wires shall be rated (see 5.1 and 5.2) so that the conductor temperature remains within the wire specification maximum when the ambient temperature and heat rise related to current-carrying capacity are taken into account. The residual heating effects caused by exposure to sunlight when aircraft are parked for extended periods shall also be taken into account. Wires such as in fire detection, fire extinguishing, fuel shutoff, and fly-by-wire flight control systems that must operate during and after a fire shall be selected from types that are qualified to provide circuit integrity after exposure to fire for a specified period. Wire insulation deteriorates rapidly when subjected to high temperatures. Do not use wire with soft polyethylene insulation in areas subject to high temperatures. Use only wires or cables with heat-resistant shielding or insulation. (Refer to FAA Advisory Circular AC 25-16 for additional guidance on electrical fault and fire prevention and protection and AC 25.869-1 for guidance on electrical system fire and smoke protection.)

7.1.15 *Movable Controls Wiring Precautions*—Clamping of wires routed near movable flight controls shall be attached with rigid hardware and spaced so that failure of a single attachment point can not result in interference with controls. The minimum separation between wiring and movable controls shall be at least ½ in. (1 cm) when the bundle is displaced by light hand pressure in the direction of the controls.

7.1.16 *Flammable Fluids and Gases*—An arcing fault between an electrical wire and a metallic flammable fluid line may puncture the line and result in a fire. Every effort shall be

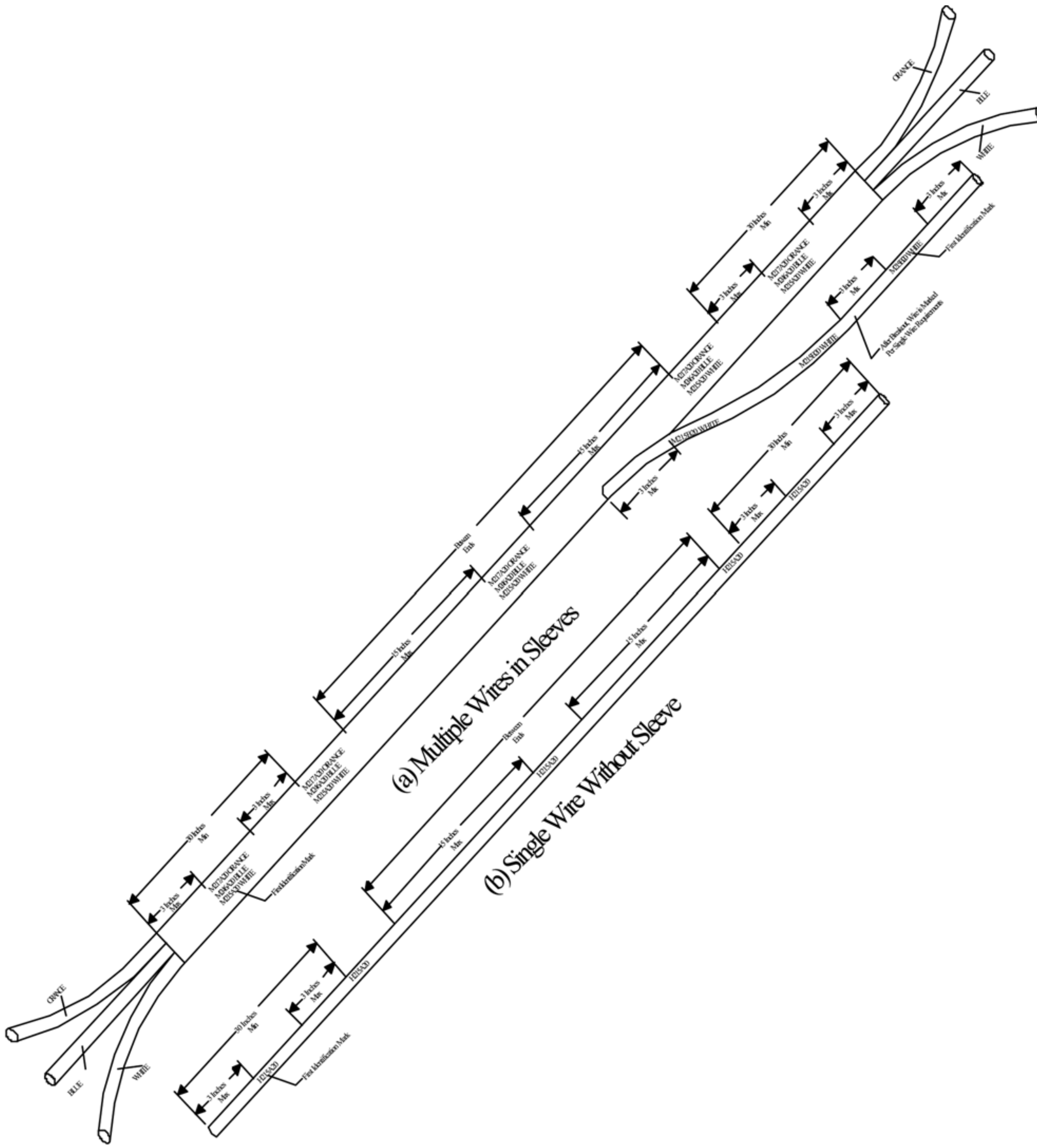


FIG. 14 Spacing of Printed Identification Marks (Direct Marking)

made to avoid this hazard by physical separation of the wire from lines and equipment containing oxygen, oil, fuel, hydraulic fluid, or alcohol. Wiring shall be routed above these lines and equipment with a minimum separation of 6 in. (15 cm) or more whenever possible. When such an arrangement is not practicable, conduits or mechanical barriers may be installed to prevent an arcing fault or wiring may be routed so that it does not run parallel to the fluid lines. A minimum of 2 in. (5 cm) shall be maintained between wiring and such lines and equipment, except when the wiring is positively clamped to maintain at least ½-in. (1-cm) separation, or when it shall be connected directly to the fluid-carrying equipment. Install clamps as shown in Fig. 22. These clamps shall not be used as a means of supporting the wire bundle. Additional clamps shall be installed to support the wire bundle and the clamps fastened to the same structure used to support the fluid line(s) to prevent relative motion. Butterfly clamping per Fig. 23 is permissible, but shall not be used when plumbing contains flammable fluids or oxygen.

7.1.17 *Insulation Tape*—Insulation tape shall be of a type suitable for the application or as specified for that particular use. Insulation tape shall be used primarily as filler under

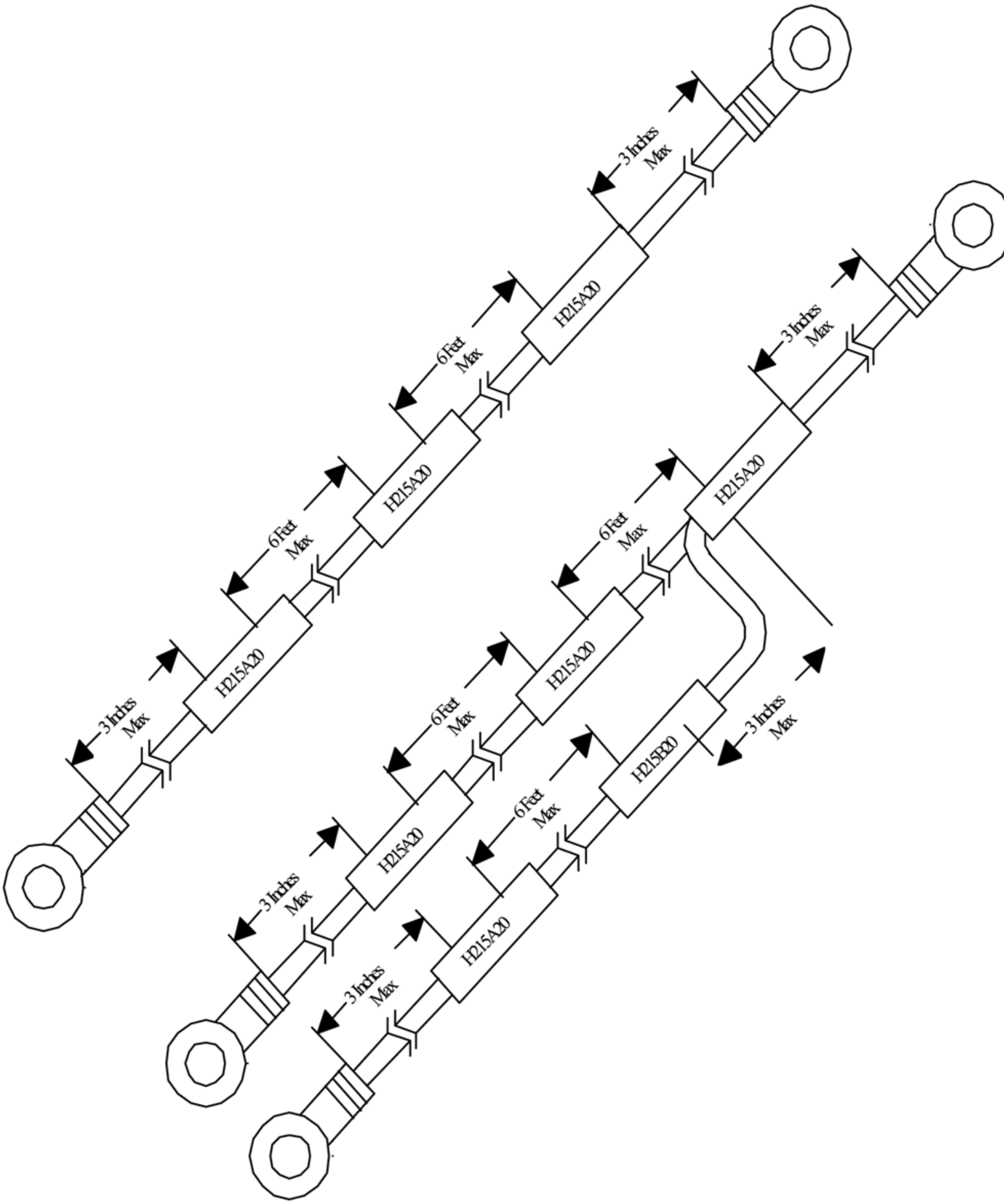


FIG. 15 Spacing of Printed Identification Marks (Indirect Marking)

clamps and as secondary support. Nonadhesive tape may be used to wrap around wiring for additional protection, such as in wheel wells. All tape shall have the ends tied or otherwise suitably secured to prevent unwinding. Tape used for protection shall be applied so that overlapping layers shed liquids. Drainage holes shall 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 shall not be used. (Reference AS 50881A.)

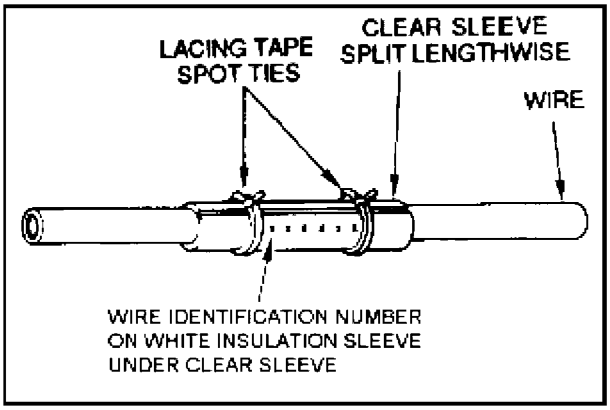


FIG. 16 Temporary Wire Identification Marker

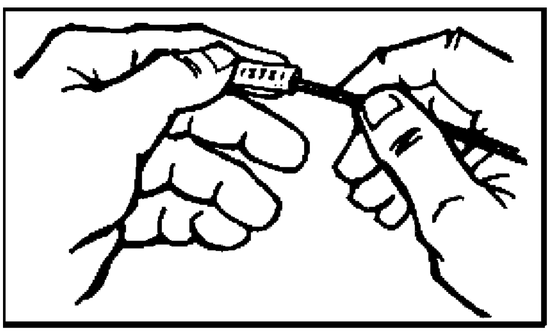


FIG. 17 Inserting Wire into Marker

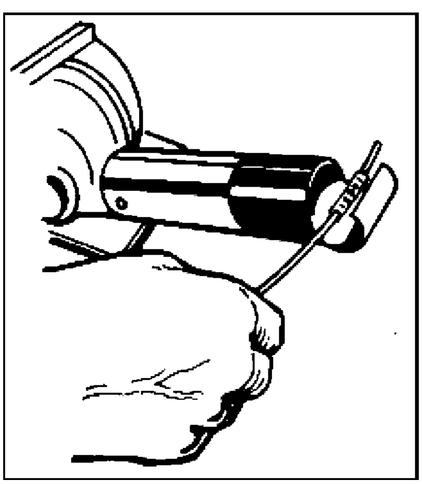


FIG. 18 Shrinking Marker on Wire

7.2 *Wire Harness Installation:*

7.2.1 *General:*

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

7.2.1.2 *Phenolic Blocks, Plastic Liners, or Rubber Grommets* shall 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.

7.2.1.3 *Insulating Tubing* shall be kept at a minimum and used to protect wire and cable from abrasion, chafing, exposure to fluid, and other conditions that could affect the cable insulation.

(1) Insulating tubing shall be secured by tying, with tie straps, or with clamps. However, the use of insulating tubing for support of wires and cable in lieu of standoffs is prohibited.

(2) Ensure drain holes are present in the lowest portion of tubing placed over the wiring.

7.2.1.4 Ensure that wires and cables are not tied or fastened together in conduit or insulating tubing.

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

7.2.1.6 Do not use tape or cord for primary support. When tie straps are used for primary support they shall be attached to a tie strap anchor or similarly secured to structure. Wires and cables in junction boxes, panels, and bundles shall be properly supported and laced to provide proper grouping and routing.

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

7.2.1.8 Ensure that wires and cables are routed so that the possibility of damage from battery electrolytes or other corrosive fluids is minimized.

7.2.1.9 Ensure that wires and cables are adequately protected in wheel wells and other areas in which they may be exposed to damage from impact of rocks, ice, mud, and so forth. (If rerouting of wires or cables is not practical, protective jacketing may be installed.) This type of installation shall be held to a minimum.

7.2.1.10 Where practical, route electrical wires and cables above fluid lines and provide 6 in. (15 cm) of separation from any flammable liquid, fuel or oxygen line, fuel tank wall, or low-voltage wiring that enters a fuel tank. Where 6-in. (15-cm) spacing cannot practically be provided, a minimum of 2 in. (5 cm) shall be maintained between wiring and such lines, related equipment, fuel tank walls, and low-voltage wiring that enters a fuel tank. Such wiring shall be closely clamped and rigidly supported and tied at intervals such that contact between such lines, related equipment, fuel tank walls, or other wires, would not occur, assuming a broken wire and a missing wire tie or clamp. (Refer to FAA Advisory Circular AC 25.981-1B for additional guidance on fuel tank ignition source prevention.)

7.2.1.11 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.

7.2.1.12 Wires and cables installed in bilges and other locations in which fluids may be trapped shall be routed as far from the lowest point as possible or otherwise provided with a moisture-proof covering.

7.2.1.13 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 PTFE. Avoid high-temperature areas when using cables having soft plastic insulation such as

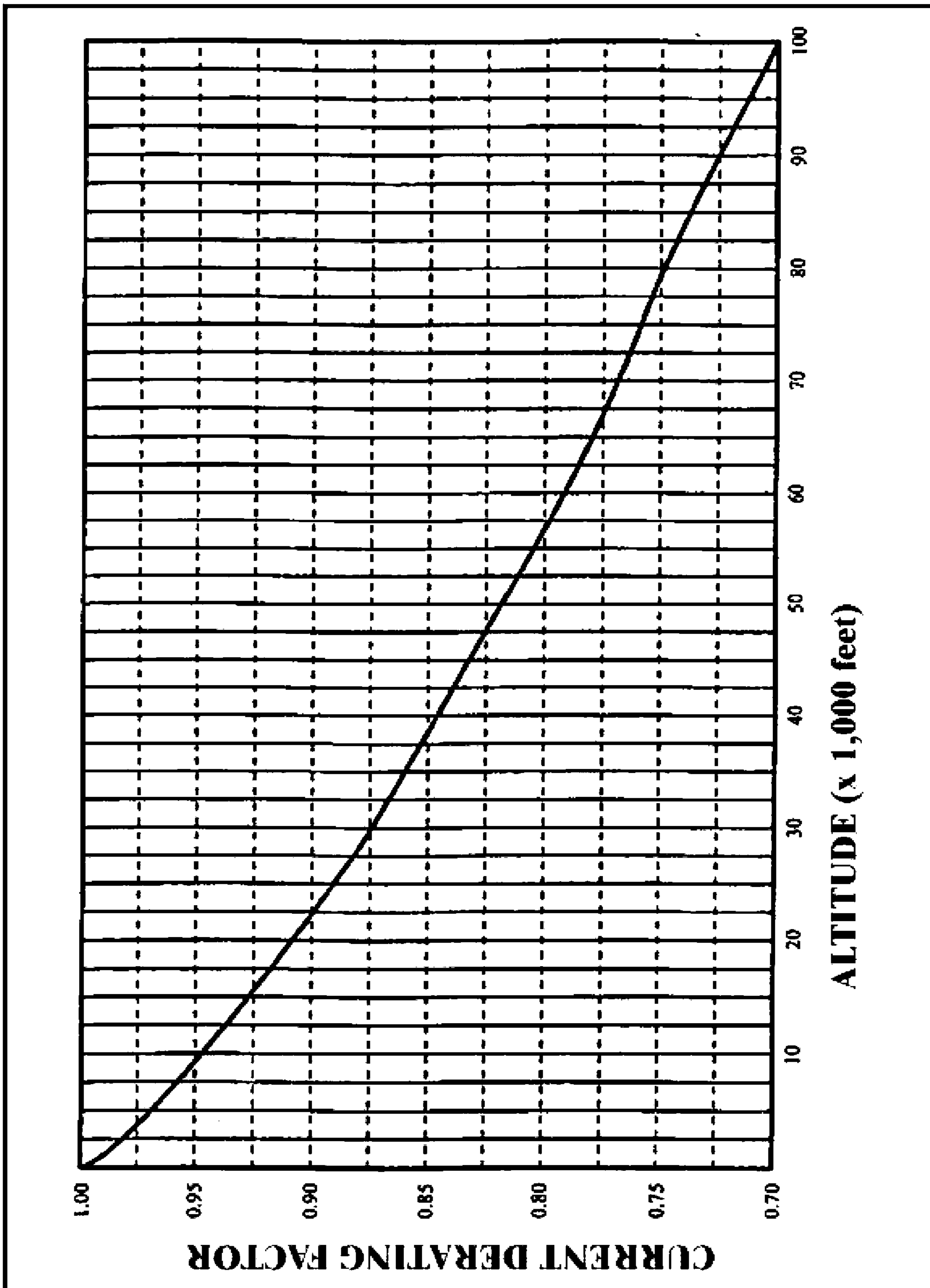
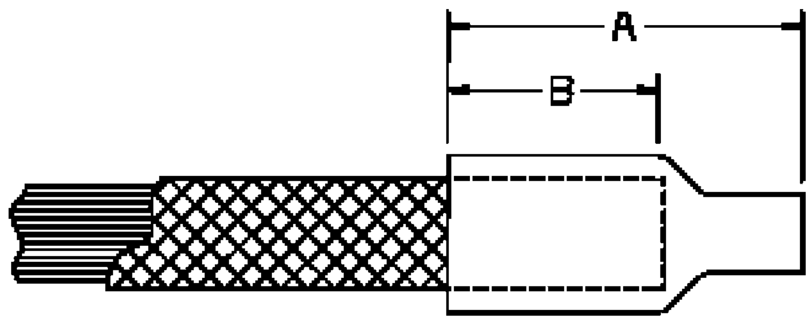


FIG. 19 Altitude Derating Curve

polyethylene, because these materials are subject to deterioration and deformation at elevated temperatures. Many coaxial cables have this type of insulation.

7.2.1.14 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 shall be enclosed in insulating tubing. The radius for thermocouple wire shall be done in accordance with the manufacturer's recommendation and shall be sufficient to avoid excess losses or damage to the cable.

7.2.1.15 *Minimum Wire Bend Radii*—The minimum radii for bends in wire groups or bundles must not be less than ten



Color Code	Overall Length "A" Dim	Minimum Open "B" Dim
White	0.750	0.656
Red	1.000	0.810
Grey	1.125	0.915

FIG. 20 Heat Shrinkable End Caps

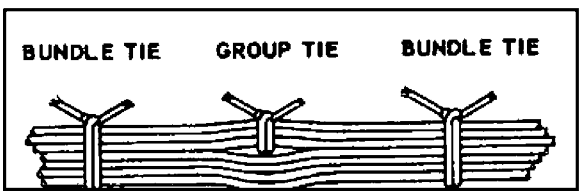


FIG. 21 Group and Bundle Ties

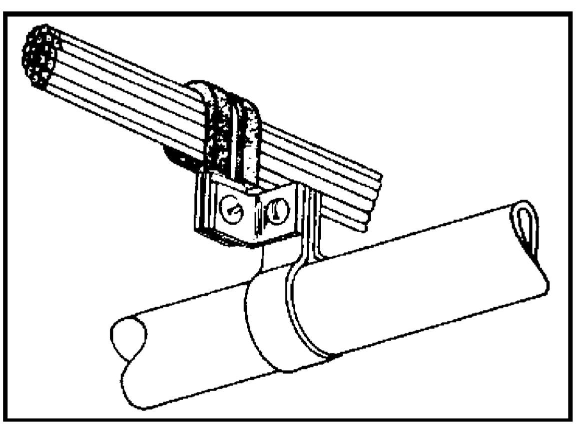


FIG. 22 Separation of Wires from Plumbing Lines

times the outside diameter of their largest wire. They may be bent at six times their outside diameters at breakouts or six times the diameter where they must reverse direction in a bundle provided that they are suitably supported.

7.2.1.16 Ensure that radio frequency (RF) cables, for example, coaxial and triaxial are bent at a radius of no less than six times the outside diameter of the cable.

7.2.1.17 All wiring needs to be protected from damage. However, coaxial and triaxial cables are particularly vulnerable to certain types of damage. Coaxial 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.

(1) Precautions:

(a) Never kink coaxial cable.

(b) Never bend coaxial cable sharply.

(c) Never loop coaxial cable tighter than the allowable bend radius.

7.2.1.18 Care shall be taken to avoid sharp bends in wires that have been marked with the hot-stamping process.

7.2.1.19 *Slack*—Wiring shall be installed with sufficient slack so that bundles and individual wires are not under tension. Wires connected to movable or shock-mounted equipment shall have sufficient length to allow full travel without tension on the bundle. Wiring at terminal lugs or connectors shall have sufficient slack to allow two reterminations without replacement of wires. When providing slack for retermination ensure compliance with other wire installation criteria such as separation and bend radii. This slack shall be in addition to the drip loop and the allowance for movable equipment. Normally, wire groups or bundles shall not exceed ½-in. (1-cm) deflection between support points as shown in Fig. 24. This measurement may be exceeded provided there is no possibility of the wire group or bundle touching a surface that may cause abrasion. Sufficient slack shall be provided at each end to:

(1) Permit replacement of terminals,

(2) Prevent mechanical strain on wires, and

(3) Permit shifting of equipment for maintenance purposes.

(4) Permit ease of maintenance.

(5) Prevent mechanical strain on the wires, cables, junctions, and supports.

(6) Permit free movement of shock- and vibration-mounted equipment.

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

7.2.1.21 Ensure that 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.

7.2.1.22 Ensure that wires and electrical cables are separated from mechanical control cables. In no instance shall wire be able to come closer than ½ in. (1 cm) to such controls when light hand pressure is applied to wires or controls. In cases in

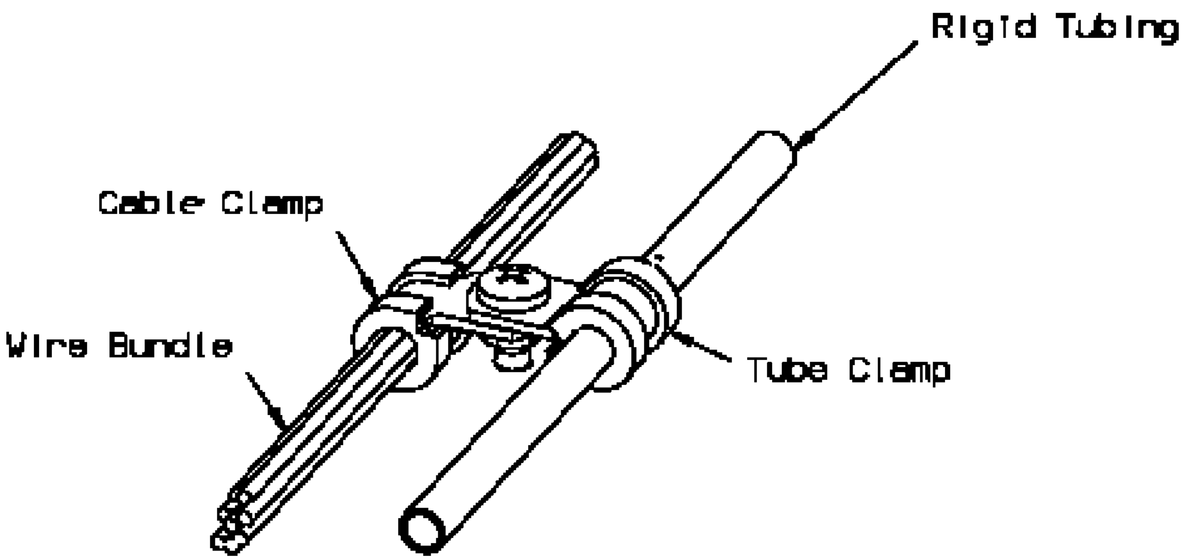


FIG. 23 Butterfly Clamping Method

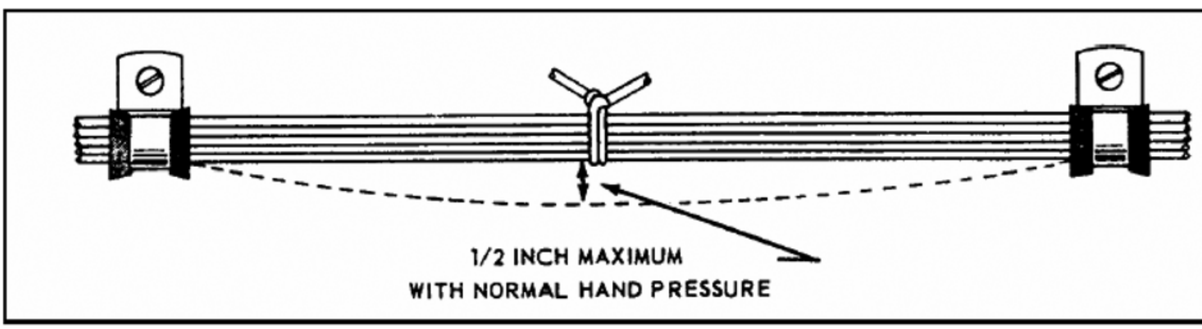


FIG. 24 Slack Between Supports

which clearance is less than this, adequate support shall be provided to prevent chafing.

7.2.1.23 Ensure that unused wires are individually dead-ended, tied into a bundle, and secured to a permanent structure. Each wire shall 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.

7.2.1.24 *Maintenance and Operations*—Wire bundles shall be routed in accessible areas that are protected from damage from personnel, cargo, and maintenance activity. They shall not be routed in areas in which they are likely to be used as handholds or as support for personal equipment or in which they could become damaged during removal of aircraft equipment. Wiring shall 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, shall be provided. Protective grommets shall be used, wherever wires cannot be clamped, in a way that ensures at least a ⅜-in. (9.5-cm) clearance from structure at penetrations. Wire shall 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 shall be made of a material and design that eliminates the potential of chafing between their internal wiring and the conduit internal walls. Wiring that must be routed across hinged panels shall be routed and clamped so that the bundle will twist, rather than bend, when the panel is moved.

7.2.1.25 *Bundle Breakout Point:*

(1) Bundle breakout point shall be adequately supported with appropriate plastic ties and anchors or string tie.

(2) Service loop shall maintain a minimum bend radius of three times the harness diameter.

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

(4) Plastic ties shall not be used between the service loop breakout and the electrical connector when they are likely to chafe against adjacent wire.

7.2.1.26 *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 shall be practiced.

(1) Make sure all cutting tools used for stripping are sharp.

(2) When using special wire stripping tools, adjust the tool to avoid nicking, cutting, or otherwise damaging the strands.

(3) Damage to wires shall not exceed the limits specified in Table 17.

TABLE 17 Allowable Nicked or Broken Strands

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

(4) When performing the stripping operation, remove no more insulation than is necessary.

7.2.2 *Lacing and Wire Ties:*

7.2.2.1 *Lacing and Ties*—Ties, lacing, and straps shall be used to secure wire groups or bundles to provide ease of maintenance, inspection, and installation. Braided lacing tape, per military standards A-A-52080, A-A-52081, A-A-52082, A-A-52083, and A-A-52084, is suitable for lacing and tying wires. In areas where the temperature may go above 185° (85°C) and shall not exceed 500°F (260°C), high temperature insulation tape per military standard A-A-59474 shall be used to tie all wire groups and cable bundles. In areas where the temperature may exceed 185° (85°C) and dimensional stability of the tape is required, high temperature insulation tape per military standard MIL-I-19166 shall be used (jet turbine engine areas where temperatures may exceed 700°F (370°C)). (**Warning—**A-A-59770 Insulation tape (replaces MIL-I-15126), including the glass fiber type, is flammable and should not be used in high temperature environments.)

7.2.2.2 In lieu of ties and straps, single-cord lacing spaced 6 in. (15 cm) apart may be used within panels and junction boxes. (Single-cord lacing spaced 6 in. apart is not acceptable outside of junction boxes and other enclosures.) Single-cord lacing method, shown in Fig. 25, and tying tape, meeting military specifications A-A-52080, A-A-52081, A-A-52082, A-A-52083, and A-A-52084, may be used for wire groups of bundles 1 in. (2.5 cm) 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. 25, Step a. Use the double-cord lacing method on wire bundles 1 in. (2.5 cm) in diameter or larger as shown in Fig. 26. When using the double-cord lacing method, use a bowline on a bight as the starting knot.

7.2.2.3 *Tying*—Use wire group or bundle ties where the supports for the wire are more than 12 in. (30 cm) apart. A tie consists of a clove hitch, around the wire group or bundle, secured by a square knot as shown in Fig. 27.

7.2.2.4 *Plastic Ties*—Straps meeting SAE AS 33671 (replaces MS3367) may be used in areas in which the temperature does not exceed 250°F (120°C). Straps conforming to SAE AS 23190 (replaces MIL-S-23190) can be supplied with either a metal or plastic locking device as suitable for aircraft use.

(1) Plastic tie-down straps shall not be used in the following situations:

(a) Where the total temperature (ambient plus rise) exceeds 185°F (85°C).

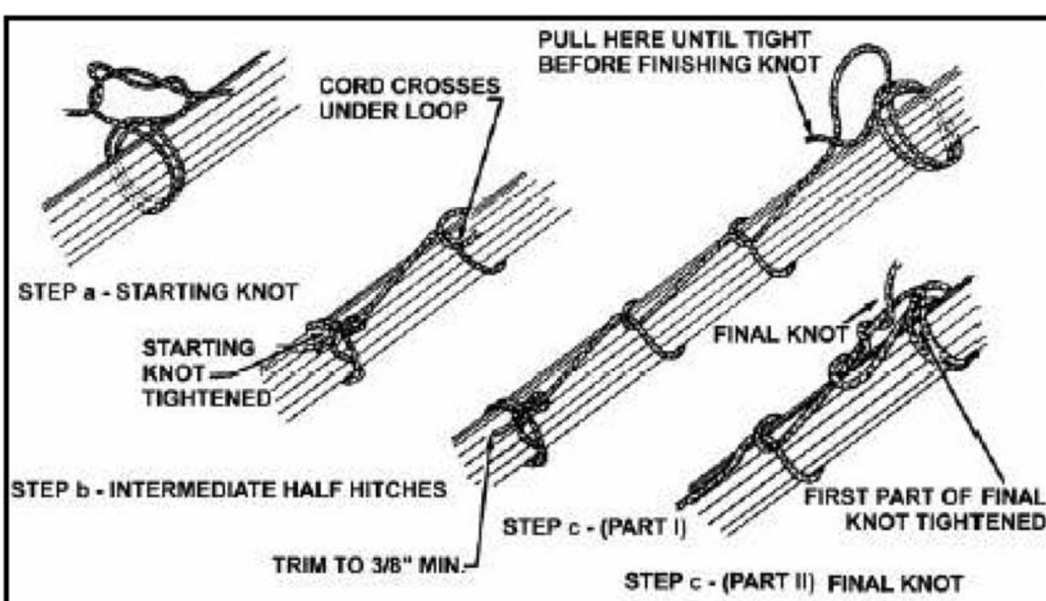


FIG. 25 Single-Cord Lacing

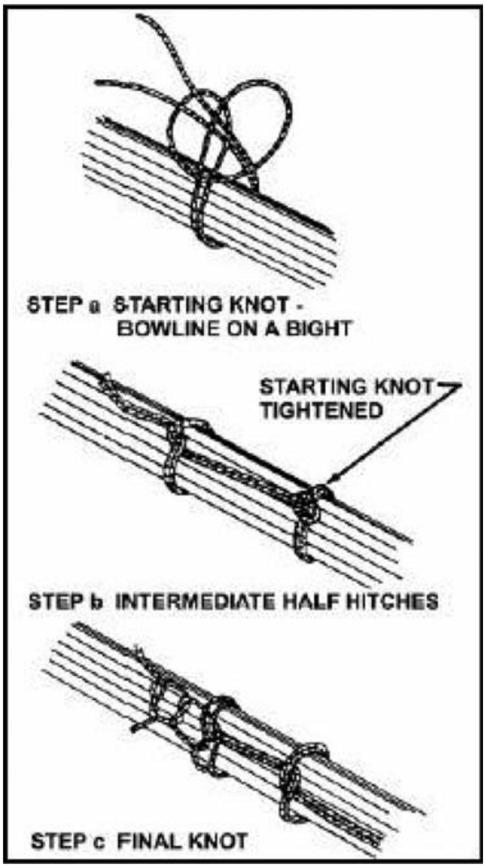


FIG. 26 Double-Cord Lacing

(b) Where failure of the strap would permit movement of the wiring against parts which could damage the insulation or allow wiring to foul mechanical linkages.

(c) Where failure would permit the strap to fall into moving mechanical parts.

(d) In high vibration areas.

(e) Outside the fuselage.

(f) In areas of SWAMP such as wheel wells, near wing flaps, or wing folds.

(g) Where exposure to ultraviolet light might exist, unless the straps are resistant to such exposure.

(h) To tie wire groups or harnesses within bundles.

(i) On coaxial cables or wire bundles containing coaxial cables which do not have solid dielectrics.

(2) Select the smallest strap that will accommodate the outside diameter of the cable. (See Table 16.) Black, UV resistant straps shall be used where straps are subjected to direct sunlight. For installation tool MS90387, tension settings specified in Table 16 are for typical wire bundle applications. Settings higher or lower than those specified may be necessary for specific applications. Tie-down straps may be used on wire bundles containing solid dielectric coaxial cables provided that the tension setting on the installation tool is not greater than that required to prevent axial slippage. (**Warning—**The use of plastic tie-down straps on coaxial RF cables may cause problems if tensioned such that the RF cable's original cross-section is distorted.)

*(3) Plastic Tie Installation—*Using the tool listed in Table 16, perform the following steps to install plastic ties:

(a) From Table 16, select a strap size and the appropriate tool for the wire bundle diameter being used. (Refer to 7.2.2.4 for restrictions on strap usage).

(b) Slip strap tip around the bundle with the boss side up.

(c) Thread the tip through the eye, then hand pull the strap tight against the bundle.

(d) Adjust the tool to the value specified in Table 16. If standard changes in the tension adjustment knob do not align the index line with the required tension locator value, the knob may be pulled out and rotated until alignment occurs.

(e) Pass the free end of the cable tie through the slot in the end of the tool. Then push the tool snuggly against the boss.

(f) While holding the strap firmly against the side of the tool and the tool face squarely against the boss, pump the handle several times without fully activating the tool's cutting knife. Once the strap has been stretched to its maximum, squeeze the handle slowly and firmly until the strap is cut. (**Warning—**The strap must be cut flush with the boss surface in order to minimize cuts and scratches from protruding strap ends.)

(g) Inspect the strap end to ensure a flush cut with the boss surface. Trim or replace the strap as required to ensure the strap end is flush with the boss surface.

(h) Dispose of all broken straps and the strap ends that were cut.

7.2.3 *Clamping:*

7.2.3.1 *General—*Wires and wire bundles shall be supported by using clamps meeting Specification MS21919 or plastic cable straps in accessible areas if correctly applied within the restrictions of 7.2.2.1. 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 UV light, and wire bundle mechanical loads. They shall be spaced at intervals not exceeding 24 in. (61 cm). Clamps on wire bundles shall be selected so that they have a snug fit without pinching wires as shown in Figs. 28-30. (**Warning—** The use of clamps on coaxial RF cables may cause problems if clamp fit is such that RF cable's original cross section is distorted.)

7.2.3.2 *Wires and Cables* shall 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 shall be of a suitable size and type with the wires and cables held securely in place without damage to the insulation.

7.2.3.3 *Clamp-Retaining Screws* shall 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.

7.2.3.4 *Clamps on Wire Bundles* shall 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 F-4 Tape per Military

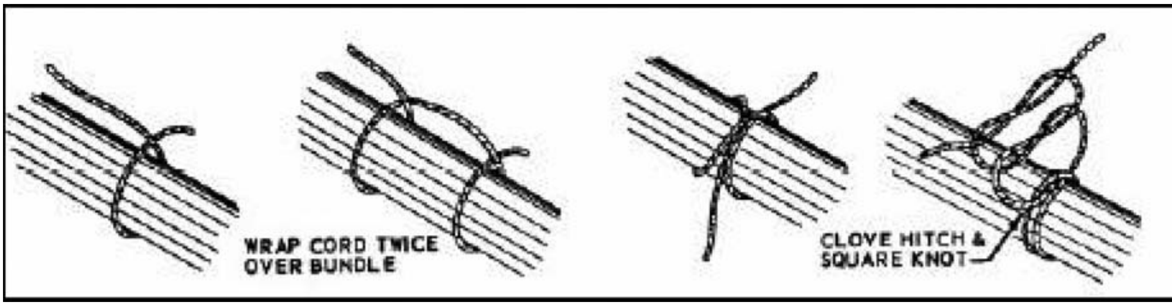


FIG. 27 Making Ties

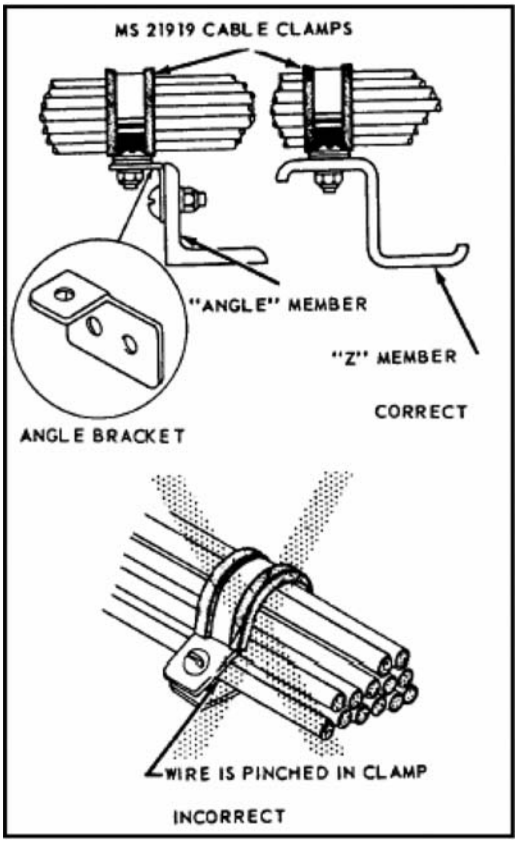


FIG. 28 Installing Cable Clamp to Structure

Specification AA-59163 (formerly MIL I-46852C) Type II, Triangular and Type I, Rectangular Self-Fusing Silicone Rubber Tape when required to achieve this fit. 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. 29.)

7.2.3.5 *Clamps* lined with nonmetallic material shall be used to support the wire bundle along the run. Tying may be used between clamps (see 7.2.3.3) but shall 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.

7.2.3.6 Do not use moisture-absorbent material as "fill" for clamps.

7.2.3.7 The back of the clamp, whenever practical, shall rest against a structural member. Use hardware, as shown in Fig. 30, to mount cable clamps to structure. Mount cable clamps directly to "Z" members of structure. Use clamp support bracket SAE AS 7431 (replaces AN7430) with two mounting screws if structural member is angled as shown in Fig. 28.

7.2.3.8 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. Where additional clearance is required between the cable and the aircraft structure or equipment, a cable clamp standoff as shown in Fig. 28 shall be used.

7.2.3.9 Sufficient slack shall be left between the last clamp and the electrical equipment to prevent strain at the terminal and minimize adverse effects on shock-mounted equipment.

7.2.3.10 Use SAE AS 7351 clamps without cushions for clamping to a tubular structure. The clamps shall fit tightly but shall not deform when locked in place. (SAE AS 7351 replaces AN735.) Attach wire bundle in MS21919 cable clamp to the AS 7351 clamp with hardware as shown in Fig. 22, Fig. 23 and Fig. 30. (**Warning—**MS21919 cable clamps are cushioned with insulating material to prevent abrasion of wires. AS 7351 metal clamps without cushions shall not be used to hold wires.)

7.2.3.11 SAE AS 25281 (replaces MS25281) plastic cable clamps may be used to support wire bundles up to 2 in. (50 mm) in diameter in open wiring, or inside junction boxes and on the back of instrument panels. AS 25281 clamps, spaced at intervals not to exceed 24 in. (60 cm), may be used for wire support provided every fourth clamp is a rubber cushion type (MS21919W). When installing plastic cable clamps, use a large diameter metal washer under the screw head or nut securing the clamp.

7.2.3.12 The use of plastic cable clamps on other than horizontal runs shall be avoided unless the installation is such that slack cannot accumulate between clamping points. Plastic clamps shall not be used to support rigid portions of harnesses. Plastic cable straps shall not be used as primary supporting devices. The primary support of wiring shall not be attached to adjacent wiring.

7.2.3.13 When a wire bundle is clamped into position, if there is less than ⅜-in. (9.5-cm) clearance between the bulkhead cutout and the wire bundle, a suitable grommet shall be installed as indicated in Fig. 31. 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.

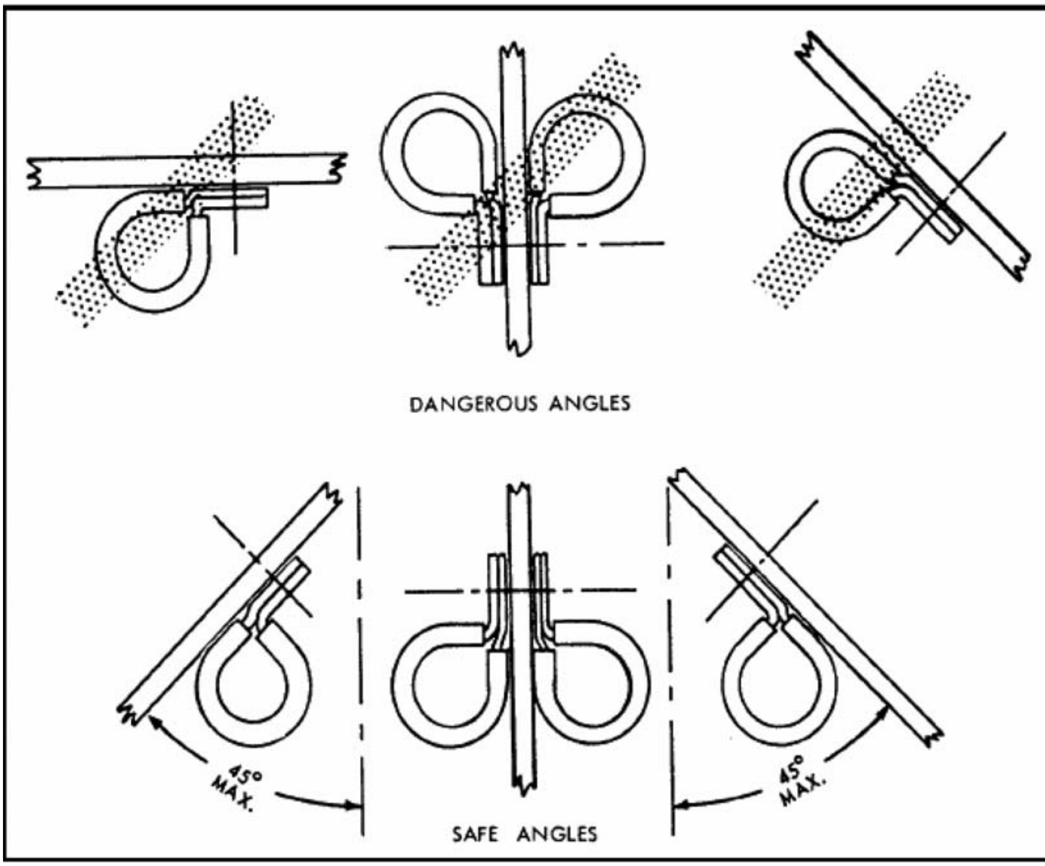


FIG. 29 Safe Angle for Cable Clamps

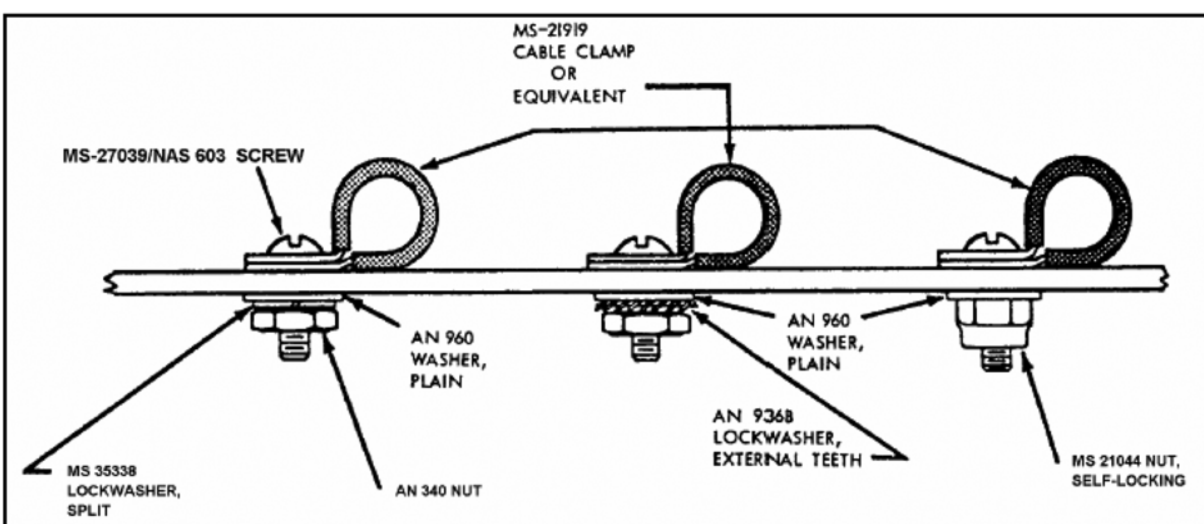


FIG. 30 Typical Mounting Hardware for MS21919 Cable Clamps

7.2.4 *Insulation of Electrical Equipment*—In some cases, electrical equipment is connected into a heavy current circuit. Such equipment is normally insulated from the mounting structure since grounding the frame of the equipment may result in a serious ground fault in the event of equipment internal failure. If the end connection is used for shock hazard, the ground wire shall be large enough to carry the highest possible current (ground wire resistance shall not exceed 0.2 Ω).

7.2.5 *Installation Clearance Provisions:*

7.2.5.1 All electrical equipment shall be installed so that inspection and maintenance may be performed and that the

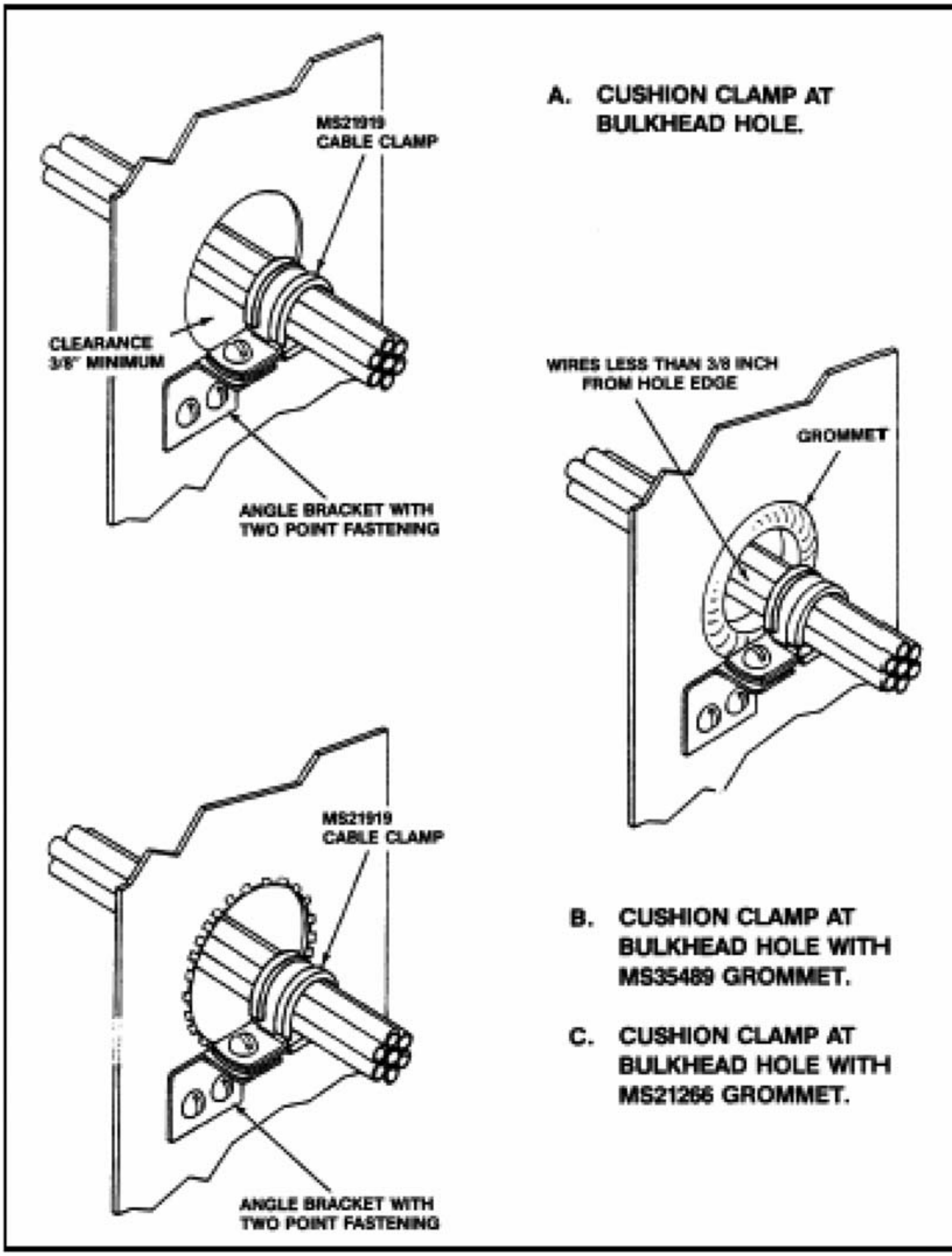


FIG. 31 Clamping at a Bulkhead Hole

installation does not interfere with other systems, such as engine or flight controls.

7.2.5.2 *Wire and Cables* shall be properly supported and bound so that there is no interference with other wires, cables, and equipment.

7.2.5.3 *Wire and Cables* shall be routed in such a manner that chafing will not occur against the airframe or other components.

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

7.3 *Power Feeders:*

7.3.1 The power feeder wires shall 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.

7.4 *Service Loops:*

7.4.1 *General*—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 must be moved to access electrical connectors, are connected to aircraft wiring through service loops. Chafing in service loop harnesses is controlled using the following techniques.

7.4.2 *Support*—Only string ties or plastic cable straps in accordance with 7.2.2.1 shall be used on service loop harnesses. A90° or "Y" type spot tie shall be installed at the harness breakout point on the harness bundle. Ties shall be installed on service loop harnesses at 4 to 6-in. (10 to 15-cm) intervals.

7.4.3 *Antichafing Material*—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 shall be held in place with string ties at 6 to 8-in. (15 to 20-cm) intervals. Harness identification labels shall be installed, with string tie, within 3 in. (8 cm) of the service loop harness installation.

7.4.4 *Primary Support* for service loop harnesses shall be a cushion clamp and a connector at the harness termination.

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

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

7.5 *Drip Loops:*

7.5.1 A drip loop is an area in which wire is dressed downward to a connector, terminal block, panel, or junction box. In addition to the service termination and strain relief, a trap or drip loop shall be provided in the wiring to prevent fluid or condensate from running into the above devices (see Fig. 32). Wires or groups of wires shall enter a junction box or piece of equipment in an upward direction where practicable. Where wires shall be routed downwards to a junction box or unit of electric equipment, the entry shall be sealed or adequate slack shall be provided to form a trap or drip loop to prevent liquid from running down the wires in the box or electric unit.

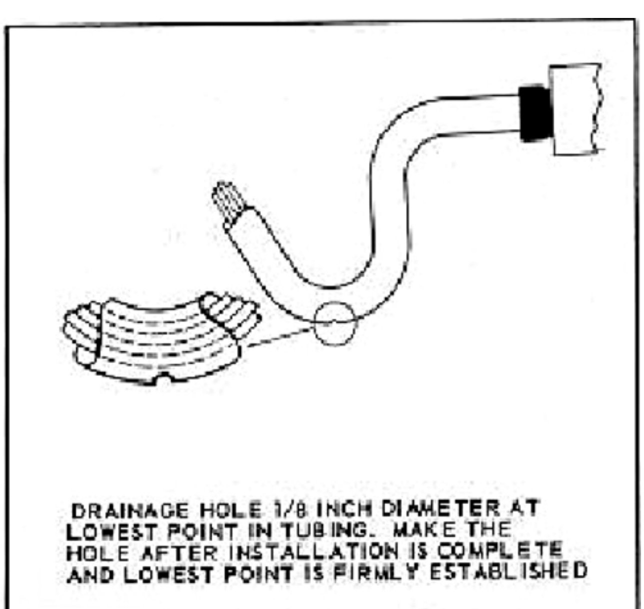


FIG. 32 Drainage Hole in Low Point of Tubing

7.5.2 Ensure drain holes are present in drip loops (see Fig. 32) using sleeving or conduit.

7.6 *Soldering:*

NOTE 7—Specific soldering instructions from the manufacturer of either the aircraft or individual component shall be followed. Recommended solder, flux, soldering temperatures, and so forth of the manufacturer shall be used. The following information can be used when manufacturer does not make recommendations.

NOTE 8—ESD precautions shall be followed during all soldering operations.

NOTE 9—SAE Aerospace Standard AS 4461 is an acceptable method of soldering criteria. It provides additional detailed specifications supplementing this section.

NOTE 10—The primary applications of soldering in aircraft use are either: *(a)* Attaching ring lugs to wire conductors; or *(b)* Soldering components in and to circuit boards and electronic connections—in this application, soldering instructions of the OEM supersede all contrary or conflicting maintenance instructions.

NOTE 11—Noninsulated crimp connections may also be soldered. The crimp provides the physical joint while solder provides and ensures a good electrical connection.

7.6.1 *Soldering Equipment:*

7.6.1.1 Soldering equipment shall not produce detrimental levels of electromagnetic, electrostatic, or electrical energy to the item(s) being soldered.

7.6.1.2 A transformer-type soldering gun shall not be used where conductors are in circuits or onboard an aircraft. Otherwise, unconnected wire may be attached to lugs using commercially available soldering guns.

7.6.1.3 *Soldering Irons* shall heat the area being soldered rapidly and maintain adequate temperature during the entire soldering process. Soldering equipment shall be of capacity to make a solder connection in a maximum of 5 seconds. Typical heat range will be 500 to 700°F (260 to 370°C).

7.6.1.4 *Soldering Iron Tips* shall be sized for the solder connection involved. Improper tip size can result in cold joints, heat damage to components, and excessive soldering time.

7.6.1.5 Mechanical holding devices including tools and fixtures to support wires and components during the soldering process shall not damage or deform the wire or component being soldered.

7.6.2 *Soldering Materials:*

7.6.2.1 Solder composition of 60/40, 62/37, or 63/37 conforming to QQ-S-571 shall be used. Flux core solder shall be Type R (rosin core) or Type RMA (rosin mildly activated) of MIL-F-14256 or ANSI J-STD-004. (**Warning—**Type RA (rosin activated) flux shall not be used on electronic or electrical components or circuits as it can lead to corroded connections.)

7.6.2.2 *Cleaning:*

(1) Physical cleaning is necessary for a good solder joint. Make sure the wire and components to be attached are clean and free of corrosion before starting to solder. Flux will not remove physical residue.

(2) Flux and flux residues shall be removed from the soldered connection after cooling. Isopropyl or ethyl alcohol may be used as a solvent for cleaning. Commercial flux cleaning solvents suitable for electronic and electrical connections may be used if approved by manufacturer. Other solvents may be sued as outlined in SAE AS 4461.

7.6.2.3 Because of the changes occurring in allowable lead use in solder (ROH regulations in E.C.), operators should be aware of the elements in the materials used and shall be in conformity with allowable lead levels.

7.6.3 *Soldering:*

7.6.3.1 *Insulation* may be removed from wire by thermal strippers, mechanical strippers, or wire-cutting tools. Mechanical strippers shall use a fixed die method or calibrated adjustable die method to prevent damage to the conductor material. Hand wire-cutting tools shall use a shear-type cutting action that does not leave burrs, excessive ridges, or sharp points. Care shall be exercised to completely avoid cut and disfigured wire strands.

7.6.3.2 After insulation removal, the insulation shall not have gouges, ragged edges or loose or frayed strands. There shall not be any nicks or broken strands of the conductor. The lay of the strands of the conductor shall be restored, if disturbed, without using bare finger contact.

NOTE 12—It is a good practice to wear lightweight cotton gloves when working with electrical and electronic components.

7.6.3.3 There shall not be any bulging or disfiguration of the wire strands.

7.6.3.4 *Stranded Wire* shall be tinned before soldering the connection. Solder shall penetrate to the inner strands of the entire wire length area being tinned. Wicking of solder under the insulation is acceptable:

(1) If the insulation is a type that can withstand soldering temperatures and there is no enlargement of the wire,

(2) The finished connection does not require the wicked portion of the wire to be bent, and

(3) The criteria for the extent of the wicking are not prohibited by the manufacturer.

(4) Solder shall not penetrate beyond the connection more than one wire width.

7.6.3.5 All items to be soldered shall be free of contamination.

7.6.3.6 *Solder Joint Heating:*

(1) Heat shall be applied to the joint to be connected. Solder shall be applied to the heated connection area and the soldering tip. The solder shall flow evenly into the connection leaving smooth fillets and a shiny appearance.

(2) "Cold-soldered" joints may have a fuzzy appearance and will not smoothly penetrate the joint. All such joints shall be resoldered until a satisfactory joint is obtained.

(3) It may be necessary to remove and discard improperly soldered lugs and connections and redo the joint to obtain a satisfactory connection.

7.6.3.7 Care shall be maintained to not disturb the connection until the solder has completely solidified. Any movement can cause an unacceptable connection, and shall be reworked until a satisfactory connection is achieved.

7.6.3.8 *Solvent Cleaning* of the soldered connection to remove all residual flux and other contaminants shall be made as soon as possible but not to exceed 2 h after the solder connection has been completed.

7.6.4 *Inspection Criteria for Soldered Connections:*

7.6.4.1 All solder joints shall be inspected using at least 2 to 4× magnification with adequate lighting.

7.6.4.2 The appearance of the completed soldered connection shall be smooth, nonporous, and continuous with a bright appearance. A dull gray appearance is cause for rework.

7.6.4.3 The solder shall wet the surfaces of all soldered components and form a fillet between the connected components over the complete connection.

7.6.4.4 Solder coverage shall be sufficient to cover all components of the connection with discernible outlines of all components. Insufficient or excessive solder shall not be acceptable (that is, lack of a smooth fillet or gobs and drips of excess material).

7.6.4.5 *Insulation* may touch the solder connection but shall not be embedded in or surrounded by the solder. Insulation shall not be melted, charred, seared, or diminished in diameter.

7.6.4.6 The solder connection shall be free of scratches, sharp edges, solder points or peaks, pinholes, pits, voids globules, flux residue or contamination. There shall be no solder bridges between adjacent connections. Solder connections shall be checked for any fractures of the solder connection due to movement of the joint before solder solidified (a gray or dull surface on the solder is an indication of a poor quality connection).

7.6.4.7 Any unacceptable solder connection shall be reworked. Reheat and addition of flux and solder may be used to correct unacceptable connections. If solder shall be removed before rework, solder removal may be done by vacuum devices or solder wick material. Care shall be made to not overheat a connection during the solder removal process.

7.7 *Strain Relief:*

7.7.1 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, heat-shrinkable boot, or a length of heat-shrinkable tubing shall be installed. The heat-shrinkable boots will provide preselected angles of wire harness termination when heat is applied. Heat-shrinkable tubing shall be held at the desired angle until cool.

7.8 *Grounding and Bonding:*

7.8.1 *General*—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.

7.8.2 *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.

7.8.2.1 *Types of Grounding*—If wires carrying return currents from different types of sources, such as signals of DC and

AC generators, are connected to the same ground point or have a common connection in the return paths, an interaction of the currents will occur. Mixing return currents from various sources shall be avoided because noise will be coupled from one source to another and can be a major problem for digital systems. To minimize the interaction between various return currents, different types of grounds shall be identified and used. As a minimum, the design shall 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 shall be labeled "AC Right." The return currents for the left generator shall be connected to a ground point labeled "AC Left."

7.8.2.2 *Current Return Paths*—The design of the ground return circuit shall 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 shall 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 shall 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 shall have an external ground connection, even when internally grounded. Direct connections to a magnesium (which may create a fire hazard) structure shall not be used for ground return.

7.8.2.3 *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 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 shall be considered for composite aircraft.

7.8.2.4 *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, make sure these connections will not arc, spark, or overheat under all possible current flow or mechanical failure conditions, including induced lightning currents. Criteria for inspection and maintenance to ensure continued airworthiness throughout the expected life of the aircraft shall 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.

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

(1) Redundant systems are normally provided with the objective of assuring continued safe operation in the event of failure of a single channel and 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 shall be incapable of reaching the ground attachment of the other channel.

(2) The use of loop-type grounding systems (several ground leads connected in series with a ground to structure at each end) 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.

(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 shall be avoided by making the ground attachments at separate locations.

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

(5) The effect of the interconnection of the circuits when ungrounded shall 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.

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

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

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

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

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

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

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

7.8.3.2 *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 shall be provided with an alternative means to conduct static charges or lightning currents or both as appropriate.

7.8.3.3 *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. (8 cm), that are subjected to appreciable electrostatic charging caused by precipitation, fluid, or air in motion shall 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.

7.8.3.4 *Self-Tapping Screws* shall not be used for bonding purposes. Only standard threaded screws or bolts of appropriate size shall be used.

7.8.3.5 Exposed conducting frames or parts of electrical or electronic equipment shall 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.

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

7.8.3.7 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.

7.8.3.8 The use of bonding testers is strongly recommended. Measurements shall 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. 33.

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

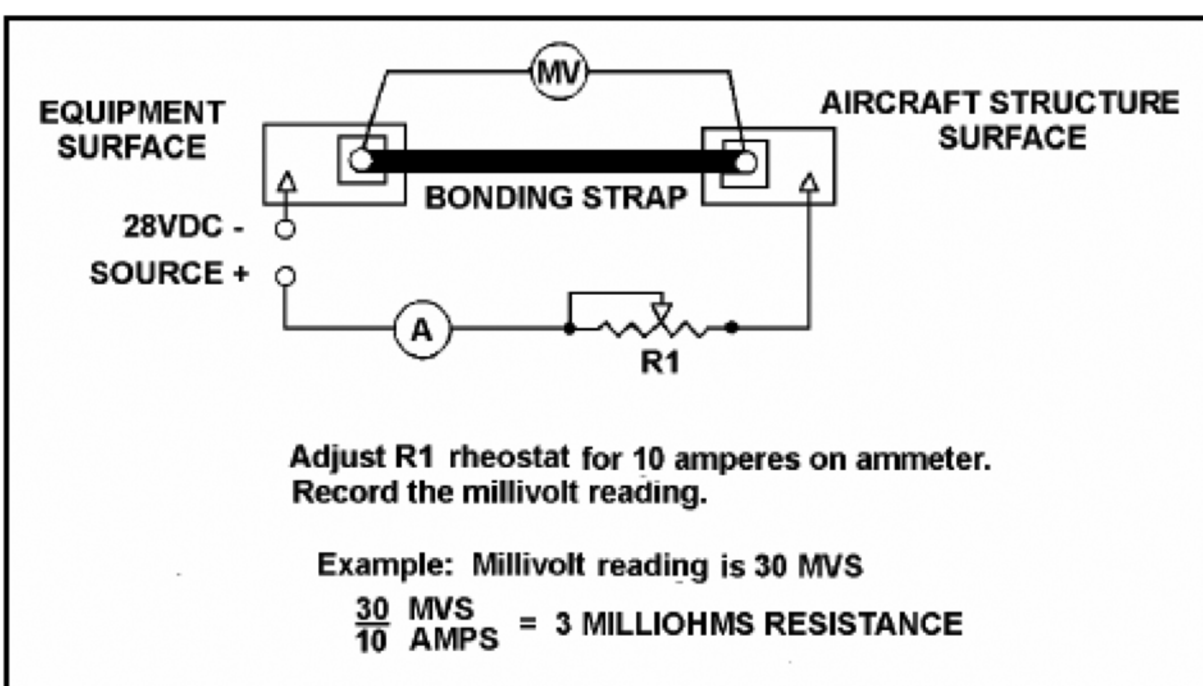


FIG. 33 Millivolt Drop Test

7.8.3.10 *Bonding Jumper Installations*—Bonding jumpers shall 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 shall not interfere with the operation of movable aircraft elements, such as surface controls, nor shall normal movement of these elements result in damage to the bonding jumper. (See 7.8.3.14.)

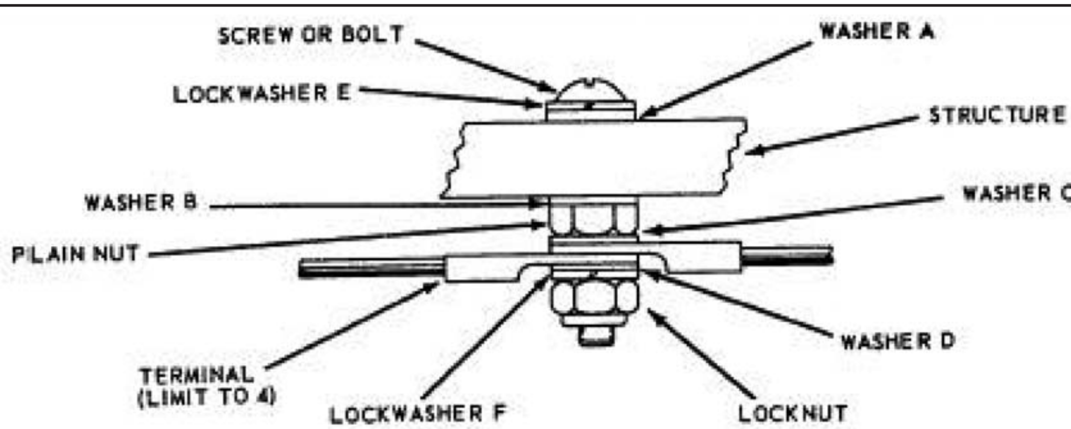
7.8.3.11 *Bonding Connections*—To ensure a low-resistance connection, nonconducting finishes, such as paint and anodizing films, shall be removed from the attachment surface to be contacted by the bonding terminal. On aluminum surfaces, a suitable conductive chemical surface treatment, such as alodine,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

7.8.3.12 *Corrosion Protection*—One of the more frequent causes of failures in electrical system bonding and grounding is corrosion. Aircraft operating near saltwater 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 shall be post-finished in accordance with the original finish requirements or with some other suitable protective finish within 24 h of the cleaning process. In applications exposed to salt spray environment, a suitable noncorrosive sealant, such as one conforming to AMS-S-8802, shall be used to seal dissimilar metals for protection from exposure to the atmosphere.

7.8.3.13 *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 shall 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 shall be such that corrosion is minimized, and the part likely to corrode would be the jumper or associated hardware. Tables 18-20 and Figs. 34-36 show the proper hardware combinations for making a bond connection. At locations where finishes are removed, a protective finish shall be applied to the completed connection to prevent subsequent corrosion.

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

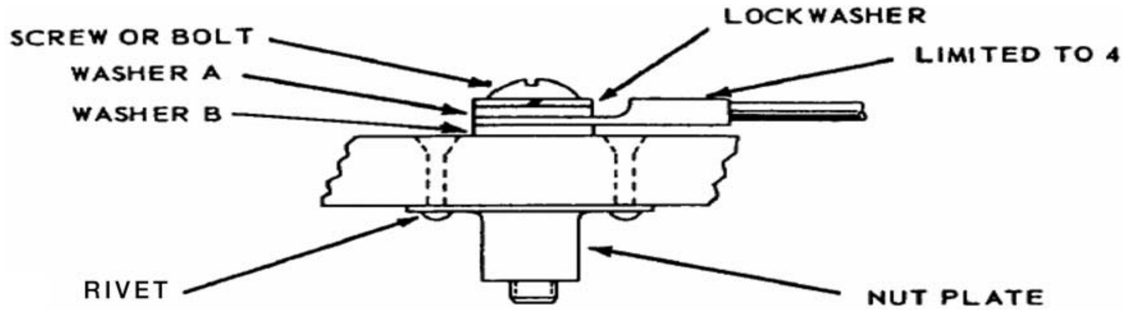
TABLE 18 Stud Bonding or Grounding to Flat Surface



Structure	Screw or Bolt and Lock Nut	Plain Nut	Washer A	Washer B	Washer 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-Resist 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.

TABLE 19 Plate Nut Bonding or Grounding to Flat Surface



Structure	Screw or Bolt and Nut Plate	Rivet	Lock Washer	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[B] Alloy
Steel, Cadmium Plated	Cadmium-Plated Steel	Corrosion-Resisting Steel	Cadmium-Plated Steel	Cadmium-Plated Steel	None
Steel, Corrosion Resisting	Corrosion-Resisting Steel	Corrosion-Resisting Steel	Cadmium-Plated Steel	Cadmium-Plated Steel	None

[A] Avoid connecting copper to magnesium.
[B] Use washers having a conductive finished treated to prevent corrosion; suggest AN960JD10L.

7.8.3.15 *Ground Return Connection*—When bonding jumpers carry substantial ground return current, the current rating of the jumper shall be determined to be adequate and that a negligible voltage drop is produced. (See Figs. 34-36.)

7.8.4 *Fuel Systems*—Small metallic objects within an aircraft fuel tank that are not part of the tank structure shall 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 shall indicate an adequate connection. Care shall be taken in designing such connections to avoid creating continuous current paths that could allow lightning or power fault currents to pass through connections not designed to tolerate these higher amplitude currents without arcing. Simulated static charge, lightning, or fault current tests may be necessary to establish or verify specific designs. All other fuel system components, such as fuel line (line-to-line) access doors, fuel line supports, structural parts, fuel outlets, or brackets shall have an electromechanical (bonding strap) secure connector that ensures 100 mΩ or less resistance to the structure. Advisory Circular 20-53A and associate manual DOT/FAA/CT-83/3 provide detailed information on necessary precautions.

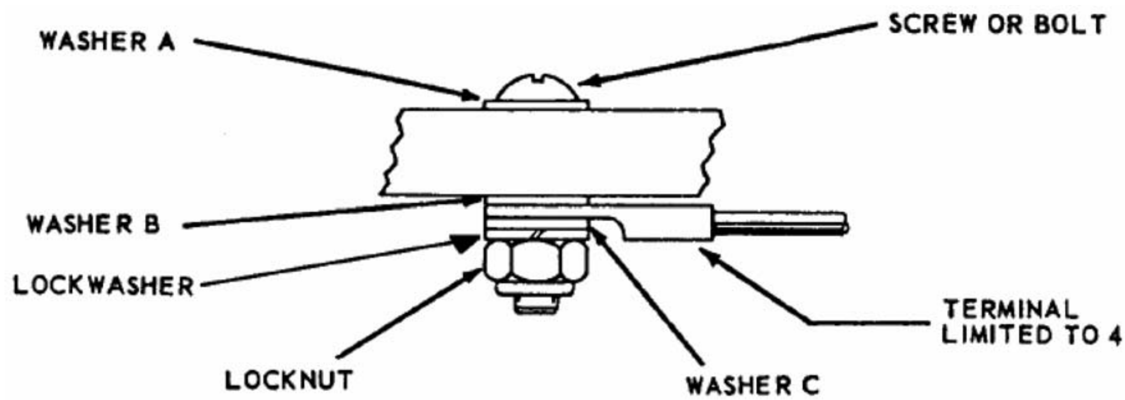
7.8.5 *Electric Shock Prevention Bonding*—Electric shock to personnel shall be prevented by providing a low-resistance path of $1/100$ Ω or less between structure and metallic conduits or equipment. The allowable ground resistance shall be such that the electric potential of the conduit or equipment housing does not reach a dangerous value under probable fault conditions. The current-carrying capacity of all elements of the ground circuit shall 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.

7.8.6 *Static-Discharge Device*—Means shall be provided to bleed accumulated static charges from aircraft before ground personnel coming in contact with an aircraft after landing. Normally, there is adequate conductivity in the tires for this, but if not; a static ground shall be applied before personnel come into contact with the aircraft. Fuel nozzle grounding receptacles shall be installed in accordance with the manufacturer's specifications. Grounding receptacles shall 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.

7.8.7 *Cleaning*—To ensure proper ground connection conductivity, all paint, primer, anodize coating, grease, and other foreign material shall be carefully removed from areas that conduct electricity. (See 7.8.3.12.)

7.8.8 *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 shall be

TABLE 20 Bolt and Nut Bonding or Grounding to Flat Surface



Structure	Screw or Bolt and Nut Plate	Lock Nut	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 Alloy Magnesium Alloy[A]	Cadmium-Plated Steel	Cadmium-Plated Steel	Cadmium-Plated Steel	Aluminum[B] Alloy	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 finished treated to prevent corrosion; suggest AN960JD10L.

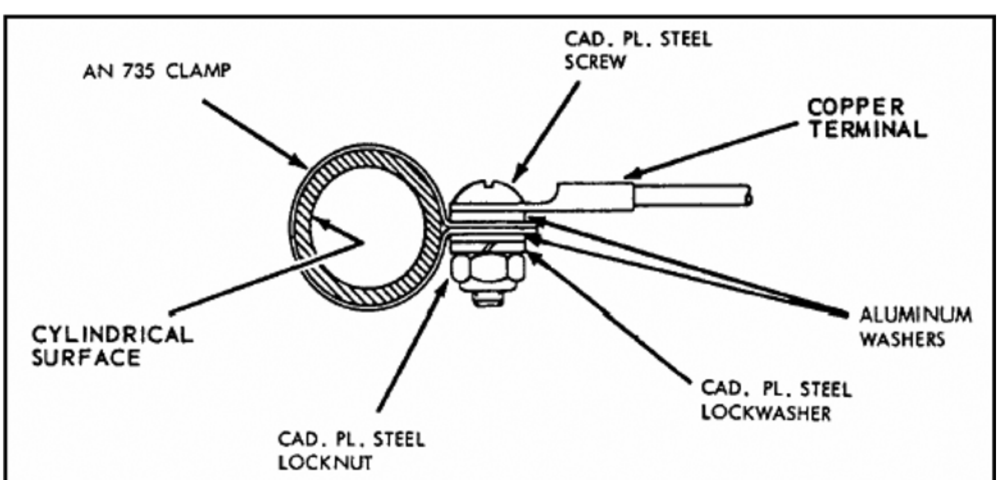


FIG. 34 Copper Jumper Connector to Tubular Structure

made in accordance with SAE ARP-1870. Threaded fasteners shall be torqued to the level required by SAE ARP-1928.

7.9 *Splicing:*

7.9.1 *General*—Splicing is permitted on wiring as long as it does not affect the reliability and the electromechanical characteristics of the wiring. Splicing of power wires, coaxial cables, multiplex bus, and large gauge wire shall have approved data.

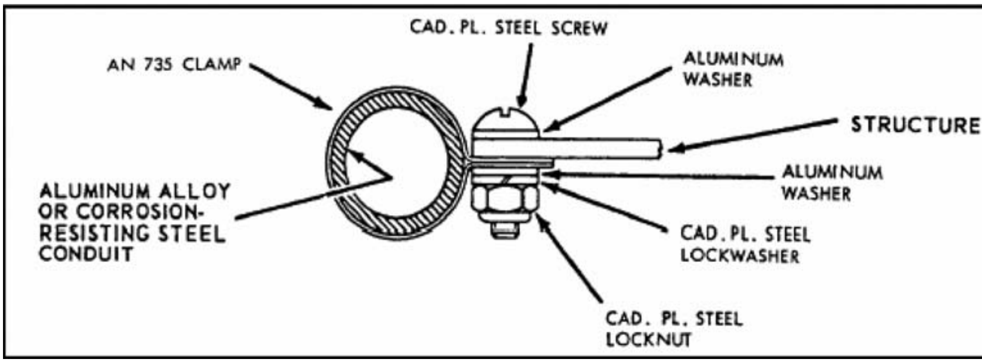


FIG. 35 Bonding Conduit to Structure

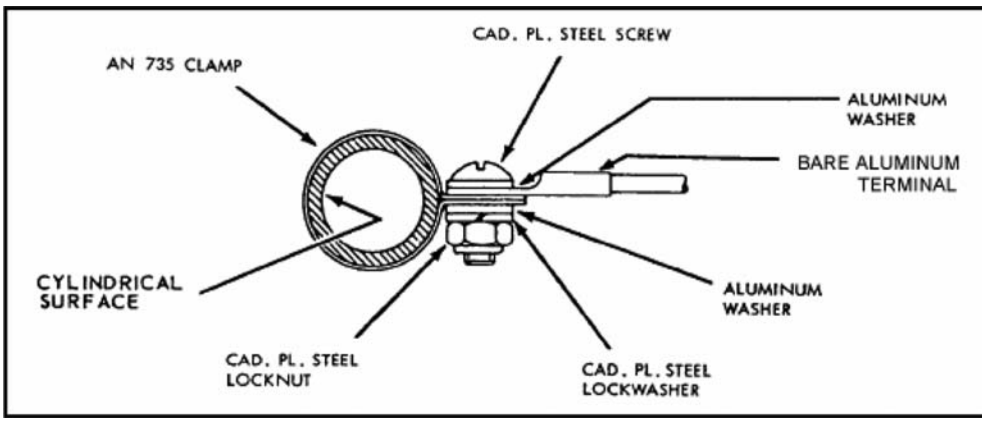


FIG. 36 Aluminum Jumper Connection to Tubular Structure

7.9.2 Splicing of electrical wire shall be kept to a minimum and avoided entirely in locations subject to extreme vibrations. During initial installation, splicing of individual wires in a group or bundle shall have engineering approval and the splice(s) shall be physically located to allow periodic inspection.

7.9.3 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 SAE AS 7928 (replaces 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.

7.9.4 There shall 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, to splice multiple wires to a single wire, to adjust wire size to fit connector contact crimp barrel size, and to make an approved repair. (Reference AS 50881A.)

7.9.5 Splices in bundles shall be staggered so as to minimize any increase in the size of the bundle, preventing the bundle from fitting into its designated space, or cause congestion that will adversely affect maintenance. (See Fig. 37.) Each end of splice must be sized separately. If the splice selected for two wires in one end will not accept the third wire in the other end (using the correct splice size per Table 21) the doubling back process as shown in Fig. 38 will be required. Where not otherwise disallowed as an alternate to doubling back the wire an approximately 3-in. (8-cm) wire of appropriate gage per Table 21 shall be stripped per 7.2.1.26 and inserted in the end of the splice with the single wire. The 3-in. (8-cm) wire shall be dead ended per 7.1.9 and secured in the bundle.

NOTE 13—Where equal size wires are to be inserted in the same splice end and the insulation of both wires are to be covered by the insulation covering of the splice, one of the two wires shall be inserted per 7.9.9 with the other being stripped to the splice covering.

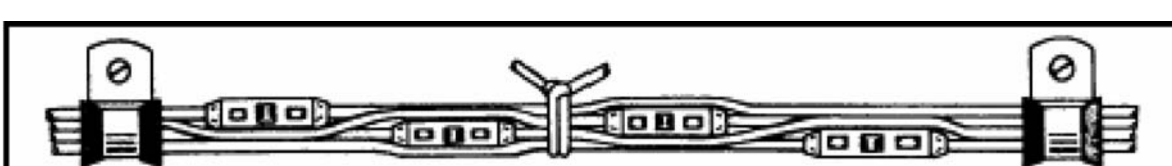


FIG. 37 Staggered Splices in Wire Bundle

TABLE 21 Three- and Four-Way Splices

Gauges of Two Wires in One End of Splice	Use Splice Size (Color)	Use Tool for Cable Size
22-22 22-20 22-18 22-16 22-14 20-20 20-18 20-16 18-18	-2 (Blue)	16-14
20-14 18-16 18-14 16-16 16-14	-3 (Yellow)	12
20-12 18-12 16-12 14-12 12-12	-3 (Yellow)	10

7.9.6 *Splices* shall not be used within 12 in. (30 cm) of a termination device, except for 7.9.7.

7.9.7 *Splices* may be used within 12 in. (30 cm) of a termination device when attaching to the pigtail spare lead of a potted termination device, to splice multiple wires to a single wire, or to adjust the wire sizes so that they are compatible with the contact crimp barrel sizes.

7.9.8 *Splices* shall not be positioned under a cable clamp.

7.9.9 The conductor in barrel-type splices shall be inserted the full length of the terminal barrel, will protrude beyond the barrel end a maximum of 0.05 in. (0.15 cm) and shall not interfere with the installation of screws, nuts, or washers. The insulation shall be inserted through the enlarged portion of the barrel insulation gripping terminals to provide the maximum amount of insulation grip. Fig. 39 shows how properly crimped terminals should appear.

7.9.10 For selection of a proper crimping tool, refer to 10.16.20.

7.10 *Fuel Tank Wiring:*

7.10.1 The primary design consideration/standard practice for compliance to 14 CFR 25.981 is to assure that no new electrical component or electrical wiring could cause an unintended ignition source in the aircraft's fuel system. This may be accomplished using complex system safety analysis, or the following steps may be taken.

7.10.1.1 Identify all existing fuel system components and wiring.

7.10.1.2 Route all new wires at least 6 in. (15 cm) from any fuel system component or wiring.

7.10.1.3 If new wiring cannot be separated from fuel system components by 6 in. (15 cm), but can be separated by at least 1 in. (2.5 cm), provide a barrier between the fuel system component or wiring that meets the following criteria.

(1) The barrier material may not be electrically conductive nor a static electricity source,

(2) Shall be chemically compatible with all fluids in the area of installation–particularly fuel,

(3) Shall meet the appropriate fire rating for the area of installation,

(4) Shall provide a barrier to the fuel system in case of a wire bundle fire. The barrier material shall have a melt temperature of 285°C or more. The typical operating temperature range for the barrier material shall be –60 to 200°C or more, and

(5) Shall be easily removable for inspection of the wire bundle.

7.10.1.4 If the new wiring is less than 1 in. (2.5 cm) from fuel system components and wiring, provide a barrier that meets the following requirements.

(1) The barrier material shall meet all of the criteria of 7.10.1.3,

(2) Shall provide physical (that is, chafe) protection to the fuel system component or wiring,

(3) Shall provide EMI and RFI protection to the fuel system component or wiring. The level of EMI/RFI protection required varies based on the type of wiring being installed. FAA approval, such as DER approval, of wiring routed less than 1 in. (2.5 cm) from fuel system wiring shall be obtained.

7.10.2 The Instructions for Continued Airworthiness (ICA) for fuel tank system electrical wiring shall be determined in accordance with the guidance provided by FAA Policy Statement ANM112-05-001 or other acceptable process.

7.10.3 Wiring designs used on aircrafts vary significantly between manufacturers and models; therefore, it is not possible to define a specific universal separation distance or the characteristics of physical barriers between wire bundles to protect critical wiring from damage. Intrinsically safe wiring for fuel tanks shall be protected from induced currents caused by lightning or close proximity to other aircraft wiring. In addition, damage to wire insulation can result in unwanted electrical energy being transmitted into the fuel tank, if the damaged wire can come into contact with the conductor of another wire that is not intrinsically safe.

NOTE 14—Current induced by adjacent wire bundles need not be considered if a minimum separation of at least 1 in. (2.5 cm) is provided.

7.10.4 Inspection means shall be provided to allow for the direct visual inspection of the wiring, physical barriers, and other physical means of protection.

7.10.5 Nondestructive inspection aids may be used where it is impracticable to provide for direct visual inspection if it is shown that the inspection is effective and the inspection procedures are specified in the maintenance manual required by Title 14 CFR 23.1529.

7.10.6 Identification means shall also be provided so wires are readily visible to maintenance, repair, or alteration personnel. The method of identification shall remain legible throughout the aircraft's operational life.

7.11 *Corrosion Preventative Compounds (CPC) (MIL-C-81309):*

7.11.1 *Intended Use:*

7.11.1.1 The ultrathin film corrosion preventive compounds covered by the MIL-PRF-81309 specification are intended for use on any metal surface. They can be used both for initial protection during shipment and storage and for in-service

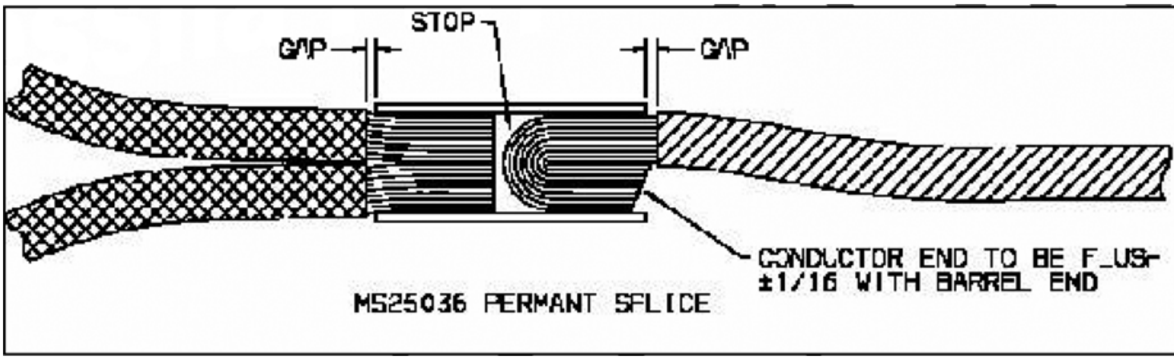


FIG. 38 Wire Splice

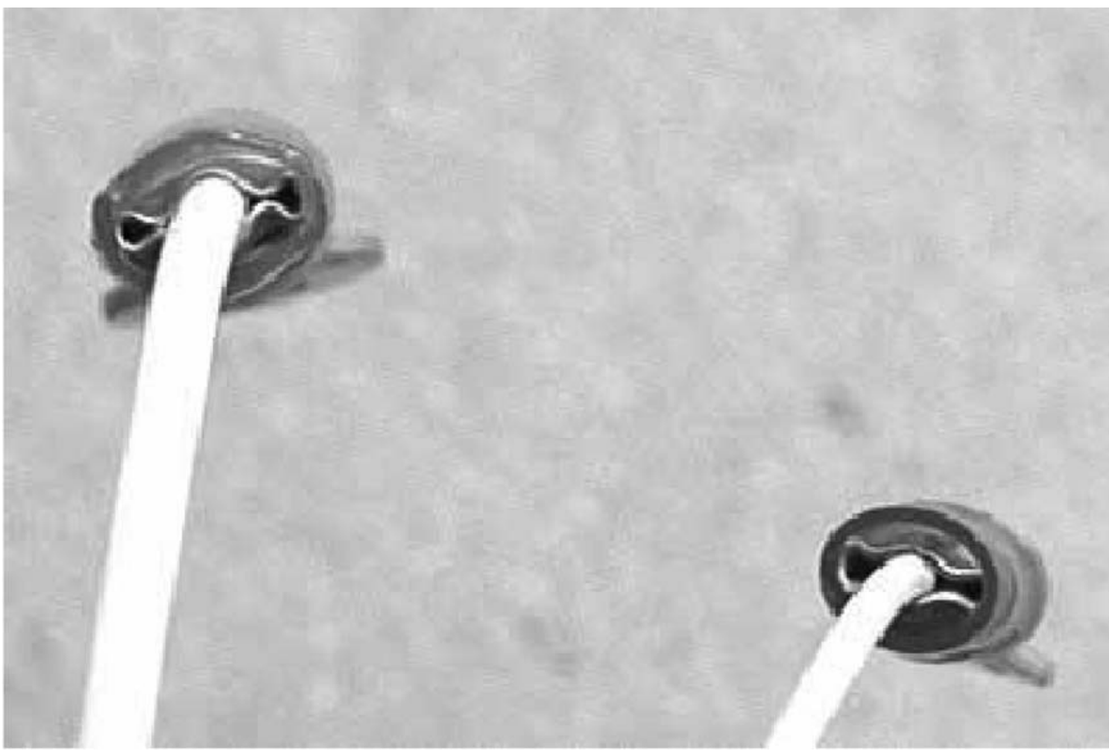


FIG. 39 Proper Terminal Crimp

treatment. They shall not be used around liquid oxygen fittings. The ability of these materials to prevent corrosion and to displace water and their ease of application when packaged as Class 2 (pressurized spray cans) make them particularly suited for service use. These materials are intended for indoor protection and short-term protection outdoors where surfaces can be recoated when required. These materials are not intended as a substitute for other corrosion preventatives specified for protection of surfaces for periods of more than one month.

7.11.1.2 When applying these compounds, ensure any adjacent wiring is protected from exposure to any chemicals that would degrade wire insulation performance.

7.11.1.3 MIL-PRF-81309 Type III, Avionics grade CPC shall be used adjacent to wiring since some of these compounds tend to migrate.

8. Electrical Load Considerations

8.1 *General:*

8.1.1 For detailed guidance for analyzing electrical loads refer to Guide F2490.

8.2 *Methods for Determining the Current-Carrying Capacity of Wires:*

8.2.1 *General:*

8.2.1.1 This section contains methods for determining the current-carrying capacity of electrical wire both as a single wire in free air and when bundled into a harness. It presents derating factors for altitude correction and examples showing how to use the graphical and tabular data provided for this purpose. Wire current-carrying capacity derating for bundling and altitude shall be addressed for all conditions expected in service. Environments in different aircraft zones may result in differing capacity of the same wire construction. In some instances, the wire may be capable of carrying more current than is recommended for the contacts of the related connector. In this instance, it is the contact rating that dictates the maximum current to be carried by a wire. Wires of larger gage may need to be used to fit within the crimp range of connector contacts that are adequately rated for the current being carried. Fig. 5 gives a family of curves whereby the bundle derating factor may be obtained.

8.2.2 *Computing Current-Carrying Capacity:*

8.2.2.1 *Example 1*—Assume a harness (open or braided), consisting of 10 wires, Size #20, 200°C rated copper and 25 wires, size #22, 200°C rated copper, will be installed in an area in which the ambient temperature is 60°C and the vehicle is capable of operating at a 60 000-ft (18 288-m) altitude. Circuit analysis reveals that 7 of the 35 wires in the bundle (7/35 = 20 %) will be carrying power currents nearly at or up to capacity.

Step 1—Refer to the "single wire in free air" curves in Figs. 3 and 4. Determine the change of temperature of the wire to determine free air ratings. Since the wire will be in an ambient of 60ºC and rated at 200°C, the change of to temperature is 200 – 60°C = 140°C. Follow the 140°C temperature difference horizontally until it intersects with wire size line on Figs. 3 and 4. The free air rating for Size #20 is 21.5 A, and the free air rating for Size #22 is 16.2 A.

Step 2—Refer to the "bundle derating curves" in Fig. 5. The 20 % curve is selected since circuit analysis indicate that 20 % or less of the wire in the harness would be carrying power currents and less than 20 % of the bundle capacity would be used. Find 35 (on the abscissa) since there are 35 wires in the bundle and determine a derating factor of 0.52 (on the ordinate) from the 20 % curve.

Step 3—Derate the Size #22 free air rating by multiplying 16.2 by 0.52 to get 8.4 A in harness rating. Derate the Size #20 free air rating by multiplying 21.5 by 0.52 to get 11.2 A in harness rating.

Step 4—Refer to the "altitude derating curve" of Fig. 19, look for 60 000 ft (18 288 m) (on the abscissa) since that is the altitude at which the vehicle will be operating. Note that the wire shall be derated by a factor of 0.79 (found on the ordinate). Derate the Size #22 harness rating by multiplying 8.4 A by 0.79 to get 6.6 A. Derate the Size #20 harness rating by multiplying 11.2 A by 0.79 to get 8.8 A.

Step 5—To find the total harness capacity, multiply the total number of Size #22 wires by the derated capacity (25 × 6.6 = 165.0 A) and add to that the number of Size #20 wires multiplied by the derated capacity (10 × 8.8 = 88 A) and multiply the sum by the 20 % harness capacity factor. Thus, the total harness capacity is (165.0 + 88.0) × 0.20 = 50.6 A. It has been determined that the total harness current shall not exceed 50.6 A, Size #22 wire shall not carry more than 6.6 A, and Size #20 wire shall not carry more than 8.8 A.

Step 6—Determine the actual circuit current for each wire in the bundle and for the whole bundle. If the values calculated in 8.2.2.1 Step 5 are exceeded, select the next larger size wire and repeat the calculations.

8.2.2.2 *Example 2*—Assume a harness (open or braided), consisting of twelve Size #12, 200°C rated copper wires, will be operated in an ambient of 25°C at sea level and 60°C at a 20 000-ft (6096-m) altitude. All twelve wires will be operated at or near their maximum capacity.

Step 1—Refer to the "single wire in free air" curve in Figs. 3 and 4. Determine the temperature difference of the wire to determine free air ratings. Since the wire will be in ambient of 25 and 60°C and is rated at 200°C, the temperature differences are 200 – 25°C = 175°C and 200 – 60°C = 140 °C, respectively. Follow the 175 and 140°C temperature difference lines on Figs. 3 and 4 until each intersects wire size line, the free air ratings of Size #12 are 68 and 61 A, respectively.

Step 2—Refer to the "bundling derating curves" in Fig. 5. The 100 % curve is selected because we know all twelve wires will be carrying full load. Find twelve (on the abscissa) since there are twelve wires in the bundle and determine a derating factor of 0.43 (on the ordinate) from the 100 % curve.

Step 3—Rate the Size #12 free air ratings by multiplying 68 and 61 A by 0.43 to get 29.2 and 26.2 A, respectively.

Step 4—Refer to the "altitude derating curve" of Fig. 19. Look for sea level and 20 000 ft (6096 m) (on the abscissa) since these are the conditions at which the load will be carried. The wire shall be derated by a factor of 1.0 and 0.91, respectively.

Step 5—Derate the Size #12 in a bundle ratings by multiplying 29.2 A at sea level and 26.6 A at 20 000 ft (6096 m) by 1.0 and 0.91, respectively, to obtain 29.2 and 23.8 A. The total bundle capacity at sea level and 25°C ambient is 29.2 × 12 = 350.4 A. At 20 000 ft (6096 m) and 60°C ambient, the bundle capacity is 23.8 × 12 = 285.6 A. Each Size #12 wire can carry 29.2 A at sea level, 25°C ambient or 23.8 A at 20 000 ft (6096 m), and 60°C ambient.

Step 6—Determine the actual circuit current for each wire in the bundle and for the bundle. If the values calculated in Step 5 are exceeded, select the next larger size wire and repeat the calculations.

8.3 *Acceptable Means of Monitoring and Controlling the Electrical Load:*

8.3.1 *Output Rating*—The generator or alternator output ratings and limits prescribed by the manufacturer shall be checked against the electrical loads that can be imposed on the affected generator or alternator by installed equipment. When a storage battery is part of the electrical power system, the battery may be continuously charged in flight.

8.3.2 The use of placards is recommended to inform the pilot or crew members or both of the combination(s) of loads that may be connected to each power source. Warning lights or messages shall be installed that will be trigger if the battery bus voltage drops below 13 V on a 14-V system or 26 V on a 28-V system.

8.3.3 For installations in which the ammeter is in the battery lead and the regulator system limits the maximum current that the generator or alternator can deliver, a voltmeter can be installed on the system bus.

8.3.4 In installations in which the ammeter is in the generator or alternator lead and the regulator system does not limit the maximum current that the generator or alternator can deliver, the ammeter can be redlined at 100 % of the generator or alternator rating.

8.3.5 Where the use of placards or monitoring devices is not practical or desired and assurance is needed that the battery will be charged in flight, the total continuous connected electrical load shall be held to approximately 80 % of the total generator output capacity. When more than one generator is used in parallel, the total rated output is the combined output of the installed generators.

8.3.6 When two or more generators and alternators are operated in parallel and the total connected system load can exceed the rated output of a single generator, a method shall be provided for quickly coping with a sudden overload that can be caused by generator or engine failure. A quick load reduction system or procedure shall be identified whereby the total load can be reduced by the pilot to a quantity within the rated capacity of the remaining operable generator or generators.

8.3.7 When acceptable to the administrator, appropriate electric load limitations may be placed in the Airplane Flight Manual (AFM) Limitations section.

9. Electrical System Components

9.1 *General:*

9.1.1 This section provides criteria for the selection of electrical system components. See Section 10 for installation details.

9.1.2 All electrical system designs shall permit inspection access. Removal of components for inspection shall be minimized.

9.1.3 All electrical system designs shall address maintenance activities.

9.2 *Alternators:*

9.2.1 Alternators are normally used to provide AC, or rectified DC, electrical current. When supplying AC electrical current, the frequency may be controlled or uncontrolled. Uncontrolled frequency AC electrical current is suitable for connection to resistive loads only such as conversion to heat for anti-ice/deice functions. Most other utilization equipment requires controlled frequencies.

9.3 *Generators:*

9.3.1 Electrical power is usually generated by engine-driven AC or DC machines. Extra care shall be exercised when using voltages in excess of 50 V as a result of the increased potential for electric shock.

9.4 *Ground Power Units:*

9.4.1 External electrical connections may be provided to connect electrical power when the aircraft is static on the ground to reduce wear on the engine(s) and engine-driven generators.

9.5 *Auxiliary Power Units:*

9.5.1 Some aircraft are fitted with on-board auxiliary power units. These units may or may not be capable of sharing electrical loads with the engine-driven generators.

9.6 *Batteries:*

9.6.1 *General:*

9.6.1.1 Aircraft batteries may be used for many functions, for example, ground power, emergency power, improving DC bus stability, and fault clearing. Most small private aircraft use lead-acid batteries. Most commercial and military aircraft use NiCad batteries. However, other types are becoming available such as lithium-ion, nickel-metal-hydride, gel cell, and sealed lead-acid batteries. The battery best suited for a particular application will depend on the relative importance of several characteristics, such as weight, cost, volume, service or shelf life, discharge rate, maintenance, and charging rate. Any change of battery type may be considered a major alteration.

9.6.1.2 *Storage Batteries* are usually identified by the material used for the plates. All battery types possess different characteristics and, therefore, shall be maintained in accordance with the manufacturer's recommendations. (**Warning—**It is extremely dangerous to store or service lead-acid and NiCad batteries in the same area. Introduction of acid electrolytes into alkaline electrolyte will destroy the NiCad and vice-versa.)

9.6.1.3 When a storage battery is part of the electrical power system, the battery may or may not be continuously charged in flight.

9.6.1.4 Operation of storage batteries beyond their ambient temperature or 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 must 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.

9.6.1.5 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 shall 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.

9.6.2 *Lead Acid:*

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

9.6.3 *Lithium-Ion (Li-Ion):*

9.6.3.1 Lithium ion batteries are a type of rechargeable battery. They have one of the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. They can be dangerous if mistreated, however; and unless care is taken, may have a short lifespan compared to other battery types.

9.6.3.2 While Li-Ion batteries do not suffer from the memory effect, they are not as durable as NiMH or NiCad designs. Li-Ion battery life cycle is dependent upon aging from time of manufacturing (shelf life) regardless if it was charged or not and not on the number of charge/discharge cycles.

9.6.3.3 Li-Ion batteries have a low self-discharge rate of only approximately 5 % per month compared with over 30 % per month and 20 % per month in NiMH and NiCad batteries, respectively.

9.6.3.4 The cathode of rechargeable lithium-ion batteries is usually made of cobalt, manganese, or a lithiated metal oxide such as $Li\ CoO_2$ or $LiMn_2O_4$. The anode is generally graphitic carbon. The electrolyte is made up of lithium salts in an organic solvent. The electrolyte can be in liquid form or it can be a solid-state electrolyte, in which case, the battery is described as a lithium polymer battery. Charging a lithium-ion battery involves the migration of lithium ions from the cathode to the carbon anode where they are deposited between carbon layers as lithium atoms. Discharging reverses the process.

9.6.3.5 Three lithium chemistries are used for lithium-based primary cells. They are lithium-thionyl chloride, lithium-manganese dioxide, and lithium-sulfur dioxide. The lithium-sulfur dioxide batteries are being phased out because of serious safety concerns. Lithium-manganese dioxide cells are considered the safest of the three as they do not develop any gas or pressure during use. Lithium manganese dioxide batteries have an anode of metallic lithium and a cathode of manganese dioxide. The electrolyte layer varies with the manufacturer. Lithium thionyl chloride batteries have a metallic lithium foil anode that gets a lithium chloride coating, or an alloy anode, and a cathode of carbon. The electrolyte is lithium tetrachloraluminate dissolved in thionyl chloride.

9.6.3.6 Li-Ion batteries have a nominal voltage of 3.6 V and a typical charging voltage of 4.2 V per cell. The charging procedure is one of constant voltage with current limiting. This means charging with constant current until a voltage of 4.2 V is reached by the cell and continuing with a constant voltage applied until the current drops close to zero. (Typically, the charge is terminated at 7 % of the initial charge current.) Li-Ion batteries cannot be fast-charged and typically need at least 4 hours to charge fully.

9.6.4 *Nickel Cadmium (NiCad):*

9.6.4.1 NiCad vented batteries have a 1.2-V nominal cell voltage. Occasional addition of distilled water is required to replace water loss as a result of 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.

9.6.4.2 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.

9.6.4.3 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 of the NiCad battery under recharge by a constant-voltage source or both 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.

(2) 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.

9.6.4.4 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 shall be closely followed.)

9.6.4.5 Shop procedures shall follow the manufacturer's recommendations. Careful examination of sealed batteries and proper reconditioning of vented batteries will ensure the longest possible service life.

9.6.5 *Nickel-Metal Hydride (NiMH):*

9.6.5.1 NiMH batteries are a type of rechargeable battery similar to a NiCad battery. NiMH batteries tend to have a higher capacity than NiCads and suffer far less from voltage depression. However, when compared with Li-Ion batteries, they have a lower energy density and a higher self-discharge rate. NiMH batteries perform better with high-drain devices.

9.6.5.2 *Chemistry:*

(1) NiMH batteries have an alkaline electrolyte.

(2) The "metal" in a NiMH battery is actually an intermetallic compound. Any of these compounds serves the same role, reversibly forming a mixture of metal hydride compounds.

9.7 *Circuit Protection Devices:*

9.7.1 *General:*

9.7.1.1 *Philosophy of Aircraft Circuit Protection*—For reliable circuit protection, the design shall provide automatic protection that will limit a fault to single circuit and more importantly minimize the danger of smoke and fire not only to the component but also the conductors (or cables) leading to and from the component. The primary consideration shall be the protection of the conductors or cables. Furthermore, the protection shall be capable isolating the fault from the power source so that nonfaulted circuits can be kept functioning in a normal manner. This is an essential safety of flight requirement. These objectives may not always be achieved by a single protective device, but by a combination of devices, wire size, and routing. Circuit designers shall use every means available to accomplish optimum protection. For example, correct sizing of wire and safe routing shall contribute to the overall circuit protection philosophy. Considerations for maintenance, inspection, and continued airworthiness shall be an integral part of the design philosophy.

9.7.1.2 Circuit protection devices shall be sized to supply open circuit capability. Proper selection should normally result in a protective device with the lowest standard rating that will not open inadvertently. It shall interrupt the fault or overload current by disconnecting the faulted line from the power distribution system before wire fusing, insulation damage, or other system damage occurs. Conventional circuit breakers shall be of the push-pull type to facilitate periodic cycling the breakers to remove contaminants from the contacts.

9.7.1.3 A circuit breaker shall be rated so that it will open before the current rating of the wire attached to it is exceeded or before the cumulative rating of all loads connected to it are exceeded, whichever is lowest. All circuit breakers used shall be of the "trip-free, push-pull" variety.

NOTE 15—Circuit breakers cannot always preclude smoke or fire from connected equipment.

9.7.1.4 All electrical wires shall be provided with some means of protection. When entirely located within an enclosure, wires less than 12 in. (30 cm) long may be installed without circuit protective devices. Electrical wire shall be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of electrical equipment will specify the fuse or breaker to be used when installing the respective equipment, or SAE publication, ARP 1199, may be referred to for recommended practices. Wires to electric starters may be installed without electrical circuit protection. Power feeder wires for starters and generators may be equipped with "ground fault" protection circuits. Care shall be exercised to ensure these wires are physically protected from chafing.

9.7.1.5 Table 22 may be used as a guide for the selection of circuit breaker and fuse rating to protect copper conductor wire. This table was prepared for the conditions specified. If actual conditions deviate materially from those stated, ratings above or below the values recommended may be justified. For example, a wire run individually in the open air may possibly be protected by the circuit breaker of the next higher rating to that shown on the chart. In general, the chart is conservative for all ordinary aircraft electrical installations.

9.7.1.6 *Circuit Breakers* are designed as circuit protection for the wire (see 9.7.1.2 and 9.7.1.3), not for protection of black boxes or components. Use of a circuit breaker as a switch is not recommended. Use of a circuit breaker as a switch will decrease the life of the circuit breaker.

9.7.2 *AFCB—Arc Fault Circuit Breakers:*

9.7.2.1 Arc fault circuit breakers are intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to deenergize the circuit when an arc fault is detected.

9.7.3 *Magnetic Circuit Breakers:*

TABLE 22 DC Wire and Circuit Protector Chart

Wire AN Gage Copper	Circuit Breaker Amp	Fuse Amp
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	30	20
10	40	30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150

Basis of chart:

(1) Wire bundles in 135°F (57.2°C) ambient and altitudes up to 30 000 ft (9144 m).

(2) Wire bundles of 15 or more wires, with wires carrying no more than 20 % of the total current-carrying capacity of the bundle as given in Specification AS 50881 (ASG).

(3) Protectors in 75 to 85°F (23.8 to 29.4°C) ambient.

(4) Copper wire Specification AS 50881.

(5) Circuit breakers to Specification MIL-C-5809 or equivalent.

(6) Fuses to Specification MIL-F-15160 or equivalent.

9.7.3.1 When a circuit breaker has only a magnetic sensing element, it is a nondelay instantaneous trip type. With this type of circuit breaker, no delay has been intentionally designed into its operation. These devices have a magnetic coil that surrounds a moveable plunger, which is held in place by a spring. The circuit current flows through the magnetic coil and produces a pull on the plunger and moves the plunger to open the contacts.

9.7.4 *Remote-Controlled Circuit Breakers:*

9.7.4.1 The remote control circuit breaker (RCCB) is a combination relay and circuit breaker that can be released or set by applying a release or set coil current electronically controlled by a command from the indicator/control unit. With the RCCB closed, an overload or fault current on any line or lines will cause the RCCB to trip and in turn will cause a controlled overload of the I/CU, causing it to trip.

9.7.5 *Resettable Circuit Breakers:*

9.7.5.1 *Resettable Circuit Protection Devices*—All resettable-type circuit breakers shall open the circuit irrespective of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as "trip free."

9.7.5.2 Automatic reset circuit breakers that automatically reset themselves periodically are not recommended as circuit protection devices for aircraft.

9.7.6 *Solid-State Power Controllers:*

9.7.6.1 Solid-state power controllers (SSPCs) combine circuit breaker, load-monitoring, and relay functions. SSPCs may be used to control, monitor, and protect circuits.

9.7.7 *Thermal Circuit Breakers:*

9.7.7.1 Thermal circuit breakers depend on temperature rise in the sensing element for actuation. In normal operation, deflection of the thermal sensing element (for example, bimetal) will cause the circuit to open when a predetermined calibration temperature is reached. To protect from unnecessarily long thermal and mechanical stress during high-fault level currents, an electromagnet is sometimes added to cause faster tripping of the thermal breaker.

9.7.8 *Fuses:*

9.7.8.1 Fuses serve two main purposes: to protect components and equipment from damage caused by overcurrents and to isolate subsystems from the main system once a fault has occurred.

9.8 *Conduit:*

9.8.1 *General*—Conduit is manufactured in metallic and nonmetallic materials and in both rigid and flexible forms. Primarily, its purpose is for mechanical protection of cables or wires. The conduit shall be designed for proper end fittings, absence of abrasion at the end fittings, proper clamping, distortion, adequate drain points that are free of obstructions and freedom from abrasion or damage as a result of moving objects such as aircraft control cables or shifting cargo.

9.8.2 *Size of Conduit*—Conduit size shall be selected for a specific wire bundle application to allow for ease in maintenance and possible future circuit expansion by specifying the conduit inner diameter (ID) larger than the maximum diameter of the wire bundle. See 10.7.1.1 for specific sizing criteria.

9.8.3 *Conduit Fittings*—Wire is vulnerable to abrasion at conduit ends. Suitable fittings shall be affixed to conduit ends in such a manner that a smooth surface comes in contact with the wire. When fittings are not used, the end of the conduit shall be flared to prevent wire insulation damage. The conduit shall be supported by use of clamps along the conduit run.

9.9 *Connectors:*

9.9.1 *General*—Ensure reliability of connectors by verifying that the following conditions are met:

9.9.1.1 Make sure unused plugs and receptacles are covered to prevent inclusion of dust and moisture. Receptacles shall have metal or composite dust caps attached by their normal mating method. Plugs may have a dust cap similar to above or have a piece of polyolefin shrink sleeving shrunk over the connector, starting from the backshell threads, with a tail sufficiently long enough to double back over the connector and be tied with polyester lacing tape behind the coupling nut. The cable identification label shall be visible behind the connector or a tag shall be attached identifying the associated circuit or attaching equipment. The connector shall be attached to structure by its normal mounting means or by the use of appropriate clamps.

9.9.1.2 Ensure that moisture-absorbent material is not used as "fill" for MS3057 clamps or adapters. See 7.2.3.4 for approved fill material.

9.9.1.3 Identical connectors in adjacent locations can lead to incorrect connections. When such installations are unavoidable, the attached wiring shall be clearly identified and shall be routed and clamped so that it cannot be mismatched.

9.9.1.4 Connectors in unpressurized areas shall be positioned so that moisture will drain out of them when unmated. Wires exiting connectors shall be routed so that moisture drains away from them.

9.9.2 *Coaxial Cable:*

9.9.2.1 *Coaxial Cable* is called "coaxial" because it includes one physical conductor that carries the signal surrounded (after a layer of insulation) by another concentric physical conductor, both running along the same axis.

9.9.2.2 *Coaxial Cable* consists of a round conducting wire, surrounded by an insulating spacer, surrounded by a cylindrical conducting sheath, and usually surrounded by a final insulating layer.

9.9.2.3 The cable is designed to carry a high-frequency or broadband signal.

9.9.2.4 *Coaxial Cables* may be rigid or flexible. Rigid types have a solid sheath, while flexible types have a braided sheath, both usually of thin copper wire.

9.9.2.5 The inner insulator, also called the dielectric, has a significant effect on the cable's properties, such as its characteristic impedance and its attenuation. The dielectric may be solid or perforated with air spaces. Coaxial cables require an internal structure of an insulating (dielectric) material to maintain the spacing between the center conductor and shield. All dielectrics have loss associated with them, which causes most coaxial lines to have higher losses than open wire lines. Most cables have a solid dielectric, while others have a foam dielectric that contains as much air as possible to reduce the losses. Foam coax will have about 15 % less attenuation but can absorb moisture in humid environments, increasing the loss.

9.9.2.6 *Velocity of Propagation (VOP)* is the speed of an electronic signal traveling down a cable compared to the speed of light in a vacuum (which is defined as 100 %). The VOP is usually expressed as a percentage where the denominator is the speed of light. The VOP in a Coaxial cable is determined by the dielectric constant of the insulating material between the center conductor and the outer conductor (or shield). A solid PTFE Teflon™, (what is used as the dielectric material in RG142) has a dielectric constant of 2.06, which equates to a VOP of 69.5 %. Thus, a signal traveling down a cable travels at 69.5 %, as it compares to the speed in the vacuum of space. Aerospace coaxial cables have a VOP range of 69.5 to 84 %. If length measurements are made on cable using a Time Domain Reflectomerter (TDR), it is important to know the VOP of the cable under test to get an accurate measurement. When calculating Aircraft installation delay (AID) for some Radio Altimeters, it is important to know the VOP of the cable. Some older Radio Altimeter installations were made using RG214 cable which has a VOP 66 %. Replacing RG214 cables, with a higher VOP cable of 83 %, the physical length of the new cable must be increased to insure the installation meets the AID.

9.9.2.7 *Triaxial Cable* or triax is coaxial cable with a second layer of shielding and sheathing. The outer shield, which is earthed, protects the inner shield from electromagnetic interference from outside sources.

9.9.2.8 *Twin-axial Cable* or twinax is a balanced, twisted pair within a cylindrical shield. It allows a nearly perfect differential signal that is both shielded and balanced to pass through.

9.9.2.9 *Biaxial Cable* or biax is a figure-eight configuration of two 50-Ω coaxial cables, used in some proprietary computer networks. Connections to the ends of coaxial cables are usually made with RF connectors. See Fig. 43 for typical coaxial cable connectors.

9.10 *Inverters and Power Converters:*

9.10.1 *Static Electrical Inverters and Power Converters* use solid-state devices to convert the aircraft's primary electrical source voltage to a different voltage or frequency for the operation of radio and electronic equipment. They contain no moving parts (with the exception of a cooling fan on some models) and are relatively maintenance free. Various types are available for AC to DC or DC to AC conversion. (**Warning—**Do not load inverters and converters beyond their rated capacity.)

9.11 *Junctions:*

9.11.1 Use approved devices, such as solderless-type terminals, terminal blocks, connectors, disconnect splices, permanent splices, and feed-through bushings for cable junctions.

9.11.2 Electrical junctions shall be protected from short circuits resulting from movement of personnel, cargo, cases, and other loose or stored materials.

9.11.3 Exposed junctions and buses shall be protected with insulating materials. Junctions and buses located within enclosed areas containing only electrical and electronic equipment are not considered as exposed.

9.12 *Junction Boxes:*

9.12.1 Junction boxes shall be fabricated from a fire-resistant, nonabsorbent material, such as aluminum or an acceptable plastic material. Where fire-proofing is necessary, a stainless steel junction box is recommended. Rigid construction will prevent "oil-canning" of the box sides that could result in internal short circuits. In all cases, drain holes shall be provided in the lowest portion of the box. Cases of electrical power equipment shall be insulated from metallic structure to avoid ground-fault-related fires. (See 7.2.4.)

9.12.2 The junction box internal arrangement shall permit easy access to any installed items of equipment, terminals, and wires. Where marginal clearances are unavoidable, an insulating material shall be inserted between current carrying parts and any grounded surface. It is not good practice to mount equipment on the covers or doors of junction boxes, since inspection for internal clearance is impossible when the door or cover is in the closed position.

9.12.3 Junction box layouts shall take into consideration the necessity for adequate wiring space and possible future additions. Electrical wire bundles shall be laced or clamped inside the box so that cables do not touch other components, prevent ready access, or obscure markings or labels. Cables at entrance openings shall be protected against chafing by using grommets or other suitable means.

9.13 *Electronic Assemblies:*

9.13.1 When incorporating electronic assemblies in a design, consideration must be given to EMI/RFI and electrostatic discharge (ESD) effects.

9.14 *Relays:*

9.14.1 *General*—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. When incorporating solid state relays in a design, consideration shall be given to EMI/RFI and ESD effects.

9.14.1.1 *Use of Relays*—Most relays are used as a switching device in which a weight reduction can be achieved or to simplify electrical controls. It should be remembered that the relay is an electrically operated switch and therefore subject to dropout under low-system voltage conditions.

9.14.1.2 *Types of Connections*—Relays are manufactured with various connective means from mechanical to plug-in devices. Installation procedures vary by the type of connection and shall be followed to ensure proper operation of the relay.

9.14.1.3 Contact ratings, as described on the relay case, describe the make, carry, and break capability for resistive currents only. Consult the appropriate specification to determine the derating factor to use for other types of current loads. (Refer to MIL-PRF-39016, MIL-PRF-5757, MIL-PRF-6106, and MIL-PRF-83536.)

9.14.1.4 Operating a relay at less than nominal coil voltage may compromise its performance and shall never be done without written manufacturer approval.

9.14.1.5 *Load Considerations*—When relays are to be used in applications in which current or voltage is substantially lower than rated conditions, additional intermediate testing shall be performed to ensure reliable operation. Contact the manufacturer on applications different from the rated conditions.

9.14.1.6 *Operating Conditions for Relays*—Relays shall be compared to their specification rating to ensure that all contacts are made properly under all conditions of operation, including vibration equivalent to that in the area of the aircraft in which the relay is to be installed.

9.14.2 Continuous duty relays are used for most applications.

9.14.3 Intermittent duty relays have higher hold in forces to prevent chattering during high current operation. These relays are sometimes referred to as contactors. They are used for applications that require high currents for short durations, such as engine starting.

9.15 *Studs:*

9.15.1 *Size of Studs*—In designing the stud for a feed-through connection, attention shall 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 shall also be given to mechanical strength.

9.16 *Switches:*

9.16.1 *General:*

9.16.1.1 In all circuits, a switch specifically approved for aircraft service shall be used. These switches are of rugged construction and have sufficient contact capacity to break, make, and carry continuously the connected load current.

9.16.1.2 *Switches* have electrical contacts and various types of switch actuators (that is, toggle plunger, push-button, knob, or rocker).

9.16.1.3 *Contacts* designed for high-level loads shall not be subsequently used for low-level applications unless testing has been performed to establish this capability.

9.16.1.4 *Switches* are specifically selected based on the design for the aircraft service current ratings for lamp loads, inductive loads, and motor loads and shall be replaced with identical make and model switches.

9.16.1.5 *Switch Rating*—The nominal current rating of the conventional aircraft switch is usually stamped on the switch housing and represents the continuous current rating with the contacts closed. Switches shall be derated from their nominal current rating for the following types of circuits:

(1) Circuits containing incandescent lamps can draw an initial current that is 15 times greater than the continuous current. Contact burning or welding may occur when the switch is closed.

(2) Inductive Circuits have magnetic energy stored in solenoid or relay coils that is released when the control switch is opened and may appear as an arc.

(3) DC Motors will draw several times their rated current during starting, and magnetic energy stored in their armature and field coils is released when the control switch is opened.

9.16.1.6 *Switch Selection*—Switches for aircraft use shall be selected with extreme caution. The contact ratings shall be adequate for all load conditions and applicable voltages at both sea level and the operational altitude. Consideration shall be given to the variation in the electrical power characteristics using MIL-STD-704 as a guide.

9.16.1.7 *Derating Factors*—Table 23 provides an approximate method for derating nominal ratings to obtain reasonable switch efficiency and service life under reactive load conditions. (**Warning—**Do not use AC derated switches in DC circuits. AC switches will not carry the same amperage as a DC switch.)

9.16.1.8 *Low-Energy Loads*—Switches rated for use at 28 VDC or more, and at 1.0 A or more, generally have silver contacts. In general, silver contacts shall not be used to control devices that have a voltage less than 8 V or a continuous current less than 0.5 A unless the switch is specifically rated for use with low-energy loads. Table 24 provides general guidelines for selecting contact materials for low-energy loads but is not applicable to hermetically sealed switches.

9.16.1.9 Typical logic load devices have a voltage of 0.5 to 28 V and a continuous current of less than 0.5 A. A suitable method of rating switches for use on logic load devices is specified in ANSI/EIA 5200000.

9.16.1.10 Typical low-level load devices have a voltage of less than 0.5 V and a continuous current of less than 0.5 A. A suitable method of rating switches for use on low-level load devices is specified in ANSI/EIA 5200000.

9.16.1.11 Most aircraft switches operate between –55 and 85°C with designs available from –185 to 260°C or more. Higher temperatures require more exotic materials, which can increase costs and limit life. Note that o-ring seals and elastomer boot seals tend to stiffen in extreme cold. This can increase operating forces and reduce release forces or stop the switch from releasing.

9.16.1.12 The materials used for sealing (o-rings, potting materials, and so forth) shall be compatible with any aircraft fluids to which the switch may be exposed.

9.16.1.13 *Load Considerations*—When switches are to be used in applications in which current or voltage is substantially lower than rated conditions, additional intermediate testing shall be performed to ensure reliable operation. Contact the manufacturer on applications different from the rated conditions.

9.16.1.14 *Operating Conditions for Switches*—Switches shall be compared to their specification rating to ensure that all contacts are made properly under all conditions of operation, including vibration equivalent to that in the area of the aircraft in which the switch is to be installed.

9.16.2 *Proximity:*

TABLE 23 Switch-Derating Factors

NOTE 1—To find the nominal rating of a switch required to operate a given device, multiply the continuous current rating of the device by the derating factor corresponding to the voltage and type of load.

NOTE 2—To find the continuous rating that a switch of a given nominal rating will handle efficiently, divide the switch nominal rating by the derating factor corresponding to the voltage and type of load.

Nominal System Voltage	Type of Load	Derating Factor
28 VDC	Lamp	8
28 VDC	Inductive (relay-solenoid)	4
28 VDC	Resistive (Heater)	2
28 VDC	Motor	3
12 VDC	Lamp	5
12 VDC	Inductive (relay-solenoid)	2
12 VDC	Resistive (Heater)	1
12 VDC	Motor	2

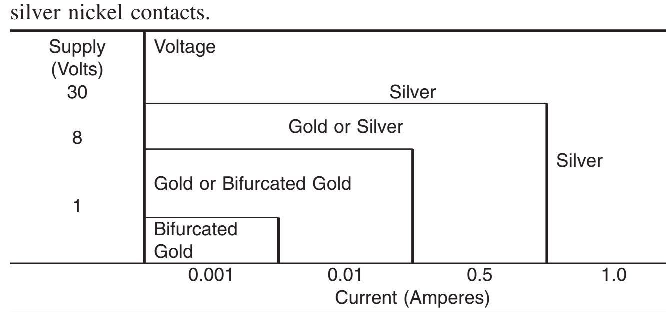
TABLE 24 Selection of Contact Material

NOTE 1—If sulfide, moisture, or any form of contamination is present, a sealed switch should be used. The degree of sealing required (environmental or hermetic) is dependent upon the environment in which the switch is intended to be operated.

NOTE 2—If particle contamination in any form is likely to reach the contacts, bifurcated contacts should be used.

NOTE 3—Low-voltage high-current loads are difficult to predict and may result in a combined tendency of noncontact, sticking, and material transfer.

NOTE 4—High-voltage high-current applications may require the use of silver nickel contacts.



9.16.2.1 These switches are usually solid-state devices that detect the presence of a predetermined target without physical contact and are usually rated 0.5 A or less.

9.16.2.2 Although proximity switches do not have moving parts, the reliability of the internal electronic parts of the switch may be reduced. Reliability and mean time between failure (MTBF) calculations shall reflect the applicable environment. Note that the mounting of both the proximity sensor and its target shall be rigid enough to withstand shock or vibration to avoid creating false responses.

9.16.2.3 Proximity switches are susceptible to an EMI/RFI environment and shall be evaluated in the application. Twisting lead wires, metal overbraids, lead wire routing, and the design of the proximity switch can minimize susceptibility. Proximity switches can also be a source of EMI. Ensure proximity switches are selected to address all EMI aspects.

9.16.2.4 Proximity sensors are normally designed for environments from –55 to 125°C. During temperature excursions, the operating and release points may shift from 5 to 10 %. Reliability of the proximity sensor will typically be highest at room temperature. The reliability and MTBF estimates shall be reduced for use under high temperatures or high thermal gradients.

9.16.2.5 Proximity switches for aircraft applications typically have a metal face and potting material surrounding any electronics and lead wire exits. The potting material shall be compatible with the fluids the switch will be exposed to in the environment. The plastic sensing face of some proximity switches may be subject to absorption of water that may cause the operating point to shift shall be protected. Proximity sensors generally use a relatively low-energy electromagnetic field to sense the target. Adequate spacing is required to prevent interference between adjacent proximity sensors or other devices susceptible to EMI/RFI. Refer to manufacturer's instructions.

9.16.3 *Pushbutton:*

9.16.3.1 Pushbutton switches may be push-on/push-off or may maintain a depressed position after actuation. When using lighted switches, ensure the system status annunciation is consistent.

9.16.4 *Rotary:*

9.16.4.1 Rotary switches are typically used for applications requiring simultaneous multiple circuit switching. These switches often include multiple switching decks actuated by a single mechanism.

9.16.5 *Electromechanical (Toggle):*

9.16.5.1 Electromechanical switches (toggle switches) are most susceptible to shock and vibration in the plane that is parallel to contact motion. Under these conditions, the switch contacts may momentarily separate. ANSI/EIA 5200000 specifies that contact separations greater than 10 μs and that closing of open contacts in excess of 1 μs are failures. Repeated contact separations during high levels of vibration or shock may cause excessive electrical degradation of the contacts. These separations can also cause false signals to be registered by electronic data processors without proper buffering.

9.16.5.2 DC-operated electromechanical switches are usually not susceptible to EMI/RFI.

(1) The arcing of electromechanical switch contacts generates short-duration EMI/RFI when controlling highly inductive electrical loads. Twisting lead wires, metal overbraids, and lead wire routing can reduce or eliminate generation problems when dealing with arcing loads.

9.16.5.3 Electromechanical switches can withstand wide temperature ranges and rapid gradient shifts without damage.

9.16.5.4 Electromechanical switches range in sealing from partially sealed to hermetically sealed. Use a sealed switch when the switch will be exposed to a dirty environment during storage, assembly, or operation. Use a higher level of sealing when the switch will not have an arcing load to self-clean the contacts. Low-energy loads tend to be more susceptible to contamination.

9.17 *Terminals and Terminal Blocks:*

9.17.1 *Creepage Distance*—Care shall 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.

9.18 *Waveguides:*

9.18.1 Equipment suppliers will specify the requirements for waveguides to ensure proper functioning of the associated system. Ensure waveguides comply with these specifications.

10. Electrical System Component Installation

10.1 *General:*

10.1.1 This section provides installation criteria for aircraft electrical system components.

10.1.2 *Adequate Length*—Components shall extend out from their mounting position a distance that permits rotating and unlocking (or locking) the electrical connector. Usually a distance of 3 to 6 in. (8 to 15 cm), with all other components installed, should be sufficient.

10.1.3 *Reverse Polarity Protection*—There shall be some means to ensure the electrical system is protected from reversed polarity of ground support equipment. Connecting the aircraft electrical system to an external power source with reverse polarity can result in equipment damage. Protection means may be physical (for example, polarized connector) or electrical.

10.1.4 All electrical system installations shall permit inspection access. Removal of components for inspection shall be minimized.

10.1.5 All electrical system installations shall include provisions for maintenance access. (Refer to FAA Advisory Circular AC 25.1353-1 for additional guidance on electrical equipment installation.)

10.2 *Alternators:*

10.2.1 Ensure alternator requirements do not exceed the engine accessory pad limitations.

10.2.2 Ensure adequate cooling is provided to keep the alternator within its operating limitations.

10.2.3 Ensure the alternator, its mounting, and cooling duct installation meet engine fireproof requirements if applicable.

10.3 *Generators:*

10.3.1 Ensure generator requirements do not exceed the engine accessory pad limitations.

10.3.2 Ensure adequate cooling is provided to keep the generator within its operating limitations.

10.3.3 Ensure the generator, its mounting, and cooling duct installation meet engine-fireproof requirements if applicable.

10.4 *Auxiliary Power Units (APUs):*

10.4.1 Ensure generator requirements do not exceed the APU accessory pad limitations.

10.4.2 Ensure adequate cooling is provided to keep the APU-mounted generator within its operating limitations.

10.5 *Batteries:*

10.5.1 *General:*

10.5.1.1 *External Surface*—Ensure the external surface of the battery is clean before installation in the aircraft.

10.5.1.2 *Replacing Lead-Acid Batteries*—When replacing lead-acid batteries with NiCad batteries, a battery temperature or current-monitoring system shall be installed.

10.5.1.3 *Battery Venting*—Battery fumes and gases may cause an explosive mixture or contaminated compartments and shall be dispersed by adequate ventilation. Venting systems often use ram pressure to flush fresh air through the battery case or enclosure to a safe overboard discharge point. The venting system pressure differential shall always be positive and remain between recommended minimum and maximum values. Line runs shall not permit battery overflow fluids or condensation to be trapped and prevent free airflow.

10.5.1.4 *Battery Sump Jars*—A battery sump jar installation may be incorporated in the venting system to dispose of battery electrolyte overflow. The sump jar shall be of adequate design and the proper neutralizing agent used. The sump jar shall be located only on the discharge side of the battery venting system. (See Fig. 40.)

10.5.1.5 *Battery Quick-Disconnect*—If a quick-disconnect type of battery connector that prohibits crossing the battery lead is not used, ensure that cross connection of the aircraft wiring is prevented by other means.

10.5.2 *Lead Acid:*

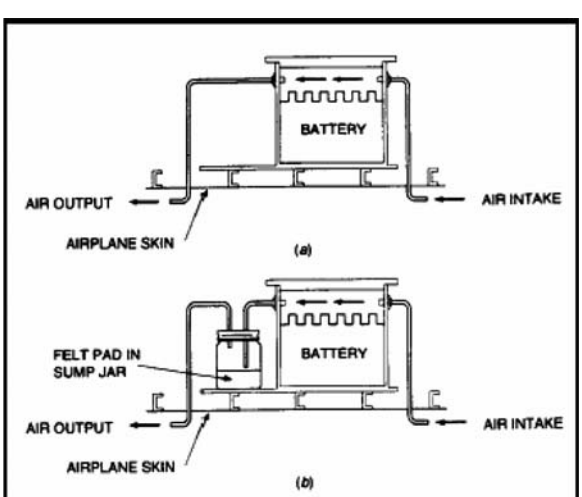


FIG. 40 Battery Ventilating Systems

10.5.2.1 Ensure lead-acid battery electrolyte temperatures are maintained above those shown in Table 25.

10.5.3 *Lithium-Ion(Li-Ion):*

10.5.3.1 Li-Ion batteries shall be charged early and often. However, if they are not used for a longer time, they shall be brought to a charge level of around 40 %.

10.5.3.2 Li-Ion batteries shall be kept cool. However, they shall not be subjected to freezing temperatures. Aging will take its toll much faster at high temperatures. (**Warning—**Li-Ion batteries can easily rupture, ignite, or explode when exposed to high temperatures or direct sunlight. Short-circuiting a Li-Ion battery can also cause it to ignite or explode. Never open a Li-Ion battery's casing. Li-Ion batteries contain safety devices that, if damaged, can cause the battery to ignite or explode.)

10.5.4 *Nickel Cadmium (NiCad):*

10.5.4.1 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 hours, 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.

10.5.5 *Nickel-Metal Hydride (NiMH):*

10.5.5.1 *Charging*—When fast charging, it is advisable to charge the NiMH batteries with intelligent chargers to prevent overcharging with large currents, which could damage the battery. Modern NiMH batteries contain catalysts to immediately deal with gases developed as a result of overcharging without being harmed. This however only works with overcharging currents of up to C/10 hours (nominal capacity divided by 10 hours). As a result of this reaction, the batteries will heat up considerably, marking the end of the charging process.

10.5.5.2 *Discharging*—Care shall be taken during discharge to ensure that a cell in a series battery does not become totally flat and then reverse charged. This reverse charge can cause irreparable damage to the cell. Nickel metal hydride batteries

TABLE 25 Lead-Acid Battery Electrolyte Freezing

Specific Gravity	Freeze Point		State of Charge (SOC) for Sealed Lead-Acid Batteries at 70		
	C	F	SOC	12 volt	24 volt
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			

have a high self-discharge rate of approximately 30 % per month and more. This is higher than that of NiCad batteries, which is around 20 % per month. The self-discharge rate is highest for full batteries and drops off somewhat for lower charges. The rate is strongly affected by the temperature at which the batteries are stored. Recommended longtime storage charge is around 40 %.

10.6 *Circuit Protection Devices:*

10.6.1 *General:*

10.6.1.1 All circuit protection devices shall be installed within the manufacturers' limitations to ensure proper functioning. Note that trip curves for circuit protective devices can vary substantially with temperature. When using alternate suppliers, ensure that all installed circuit breakers provide equivalent or superior protection. Ensure the time to trip of the replacement circuit breaker is less than or equal to the unit being replaced even though both units have equivalent current ratings. (Refer to FAA Advisory Circular AC 25.1357-1 for additional guidance on circuit protective device accessibility.)

10.6.2 *Arc Fault Circuit Breakers (AFCBs):*

10.6.2.1 AFCB circuitry continuously monitors current flow through and uses unique current sensing circuitry to discriminate between normal and unwanted arcing conditions. Once an unwanted arcing condition is detected, the control circuitry in the AFCB trips the internal contacts, thus deenergizing the circuit and reducing the potential for a fire to occur. An AFCB should not trip during normal arcing conditions, which can occur when a switch is opened. Arc fault circuit breaker installations shall provide adequate wire-routing provisions for all terminations including indication connections. Installations shall consider proper viewing fields for any included visual indications.

10.6.3 *Magnetic Circuit Breakers:*

10.6.3.1 Magnetically actuated circuit breakers rely on the magnetic field generated by the conductor to function and, therefore, shall not be installed in proximity to large magnetic fields.

10.6.4 *Remote-Controlled Circuit Breakers:*

10.6.4.1 Remote circuit breakers require installation considerations for both the primary connections and the remote control device.

10.6.5 *Resettable Circuit Breakers:*

10.6.5.1 Automatic resetting circuit breakers are not recommended for installation in aircraft. All circuit breakers shall be manually resettable.

10.6.6 *Solid-State Power Controllers (SSPC):*

10.6.6.1 Solid-state power controller installations shall consider all aspects of these devices including monitoring, protection, and control.

10.6.6.2 When incorporating SSPCs in a design, consideration shall be given to EMI/RFI and ESD effects.

10.6.7 *Thermal Circuit Breakers:*

10.6.7.1 Thermal circuit breakers shall not be installed in thermally elevated areas. Installation of these breakers in groups shall consider the heat generated during normal operation.

10.6.8 *Fuses:*

10.6.8.1 Fuses cannot be reset and shall be installed in easily accessible locations.

10.6.8.2 Spares for fuses requiring renewal in flight shall be provided per 14CFR91.205c(6).

10.6.9 *Coaxial Cable:*

10.6.9.1 Extra care shall be exercised when installing coaxial cable. Some coaxial cable shall be of a specified length to ensure proper system operation. When required coaxial cable length results in cable lengths exceeding the wire routing path, ensure the excess cable length is properly supported. Ensure loops in the coaxial cable do not exceed the proper bend radius (see 7.2.1.16 and 7.2.1.17) or create victim or culprit EMI issues (see Section 11).

10.6.9.2 Extra care shall be taken when securing coaxial cables with tie-straps. Coaxial cables are somewhat fragile and it is possible to crush them when installing tie-straps. Crushing a coax will alter the signal passing through it and could result in equipment failure. Once damaged, the coax shall be replaced. Tie straps may also be used on bundle assemblies containing coaxial cable that has a solid dielectric; however, a strapping pressure just enough to prevent axial slippage shall be used (see 7.2.3.4).

10.7 *Conduit:*

10.7.1 *General:*

10.7.1.1 Conduit shall be used to protect wiring at points where abrasion might result or to carry it through areas in which damage or deterioration might occur. Flexible plastic conduit shall not be installed in lengths greater than necessary (maximum of 6 in. (15 cm) on either side of the danger area). Plastic tubing, not terminated in ferrules, shall be secured in place by clamps or supporting devices. The diameter of the conduit shall be determined by grouping wires or cables installed therein or both and measuring the maximum diameter which shall not exceed 85 % of the internal diameter of the conduit.

10.7.1.2 Consideration shall be given to accessibility of wiring in conduit for inspection, repair, or replacement.

10.7.2 *Conduit Installation*—Conduit problems can be avoided by following these guidelines:

10.7.2.1 Do not locate the conduit where passengers or maintenance personnel might use it as a handhold or footstep.

10.7.2.2 Provide drain holes at the lowest point in a conduit run. Drilling burrs shall be carefully removed.

10.7.2.3 Support the conduit to prevent chafing against the structure and avoid stressing its end fittings.

10.7.3 *Rigid Conduit:*

10.7.3.1 Minimum acceptable tube bend radii for rigid conduit are shown in Table 26. Tubing that has been formed and cut to final length shall be deburred to prevent wire insulation damage. When installing tube sections with fittings at both ends, care shall be taken to eliminate mechanical strain.

10.7.4 *Flexible Conduit*—Flexible aluminum conduit conforming to Specification SAE AS 6136 (replaces MIL-C-6136) is available in two types: Type I, bare flexible conduit, and Type II, rubber-covered flexible conduit. Flexible brass conduit conforming to Specification SAE AS 25064 (replaces MS25064) is available and normally used instead of flexible aluminum where necessary to minimize radio interference.

TABLE 26 Bend Radii for Rigid Conduit

Nominal Tube OD, in.[A]	Minimum Bend Radii, in.[A]
1⁄8	3⁄8
3⁄16	7⁄16
1⁄4	9⁄16
3⁄8	15⁄16
1⁄2	1 1⁄4
5⁄8	1 1⁄2
3⁄4	1 3⁄4
1	3
1 1⁄4	3 3⁄4
1 1⁄2	5
1 3⁄4	7
2	8

[A] 1 in. = 2.54 cm.

Also available is plastic flexible tubing. (Reference SAE AMS-T-81914 replaces MIL-T-81914.) Flexible conduit may be used where it is impractical to use rigid conduit, such as areas that have motion between conduit ends or where complex bends are necessary. The use of transparent adhesive tape is recommended when cutting flexible tubing with a hacksaw to minimize fraying of the braid. The tape shall be centered over the cutting reference mark with the saw cutting through the tape. After cutting the flexible conduit, the transparent tape shall be removed, the frayed braid ends trimmed, burrs removed from inside the conduit, and coupling nut and ferrule installed. Minimum acceptable bending radii for flexible conduit are shown in Table 27.

10.7.4.1 Electrically conductive conduit shall be electrically bonded to basic structure.

10.7.4.2 Ensure conduit is relieved of strain and flexing of ferrules.

10.7.4.3 Ensure conduits will not trap fluids or condensed moisture. Suitable drain holes shall be provided at the low points.

10.7.4.4 Ensure bonding clamps do not cause damage to the conduit.

10.7.4.5 Ensure ends of open conduits are flared or routed to avoid sharp edges that could chafe wires exiting from the conduit. All conduits shall be clear of loose particles, chips, or other scrap before insertion of wires or cables to minimize the possibility of future defects in the system.

TABLE 27 Minimum Bending Radii for Flexible Aluminum or Brass Conduit

Nominal ID of Conduit, in.[A]	Minimum Bending Radius Inside, in.[A]
3⁄16	2 1⁄4
1⁄4	2 3⁄4
3⁄8	3 3⁄4
1⁄2	3 3⁄4
5⁄8	4 1⁄4
3⁄4	5 3⁄4
1	5 3⁄4
1 1⁄4	8
1 1⁄2	8 1⁄4
1 3⁄4	9
2	9 3⁄4
2 1⁄2	10

[A] 1 in. = 2.54 cm.

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

10.7.5 *Flexible:*

10.7.5.1 Ensure weatherproof shields on flexible conduits of the nose and main landing gear and in wheel wells are installed properly.

10.7.5.2 Thimbles and ferrules shall be swaged to flexible conduit.

10.7.6 *Rigid:*

10.7.6.1 No sharp edges shall be left on the ends of rigid conduit and conduit fittings. All sharp edges shall be removed.

10.8 *Connectors:*

10.8.1 *General*—There is a multitude of types of connectors. Crimped contacts are generally used. Some of the more common are the round, the rectangular, and the module blocks. Environmentally resistant connectors shall be used in applications subject to fluids, vibration, thermal, mechanical shock, and/or corrosive elements. When high-intensity radio frequency (HIRF)/lightning protection is required, special attention shall be given to the terminations of individual or overall shields. Some method shall be incorporated to ensure the electrical bonding of the connector and shields is maintained. The number and complexity of wiring systems have resulted in an increased use of electrical connectors. The proper choice and application of connectors is a significant part of the aircraft wiring system. Connectors shall be kept to a minimum, selected, and installed to provide the maximum degree of safety and reliability to the aircraft. For the installation of any particular connector assembly, the specification of the manufacturer or the appropriate governing agency shall be followed.

10.8.2 *Selection*—Connectors shall be selected to provide the maximum degree of safety and reliability considering electrical and environmental requirements. Consider the size, weight, tooling, logistic, maintenance support, and compatibility with standardization programs. For ease of assembly and maintenance, connectors using crimped contacts are generally chosen for all applications except those requiring a hermetic seal. (Reference SAE ARP 1308.) A replacement connector of the same basic type and design as the connector it replaces shall be used. With a crimp-type connector for any electrical connection, the proper insertion or extraction tool shall be used to install or remove wires from such a connector. Refer to manufacturer or aircraft instruction manual. After the connector is disconnected, inspect it for loose soldered connections to prevent unintentional grounding. Connectors that are susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly.

10.8.3 *Types of Connectors*—Connectors shall be identified by an original identification number replaces a MIL Specification (MS) or OEM specification. Fig. 41 provides some examples of MS connector types. Several different types are shown in Fig. 42. Different types of coaxial cable connectors are shown in Fig. 43. See 10.6.9 for details on coaxial cable installation.

10.8.3.1 *Environmental Classes*—Environmentally resistant connectors are used in applications in which they will probably

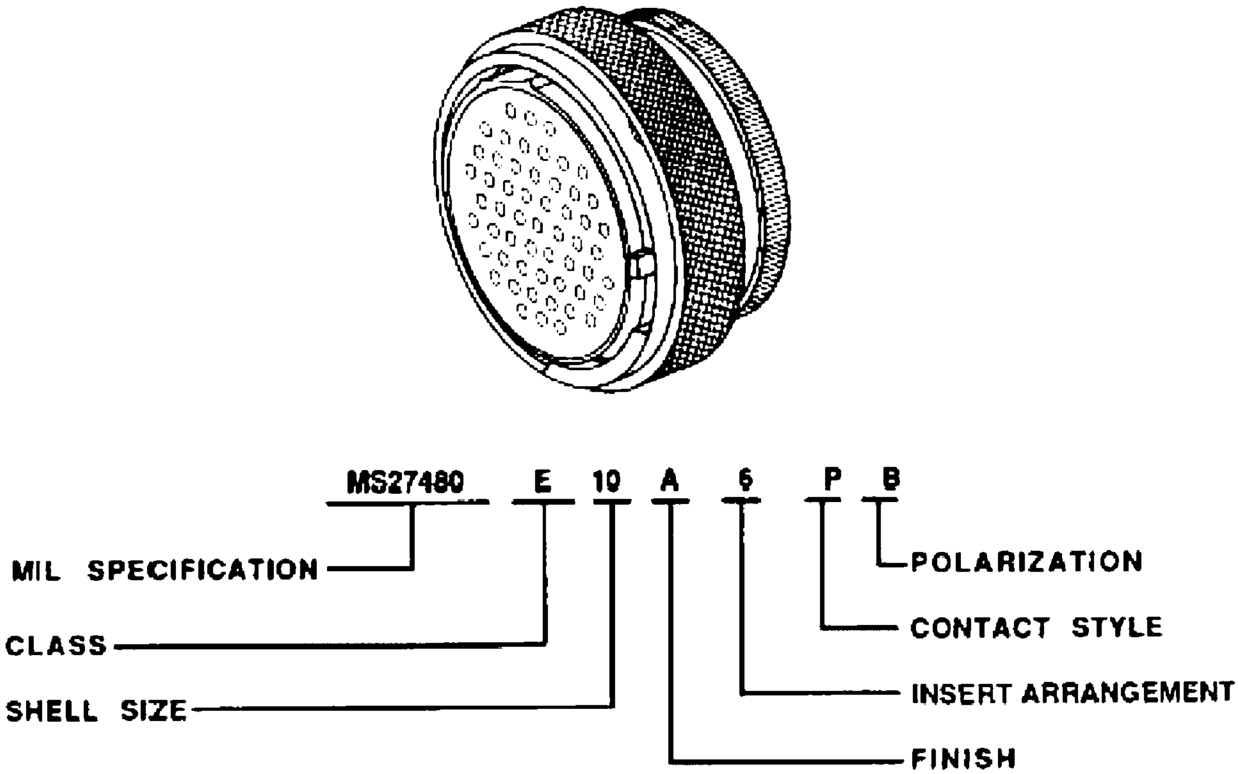


FIG. 41 Connector Information Example

be subjected to fluids, vibration, thermal, mechanical shock, corrosive elements, and so forth. Firewall class connectors incorporating these same features shall, in addition, be able to prevent the penetration of the fire through the aircraft firewall connector opening and continue to function without failure for a specified period of time when exposed to fire. Hermetic connectors provide a pressure seal for maintaining pressurized areas. When EMI/RFI protection is required, special attention shall be given to the termination of individual and overall shields. Backshell adapters designed for shield termination, connectors with conductive finishes, and EMI grounding fingers are available for this purpose.

10.8.3.2 *Rectangular Connectors*—The rectangular connectors are typically used in applications in which a very large number of circuits are accommodated in a single mated pair. They are available with a great variety of contacts, which can include a mix of standard, coaxial, and large power types. Coupling is accomplished by various means. Smaller types are secured with screws that hold their flanges together. Larger ones have integral guide pins that ensure correct alignment or jackscrews that both align and lock the connectors. Rack and panel connectors use integral or rack-mounted pins for alignment and box mounting hardware for couplings.

10.8.3.3 *Module Blocks*—These junctions accept crimped contacts similar to those on connectors. Some use internal busing to provide a variety of circuit arrangements. They are useful when a number of wires are connected for power or signal distribution. When used as grounding modules, they save and reduce hardware installation on the aircraft. Standardized modules are available with wire end grommet seals for environmental applications and are track mounted. Function module blocks are used to provide an easily wired package for environmentally resistant mounting of small resistors, diodes, filters, and suppression networks. In-line terminal junctions are sometimes used in lieu of a connector when only a few wires are terminated and the ability to disconnect the wires is desired. The in-line terminal junction is environmentally resistant. The terminal junction splice is small and may be tied to the surface of a wire bundle when approved by the OEM.

10.8.4 *Voltage and Current Rating*—Selected connectors shall be rated for continuous operation under the maximum combination of ambient temperature and circuit current load. Hermetic connectors and connectors used in circuit applications involving high-inrush currents shall be derated. It is good engineering practice to conduct preliminary testing in any situation in which the connector is to operate with most or all of its contacts at maximum rated current load. When wiring is operating with a high conductor temperature near its rated temperature, connector contact sizes shall be suitably rated for the circuit load. This may require an increase in wire size also. Voltage derating is required when connectors are used at high altitude in nonpressurized areas. Derating of the connectors shall be covered in the specifications.

10.8.5 *Spare Contacts (Future Wiring)*—To accommodate future wiring additions, spare contacts are normally provided. Locating the unwired contacts along the outer part of the connector facilitates future access. A good practice is to provide: two spares on connectors with 25 or less contacts, 4 spares on connectors with 26 to 100 contacts, and 6 spares on connectors with more than 100 contacts. Spare contacts are not normally provided on receptacles of components that are unlikely to have added wiring. Depending on the connector

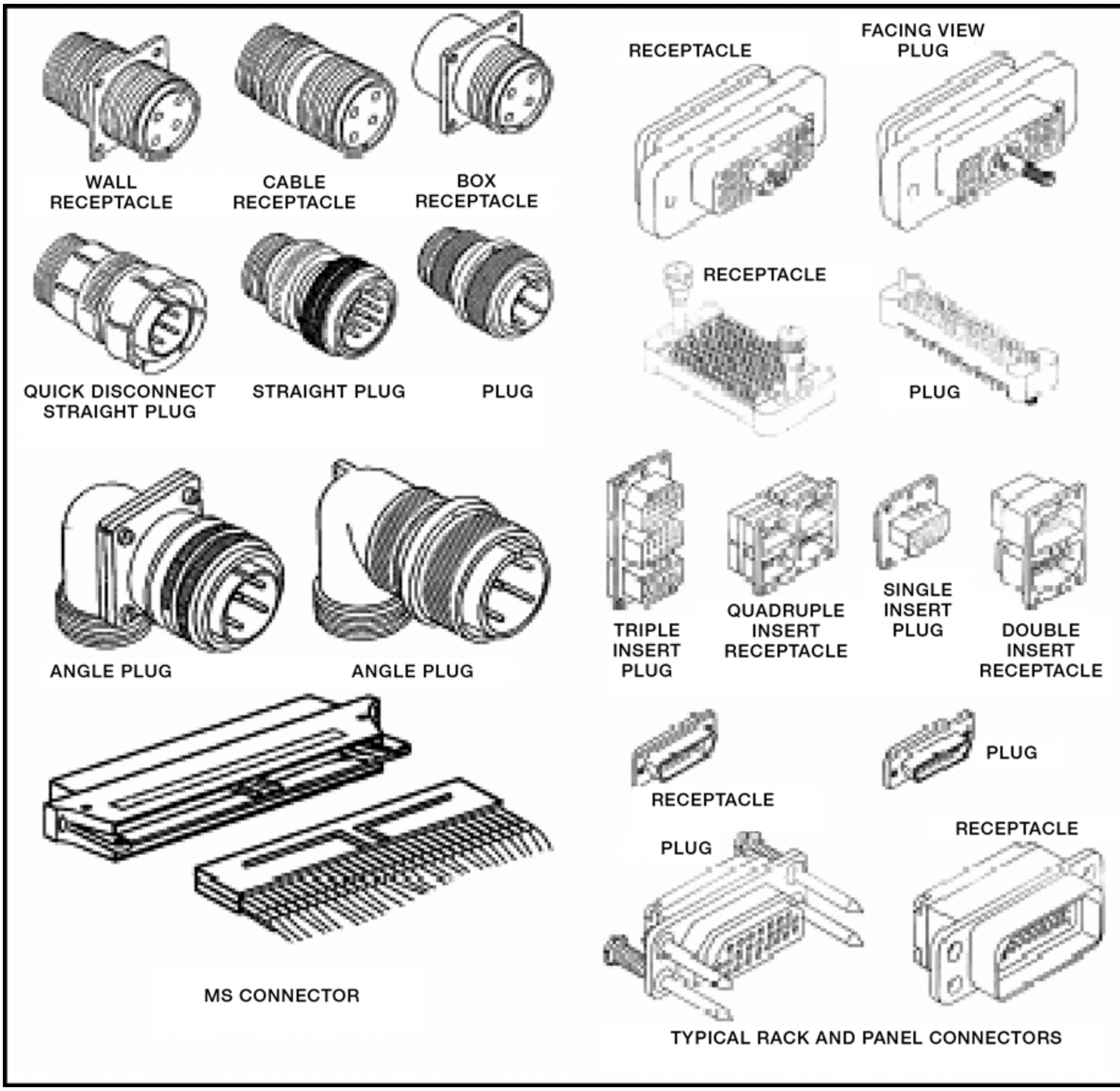


FIG. 42 Different Types of Connectors

installation, unused connector contact cavities may need to be properly sealed to avoid damage to the connector or have stub wire installed. Unwired contacts shall be provided with a plastic grommet sealing plug. See Fig. 44.

10.8.6 *Installation:*

10.8.6.1 *Crimp Contacts:*

(1) Removable crimp-type contacts conforming to MIL-C-39029 are used with the connector types such as MIL-DTL-5015, MIL-C-26482, MIL-C-26500 and MIL-DTL-38999 Series I, II, III and IV, MIL-C- 81511, and MIL-DTL-83723. Connectors manufactured in accordance with military specifications are designated in one of two ways. In some specifications such as MIL-DTL-5015, MIL-C-26482, MIL-C-26500, and MIL-DTL-38999 Series I and II, the connector is designated by an "MS" number, such as MS3101. In specifications MIL-DTL-38999 Series III and IV, MIL-C- 81511, MIL-DTL-83723, and later specifications, the connector is designated by a D or M preceding the specification number followed by a slash and the connector number, such as D38999/21 or M83723/65.

(2) The method of crimping wires to these contacts is essentially the same throughout the entire group of connectors. Standard crimping tools conforming to MIL-DTL-22520 are used to crimp the contacts. Contacts manufactured after April 1978 will be identified with BIN (basic identification on number) code color bands (see Fig. 45). Each digit of the BIN code will be designated on the contact by a color band in accordance with the following:

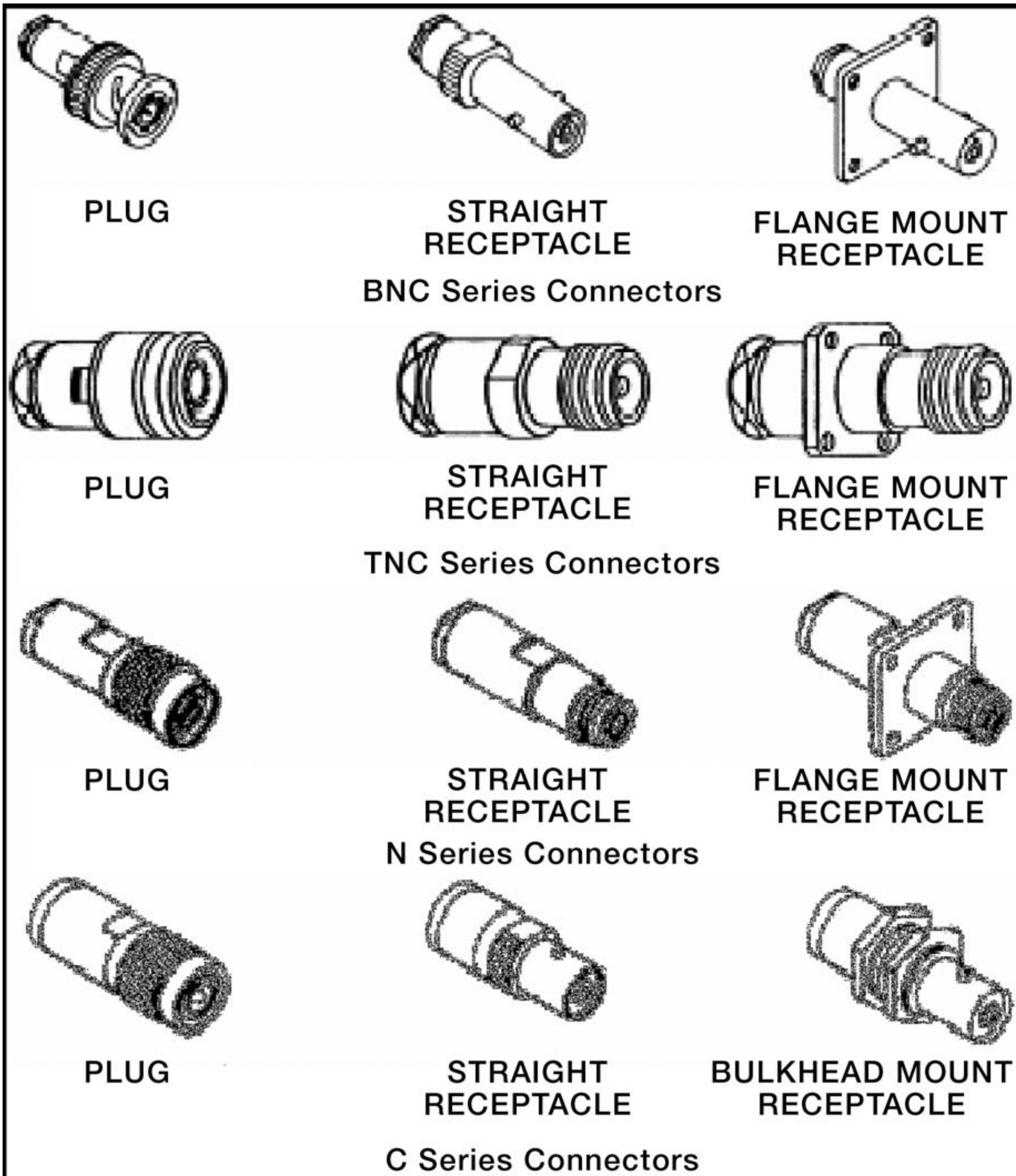


FIG. 43 Coax Cable Connectors

0 – Black	5 – Green
1 – Brown	6 – Blue
2 – Red	7 – Violet
3 – Orange	8 – Grey
4 – Yellow	9 – White

(3) See Table 28 for contact to BIN code cross reference.

10.8.6.2 *Crimping Tools:*

(1) Crimping tools used for crimping removable contacts to wire conductors for use in electrical connectors, terminal junction systems, and other electrical or electronic components, shall conform to MIL-DTL-22520 and one of its associated specification sheets. These tools are capable of crimping a range of contact wire barrel Sizes 12 to 28, to a

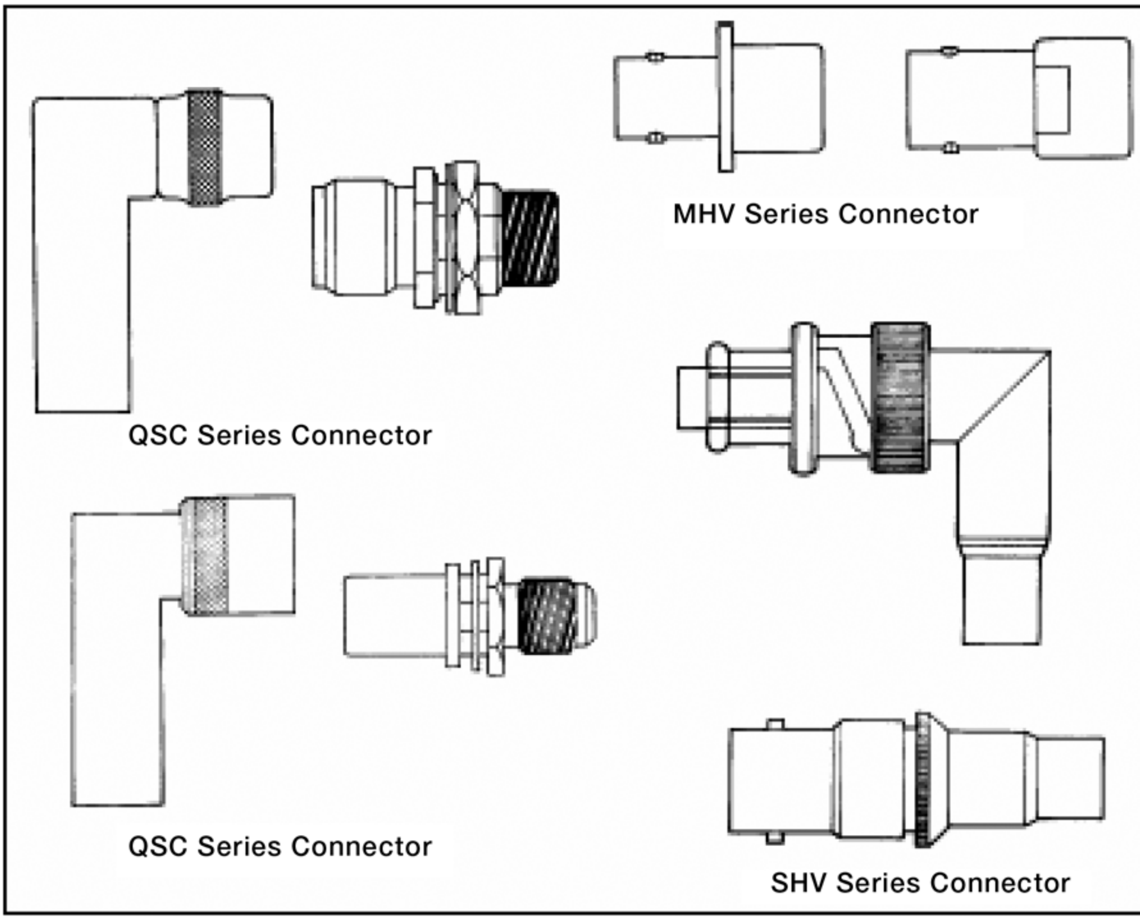


FIG. 43 Coax Cable Connectors *(continued)*

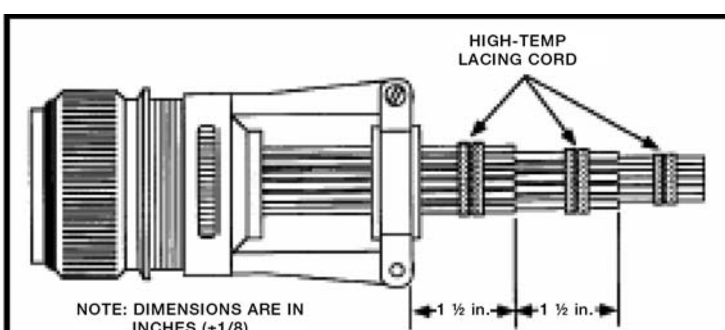


FIG. 44 Stub Wire Installation

range of wire Sizes 12 to 32. All MIL-DTL-22520 hand-operated tools are cycle controlled by means of a ratchet mechanism that will not release until the crimping cycle has been completed. A brief description of each of these tools follows:

Note—Do not disassemble any crimping tools. Do not tighten or loosen nuts or otherwise attempt to adjust. Required adjustments shall be made only by the manufacturer or by a calibration laboratory.

(2) MIL-DTL-22520/1 Crimping Tool—The basic crimping tool, M22520/l-0l, accommodates contacts with wire barrel Sizes 12 through 20 and has a provision for selecting the proper depth of crimp depending on the contact/wire combination being used. The contact is crimped by the creation of four sets of double impressions caused by the closure of the four indenters. Appropriate turret or positioner heads are installed depending on the application.

(3) MIL-DTL-22520/2 Crimping Tool—The basic crimping tool, M22520/2-01, accommodates contacts with wire barrel Sizes 20 through 28 and has a provision for selecting the proper depth of crimp depending on the contact/wire combination

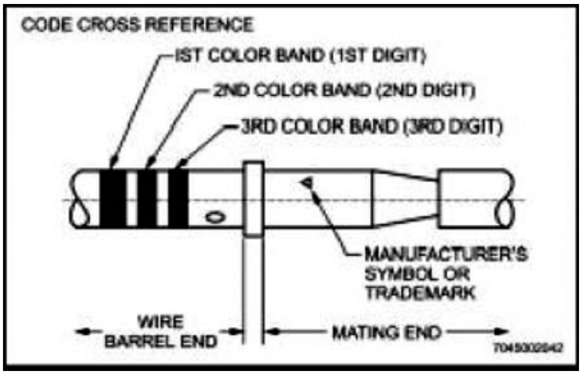


FIG. 45 Contact Marking

being used. The contact is crimped by the creation of four sets of double impressions caused by the closure of the four indenters. Appropriate positioners are installed depending on the application.

(4) MIL-DTL-22520/4 Crimping Tool—The basic tool, MS22520/4-01, is used only with the M22520/4-02 single-positioner head. This tool head combination is used to crimp outer pin and socket coaxial contacts to the shielded cables specified for them. The tool, which is not operator adjustable, creates a circular crimp around the contact. For specific tool application, see MIL-DTL-22520/4.

(5) MIL-DTL-22520/7 Crimping Tool—The basic crimping tool, M22520/7-01, accommodates contacts with wire barrel Sizes 16 through 22 and has a provision for selecting the proper depth of crimp depending on the contact/wire combination being used. It is similar to the M22520/2- 01 in that it is smaller than the M22520/1-01 and is therefore easier to handle. It is also similar in appearance and has the same method of operation.

10.8.6.3 *Connector Pin BIN Codes*—Table 28 lists common connector pin and sockets and the part(s) they superseded by Bin code number.

10.8.6.4 *Connector Specifications*—Table 29 lists superseded connector specifications.

10.8.7 *Inspection of M22520/1-01, M22520/2-01, M22520/4-01, and M22520/7-01 Basic Tools:*

10.8.7.1 Inspection gauging is preformed on the basic tool only. However, the tools may be gauged with a positioning device installed as long as it does not interfere with the gauging operation. If the presence of the positioning device makes gauging difficult, remove it before inspecting. The inspection procedure is as follows:

(1) Select the proper inspection gauge to be used from Table 30.

(2) Set the selector at the proper selector number as specified in Table 30.

(3) Close the handles completely and hold.

(4) The GO gauge (green end) shall pass freely through the indenter tips.

(5) The NO GO gauge (red end) shall not enter through the indenter tips.

10.8.8 *Types of Contact Positioning Devices:*

10.8.8.1 All crimping tools have positioning devices available that are used for locating contacts in the proper relation to the tool indenters. The following is a brief description of the types of positioners used for the various types of tools:

(1) M22520/1-01 Basic Tools:

(a) These tools use turret heads, single positioner heads, and universal heads.

(b) Turret Heads—These heads have a turret that has three separate positioners that are color coded and marked with the applicable contact size accommodated by each individual positioner within the head. The color and contact size correspond to the information on the foil label (data plate) attached to the side of the head. The proper positioner is selected for the contact type and size to be crimped by referring to the data plate.

(c) Single-Position Heads—These heads have only one positioner and are not adjustable. They also have data plates which provide crimping information.

(d) Universal Heads—These heads are used for locating contacts that are not military standard or no positioning heads are available. They are adjusted for each application while attached to the tool as described in 10.8.10.2, but have no data plate with crimping information.

10.8.9 *M22520/2-01and M22520/7-01 Basic Tools:*

10.8.9.1 These tools use locating devices known as positioners. They are individual locators with a data plate attached to the top that specifies the contact part numbers(s) accommodated, and correlates the wire sizes.

10.8.9.2 *M22520/4-01 Basic Tool*—This is a single-purpose tool that only uses the M22520/4-02 single-positioner head that is not operator adjustable (see 10.8.6.2*(4)*).

10.8.10 *Crimping Procedures:*

10.8.10.1 *M22520/1-01 Crimping Tools with Turret Heads and Single-Position Heads:*

(1) The procedure for crimping contacts to wire conductors is as follows:

(a) Select the proper positioning head to be used for the contacts being crimped.

(b) If the head to be used is a turret head, first depress the turret trigger to release the turret portion to the indexing or extended position as shown in Fig. 46.

(c) Place the head over the retaining ring on the back of too1 (selector side) and seat against the tool body; secure the 3.5-mm socket head screws with Allen wrench (see Fig. 46). If the positioning head is the single-positioner type, omit Steps *(d)* and *(e)*.

(d) If the positioning head is the turret type, it has three separate positioners that are color coded and marked with the applicable contact size accommodated by each individual positioner. The color code and contact size correspond to the information contained on the data plate. Refer to the data plate to select the proper positioner to be used for the contact being crimped.

(e) Rotate the turret until the correct positioner is lined up with the index mark on the turret head and push the turret in until it snaps into the locked position (see Fig. 46).

TABLE 28 Electrical Contact BIN Code Listing

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
100	M39029/1-100	M39029/1-16-22	P
101	M39029/1-101	M39029/1-16-20	P
102	M39029/1-102	M39029/1-14-16	P
103	M39029/1-103	M39029/1-12-12	P
104	M39029/2-104	M39029/2-22-22	P
105	M39029/2-105	M39029/2-20-20	P
106	M39029/2-106	M39029/2-16-16	P
107	M39029/3-107	M39029/3-22-22	S
108	M39029/3-108	M39029/3-20-20	S
109	M39029/3-109	M39029/3-16-16	S
110	M39029/4-110	M39029/4-20-20	P
		M83723-33B20	P
111	M39029/4-111	M39029/4-16-16	P
		M83723-33B16	P
112	M39029/4-112	M39029/4-16-20	P
113	M39029/4-113	M39029/4-12-12	P
		M83723-33B12	P
114	M39029/4-114	M39029/4-12-16	P
115	M39029/5-115	M39029/5-20-20	S
		M83723-34B20	S
116	M39029/5-116	M39029/5-16-16	S
		M83723-34B16	S
117	M39029/5-117	M39029/5-16-20	S
118	M39029/5-118	M39029/5-12-12	S
		M83723-34B12	S
119	M39029/5-119	M39029/5-12-16	S
120	M39029/6-120	M39029/6-01	P
121	M39029/6-121	M39029/6-02	P
122	M39029/6-122	M39029/6-03	P
123	M39029/6-123	M39029/6-04	P
124	M39029/6-124	M39029/6-05	P
125	M39029/6-125	M39029/6-06	P
126	M39029/7-126	M39029/7-001	P
127	M39029/7-127	M39029/7-002	P
128	M39029/7-128	M39029/7-003	P
129	M39029/8-129	M39029/8-001	S
130	M39029/8-130	M39029/8-002	S
131	M39029/8-131	M39029/8-003	S
132	M39029/9-132	M39029/9-20-20-C1	P
133	39029/9-133	M39029/9-20-20-C2	P
134	M39029/9-134	M39029/9-20-20-C3	P
135	M39029/9-135	M39029/9-20-20-C4	P
136	M39029/9-136	M39029/9-20-20-C5	P
138	M39029/10-138	M39029/10-20-20-C1	S
139	M39029/10-139	M39029/10-20-20-C2	S
140	M39029/10-140	M39029/10-20-20-C3	S
141	M39029/10-141	M39029/10-20-20-C4	S
142	M39029/10-142	M39029/10-20-20-C5	S
144	39029/11-144	M39029/11-22-22	P
145	M39029/11-145	M39029/11-20-20	P
146	M39029/11-146	M39029/11-16-16	P
147	M39029/11-147	M39029/11-12-12	P
148	M39029/12-148	M39029/12-22-22	S
149	M39029/12-149	M39029/12-20-20	S
150	M39029/12-150	M39029/12-16-16	S
151	M39029/12-151	M39029/12-12-12	S
152	M39029/13-152	M39029/13-01	S
153	M39029/13-153	M39029/13-02	S
154	M39029/13-154	M39029/13-03	S
155	M39029/13-155	M39029/13-04	S
156	M39029/13-156	M39029/13-05	S
157	M39029/13-157	M39029/13-06	S
158	M39029/14-158	M39029/14-01	S
159	M39029/14-159	M39029/14-02	S
160	M39029/14-160	M39029/14-03	S
161	M39029/14-161	M39029/14-04	S
162	M39029/14-162	M39029/14-05	S
163	M39029/14-163	M39029/14-06	S
166	M39029/16-166	M39029/16-23-28	S
167	M39029/16-167	M39029/16-23-22	S
168	M39029/16-168	M39029/16-20-20	S
169	M39029/16-169	M39029/16-16-16	S
170	M39029/16-170	M39029/16-12-12	S
171	M39029/17-171	M39029/17-23-28	S

TABLE 28 *Continued*

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
172	M39029/17-172	M39029/17-23-22	S
173	M39029/17-173	M39029/17-20-20	S
174	M39029/17-174	M39029/17-16-16	S
175	M39029/17-175	M39029/17-12-12	S
176	M39029/18-176	M39029/18-23-28	P
177	M39029/18-177	M39029/18-23-22	P
178	M39029/18-178	M39029/18-20-20	P
179	M39029/18-179	M39029/18-16-16	P
180	M39029/18-180	M39029/18-12-12	P
181	M39029/19-181	M39029/19-01	P
182	M39029/19-182	M39029/19-02	P
183	M39029/19-183	M39029/19-03	P
184	M39029/20-184	M39029/20-01	P
185	M39029/20-185	M39029/20-02	P
186	M39029/20-186	M39029/20-03	P
187	M39029/21-187	M39029/21-01	S
188	M39029/21-188	M39029/21-02	S
189	M39029/21-189	M39029/21-03	S
190	M39029/22-190	M39029/22-22-28	S
		M39029/15-22-28	S
191	M39029/22-191	M39029/22-22-22	S
		M39029/15-22-22	S
192	M39029/22-192	M39029/22-20-20	S
193	M39029/22-193	M39029/22-16-16	S
194	M39029/23-194	M39029/23-01	P
195	M39029/23-195	M39029/23-02	P
196	M39029/23-196	M39029/23-02	P
197	M39029/23-197	M39029/23-04	P
198	M39029/23-198	M39029/23-05	P
199	M39029/24-199	M39029/24-01	S
200	M39029/24-200	M39029/24-02	S
201	M39029/24-201	M39029/24-03	S
202	M39029/24-202	M39029/24-04	S
203	M39029/24-203	M39029/24-05	S
204	M39029/25-204	M39029/25-01	P
205	M39029/25-205	M39029/25-02	P
206	M39029/25-206	M39029/25-03	P
207	M39029/26-207	M39029/26-01	S
208	M39029/26-208	M39029/26-02	S
209	M39029/26-209	M39029/26-03	S
210	M39029/27-210	M39029/27-12A	S
211	M39029/28-211	M39029/28-12A	P
212	M39029/29-212	M39029/29-16-16	P
		M83723-29T16	P
		M53162-16-16	P
213	M39029/29-213	M39029/29-12-12	P
		M83723-29T12	P
		M53162-12-12	P
214	M39029/29-214	M39029/29-8-8	P
		M83723-29T8	P
		M53162-8-8	P
215	M39029/29-215	M39029/29-4-4	P
		M83723-29T4	P
		M53162-4-4	P
216	M39029/29-216	M39029/29-0-0	P
		M83723-29T0	P
		M53162-0-0	P
217	M39029/30-217	M39029/30-16S-16	S
		M83723-30T16	S
		M53163-16S-16	S
218	M39029/30-218	M39029/30-16-16	S
		M83723-30T16	S
		M53163-16-16	S
219	M39029/30-219	M39029/30-12-12	S
		M83723-30T12	S
		M53163-12-12	S
220	M39029/30-220	M39029/30-8-8	S
		M83723-30T8	S
		M53163-8-8	S
221	M39029/30-221	M39029/30-4-4	S
		M83723-30T4	S
		M53163-4-4	S
222	M39029/30-222	M39029/30-0-0	S
		M83723-30T0	S

TABLE 28 *Continued*

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
		M53163-0-0	S
223	M39029/31-223	MS3192-20-20A	P
224	M39029/31-224	MS3192-20-20C4	P
225	M39029/31-225	MS3192-20-20C1	P
226	M39029/31-226	MS3192-20-20C2	P
227	M39029/31-227	MS3192-20-20C3	P
228	M39029/31-228	MS3192-16-16A	P
229	M39029/31-229	MS24254-16P	P
230	M39029/31-230	MS3192-16-16C4	P
231	M39029/31-231	MS3192-16-16C1	P
232	M39029/31-232	MS3192-16-16C2	P
233	M39029/31-233	MS3192-16-16C3	P
234	M39029/31-234	MS3192-12-12A	P
235	M39029/31-235	MS24254-12P	P
236	M39029/31-236	MS3192-12-12C4	P
237	M39029/31-237	MS3192-12-12C1	P
238	M39029/31-238	MS3192-12-12C2	P
239	M39029/31-239	MS3192-12-12C3	P
240	M39029/31-240	MS3192-A20-20A	P
241	M39029/31-241	MS24254-20P	P
242	M39029/32-242	MS3193-20-20A	S
243	M39029/32-243	MS3193-20-20C4	S
244	M39029/32-244	MS3193-20-20C1	S
245	M39029/32-245	MS3193-20-20C2	S
246	M39029/32-246	MS3193-20-20C3	S
247	M39029/32-247	MS3193-16-16A	S
248	M39029/32-248	MS24255-16S	S
249	M39029/32-249	MS3193-16-16C4	S
250	M39029/32-250	MS3193-16-16C1	S
251	M39029/32-251	MS3193-16-16C2	S
252	M39029/32-252	MS3193-16-16C3	S
253	M39029/32-253	MS3193-12-12A	S
254	M39029/32-254	MS24255-12S	S
255	M39029/32-255	MS3193-12-12C4	S
256	M39029/32-256	MS3193-12-12C1	S
257	M39029/32-257	MS3193-12-12C2	S
258	M39029/32-258	MS3193-12-12C3	S
259	M39029/32-259	MS3193-A20-20A	S
260	M39029/32-260	MS24255-20S	S
261	M39029/33-261	MS3343A23-28	S
262	M39029/33-262	MS3343B23-28	S
263	M39029/33-263	MS3343A23-22	S
264	M39029/33-264	MS3343B23-22	S
265	M39029/33-265	MS3343A20-20	S
266	M39029/33-266	MS3343B20-20	S
267	M39029/33-267	MS3343A16-16	S
268	M39029/33-268	MS3343B16-16	S
269	M39029/33-269	MS3343A12-12	S
270	M39029/33-270	MS3343B12-12	S
271	M39029/34-271	MS17803-20-20	P
272	M39029/34-272	MS17803-16-20	P
273	M39029/34-273	MS17803-16-16	P
274	M39029/35-274	MS17804-20-20	S
275	M39029/35-275	MS17804-16-20	S
276	M39029/35-276	MS17804-16-16	S
277	MS39029/36-277	MS17807-16-20	P
278	MS39029/36-278	MS17807-16-16	P
279	MS39029/36-279	MS17808-16-20	S
280	MS39029/37-280	MS17808-16-16	S
287	MS39029/44-287	MS90453-16-22	P
288	MS39029/44-288	MS90453-16-16	P
289	MS39029/44-289	MS90453-12-16	P
290	MS39029/44-290	MS90453-12-12	P
291	MS39029/44-291	MS90453-8-8	P
292	MS39029/44-292	MS90453-4-4	P
293	MS39029/44-293	MS90453-0-0	P
294	MS39029/45-294	MS90454-16-22	S
295	MS39029/45-295	MS90454-16-16	S
296	MS39029/45-296	MS90454-12-16	S
297	MS39029/45-297	MS90454-12-12	S
298	MS39029/45-298	MS90454-8-8	S
299	MS39029/45-299	MS90454-4-4	S
300	MS39029/45-300	MS90454-0-0	S
301	M39029/46-301	MS90460A23-28	S

TABLE 28 *Continued*

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
302	M39029/46-302	MS90460B23-28	S
303	M39029/46-303	MS90460A23-22	S
304	M39029/46-304	MS90460B23-22	S
305	M39029/46-305	MS90460A20-20	S
306	M39029/46-306	MS90460B20-20	S
307	M39029/46-307	MS90460A16-16	S
308	M39029/46-308	MS90460B16-16	S
309	M39029/46-309	MS90460A12-12	S
310	M39029/46-310	MS90460B12-12	S
311	M39029/47-311	MS90461-A23-28	P
312	M39029/47-312	MS90461-B23-28	P
313	M39029/47-313	MS90461-A23-22	P
314	M39029/47-314	MS90461-B23-22	P
315	M39029/47-315	MS90461-A20-20	P
316	M39029/47-316	MS90461-B20-20	P
317	M39029/48-317	MS90559-11	P
318	M39029/48-318	MS90559-12	P
319	M39029/48-319	MS90559-14	P
320	M39029/48-320	MS90559-8	P
321	M39029/48-321	MS90559-9	P
322	M39029/48-322	MS90559-13	P
323	M39029/48-323	MS90559-5	P
324	M39029/48-324	MS90559-6	P
325	M39029/48-325	MS90559-3	P
326	M39029/48-326	MS90559-4	P
327	M39029/48-327	MS90559-1	P
328	M39029/48-328	MS90559-2	P
329	M39029/49-329	MS90560-7	S
330	M39029/49-330	MS90560-8	S
331	M39029/49-331	MS90560-5	S
332	M39029/49-332	MS90560-9	S
333	M39029/49-333	MS90560-3	S
334	M39029/49-334	MS90560-2	S
335	M39029/49-335	MS90560-1	S
336	M39029/47-336	MS90461-A16-16	P
337	M39029/47-337	MS90461-B16-16	P
338	M39029/47-338	MS90461-A12-12	P
339	M39029/47-339	MS90461-B12-12	P
340	M39029/50-340	N83733/13-12	P
341	M39029/51-341	N83733/14-12	S
342	M39029/54-342	MS27184-22P	P
343	M39029/54-343	MS27184-20P	P
344	M39029/55-344	MS27185-22S	S
345	M39029/55-345	MS27185-20S	S
348	M39029/56-348	MS27490-22D	S
349	M39029/56-349	MS27490-22M	S
350	M39029/56-350	MS27490-22	S
351	M39029/56-351	MS27490-20	S
352	M39029/56-352	MS27490-16	S
353	M39029/56-353	MS27490-12	S
354	M39029/57-354	MS27491-22D	S
355	M39029/57-355	MS27491-22M	S
356	M39029/57-356	MS27491-22	S
357	M39029/57-357	MS27491-20	S
358	M39029/57-358	MS27491-16	S
359	M39029/57-359	MS27491-12	S
360	M39029/58-360	MS27493-22D	P
361	M39029/58-361	MS27493-22M	S
362	M39029/58-362	MS27493-22	S
363	M39029/58-363	MS27493-20	S
364	M39029/58-364	MS27493-16	P
365	M39029/58-365	MS27493-12	P
366	M39029/59-366	MS27535	P
367	M39029/60-367	MS27536	P
368	M39029/63-368	MS24308/10-1	P
369	M39029/64-369	MS24308/11-1	P
384	M39029/69-384	M39029/69-1	P
385	M39029/69-385	M39029/69-2	P
386	M39029/69-386	M39029/69-3	P
387	M39029/70-387	M39029/70-1	P
388	M39029/70-388	M39029/70-2	P
389	M39029/70-389	M39029/70-3	P
390	M39029/71-390	M39029/71-1	P
391	M39029/71-391	M39029/71-2	P

TABLE 28 *Continued*

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
392	M39029/71-392	M39029/71-3	P
393	M39029/72-393	M39029/72-1	S
394	M39029/72-394	M39029/72-2	S
395	M39029/72-395	M39029/72-3	S
396	M39029/73-396	M39029/73-12A	S
397	M39029/73-397	M39029/73-12B	S
398	M39029/73-398	M39029/73-12C	S
399	M39029/74-399	M39029/74-12A	P
400	M39029/74-400	M39029/74-12B	P
401	M39029/74-401	M39029/74-12C	P
402	M39029/27-402	M39029/27-12B	S
403	M39029/27-403	M39029/27-12C	S
404	M39029/27-404	M39029/27-12D	S
405	M39029/27-405	M39029/27-12E	S
406	M39029/27-406	M39029/27-12F	S
407	M39029/27-407	M39029/27-12G	S
408	M39029/27-408	M39029/27-12H	S
409	M39029/28-409	M39029/28-12B	P
410	M39029/28-410	M39029/28-12C	P
411	M39029/28-411	M39029/28-12D	P
412	M39029/28-412	M39029/28-12E	P
413	M39029/28-413	M39029/28-12F	P
414	M39029/28-414	M39029/28-12G	P
415	M39029/28-415	M39029/28-12H	P
416	M39029/75-416	M39029/75-12A	S
417	M39029/75-417	M39029/75-12B	S
418	M39029/75-418	M39029/75-12C	S
419	M39029/75-419	M39029/75-12D	S
420	M39029/75-420	M39029/75-12E	S
421	M39029/75-421	M39029/75-12F	S
422	M39029/75-422	M39029/75-12G	S
423	M39029/75-423	M39029/75-12H	S
424	M39029/76-424	M39029/76-16A	P
425	M39029/76-425	M39029/76-16B	P
426	M39029/76-426	M39029/76-16C	P
427	M39029/76-427	M39029/76-16D	P
428	M39029/77-428	M39029/77-16A	S
429	M39029/77-429	M39029/77-16B	S
430	M39029/77-430	M39029/77-16C	S
431	M39029/77-431	M39029/77-16D	S
432	M39029/78-432	M39029/78-16A	S
433	M39029/78-433	M39029/78-16B	S
434	M39029/78-434	M39029/78-16C	S
435	M39029/78-435	M39029/78-16D	S
436	M39029/79-436	M39029/79-16A	P
437	M39029/79-437	M39029/79-16B	P
438	M39029/80-438	M39029/80-16A	S
439	M39029/80-439	M39029/80-16B	S
440	M39029/34-440	M39029/34-22-22	P
441	M39029/35-441	M39029/35-22-22	S
448	M39029/31-448	M39029/31-20-20	P
449	M39029/32-449	M39029/32-20-20	S
450	M39029/83-450	M39029/83-20-22	P
451	M39029/83-451	M39029/83-20-28	P
452	M39029/84-452	M39029/84-20-22	S
453	M39029/84-453	M39029/84-20-28	S
454	M39029/85-454	M39029/85-16-16-C1	P
455	M39029/85-455	M39029/85-16-16-C2	P
456	M39029/85-456	M39029/85-16-16-C3	P
457	M39029/85-457	M39029/85-16-16-C4	P
458	M39029/85-458	M39029/85-12-12-C1	P
459	M39029/85-459	M39029/85-12-12-C2	P
460	M39029/85-460	M39029/85-12-12-C3	P
461	M39029/85-461	M39029/85-12-12-C4	P
462	M39029/86-462	M39029/86-16-16-C1	S
463	M39029/86-463	M39029/86-16-16-C2	S
464	M39029/86-464	M39029/86-16-16-C3	S
465	M39029/86-465	M39029/86-16-16-C4	S
466	M39029/86-466	M39029/86-12-12-C1	S
467	M39029/86-467	M39029/86-12-12-C2	S
468	M39029/86-468	M39029/86-12-12-C3	S
469	M39029/86-469	M39029/86-12-12-C4	S
470	M39029/87-470	M39029/87-22-22-C1	P
471	M39029/87-471	M39029/87-22-22-C2	P

TABLE 28 *Continued*

Bin Code	Current Part Number	Superseded Part Number	Pin or Socket
472	M39029/87-472	M39029/87-22-22-C3	P
473	M39029/87-473	M39029/87-22-22-C4	P
474	M39029/87-474	M39029/87-20-20-C1	P
475	M39029/87-475	M39029/87-20-20-C2	P
476	M39029/87-476	M39029/87-20-20-C3	P
477	M39029/87-477	M39029/87-20-20-C4	P
478	M39029/87-478	M39029/87-16-16-C1	P
479	M39029/87-479	M39029/87-16-16-C2	P
480	M39029/87-480	M39029/87-16-16-C3	P
481	M39029/87-481	M39029/87-16-16-C4	P
482	M39029/88-482	M39029/88-22-22-C1	S
483	M39029/88-483	M39029/88-22-22-C2	S
484	M39029/88-484	M39029/88-22-22-C3	S
485	M39029/88-485	M39029/88-22-22-C4	S
486	M39029/88-486	M39029/88-20-20-C1	S
487	M39029/88-487	M39029/88-20-20-C2	S
488	M39029/88-488	M39029/88-20-20-C3	S
489	M39029/88-489	M39029/88-20-20-C4	S
490	M39029/88-490	M39029/88-16-16-C1	S
491	M39029/88-491	M39029/88-16-16-C2	S
492	M39029/88-492	M39029/88-16-16-C3	S
493	M39029/88-493	M39029/88-16-16-C4	S
494	M39029/89-494	M39029/89-22-22-C1	S
495	M39029/89-495	M39029/89-22-22-C2	S
496	M39029/89-496	M39029/89-22-22-C3	S
497	M39029/89-497	M39029/89-22-22-C4	S
498	M39029/89-498	M39029/89-20-20-C1	S
499	M39029/89-499	M39029/89-20-20-C2	S
500	M39029/89-500	M39029/89-20-20-C3	S
501	M39029/89-501	M39029/89-20-20-C4	S
502	M39029/89-502	M39029/89-16-16-C1	S
503	M39029/89-503	M39029/89-16-16-C2	S
504	M39029/89-504	M39029/89-16-16-C3	S
505	M39029/89-505	M39029/89-16-16-C4	S
506	M39029/89-506		S
507	M39029/89-507	M39029//-20-22D	S
508	M39029/83-508		P
509	M39029/84-509		S
528	M39029/58-528		P
529	M39029/90-529		S

(2) Refer again to the data plate for the correct selector setting for the wire size being used. With the handles fully open, remove spring clip lock wire from selector knob, lift and rotate the selector knob (or slide the thumb button) to the correct setting and release (see Fig. 47) and reinstall spring clip lock wire.

NOTE—When crimping contacts with an insulation support cup, make sure the insulation extends into it 0.15 to 0.32 in. (0.4 to 0.8 mm) from bottom of cup. (The contact shown in Fig. 48 has this feature.)

(3) Determine the proper length of insulation to be removed. Wire shall be visible in inspection hole; insulation must be between 0.15 and 0.32 in. (0.4 to 0.8 mm) from end of contact. Strip the insulation from the conductor by using any of the methods described in 7.2.1.26.

(4) Insert the stripped wire into the wire barrel of the contact until the end of the wire can be seen through the inspection hole. Insert the wire and contact through the indenters on the front side of tool (opposite from selector side) until it bottoms and fully seats in the positioner.

(5) Hold the wire and contact in place and squeeze the tool handles until they fully bottom and the ratchet releases, allowing the handles to return automatically to the open position.

(6) Remove the crimped contact and inspect making sure the wire strands are visible through the inspection hole in the contact wire barrel (see Fig. 48).

10.8.10.2 *M22520/1-01 Crimping Tools with Universal Heads:*

(1) The universal head may be used when a turret or single position head is not available. The procedure is as follows:

(a) Rotate the lock nut counterclockwise to the released position and turn adjustment nut counterclockwise until head can be seated on tool.

(b) Place the head over the retaining ring on the back of the tool (selector side) and seat against the tool body; secure the 3.5-mm socket head screws with an Allen wrench. With the tool handles fully open, remove spring clip lock wire from selector knob, raise and rotate the selector knob (or slide the thumb button) until the arrow is in line with the wire size being crimped, release selector knob, and reinstall spring clip lock wire.

NOTE—The wire sizes are for reference only. They are based on the use of SAE AS 22759 (replaces MIL-W-22759) silver-plated wire crimped in MS3190 wire barrels. Settings shall be established when using other contact/wire combinations.

TABLE 29 Connector Specification Replacements

MIL-DTL-83723, Series I are replaced by MIL-C-26482 as shown below	
MIL-DTL-83723 Specification Sheet	Superseded By
1 and 2	MS3470
3 and 4	MS3472
5 and 6 MS3474	
7 and 8	MS3471
9 and 10	MS3440
11 and 12	MS3443
13 and 14	MS3476
33	MIL-C-39029/4
34	MIL-C-39029/4
36, 37, 38, 39, 40 and 41	No superseding document
42 and 43	MS3475
44	MS3181
45	MS3115
46	MS3180
48 and 49	No superseding document
MIL-DTL-83723, Series II are replaced by MIL-DTL-5015 as shown below	
MIL-DTL-83723 Specification Sheet	Superseded By
17 and 18	MS3451
19 and 20	MS3450
21 and 22	MS3452
23 and 24	MS3456
25	MS3142
26	MS3143
27	MS3109 or MS3117 and MS3158 or MS3416
29	MIL-C-39029/29
30	MIL-C-39029/30
35	No superseding document
50	No superseding document
52 and 53	MS3459

TABLE 30 Crimping Tool Inspection Gauges and Selector Settings

Crimping Tool Part Number	Inspection Gauge Part Number	Selector Setting
M22520/1-01	M22520/3-1	4
M22520/2-01	M22520/3-1	8
M22520/4-01	M22520/3-2	Not applicable
M22520/7-01	M22520/3-3	8

(c) Turn adjustment screw on head clockwise until it stops. With the tool opening facing up, insert contact through indenter opening into positioner until it bottoms. Begin turning adjustment screw out until indenters are cantered between inspection hole and end of wire barrel. If contact has insulation support cup, center the indenters between inspection hole and bottom of cup.

(d) Without turning the adjustment screw, tighten lock nut against head.

(e) Strip wire as specified in 10.8.10.1.

(f) Insert wire and contact, crimp and inspect as specified in 10.8.10.1.

10.8.10.3 *M22520/2-01 and M22520/7-01 Crimping Tools with Positioners:*

(1) The procedure for the crimping contacts with these tools is as follows:

(a) Select the proper positioner to be used for the contact being crimped.

(b) Insert the positioner into the retaining ring on the back of the tool (selector side). The positioner is spring-loaded and must be pushed in and then rotated 90° clockwise until it locks into position. Insert the spring clip lock wire (if present) through the retaining ring.

(c) Refer to the data plate for the correct selector setting for the wire size being used. With the handles fully open, remove spring clip lock wire from selector knob, lift and rotate the selector knob to the correct setting and release and reinstall spring clip lock wire.

(d) Strip wire as described in 10.8.10.1.

(e) Insert wire and contact, crimp, and inspect as specified in 10.8.10.1.

10.8.10.4 *Crimping Tool Kits:*

(1) There are several crimping tool kits available for maintenance use.

10.8.10.5 *Installing and Removing Crimp-Type Contacts:*

(1) Insertion Tools for Front Release Crimp-Type Contacts:

(a) Type tools for inserting contacts into front release connector inserts are shown in Fig. 49. There is a separate tool for each contact size. Contact sizes are listed in Table 31. An indicating band on the working end of the tool determines the correct depth of tool insertion. Use these tools to insert contacts in front release connectors with removable contacts.

NOTE—Do not use tools that have burrs or sharp edges. Burrs or sharp edges can cut through grommet wire-sealing webs and destroy the environmental sealing capabilities of a connector.

(2) Assembling Wired Contacts into Front Release Connector:

(a) Insert the crimped contact into the connector as follows:

(1) Slide rear accessories back onto wire bundle.

NOTE—Before attempting any insertion of contacts into MIL-C-81511 Series 1 or 2 connectors, determine that the rear nut assembly is in the unlocked position. A colored stripe will

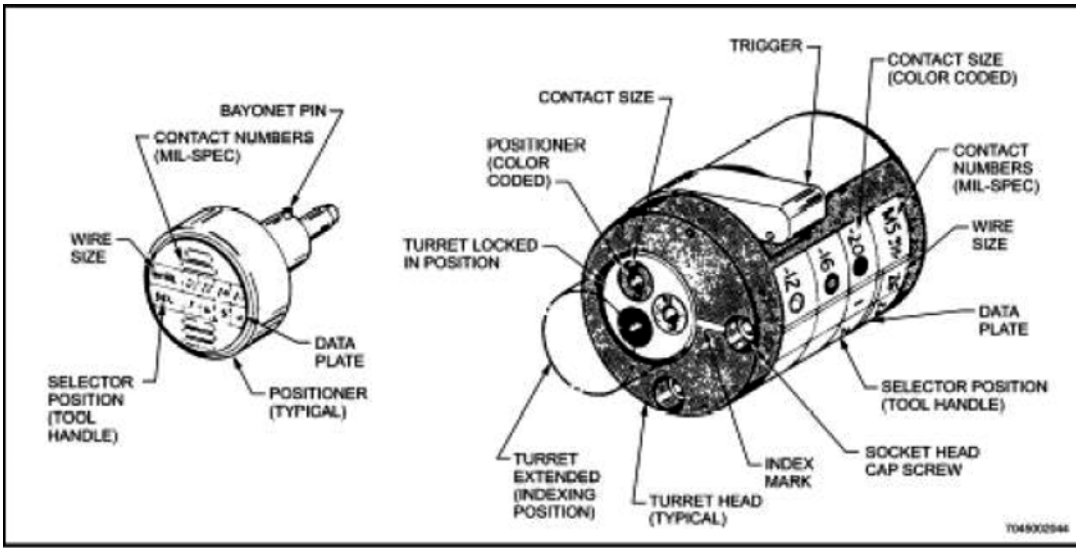


FIG. 46 Typical M22520 Positioner and Turret Head

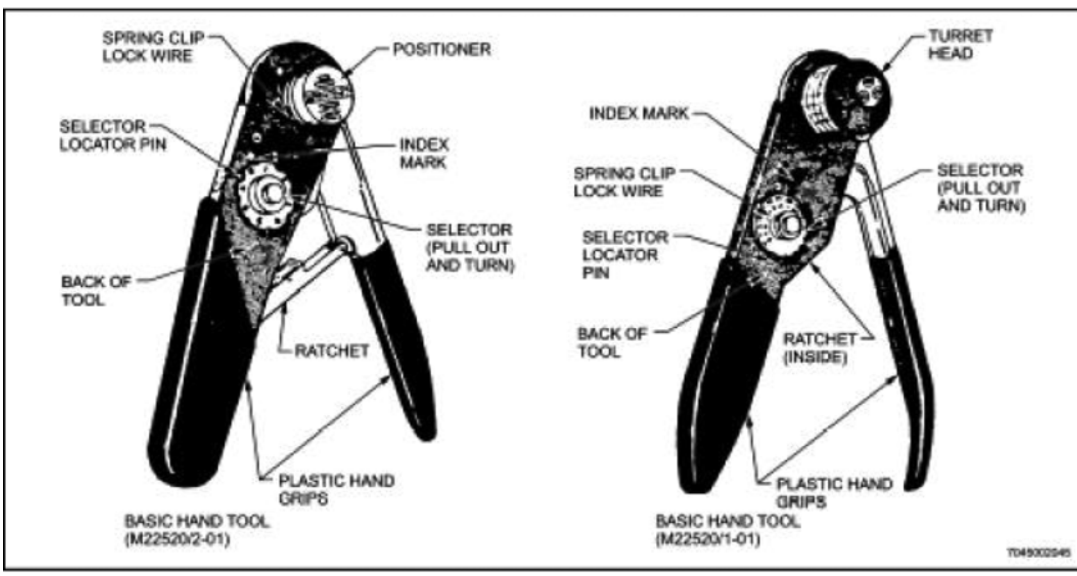


FIG. 47 M22520 Crimping Tools

appear when the rear nut assembly is rotated. counterclockwise. At this point, the connector is in position for both insertion and removal of contacts.

(2) Select the correct insertion tool. Insert the crimped end of the contact into the hollow end of the insertion tool, and lay along handle (see Fig. 50).

(3) Guide the contact into the correctly numbered grommet hole in the rear face of the insert and feed the contact carefully into the hole.

(4) Push the tool straight in at right angles to the grommet surface until the contact is fully seated.

(5) Withdraw the tool, keeping it perpendicular to the grommet face.

(6) Gently pull on wire to make sure contact is held in place.

(7) Fill all unused holes with unwired contacts and sealing plugs of appropriate size.

Note—After all contacts and sealing plugs have been inserted into MIL-C-81511 Series 1 and 2 connectors, tighten the rear nut by turning clockwise until the locking nut is tight.

Note—Do not attempt to reseat a contact once the insertion tool has been removed. Remove contact and start again with contact barrel properly located in tool. Failure to follow this precaution will cause insertion tool to shear barrel while inside grommet. Sharp edge of sheared material will cut through grommet web and cause short circuit.

10.8.10.6 *Alternative Front Release Contact Assembly Procedure:*

(1) If desired, the following procedure may be used to insert wired contacts into the connector:

(a) Push the wired contact carefully into the correct grommet hole. Do not push all the way in.

(b) Slide the insertion tool over the contact barrel. (See Fig. 50.)

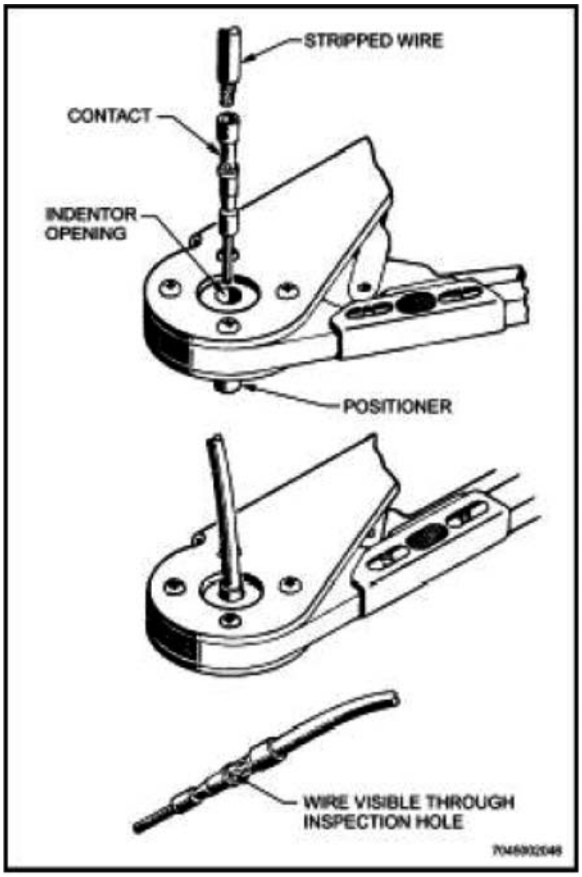


FIG. 48 Assembling Wires to Crimp Type Contacts

(c) Complete the procedure by following steps in 10.8.10.5 *(2)(a)(4)* through 10.8.10.5*(2)(a)(7)*. Observe caution and note in 10.8.10.5*(2)(a)*.

10.8.10.7 *Extraction Tools for Front Release Crimp-Type Contacts:*

(1) Typical tools for extracting contacts from front release connector inserts are shown in Fig. 49. The sizes for each contact are listed in Table 31. This tool has a hollow cylindrical probe that fits snugly over the pin or socket end of the contact and releases the insert retention clip when pushed over the contact. Two indicating bands determine correct depth; the band nearest the working end of the tool is for pin contacts, the other for socket contacts. The extraction tool has a thrust assist collar (or slide) that is pushed forward to eject the contact from the insert retention clip by means of an internal plunger. Use these tools to remove contacts from front release connectors with removable contacts.

10.8.10.8 *Removing Contacts from Front Release Connectors:*

Note 16—This procedure does not apply to rear release connectors.

(1) Remove contacts from the connector as follows:

(a) Select the correct extraction tool for the contact to be removed.

(b) Slide rear accessories back on the wire bundle.

Note—On MIL-C-81511 Series 1 and 2 connectors, loosen the rear nut assembly by turning it counterclockwise when viewed from the wire end. Approximately 0.59 in. (1.5 mm) of axial movement unlocks the contacts. The colored stripe will fully appear. The connector is now in position for removal of contacts.

(2) Series 1 and 2 (gauge release) contacts are removed from the front of the connector as follows:

(a) The pin contact removal tool has a hole to accept the pin contact. The socket removal tool has a pin tip to insert in the socket.

(b) Grasp the tool by the handle. Locate the contact to be removed by numbers on the insert face. (See Fig. 51.)

(c) Mate the tool with the contact and, holding the tool at right angles with the insert face, push axially against the tip of the contact until the contact appears at the grommet (rear) end of the connector. The removal tools are designed to bottom against the insert face when the contact is completely released and pushed out.

(d) The wire and contact can now be removed from the connector.

(3) Working from the front or mating end of the connector, slip the hollow end of the extraction tool over the contact, with the tool parallel to the contact, and squarely perpendicular to the insert face. (See Fig. 51.)

Note—Some extraction tools have a spacer sleeve with positions for either pin or socket contacts. Set to correct position before installing tool on contact. (See Fig. 49.)

(4) Push the tool toward the rear of the connector with a firm steady push until the tool comes to a positive stop and bottoms in the insert hole. A slight rotation of the tool may aid the tool insertion.

(5) Push the thrust assist collar or slide forward as far as it will go.

(6) Withdraw the tool from the contact, keeping the tool perpendicular to the insert face.

(7) Remove the contact from the back of the connector.

Note—Ensure the extraction tool is always exactly aligned with the contact to avoid damage to the contact or insert.

10.8.10.9 *Insertion and Extraction Tools for Rear-Release Crimp-Type Contacts:*

(1) There is a separate tool for each contact size. The tools may be plastic or metal, single- or double-ended tools (see Fig. 52), or metal tweezer-type tools. See Figs. 53 and 54 for contact installation instructions. See Figs. 55 and 56 for contact removal instructions.

Note 17—Connector rear accessory (cable clamp and so forth) shall be removed before installation or removal of contacts.

Note 18—Insertion/extraction tools are color coded according to contact size; the insertion tool being colored and the extraction tool white. For unwired contacts, an additional tool may have to be used in conjunction with the extraction tool to push the unwired contact from the front after the locking tines have been released by the extraction tool in the rear.

10.8.10.10 *Redundancy*—Wires that perform the same function in redundant systems shall be routed through separate connectors. On systems critical to flight safety, system operation wiring shall be routed through separate connectors from the wiring used for system failure warning. It is also good practice to route a system's indication wiring in separate connectors from its failure warning circuits to the extent

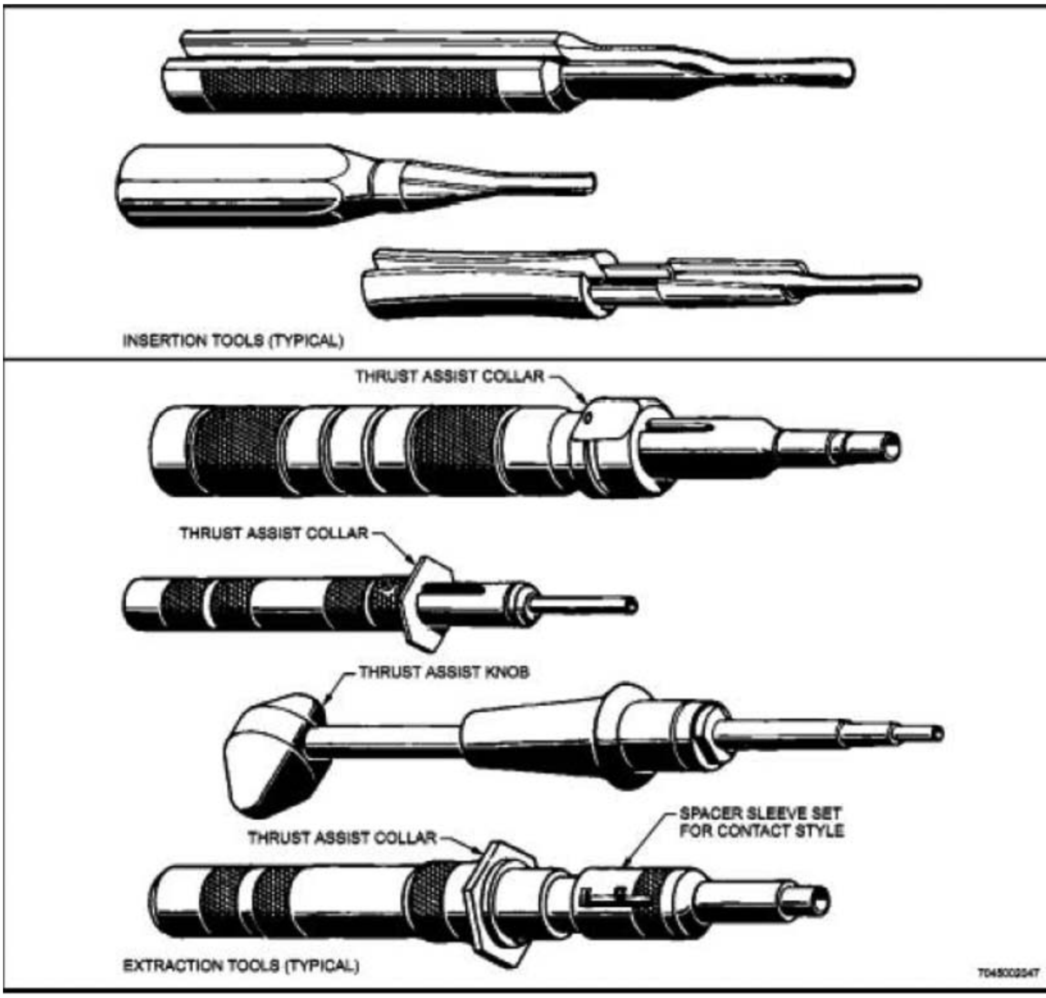


FIG. 49 Insertion and Extraction Tools for Front Release Crimp-Type Contacts

TABLE 31 Contacts and Their Wire Size Range

Contact Size	Wire Size Range
20	24-20
16	22-16
12	14-12
8	10-8
4	6-4
0	2-0

practicable. These steps can reduce an aircraft's susceptibility to incidents that might result from connector failures.

10.8.10.11 *Adjacent Locations*—Mating of adjacent connectors shall not be possible. To ensure this, adjacent connector pairs shall be different in shell size, coupling means, insert arrangement, or keying arrangement. When such means are impractical, wires shall be routed and clamped so that incorrectly mated pairs cannot reach each other. Reliance on markings or color stripes is not recommended as they are likely to deteriorate with age.

10.8.10.12 *Sealing*—Connectors shall be of a type that excludes moisture entry through the use of peripheral and interfacial seals that are compressed when the connector is mated. Moisture entry through the rear of the connector shall be avoided by correctly matching the wire's outside diameter with the connector's rear grommet sealing range. It is recommended that no more than one wire be terminated in any crimp-style contact. The use of heat-shrinkable tubing to build up the wire diameter or the application of potting to the wire entry area as additional means of providing a rear compatibility with the rear grommet is recommended. These extra means have inherent penalties and shall be considered only when other means cannot be used. Unwired spare contacts shall have a correctly sized plastic plug installed. (See Tables 31 and 32.)

10.8.10.13 *Drainage*—Connectors shall be installed in a manner that ensures that moisture and fluids will drain out of and not into the connector when unmated. Wiring shall be routed so that moisture accumulated on the bundle will drain away from connectors. When connectors shall be mounted in a vertical position, as through a shelf or floor, the connectors shall be potted or environmentally sealed. In this situation, it is better to have the receptacle faced downward so that it will be less susceptible to collecting moisture when unmated.

10.8.10.14 *Wire Support*—A rear accessory backshell shall be used on connectors that are not enclosed. Connectors having very small size wiring that are subject to frequent maintenance activity or located in high-vibration areas shall be provided with a strain-relief-type backshell. The wire bundle shall be protected from mechanical damage with suitable cushion

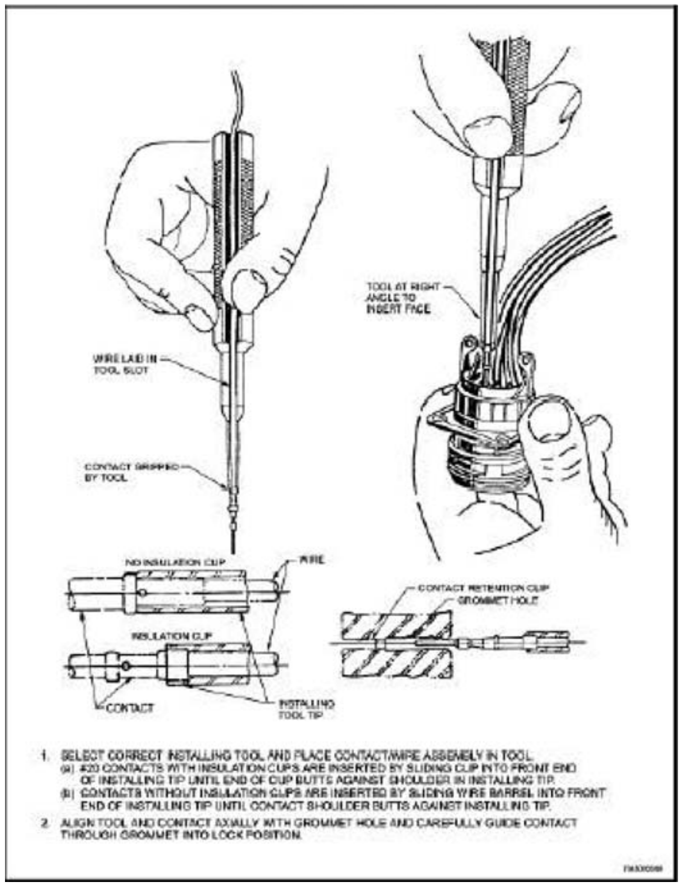


FIG. 50 Assembling Wired Contacts into Connector

material where it is secured by the clamp. Connectors that are potted or have molded rear adapters do not normally use a separate strain relief accessory. Strain relief clamps shall not impart tension on wires between the clamp and contact.

10.8.10.15 *Slack*—Sufficient wire length shall be provided at connectors to ensure a proper drip loop and that there is no strain on termination after a complete replacement of the connector and its contacts.

10.8.10.16 *Identification*—Each connector shall have a reference identification that is legible throughout the expected life of the aircraft.

10.8.11 *Feed-Through Bulkhead Wire Protection*—Feed-through bushing protection shall be given to wire bundles that pass through bulkheads, frames, and other similar structures. Feed-through bushings of hard dielectric material are satisfactory. The use of split plastic grommets (nylon) is recommended in lieu of rubber grommets in areas subject to fluids since they eliminate the unsatisfactory features of rubber grommets and are resistant to fluids usually encountered in aircraft.

10.8.12 *Special Purpose Connector*—Many special-purpose connectors have been designed for use in aircraft applications such as: subminiature connector, rectangular shell connector, connectors with short body shells, or connector of split-shell construction used in applications in which potting is required. Make every attempt to identify the connector part number from the maintenance manual or actual part and the manufacturer's instruction used for servicing.

10.8.13 *Potting Compounds*—Many types of potting compounds, both commercial and per military specifications, are available and offer various characteristics for different applications. Carefully consider the characteristics desired to ensure the use of the proper compound. Preparation and storage of potting materials shall receive special attention. Careful inspection and handling during all stages of the connector fabrication until the potting compound has fully cured is recommended. Potting compounds selected shall not revert to liquid or become gummy or sticky as a result of high humidity or contact with chemical fluids.

10.8.13.1 Potting compounds meeting Specification MIL-S-8516 are prepared in ready-to-use tube-type dispensers and in the unmixed state, consisting of the base compound and an accelerator packed in paired containers. To obtain the proper results, it is important that the manufacturer's instructions be closely followed.

10.8.13.2 Potting compounds normally cure at temperatures of 70 to 76°F (21.1 to 24.4°C). If the mixed compound is not used at once, the working pot life (normally 90 min) can be prolonged by storing in a deep freeze at -20°F (-6.7°C) for a maximum of 36 hours. The time factor starts from the instant the accelerator is added to the base compound and includes the time expended during the mixing and application processes.

10.8.13.3 Mixed compounds that are not to be used immediately shall be cooled and thawed quickly to avoid wasting the short working life. Chilled compounds shall be thawed by

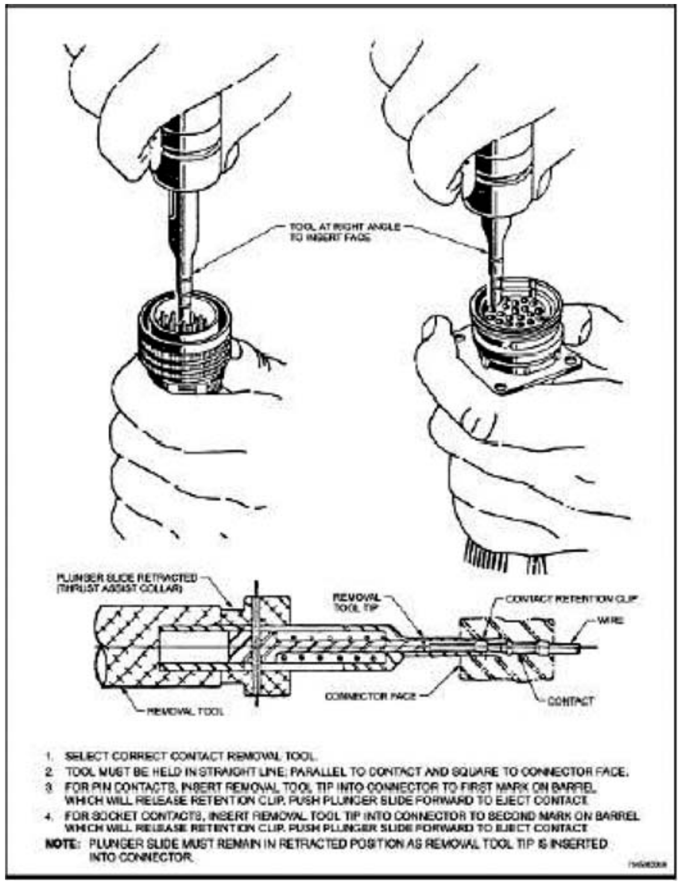


FIG. 51 Removing Crimp-Type Contacts from Front Release Connectors

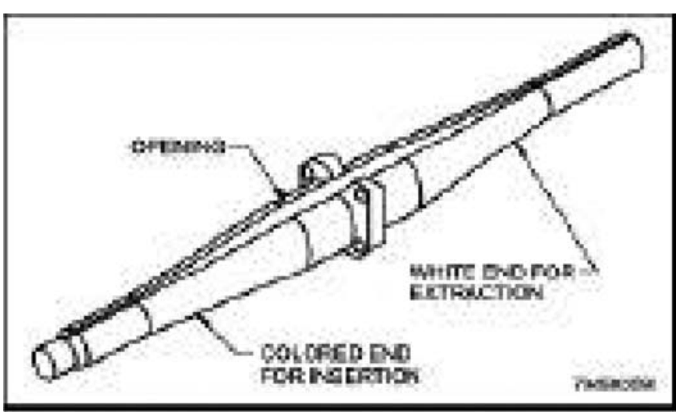


FIG. 52 Insertion and Extraction Tool for Rear-Release Crimp Contacts

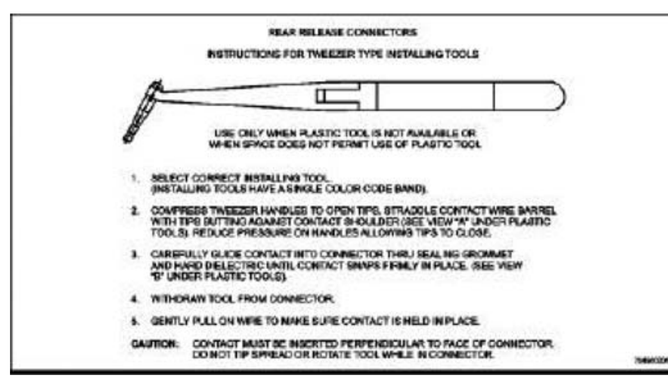


FIG. 53 Tweezer-Type Installing Tools

blowing compressed air over the outside of the container. Normally the compound will be ready for use in 5 to 10 min. (**Warning—**Do not use heat or blow compressed air into the container when restoring the compound to the working temperature.)

10.8.14 *Potting Connectors*—Connectors that have been potted primarily offer protection against concentration of moisture in the connectors. A secondary benefit of potting is the reduced possibility of breakage between the contact and wire as a result of vibration.

10.8.14.1 Connectors specifically designed for potting compounds shall be potted to provide environment resistance. An O-ring or sealed gasket shall be included to seal the interface area of the mated connector. A plastic potting mold that remains on the connector after the potting compounds have cured shall also be considered. To facilitate circuit changes, spare wires may be installed to all unused contacts before filling the connector with potting compound.

10.8.14.2 Connect wires to all contacts of the connector before the application of the potting compound. Wires that are not to be used shall be long enough to permit splicing at a later date. Unused wires shall be as shown in Fig. 57 and the cut ends capped with heat-shrinkable caps or crimped insulated

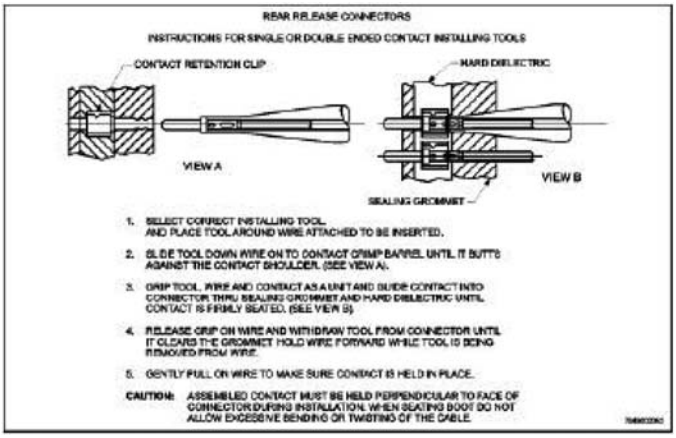


FIG. 54 Single- or Double-Ended Contact Installing Tools

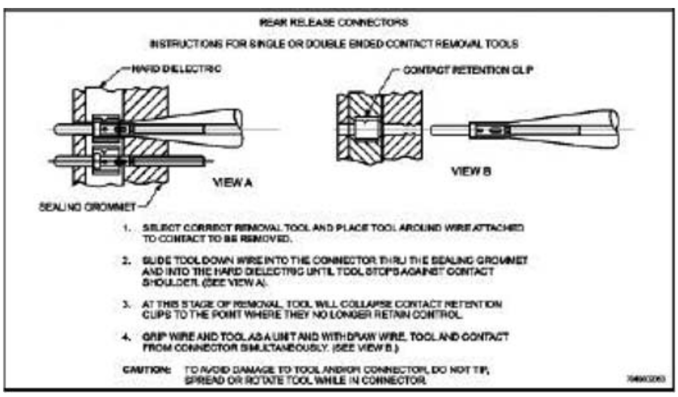


FIG. 55 Single- or Double-Ended Contact Removal Tools

end caps such as the MS25274 before securing to the wire bundle. Clean the areas to be potted with dry solvent and complete the potting operation within 2 hours after this cleaning. Allow the potting compound to cure for 24 hours at a room temperature of 70 to 75°F (21.1 to 23.8°C) or carefully placed in a drying oven at 100°F (37.7 °C) for 3 to 4 hours. In all cases, follow manufacturer's instructions.

10.8.15 *Through Bolts*—Through bolts are sometimes used to make feeder connections through bulkheads, fuselage skin, or firewalls. Mounting plates for through bolts shall be a material that provides the necessary fire barrier, insulation, and thermal properties for the application. Sufficient cross section shall be provided to ensure adequate conductivity against overheating. Secure through bolts mechanically and independently of the terminal mounting nuts, taking particular care to avoid dissimilar metals among the terminal hardware. During inspection, pay particular attention to the condition of the insulator plate or spacer and the insulating boot that covers the completed terminal assembly.

10.8.16 *Unused Connectors and Unused Wires:*

10.8.16.1 *General*—Connectors may have one or more contact cavities that are not used. Depending on the connector installation, unused connector contact cavities may need to be properly sealed to avoid damage to the connector or have string wire installed. Unused wires can be secured by tying into a bundle or secured to a permanent structure, individually cut with strands even with insulation, or secured with preinsulated closed end connector or 1-in. (2.5-cm) piece of insulating tubing folded and tied back.

10.8.16.2 *Quick Reference Chart*—A quick reference chart of unused connector contact cavity requirements is given in Table 33. These requirements apply to harness manufacturing or connector replacement only.

10.8.16.3 *Unpressurized Area Connectors*—Connectors may be installed in unpressurized areas of the aircraft. Unused connector contact cavities installed in unpressurized areas shall be properly sealed as follows:

(1) Firewall Connectors Installations—Firewall unused connector contact cavities shall be filled with spare contacts and stub wires. (See Fig. 44.)

(a) Construct stub wires using high-temperature wire (260°C). Ensure that stub wires are of the same type of wires in the bundle.

(b) Crimp the proper contact for the connector and cavity being used onto the wire. Install the crimped contact into the unused cavity.

(c) Extend stub wires beyond the back of the connector clamp from 1.5 to 6 in. (4 to 15 cm). Feather trim stub wires to taper wire bundle.

(d) Secure wire ends with high-temperature (greater than 250°C) lacing cord. Nylon cable ties are not allowed for this installation.

Note—Both connectors mating through the engine fire seal are considered firewall connectors. Connectors mounted on or near, but not through, the engine fire seal are not considered firewall connectors.

(2) Nonfirewall Connector Installations—In this type of installation, all unused connector cavities shall also be filled with spare contacts. It is not required, however, to crimp stub wires on filling contacts. Fill unused contact cavities with spare contacts and FEP sealing plugs or rods. (See Fig. 58.) Rods shall be cut so that they extend ⅛ to ¼ in. (0.3 to 0.6 cm) beyond the surface of the grommet when bottomed against the end of the spare contact. (See Table 32 for dimensions.)

10.8.16.4 *Pressurized Areas*—Connectors installed in pressurized areas of the aircraft may be divided into two main installation categories–sealed and unsealed.

(1) Sealed Connector Installations—Sealed connectors installed in pressurized areas shall have their unused contact cavities filled with FEP sealing plugs or rods. (See Fig. 58.) Installation of spare contacts is optional except for future wiring addition requirements. (See 10.8.5.) No stub wires are required.

(2) Unsealed Connector Installations—It is not required to fill unused contact cavities of unsealed connectors installed in pressurized areas with FEP sealing plugs or rods. Installation of spare contacts is optional except for future wiring addition requirements. (See 10.8.5.)

10.8.17 *Coaxial Cable:*

10.8.17.1 Extra care shall be exercised when installing coaxial cable. Some coaxial cable shall be of a specified length to ensure proper system operation. When required coaxial cable length results in cable lengths exceeding the wire routing path, ensure the excess cable length is properly supported. Ensure loops in the coaxial cable do not exceed the proper bend

FIG. 56 Tweezer-Type Removal Tools

TABLE 32 Sealing Rod Dimensions

Contact Size, AWG	Diameter, in.	Rod Length, in.	
		min	max
20	1⁄16	5⁄8	3⁄4
16	3⁄32	7⁄8	1
12	1⁄8	7⁄8	1

radius (see 7.2.1.25) or create victim or culprit EMI issues (see Section 11). Extra care shall be exercised when installing coaxial cable. Some coaxial cable shall be of a specified length to ensure proper system operation. [from 10.6.9.1—When required coaxial cable length results in cable lengths exceeding the wire routing path, ensure the excess cable length is properly supported. Ensure loops in the coaxial cable do not exceed the proper bend radius (see 7.2) or create victim or culprit EMI issues (see Section 11).]

10.8.17.2 Extra care shall be taken when securing coaxial cables with tie-straps. Coaxial cables are somewhat fragile and it is possible to crush them when installing tie-straps. Crushing a coax will alter the signal passing through it and could result in equipment failure. Once damaged the coax shall be replaced. Tie straps may also be used on bundle assemblies containing coaxial cable that has a solid dielectric; however, a strapping pressure just enough to prevent axial slippage shall be used. (See 7.2.3.4.)

10.9 *Inverters and Power Converters:*

10.9.1 *Static Electrical Power Converters*—Location of static converters shall be carefully chosen to ensure adequate ventilation for cooling purposes. (**Warning—**Do not load converters beyond their rated capacity.)

10.10 *Junctions:*

10.10.1 Ensure that only aircraft-manufacturer-approved devices, such as solderless-type terminals, terminal blocks, connectors, disconnect splices, permanent splices, and feed-through bushings are used for cable junctions for the provisions outlined below:

10.10.2 *Electrical Junctions* shall be protected from short circuits resulting from movement of personnel, cargo, cases, and other loose or stored materials. Protection shall be provided by covering the junction, installing them in junction boxes or by locating them in such a manner that additional protection is not required, and so forth.

10.10.3 *Exposed Junctions* and buses shall be protected with insulating materials. Junctions and buses located within enclosed areas containing only electrical and electronic equipment are not considered as exposed.

10.10.4 *Electrical Junctions* shall be mechanically and electrically secure. They shall not be subject to mechanical strain or used as a support for insulating materials, except for insulation on terminals.

10.11 *Junction Boxes, Panels, Shields, and Microswitch Housings:*

10.11.1 *Junction Boxes* shall be securely mounted to the aircraft structure in such a manner that the contents are readily accessible for inspection. When possible, the open side should face downward or at an angle so that loose metallic objects, such as washers or nuts, will tend to fall out of the junction box rather than wedge between terminals.

10.11.2 Ensure housing assemblies meet the following requirements:

10.11.2.1 Ensure that one or more suitable holes, about 3⁄8-in. (9.5-cm) diameter, but not less than 1⁄8-in. (3-cm) diameter, are provided at the lowest point of the box, except vaportight boxes, to allow for drainage with the aircraft on the ground or in level flight.

10.11.2.2 Ensure that vaportight or explosion-proof boxes are externally labeled VAPORTIGHT or EXPLOSION PROOF.

10.11.2.3 Ensure that boxes are securely mounted.

10.11.2.4 Ensure that safety wiring is installed on all lid fasteners on J-boxes, panels, shields, or microswitch housings that are installed in areas not accessible for inspection in flight, unless the fasteners incorporate self-locking devices.

10.11.2.5 Ensure that box wiring is properly aligned.

10.11.2.6 Ensure that there are no unplugged, unused holes (except drainage holes) in boxes.

10.12 *PC Board Assemblies:*

10.12.1 *General:*

10.12.1.1 *PC Board Assemblies* are commonly used to provide system logic, control, and monitoring. They shall be installed in enclosures protecting them from physical damage. These assembles shall be retained such that vibration and other environmental elements encountered in operation do not result in intermittent, open, or shorted circuits.

10.12.2 *EMI/RFI Considerations:*

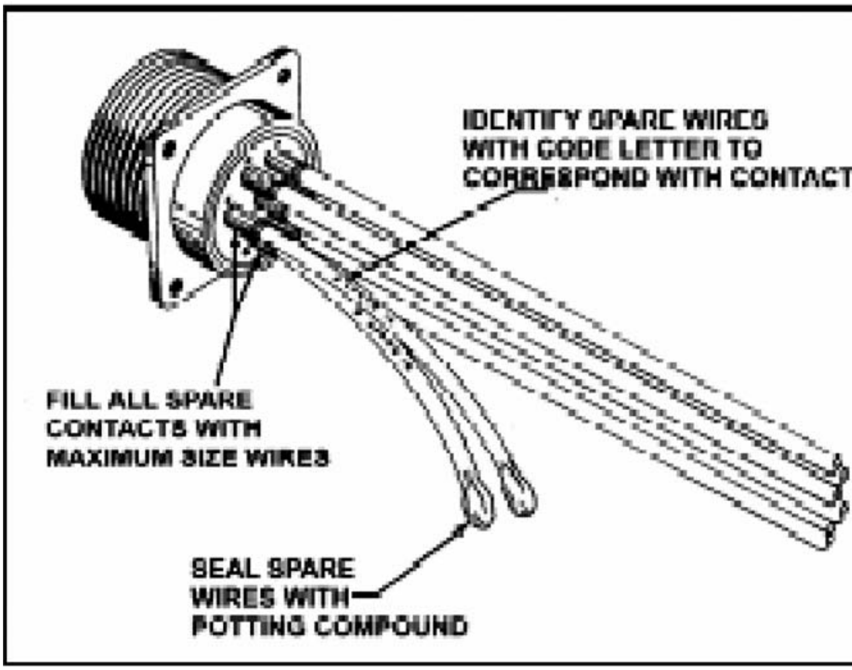


FIG. 57 Spare Wires for Potting Connector

TABLE 33 Contact Cavity Sealing Quick Reference[A]

Sealing Means	Connector Installation Types	
	Unpressurized Area	
	Firewall	Non-Firewall
Sealing Plugs or PTFE Sealing Rods	No	Yes
Stub Wires[B]	Yes	No
Spare Contacts	Yes	Yes

[A] Sealing plugs may be included with the spare connector and may be used for sealing unused contacts. Sealing rods are procured from stock by the foot. (See Table 31 for sealing rod dimensions.)
[B] Stub wires must be of the same type as the other wires of the bundle.

10.12.2.1 *PC Board Assemblies* can generate or be affected by EMI (see Section 11) and shall be protected and isolated to ensure proper system operation.

10.12.3 *ESD Considerations:*

10.12.3.1 Many components used in 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.

10.13 *Relays:*

10.13.1 *General:*

10.13.1.1 *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 over torquing.

10.13.1.2 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 closely followed.

10.13.2 *Continuous Duty:*

10.13.2.1 Continuous-duty relays are used for circuits in which voltage drop is not a concern for creating unintended intermittent operation. These relays are commonly used for generator circuits and may include "economizer" features that reduce hold-in current after initial engagement.

10.13.3 *Intermittent Duty:*

10.13.3.1 Intermittent-duty relays use higher contact pressure to keep the relay engaged during high-current, low-voltage operations such as during electrical engine starting.

10.14 *Studs:*

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

10.14.2 *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 shall not be greater than that of the wire.

10.14.3 *Support for Studs*—The main stud support in the feed-through insulation shall 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 shall not in any way be affected by the loosening of the stud in the insulator.

10.14.4 *Support of Wire at Studs*—Unless some other positive locking action is provided, the lug or wire shall 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,

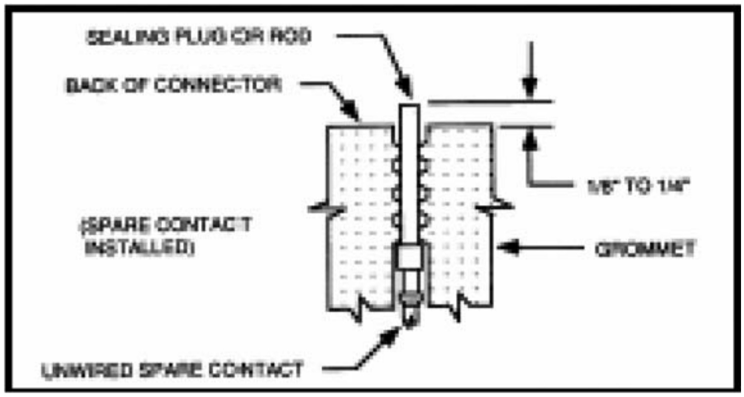


FIG. 58 Sealing Unused Contact Cavities—Unpressurized Areas (Cutaway View)

studs, posts, and so forth, are normally found in the manufacturer's maintenance instruction manual.

10.15 *Switches:*

10.15.1 *General:*

10.15.1.1 *Switch Installation*—Hazardous errors in switch operation may be avoided by logical and consistent installation. "On-off" two-position switches shall be mounted so that the "on" position is reached by an upward or forward movement of the toggle. When the switch controls movable aircraft elements, such as landing gear or flaps, the toggle shall move in the same direction as the desired motion. Inadvertent operation of switches can be prevented by mounting suitable guards over the switches.

10.15.2 *Proximity:*

10.15.2.1 *Proximity Switches* incorporate electronic features to determine when to actuate. These switches can be sensitive to both EMI and ESD and therefore care shall be used to ensure proper system operation when installing these switches in areas susceptible to ESD or EMI.

10.15.3 *Pushbutton:*

10.15.3.1 *Pushbutton Switches* may incorporate illuminated labels annunciating system function or status. Human factors for viewing angles shall be considered along with operational access.

10.15.4 *Rotary:*

10.15.4.1 *Rotary Switches* are used when multiple circuits require switching simultaneously. These switches may incorporate multiple decks that shall be wired individually. Care shall be exercised when routing these wires to prevent cross-circuit shorts.

10.15.5 *Toggle:*

10.15.5.1 *Toggle Switches* shall incorporate labeling to indicate function. Simple up and down positions are not sufficient to indicate system function. These switches may incorporate a third position. Switch positions may be maintained or momentary.

10.16 *Terminals and Terminal Blocks:*

10.16.1 *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 shall be at least equivalent to the tensile strength of the wire itself, and its resistance negligible relative to the normal resistance of the wire. Ensure that the following installation requirements are met:

10.16.2 *Insulating Tubing* is placed over terminals (except pre-insulated types) to provide electrical protection and mechanical support and is secured to prevent slippage of the tubing from the terminal.

10.16.3 Terminal module blocks are securely mounted and provided with adequate electrical clearances or insulation strips between mounting hardware and conductive parts except when the terminal block is used for grounding purposes.

10.16.4 The number of terminal connections to a terminal block stud does not exceed four unless specifically authorized.

10.16.5 Shielding shall be dead-ended with suitable insulated terminals.

10.16.6 All wires, terminal blocks, and individual studs shall be clearly identified to correspond to aircraft wiring manuals.

10.16.7 *Terminations* shall be made using terminals of the proper size.

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

10.16.8.1 Current rating,

10.16.8.2 Wire size (gage) and insulation diameter,

10.16.8.3 Conductor material compatibility,

10.16.8.4 Stud size,

10.16.8.5 Insulation material compatibility,

10.16.8.6 Application environment, and

10.16.8.7 Solder/solderless.

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

10.16.10 *Terminal Strips*—Wires are usually joined at terminal strips. A terminal strip fitted with barriers shall be used to prevent the terminals on adjacent studs from contacting each other. Studs shall be anchored against rotation. When more than four terminals are to be connected together, a small metal bus shall be mounted across two or more adjacent studs. In all cases, the current shall be carried by the terminal contact surfaces and not by the stud itself. Defective studs shall be replaced with studs of the same size and material since terminal strip studs of the smaller sizes may shear because of overtightening the nut. The replacement stud shall be securely mounted in the terminal strip and the terminal securing nut shall be tight. Terminal strips shall 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. Terminal strips that provide connection of radio and electronic systems to the aircraft electrical system shall 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 that may result in a fire or system failures.

10.16.11 *Terminal Lugs*—Wire terminal lugs shall be used to connect wiring to terminal block studs or equipment terminal studs. No more than four terminal lugs or three terminal lugs and a bus bar shall 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. Terminal lugs shall 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 shall be placed on the bottom and the smallest diameter on top. Tightening terminal connections shall not deform the terminal lugs or the studs. Terminal lugs shall 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.

10.16.12 *Copper Terminal Lugs*—Solderless, crimp-style, copper wire, terminal lugs shall be used and conform to SAE AS 7928 (replaces MIL-T-7928). Spacers or washers shall not be used between the tongues of terminal lugs.

10.16.13 *Aluminum Terminal Lugs*—The aluminum terminal lugs conforming to SAE AS 70991 (replaces MIL-T-7099), AS 25435 (replaces MS25435), AS 25436 (replaces MS25436), MS25437, and AS 25438 (replaces MS25438) shall be crimped to aluminum wire only. The tongue of the aluminum terminal lugs or the total number of tongues of aluminum terminal lugs when stacked shall be sandwiched between two MS25440 flat washers when terminated on terminal studs. Spacers or washers shall not be used between the tongues of terminal lugs. Special attention shall 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.

10.16.14 *Class 2 Terminal Lugs*—The Class 2 terminal lugs conforming to MIL-T-7928 may be used for installation provided that in such installations Class 1 terminal lugs are adequate for replacement without rework of installation or terminal lugs. Class 2 terminal lugs shall be the insulated type, unless the conductor temperature exceeds 105°C. In that case, uninsulated terminal lugs shall be used. Parts lists shall indicate the appropriate Class 1 terminal lugs to be used for service replacement of any Class 2 terminal lugs installed.

10.16.15 *Attachment of Terminals to Studs*—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 shall be addressed in the design. Electrical equipment malfunction has frequently been traced to poor terminal connections at terminal boards. Loose, dirty, or corroded contact surfaces can produce localized heating that may ignite nearby combustible materials or overheat adjacent wire insulation. (See 10.16.18.)

10.16.16 *Feed-Through Insulator and Stud:*

10.16.16.1 *Design*—Feed-through insulator design shall be such as to prevent a loose insulator from failing to provide circuit isolation. It shall not be able to move from between the stud and the structure, thus allowing the two to come into contact. The assembly shall 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.

10.16.17 *Wire Terminals and Binding Posts*—All wire terminals in or on electrical equipment, except case ground, shall be firmly held together with two nuts or suitable locking provisions or 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. Terminal studs or binding posts shall 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 shall have appropriate barriers and covers installed.

10.16.18 *Crimp on Terminal Lugs and Splices (Preinsulated Crimp Type)*—The crimp on terminal lugs and splices shall be installed using a high-quality, ratchet-type, crimping tool. The use of a 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 as a result of 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.

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

10.16.20 *Crimp Tools* shall be carefully selected:

10.16.20.1 Ensure that the full cycle ratchet mechanism is tamperproof so that it cannot be disengaged before or during the crimp cycle.

10.16.20.2 The tool calibration and adjustments are made only by the manufacturer or an approved calibration laboratory.

10.16.20.3 Ensure suitable gages of the go/no go type are available and used before any crimping operation and whenever possible during operation to ensure crimp dimensions.

10.16.21 *Lock Washers for Terminals for Equipment*—Where locknuts are used to ensure binding and locking of electrical terminals, they shall 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 shall 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.

10.17 *Waveguides:*

10.17.1 Proper installation of waveguides is critical to proper functioning of the associated system. Ensure the waveguide is installed in accordance with the manufacturer's limitations. Ensure the waveguide fits without binding or deforming. Ensure there is sufficient space around the waveguide prevent direct contact with other installed equipment in all flight regimes and environments.

11. EMI/RFI

11.1 *General:*

11.1.1 *Electromagnetic Interference (EMI)*—Wiring of sensitive circuits that may be affected by EMI shall be routed away from other wiring interference or provided with sufficient shielding to avoid system malfunctions under operating conditions. EMI between susceptible wiring and wiring that is a source of EMI increases in proportion to the length of parallel runs and decreases with greater separation. EMI shall be limited to negligible levels in wiring related to critical systems, that is, the function of the critical system shall not be affected by the EMI generated by the adjacent wire. Use of shielding with 85 % coverage or greater is recommended. Coaxial, triaxial, twin-axial, or quad-axial cables shall be used, wherever appropriate, with their shields connected to ground at a single point or multiple points, depending upon the purpose of the shielding. It is always critical that the shielding be grounded separate from all other types of grounds (that is, power and/or signal). The airframe-grounded structure may also be used as an EMI shield and all wiring shall be routed as close to the ground plane as possible. This reduces the "loop area" of the wiring, thereby reducing the coupling of energy into the wiring. EMI considerations shall address high-intensity radiated fields (HIRF). Refer to RTCA DO-160 Sections 16-22 for details on how to test for EMI issues. (Refer to FAA Advisory Circular AC 21-160E for additional guidance on the use of RTCA DO-160.)

11.2 *Grounding and Bonding*—Static power converters often emit unacceptable levels of EMI that may disrupt communication equipment and navigation instruments. Properly shielded connectors, terminal blocks, and wires may be required with all shields well grounded to the airframe.

11.3 *HIRF:*

11.3.1 *General:*

11.3.1.1 The electromagnetic HIRF environment results from the transmission of electromagnetic energy from radar, radio, television, and other ground-based, shipborne, or airborne RF transmitters. The HIRF environment has the capability of adversely affecting the operation of aircraft electrical and electronic systems. Although HIRF does not pose a significant threat to earlier generations of aircraft, in the late 1970s, designs for civil aircraft began to incorporate flight-critical electronic controls, electronic displays, and electronic engine controls. These systems are more susceptible to the adverse effects of operating in a HIRF environment.

11.3.1.2 Sensitive wiring is defined as wiring that is connected to equipment that is especially susceptible to EMI and is therefore more likely to create disruption of the equipment to which it is connected. See Section 6 for proper marking of EMI-sensitive wiring.

11.3.1.3 Concern for protection of electrical and electronic aircraft systems is important because of:

(1) A greater dependence on electrical and electronic systems performing functions required for the continued safe flight and landing of aircraft;

(2) The reduced electromagnetic shielding of some composite materials used in aircraft designs;

(3) The increased susceptibility of electrical and electronic systems to HIRF as a result of increased data bus or processor operating speeds or both, higher density integrated circuits and cards, and greater sensitivities of electronic equipment;

(4) Expanded frequency usage, especially above 1 GHz;

(5) Increased severity of the HIRF environment as a result of an increase in the number and power of RF transmitters; and

(6) The adverse effects experienced by some aircraft when exposed to HIRF conditions.

11.3.1.4 The following elements shall be included in a HIRF certification program:

(1) Identify systems through a safety assessment,

(2) Establish the applicable external HIRF environment,

(3) Establish the test environment for installed systems,

(4) Apply the appropriate method of HIRF compliance verification, and

(5) Verify compliance with HIRF certification requirements. (Refer to SAE ARP 5583 for additional detail on the process for HIRF certification.)

11.3.1.5 Only those systems identified as performing or contributing to functions whose failure condition classification is catastrophic, hazardous, or major failure conditions are subject to HIRF regulations. Failure condition classifications are defined in FAA Advisory Circular 23.1309-1C.

11.3.2 *Shields:*

11.3.2.1 Do not intermix shield and electrical power grounds or signal grounds or both on the same ground termination. If shield, signal, and/or power grounds are intermixed on the same termination, it is possible that the integrity of the electrical bond could be lost when electrical current flows thru the ground termination, then the resulting shield termination is inadequate (requirement is 2.5 mΩ or less). In addition, the energy that is coupled onto the shield has a direct path into the unit's power supply or circuit reference or both when they items are terminated in the same location. It is critical to the protection of the unit from EMI/EMC not to intermix signal and power grounds together on the same ground termination.

11.3.2.2 The best method of EMI/EMC protection is to use a 360° overbraid terminated into an EMI back shell. However, this is not always possible, nor is it always needed (especially for lower criticality equipment). If single-shielded wires are used with pigtails as the means to terminate the shield, it is critical that the use of daisy-chaining of shields is limited. Do not daisy-chain shields in the wiring definition, if possible and if not possible, no more than two shields shall be tied together and then terminated. Daisy-chaining shield terminations creates RF antennas, defeating the purpose of shielding against RF.

11.3.2.3 In general, shields shall be terminated to an EMI/HIRF connector backshell using a HIRF braid. When this is not possible, there may be other means to terminate the shields, so long as the shield termination length is not more than 4 in. (10 cm). Using braid instead of wire for shield termination provides essential ground path for RF protection (braided mesh versus parallel wire strands) and adequate lightning protection (current capacity). It also allows for physical examination of shield integrity.

11.3.3 *Grounds:*

11.3.3.1 Equipment case grounds and power grounds shall not be intermixed. The exception is if equipment power and case grounds are tied together internal to the equipment. Regardless of internal equipment ground configuration, shields shall never be terminated to the equipment power ground.

11.3.4 *External Wiring:*

11.3.4.1 Always review the aircraft lightning zoning when defining wiring external to the fuselage. See SAE ARP 5414 for the definition of aircraft lightning zoning. If wiring/equipment is installed in a "Zone 1" or "Zone 2," always use shielded wires with one shield end terminated at a local ground within 4 in. (10 cm) of equipment/components using HIRF braid. The other end of the shield shall be terminated to a fuselage bulkhead EMI/HIRF connector backshell.

11.3.4.2 Equipment requiring electrical power that is external to the fuselage shall have ground points on or in the fuselage. Use ground points external to the fuselage for shield terminations only.

11.3.4.3 It is more difficult to couple energy into a wire bundle external to the fuselage that contains both power and ground for the equipment installed; therefore, routing the power and return for a given device together is recommended. It is also easier to shield a wire in this configuration.

11.3.4.4 Shield wiring (as required) for electronic devices, actuators, valves, and so forth routed external to the fuselage from the electrical device to the appropriate fuselage interface connector.

(1) The shield will be required to be terminated at the equipment on one end and on the EME/HIRF backshell for the fuselage interface connector.

(2) For systems that contain wiring that is external/internal/external to the fuselage, shielding is required for wires external to the fuselage only, as long as there are already seven or more shields in each of the main cabin wire bundles.

11.3.5 *Electronic Devices:*

11.3.5.1 Two shields minimum are required for each electronic device installed in the aircraft, regardless of electronic device installation location.

11.3.5.2 Terminate one of the shields directly to the electronic device enclosure. Terminate the other end of the shield to an electrically bonded EMI/HIRF connector backshell.

11.3.5.3 Ensure electronic device enclosure is electrically bonded to the aircraft structure.

11.3.5.4 For determining which wires to shield in the PCB wire bundle, one consideration is that shield length must be 140 in. (3.3 m) or greater for it to be effective for RF and indirect lightning effects protection.

11.3.5.5 This shielding practice will improve the survivability of the shielded electronic device for both aircraft operation and system test conditions for lightning effects.

11.3.6 *Engine Wiring:*

11.3.6.1 Shields are required for all wiring that is installed on the engine.

11.3.6.2 Shields are to be terminated at both ends.

11.3.6.3 Terminate the engine wiring shields at one end on the EMI/HIRF backshell for the firewall connector and terminate at the other end on a local engine ground.

11.4 *Lightning:*

11.4.1 *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 shall 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, pushrods, or other conducting objects that extend to airframe extremities. This may require that these conductors be electrically bonded to the airframe or that electrical insulators be used to interrupt lightning currents. For additional information on lightning protection measures, refer to DOT/FAA/CT-89-22. Report DOT/FAA/ CT 86/8, April 1987, may provide additional information for composite materials.

11.4.2 *Control Surface Lightning Protection Bonding*—Control surface bonding is intended to prevent the burning/welding of hinges on a surface that receives a lightning strike thus causing possible loss of control. Therefore, bonding jumpers shall be used across each hinge. The installation location and current-carrying capacity of these jumpers shall be carefully chosen to provide a low-impedance shunt for lightning current across the hinge to the structure. When jumpers may be subjected to arcing, substantially larger wire sizes of 40 000 circular mils or a larger cross section may be 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 shall be avoided.

11.4.3 *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 may 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. Lightning protection may also be accomplished by electrical isolation as long as the dielectric is sufficient.

11.4.4 *Lightning Protection for Antennas and Air Data Probes*—Antenna and air data probes that are mounted on exterior surfaces within lightning strike zones shall 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 may also be sufficient to fulfill these requirements. It is important that it connects to something exposed to the outside of the aircraft (for example, antenna coax cables, power lines for lights, and so forth) be connected to a bulkhead before connection to the receiver of other electrical/electronic equipment. Candidate designs shall be verified by simulated lightning tests in accordance with RTCA DO-160, Section 23. (Refer to FAA Advisory Circular AC 20-136 for additional guidance on the protection of electrical and electronic systems against the indirect effects of lightning.)

12. Alterations

12.1 *General:*

NOTE 19—Direct replacement of components with original part number components is considered a repair. Replacement of a component with an equivalent part is considered an alteration.

12.1.1 Structural repairs, installation of STCs, modifications, or field-approved repair and alteration activity inherently introduces tooling and residual debris that is harmful to aircraft wiring. They often require displacement or removal of wiring to provide access to the work area. Even minor displacement of wiring, especially while clamped, can damage its insulation and result in degraded performance, leading to subsequent arcing or circuit failure.

12.1.2 When substituting original equipment manufacturer (OEM)-installed equipment, follow this three-step process to ensure approved parts are installed:

12.1.2.1 Contact the OEM to see if alternate parts have been approved;

12.1.2.2 Use the tables in this practice to identify acceptable alternates; and

12.1.2.3 Install parts not previously approved for the application. This will require some certification process. See Section 13.

12.2 *Wire Substitutions:*

NOTE 20—Direct replacement of wire with original part number components is considered a repair. Replacement of wire with an equivalent part is considered an alteration.

12.2.1 Sections of wire in which splices occur at less than 10-ft (3-m) intervals, unless specifically authorized, because of parallel connections, locations, or inaccessibility shall be replaced.

12.2.2 *Wire Substitution*—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 OEM has approved any substitution. If not, then the OEM shall be contacted for an acceptable replacement. If acceptable replacement is not available from the OEM, then use Tables 5 and 6.

12.2.3 Replacement wire performance capabilities shall be equal to or superior to the wire being replaced. Existing installed wire that needs replacement shall be identified as to its performance capabilities to avoid the inadvertent use of a lower-performance unsuitable replacement.

12.3 *Commercial Off-the-Shelf (COTS) Components:*

12.3.1 When installing COTS components, ensure the installed equipment complies with the aircraft-type certification requirements.

12.4 *Electrical Load Considerations:*

12.4.1 Before any aircraft electrical load is increased, the new total electrical load (previous maximum load plus added load) shall be checked to determine if the design levels are being exceeded. Where necessary, wires, wire bundles, and circuit-protective devices having the correct ratings shall be added or replaced. Refer to Guide F2490 for acceptable practices and processes for development of electrical load analyses.

12.5 *Batteries:*

12.5.1 When replacing lead-acid batteries with NiCad batteries, neutralize the battery box or compartment and thoroughly flush with water and dry. A flight manual supplement shall also be provided for the NiCad battery installation. Acid residue can be detrimental to the proper functioning of a NiCad battery, as alkaline will be to a lead-acid battery.

NOTE 21—Replacement of lead-acid batteries with NiCad batteries will require the installation of some means to monitor the battery temperature.

12.5.2 When replacing NiCad batteries with lead acid batteries, the battery temperature-monitoring system may be removed. However removing the battery temperature-monitoring system may require changes to the flight manual. Some OEMs have installed provisions for battery type conversion. When available, follow the OEM instructions for battery substitutions.

12.5.3 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. Remove the grounding lead first for battery removal, then the positive lead. Connect the grounding lead of the battery last to minimize the risk of shorting the "hot terminal" of the battery during installation.

12.5.4 *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 causing internal shorting of the battery.

12.5.5 *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.

12.6 *Circuit Breakers:*

12.6.1 When replacing original equipment circuit breakers with units of an equivalent rating from a different supplier, ensure the trip curves are compatible. The replacement breaker time to trip shall be equal to, or less than, the unit being replaced.

12.7 *Junction Boxes:*

12.7.1 Replacement junction boxes shall be fabricated using the same material as the original or from a fire-resistant, nonabsorbent material, such as aluminum, or an acceptable composite material.

12.8 *Relays:*

12.8.1 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.

12.9 *Switches:*

12.9.1 When substituting switches for OEM installed equipment refer to 10.15 and 12.1 to ensure an approved and appropriate part is installed.

12.10 *Wire Marking:*

12.10.1 When adding wiring, ensure the added wiring is marked per the guidance in Section 6.

12.11 *Wire Bundle Routing:*

12.11.1 When adding wires to existing bundles, ensure the added wiring does not degrade system safety. Added wiring between bundles may result in compromise of required redundant systems. Critical wire bundles, such as fly-by-wire and FADEC, shall not have wiring added unless the added wire is integral to that system.

12.11.2 Ensure all wire ties and anchors, which were removed to facilitate additional wire installation, are replaced and properly installed. Refer to Section 7 for proper wiring installation practices.

12.11.3 Do not loop excess wire. Wires shall be trimmed to fit. If additional wire length is installed to permit reterminations, ensure the wire is properly secured and wire bend radii comply with the requirements in 7.2.1.

12.12 *Wire Bundle Combing:*

12.12.1 Comb the wire groups and bundles so that the wires will lie parallel to each other and minimize the possibility of insulation abrasion. A combing tool, similar to that shown in Fig. 59, may be made from any suitable insulating material taking care to ensure all edges are rounded to protect the wire insulation.

12.13 *Interference Tests:*

12.13.1 When altering aircraft wiring, additional EMI may be introduced. Tests may be required to ensure EMI is maintained within acceptable limits. See Section 11 for proper EMI considerations.

12.13.2 Audio and data signals are often the most susceptible to EMI. Other typical waveforms that are more susceptible to EMI have the following characteristics:

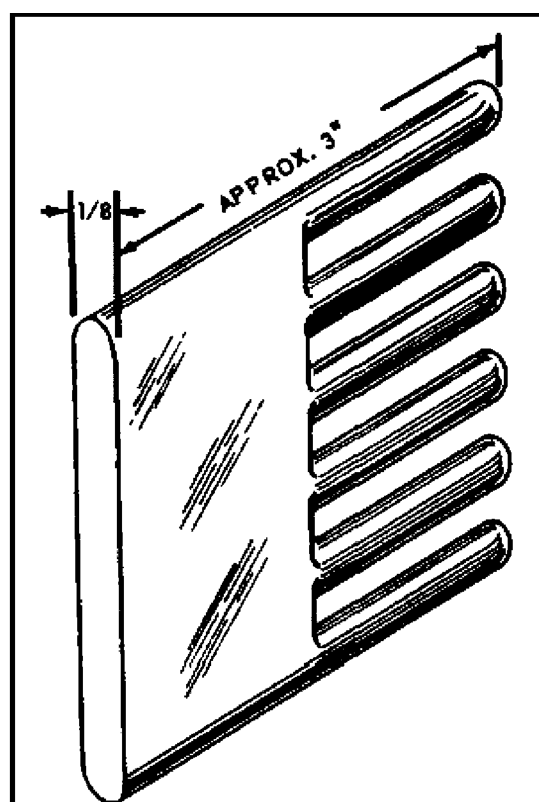
12.13.2.1 Low voltage,

12.13.2.2 Low current, and/or

12.13.2.3 Slow rise times.

12.13.3 SAE AS 50881 Wiring, Aerospace Vehicle, requires sensitive wiring to be routed to avoid electromagnetic interference. SAE AS 50881 Appendix B allows for, but does not mandate, the identification of EMI-sensitive wires and cables with a category code added to the significant wire number. In the past, EMI-sensitive wires and cables added during modification of aircraft have been isolated in accordance with the specification; however, they have not been identified as EMI sensitive, and therefore, their integrity may be compromised during subsequent aircraft modification.

12.13.4 Where wires and cables are susceptible to EMI and are identified as critical to the safety of flight (SOF) of the aircraft, they shall be identified with red sleeves. (This is in addition to the EMI suffix on the wire identification code.) The



(1 in. = 2.54 cm)

FIG. 59 Comb for Straightening Wires in Bundles

red sleeves (heat shrink is appropriate) shall be a minimum of 2-in. (5-cm) length and positioned at intervals no greater than 15 in. (38 cm) along the entire length of the wire or loom using application methods detailed in this manual. Marking of the sleeving to highlight further the EMI sensitivity is optional, but shall be consistent with existing aircraft labeling practices and clearly documented in wiring publications (see Fig. 6).

12.14 *System Safety Assessments:*

12.14.1 A system safety assessment shall be accomplished for all wiring alterations. System safety assessment information may or may not be available from the OEM, but the modification assessment shall be accomplished to ensure the alteration does not degrade system safety. (Refer to SAE ARP 4761 for additional detail on the safety assessment process.)

13. Certification Processes

13.1 *General:*

13.1.1 Federal regulations define the requirements for certifying and maintaining an aircraft in an airworthy condition. The following sections are intended to provide some general information relative to certification and maintenance requirements and procedures and sources of additional information.

13.1.2 Certification is the process of designing and substantiating an aircraft to meet the regulations applicable to that aircraft. For aircraft designed and certified in the United States, these regulations are all defined in the Code of Federal Regulations, Chapter I–Federal Aviation Administration, Department of Transportation. Certification generally consists of analyses and tests to substantiate that an aircraft or product meets the regulations applicable to it. Certification will normally be accomplished under either the Standard Process or a Delegated Organization. Under the Standard Process, the applicant works directly with the FAA and generally makes use of Designated Engineering Representatives (DER). Under a delegated process, the applicant is the Delegated Organization and the work will be done in accordance with the procedures agreed to by the FAA and included in the organization manual.

13.1.3 All of the Regulations and Orders mentioned in this practice plus others that may be applicable to a particular situation can found on the FAA Website at www.faa.gov.

13.2 *Certification:*

13.2.1 The regulations defining the process for certification are found in Title 14 of the Code of Federal Regulations Part 21, Certification Procedures for Products and Parts. These regulations define the requirements related to the certification, production, licensing, and maintenance of the aircraft. Some of the requirements of this section that may be of particular concern to maintenance operations are as follows:

(1) Subpart A, Section 21.3, Reporting of failures, malfunctions, and defects.

(2) Subpart D, Changes to Type Certificates.

(3) Subpart E, Supplemental Type Certificates.

(4) Subpart H, Airworthiness Certificates.

(5) Subpart K, Approval of Materials, Parts, Processes, and Appliances.

(6) Subpart L, Export Airworthiness Approval.

(7) Subpart M, Designated Alteration Station Authorization Procedures.

(8) Subpart N, Approval of Engines, Propellers, Materials, Parts, and Appliances: Import.

13.2.1.1 In addition to these regulations, there are FAA Orders that define acceptable practices to be used in the Certification and Repair/Alteration process. Following are some of those Orders:

(1) Type Certification,

(2) DAS, DOA, and SFAR 36 Authorization Procedures,

(3) Supplemental Type Certificate (STC) Approvals, "One Aircraft Only",

(4) Designee Management Handbook,

(5) Designated Engineering Representative (DER) Guidance Handbook,

(6) Aircraft Certification Service FAA Flight Test Responsibilities, Procedures, and Training,

(7) Conformity Inspection Notification Process,

(8) How to Establish the Certification Basis for Changed Aeronautical Products,

(9) Submitting Instructions for Continued Airworthiness for Type Certificates, Amended Type Certificates and Supplemental Type Certificates, and

(10) Instructions for Continued Airworthiness Responsibilities.

13.2.2 *Certification Regulations Applicable to the Different Products:*

13.2.2.1 The certification regulations applicable to the various categories of aircraft, engines, and propellers are listed in the following. These regulations define the minimum performance requirements that a product shall meet to be certified.

(1) Title 14 Code of Federal Regulations Part 23, Airworthiness standards: normal, utility, acrobatic, and commuter category airplanes.

(2) Title14 Code of Federal Regulations Part 25, Airworthiness standards: transport category airplanes.

(3) Title14 Code of Federal Regulations Part 27, Airworthiness standards: normal category rotorcraft.

(4) Title14 Code of Federal Regulations Part 29, Airworthiness standards: transport category rotorcraft.

(5) Title14 Code of Federal Regulations Part 31, Airworthiness standards: manned free balloons.

(6) Title14 Code of Federal Regulations Part 33, Airworthiness standards: aircraft engines.

(7) Title14 Code of Federal Regulations Part 34, Fuel venting and exhaust emission requirements for turbine engine powered airplanes.

(8) Title14 Code of Federal Regulations Part 35, Airworthiness standards: propellers.

(9) Title14 Code of Federal Regulations Part 36, Noise standards: aircraft type and airworthiness certification.

13.2.3 *Certification Tests:*

13.2.3.1 Certification tests are normally conducted to substantiate that product performance characteristics meet the minimum requirements of the regulations and that there are no unsafe characteristics. Before conducting any such tests, the applicant shall produce a test plan and have that test plan approved by the FAA. In addition, the applicant shall provide verification that the test article conforms to the type design of the product. The FAA may then either witness or perform the test themselves or delegate it to an appropriately qualified Designated Engineering Representative (DER). In a delegated organization, this will be accomplished according to the agreed to procedures in the organization manual.

13.2.4 *Type Certificates:*

13.2.4.1 A Type Certificate for a product may be issued by the FAA when the FAA is satisfied that the product meets all of the applicable regulations. The Type Certificate allows the applicant to obtain an Airworthiness Certificate and to manufacture that product. In addition to the Type Certificate, a Type Certificate Data Sheet (TCDS) will be prepared that defines specific performance and operational characteristics of the product. Any changes to the data defined in the TCDS may require retesting and recertification to verify that the minimum performance requirements are still met or that there are no unsafe characteristics introduced by the changes. Changes accomplished by the TC holder will normally result in modifications to the TCDS. Changes by someone other than the TC holder will be accomplished under the rules for Supplemental Type Certificates (STC).

13.3 *Alterations and Maintenance:*

13.3.1 *Regulations and Orders Relating to the Alteration and Maintenance of Aircraft:*

13.3.1.1 Once the aircraft is certified and produced, it is required that it be maintained in a manner that assures the aircraft continues to comply with applicable design and certification requirements and allows the aircraft to continue to operate in a safe manner. The following regulations are applicable in the maintenance of the aircraft to the standards used in the design and certification and to maintain safe products in the field:

(a) 14.CFR 21.289, Major repairs, alterations, and rebuilding (Form 337).

(b) 14 CFR 39, Airworthiness directives.

(c) 14 CFR 43, Maintenance, preventive maintenance, rebuilding, and alteration.

(1) Following are FAA Orders and Advisory Circulars that may be consulted for guidance on repair and modification activities:

(a) FAA Approvals of Modifications/Alterations.

(b) DER Data Approvals Related to Repair and Alteration of Foreign Registered Aircraft.

(c) Airworthiness Inspector's Handbook, Volume 2.

(d) AC 43.13 Acceptable Methods, Techniques, and Practices—Aircraft Inspection and Repair

13.3.2 *Field Approvals:*

13.3.2.1 The Field Approval Process is defined in FAA Order 8300.10, Airworthiness Inspector's Handbook, and Volume 2. Acceptable data for Field Approvals may be in the form of manufacturer's manuals, previously approved FAA Form 337s, and the OEM structural repair manuals, although the latter are not FAA approved. Field approvals shall not install equipment or modify an aircraft or product in a manner that would require certification to be accomplished to show compliance with any of the regulations applicable to that product.

13.3.3 *Approvals:*

13.3.3.1 Major repairs and alterations may be accomplished and approved in accordance with the provisions of 14 CFR 43, Appendixes A and B. A record of the change will be made as required by 14 CFR 43.9.

13.3.4 *Supplemental Type Certificates (STCs):*

13.3.4.1 STC requirements are defined under Subpart E of 14 CFR 21, Certification Procedures for Products and Parts. STCs are issued when a major change in type design is incorporated but the change is not sufficient to require a new type certificate under 14 CFR 21.19. STCs are frequently used for installing additional equipment or replacing equipment that was originally installed by the OEM. They normally require support from the FAA Aircraft Certification Office unless accomplished by a Designated Alteration Station (DAS). An STC will normally require analyses or testing to verify that the change will comply with all of the regulations applicable to the product.

13.3.5 *Design and Maintenance Organizations:*

13.3.5.1 For the FAA to accomplish the oversight of all certification and repair activities, they have created delegated organizations that may perform these activities under specific guidelines. These organizations provide the same level of certification and repair oversight as the FAA. Currently, the FAA regulations governing these organizations are defined in 14 CFR Part 21 Subparts J and M and FAA Order 8100.9. The FAA plan is to move toward more delegated organizations, and the next step in the process is the Organization Designation Authorization (ODA) to be implemented between 2006 and 2009. In 2010, the FAA plans to have the Certified Design Organization (CDO) requirements available.

13.3.6 *Delegation Option Authorization (DOA) Procedures:*

13.3.6.1 The DOA regulatory basis is defined in 14 CFR 21, Subpart J and, by regulation, is currently limited to type, production, and airworthiness certification of small aircraft, engines, and propellers and to issuing airworthiness approval tags for engines, propellers, and part of products covered under this rule. Because of the direction that the FAA is going with the delegated process, they are now allowing exemptions to the rule that allow large aircraft to use the DOA procedures in preparation for the change to the ODA process. FAA Order 8100.9 provides the detail requirements for meeting the DOA regulations.

13.3.7 *Designated Alteration Station (DAS) Authorization Procedures:*

13.3.7.1 The DAS regulatory basis is defined in 14 CFR 21, Subpart M and is limited to issuing supplemental type certificates and experimental certificates and amending standard airworthiness certificates. It is applicable to domestic repair stations, air carriers, commercial operators of large aircraft, and manufacturers of aircraft. FAA Order 8100.9 provides detail requirements for meeting the DAS requirements.

13.3.8 *Organization Designation Authorization (ODA):*

13.3.8.1 ODA is the next step in the evolution to increased autonomy by the manufacturers and repair facilities. FAA Regulation 14 CFR Part 183 established the ODA program and it will replace the DOA, DAS, ODAR, and SFAR 36 delegation programs. It is similar in nature to the DOA process but with additional responsibilities transferred to the applicants. An ODA may have multiple functions under it such as Type

Certification, Production Certification, TSO Approval, Supplemental Type Certification, Major Repair and Alteration, Parts Manufacturer Approval, and General Aviation Operations Functions.

13.3.9 *Certified Design Organization (CDO):*

13.3.9.1 The CDO is the final step in the currently defined transition. The CDO requirements are still in the concept and planning stages and are not available but provide the most autonomy to the applicants. It will also require much more structured procedures and processes.

13.3.10 *Delegated Personnel:*

13.3.10.1 *Designated Engineering Representative (DER):*

(1) Section 183.29 defines the types of DER appointments and what approvals they are allowed to make. They include Structure, Powerplant, Systems and Equipment, Radio, Engine, Propeller, Acoustical, Flight Analyst, and Flight Test Pilot. These designees work closely with the FAA Aircraft Certification Office (ACO) to assist in the certification of aircraft and aircraft products. Significant changes to an aircraft shall be reviewed by an FAA ACO engineer or a DER to determine what substantiation may be required. An appropriately delegated DER may be able to find compliance and submit the appropriate paperwork to support FAA approval of the change.

13.3.10.2 *Delegated Option Authorization Airworthiness Representative (DOA AR):*

(1) A DOA AR serves a similar role to the DER but within a delegated organization. Their authorization is limited to activities within the organization for which they work.

13.3.10.3 *Designated Airworthiness Representative (DAR):*

(1) The responsibilities and functions of the DAR are prescribed by 14 CFR 183.33. The DAR may perform examination, inspection, and testing services necessary to issue, and to determine the continuing effectiveness of, certificates, as authorized by the Director of Flight Standards Service in the area of maintenance or as authorized by the Director of Aircraft Certification Service in the areas of manufacturing and engineering.

13.3.10.4 *Designated Manufacturing Inspection Representative (DMIR):*

(1) The responsibilities and functions of the DMIR are prescribed 14 CFR 183.31.

(2) A designated manufacturing inspection representative (DMIR) may, within limits prescribed by, and under the general supervision of, the Administrator, do the following:

(a) Issue:

(1) Original airworthiness certificates for aircraft and airworthiness approvals for engines, propellers, and product parts that conform to the approved design requirements and are in a condition for safe operation;

(2) Export certificates of airworthiness and airworthiness approval tags in accordance with Subpart L of Part 21 of this chapter;

(3) Experimental certificates for aircraft for which the manufacturer holds the type certificate and which have undergone changes to the type design requiring a flight test; and

(4) Special flight permits to export aircraft.

(b) Conduct any inspections that may be necessary to determine that:

(1) Prototype products and related parts conform to design specifications, and

(2) Production products and related parts conform to the approved type design and are in condition for safe operation.

(c) Perform functions authorized by this section for the manufacturer, or the manufacturer's supplier, at any location authorized by the FAA.

14. Keywords

14.1 aircraft; aircraft electrical wiring systems; alteration; aviation; certification; design

APPENDIXES

(Nonmandatory Information)

X1. COMMON ELECTRONIC/ELECTRICAL SYMBOLS

Common Electronic/Electrical Symbols

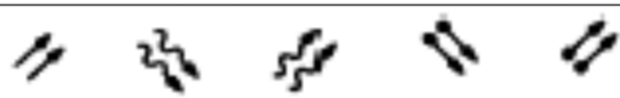
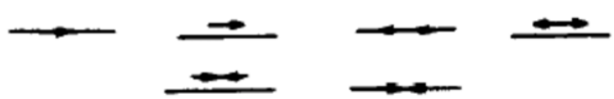
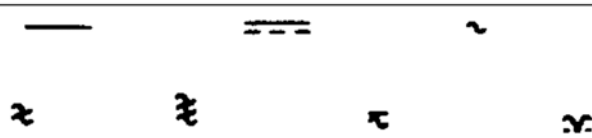
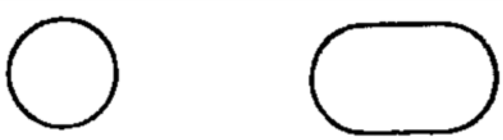
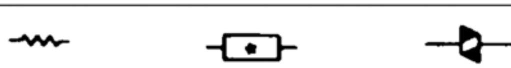
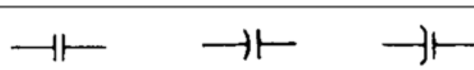
Symbol	Meaning
	Adjustability variability
	Radiation indicators
	Physical state recognition
	Test-point recognition
	Polarity markings
	Direction of flow of power, signal, or information
	Kind of current
	Envelope enclosure
	Shield shielding
	Special connector or cable indicator
	Resistor
	Capacitor

FIG. X1.1 Common Electronic/Electrical Symbols

Common Electronic/Electrical Symbols

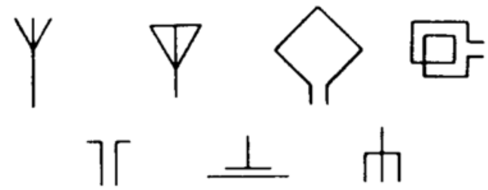
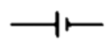
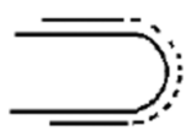
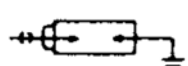
Symbol	Meaning
	Antenna
	Battery
	Thermal element thermomechanical transducer
	Thermocouple
	Spark gap ignitor gap
	Continuous loop fire detector (temperature sensor)
	Ignitor plug

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

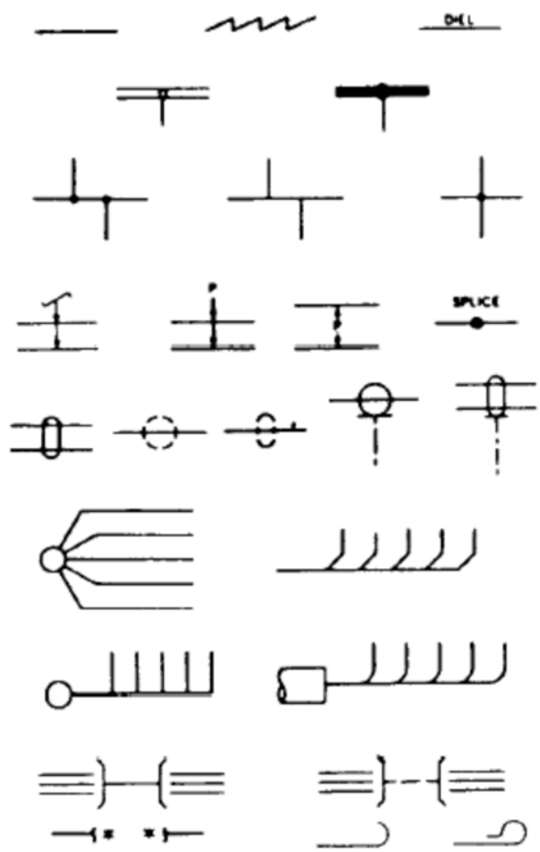
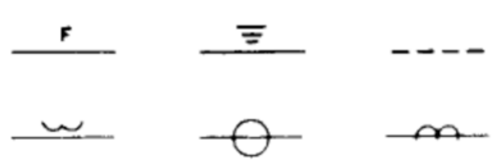
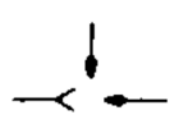
Symbol	Meaning
	Transmission patch Conductor Cable Wiring
F S T V 	Distribution lines Transmission lines
	Alternative or conditioned wiring
	Associated or future

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

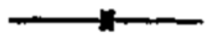
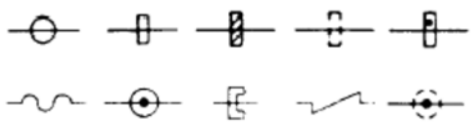
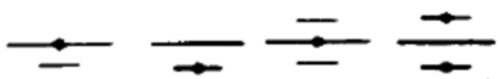
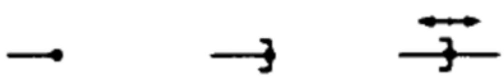
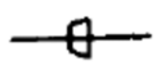
Symbol	Meaning
	Intentional isolation of DC path in coaxial or wave guide applications
	Waveguide
	Strip-type transmission line
	Termination
	Circuit return
	Pressuretight bulkhead cable gland Cable sealing end
	Switching function
	Electrical contact

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

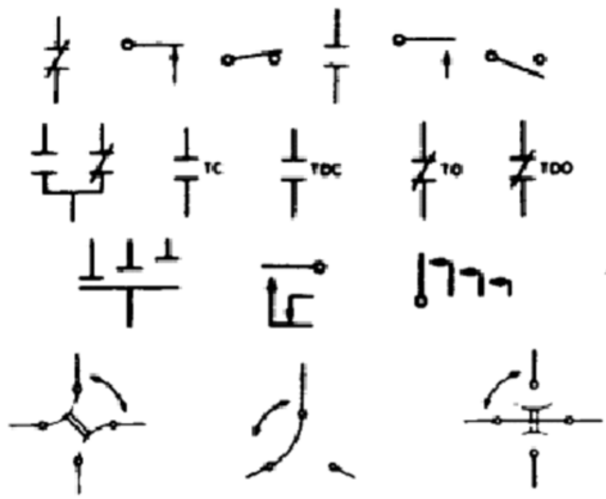
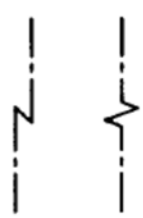
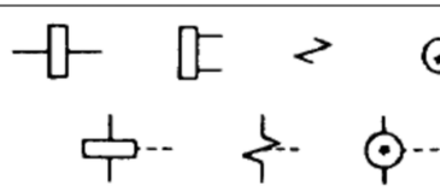
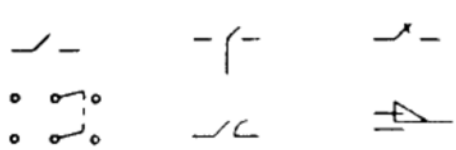
Symbol	Meaning
	Basic contact assemblies
	Magnetic blowout coil
	Operating coil Relay coil
	Switch
	Pushbutton, momentary, or spring return

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

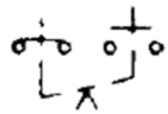
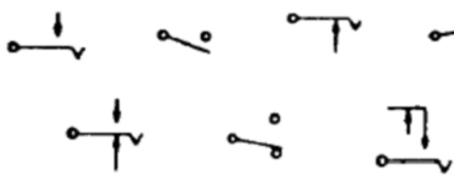
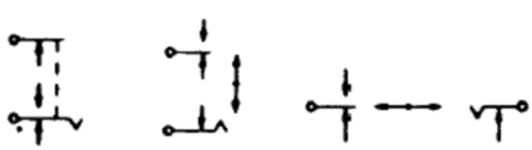
Symbol	Meaning
	Two-circuit, maintained, or not spring return
	Nonlocking switching, momentary, or spring return
	Locking switch
	Combination locking and nonlocking switch
	Key-type switch lever switch

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

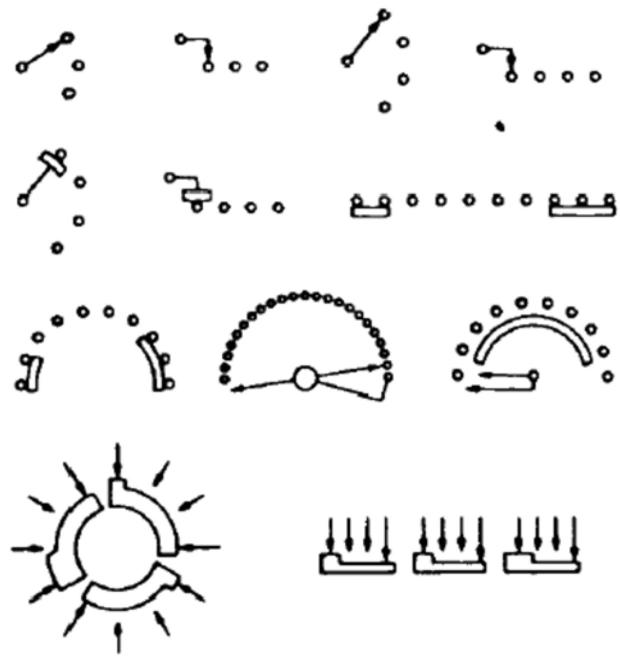
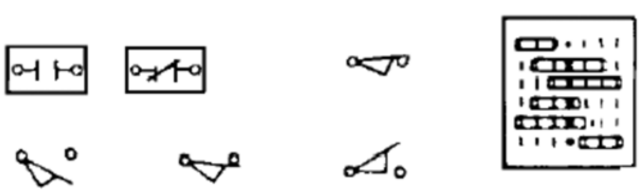
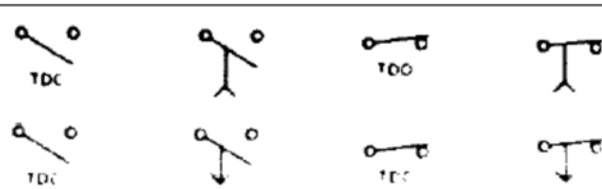
Symbol	Meaning
	Selector or multiposition switch
	Safety interlock
	Limit switch Sensitive switch
	Switches with time-delay feature
	Flow-actuated switch
	Liquid-level actuated switch

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

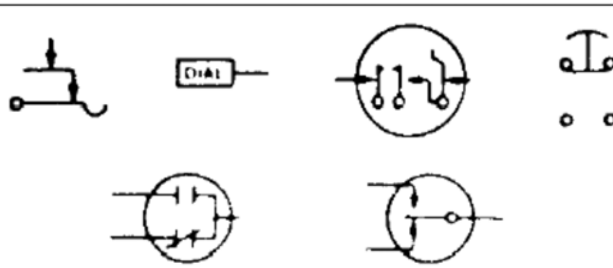
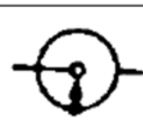
Symbol	Meaning
	Pressure- or vacuum-actuated switch
	Temperature-actuated switch
	Thermostat
	Flasher Self-interrupting switch
	Foot-operated switch Foot switch
	Switch operated by shaft rotation and responsive to speed or direction
	Switches with specific features
	Governor Speed regulator

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

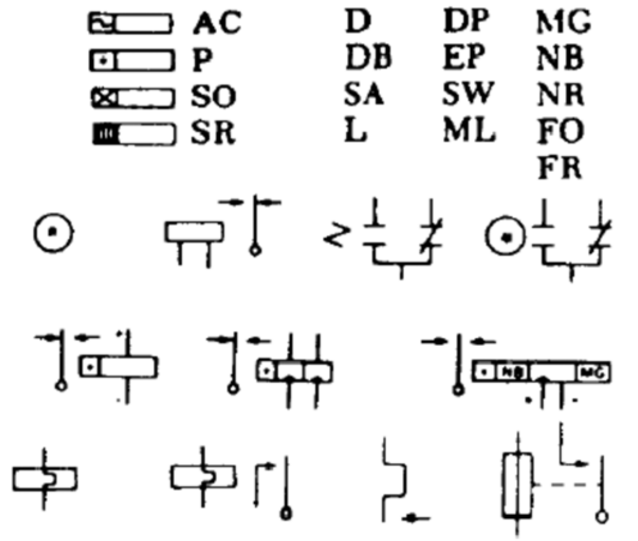
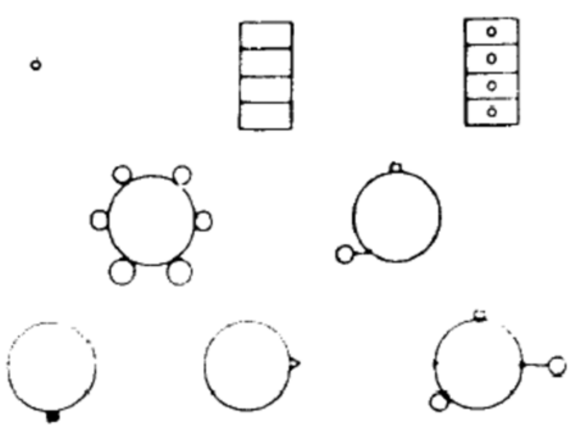
Symbol	Meaning
	Relay
	Inertia switch
	Mercury switch
	Terminals
	Cable termination

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

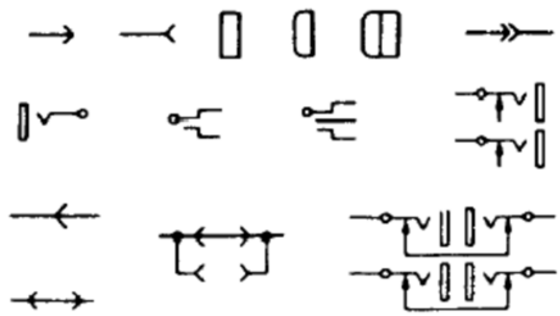
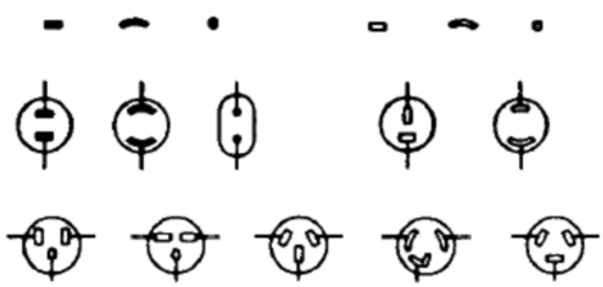
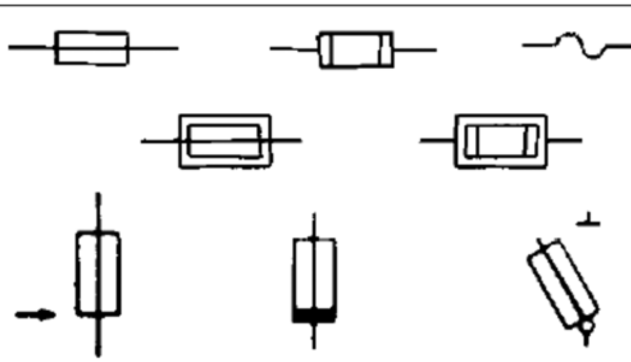
Symbol	Meaning
	Connector Disconnecting device
	Connectors of the type commonly used for power-supply purposes
	Test blocks
	Coaxial connector
	Waveguide flanges Waveguide junction
	Fuse

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

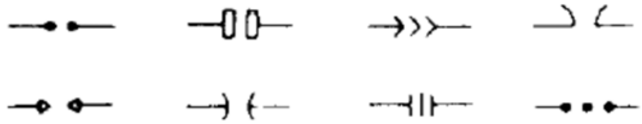
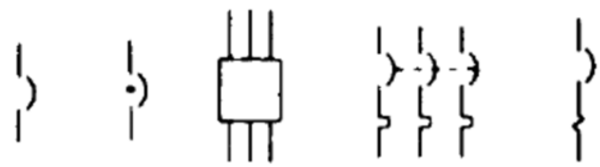
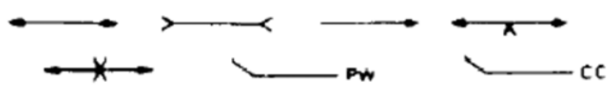
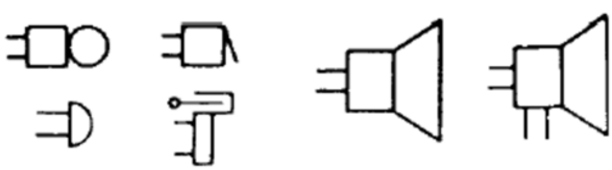
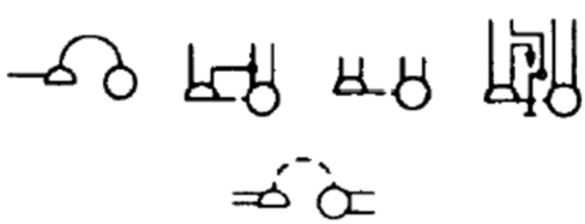
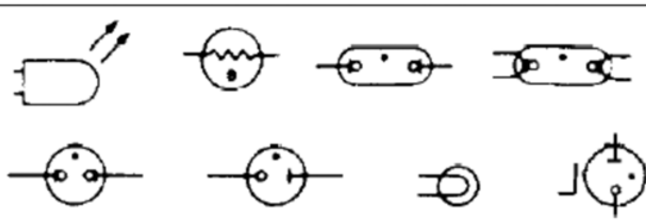
Symbol	Meaning
	Lightning arrester Arrester Gap
	Circuit breaker
 C F φ S V Z GP W T	Protective relay
	Audible-signaling device
	Microphone
	Handset Operator's set
	Lamp

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

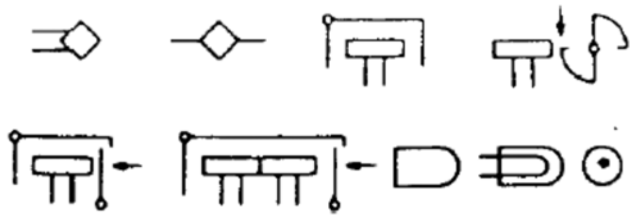
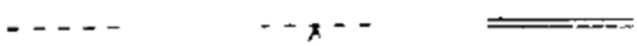
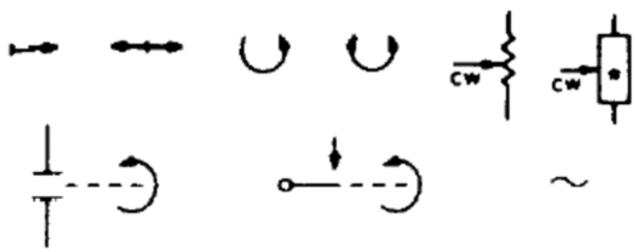
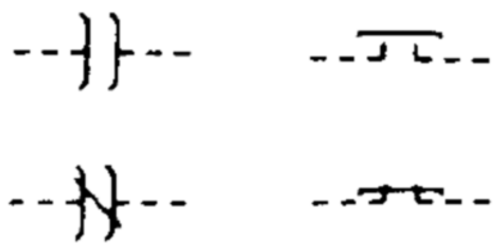
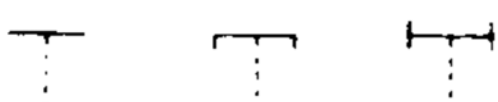
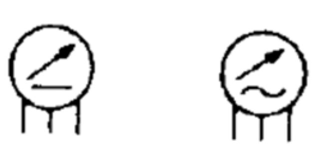
Symbol	Meaning
	Visual-signaling device
	Mechanical connection Mechanical interlock
	Mechanical motion
	Clutch brake
	Manual control
	Gyro Gyroscope Gyrocompass
	Position indicator

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

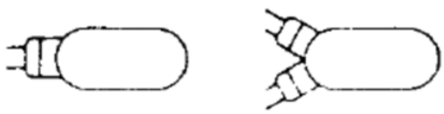
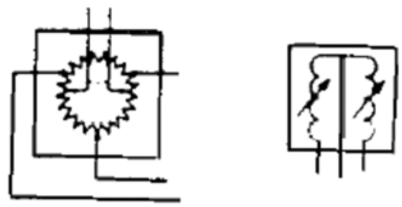
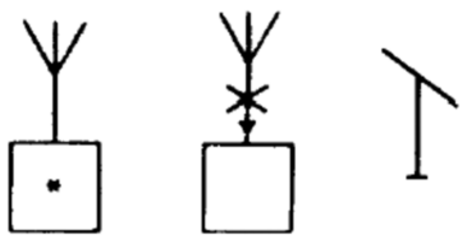
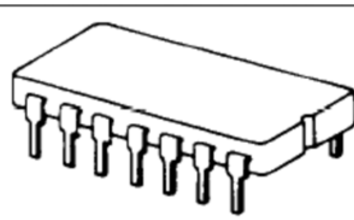
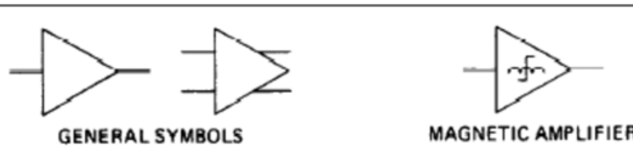
Symbol	Meaning
	Fire extinguisher actuator head
	Position transmitter
	Radio station
	Space station
	Integrated circuit
	Amplifiers

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

Common Electronic/Electrical Symbols

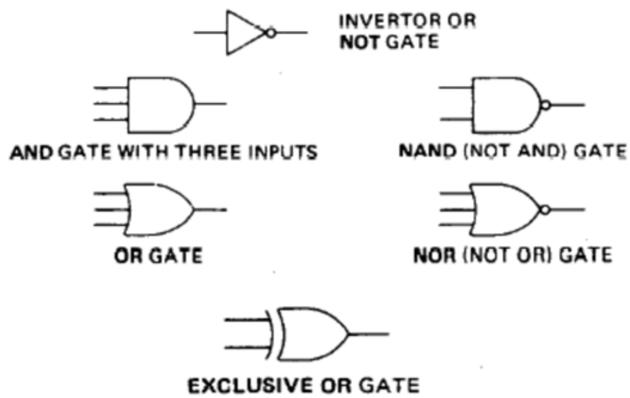
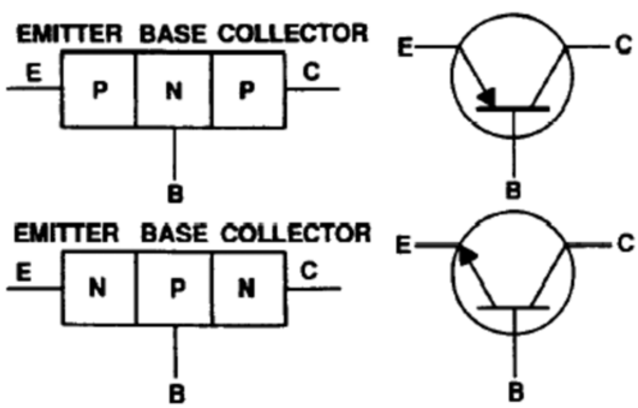
Symbol	Meaning
	Logic gates
	Diode
	Transistor symbols

FIG. X1.1 Common Electronic/Electrical Symbols *(continued)*

X2. SI-BASED PREFIXES AND POWERS OF 10

X2.1 Atto (a) = quintillionth of = 10^{-18} times

X2.2 Femto (f) = quadrillionth of = 10^{-15} times

X2.3 Pico (p), or μμ = trillionth of = 10^{-12} times

X2.4 Nano (n), or m μ = billionth of = 10^{-9} times

X2.5 Micro (μ) = millionth of = 10^{-6} times

X2.6 Milli (m) = thousandth of = 10^{-3} times

X2.7 Centi (c) = hundredth of = 10^{-2} times

X2.8 Deci (d) = tenth of = 10^{-1} times

X2.9 Unity = 10^{0} = 1

X2.10 Deka (da) = ten times = 10 times

X2.11 Hecto (h) = hundred times = 10^{2} times

X2.12 Kilo (k) = thousand times = 10^{3} times

X2.13 Mega (M) = million times = 10^{6} times

X2.14 Giga (G), or kM = billion times = 10^{9} times

X2.15 Tera (T) = trillion times = 10^{12} times