



Designation: F2639 – 18

# Standard Practice for Design, Alteration, and Certification of Aircraft Electrical Wiring Systems<sup>1</sup>

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:

	Title	Section
Wire Selection		5
General		5.1
Aircraft Wire Materials		5.2
Table of Acceptable Wires		5.3
Severe Wind and Moisture Problems (SWAMP)		5.4

<sup>1</sup> 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 Oct. 1, 2018. Published November 2018. Originally approved in 2007. Last previous edition approved in 2015 as F2639 – 15. DOI: 10.1520/F2639-18.

Grounding and Bonding	5.5
Electrical Wire Chart	5.6
Wire and Cable Identification	6
General	6.1
Wire and Cable Identification	6.2
Types of Markings	6.3
Sleeve and Cable Marker Selection	6.4
Placement of Identification Markings	6.5
Wiring Installation	7
General	7.1
Wire Harness Installation	7.2
Power Feeders	7.3
Service Loops	7.4
Drip Loops	7.5
Soldering	7.6
Strain Relief	7.7
Grounding and Bonding	7.8
Splicing	7.9
Fuel Tank Wiring	7.10
Corrosion Preventative Compounds (CPC) (MIL-C-81309)	7.11
Electrical Load Considerations	8
General	8.1
Methods for Determining the Current-Carrying Capacity of Wires	8.2
Acceptable Means of Monitoring and Controlling the Electrical Load	8.3
Electrical System Components	9
General	9.1
Alternators	9.2
Generators	9.3
Ground Power Units	9.4
Auxiliary Power Units	9.5
Batteries	9.6
Circuit Protection Devices	9.7
Conduit	9.8
Connectors	9.9
Inverters and Power Converters	9.10
Junctions	9.11
Junction Boxes	9.12
Electronic Assemblies	9.13
Relays	9.14
Studs	9.15
Switches	9.16
Terminals and Terminal Blocks	9.17
Waveguides	9.18
Electrical System Component Installation	10
General	10.1
Alternators	10.2
Generators	10.3
Auxiliary Power Units (APUs)	10.4
Batteries	10.5
Circuit Protection Devices	10.6
Conduit	10.7
Connectors	10.8
Inverters and Power Converters	10.9

Junctions	10.10
Junction Boxes, Panels, Shields, and	10.11
Microswitch Housings	
PC Board Assemblies	10.12
Relays	10.13
Studs	10.14
Switches	10.15
Terminals and Terminal Blocks	10.16
Waveguides	10.17
EMI/RFI	11
General	11.1
Grounding and Bonding	11.2
HIRF	11.3
Lightning	11.4
Alterations	12
General	12.1
Wire Substitutions	12.2
Commercial Off-the-Shelf (COTS) Components	12.3
Electrical Load Considerations	12.4
Batteries	12.5
Circuit Breakers	12.6
Junction Boxes	12.7
Relays	12.8
Switches	12.9
Wire Marking	12.10
Wire Bundle Routing	12.11
Wire Bundle Combing	12.12
Interference Tests	12.13
System Safety Assessments	12.14
Certification Processes	13
General	13.1
Certification	13.2
Alterations and Maintenance	13.3

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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

## 2. Referenced Documents

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

### 2.2 ASTM Standards:<sup>2</sup>

**F2490** Guide for Aircraft Electrical Load and Power Source Capacity Analysis

### 2.3 ANSI Standards:<sup>3</sup>

**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:<sup>4</sup>

**Advisory Circular 20-53()** 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 21-16()** RTCA Document DO-160D/E/F/G

**AC 23.1309-1E** Systems Safety Analysis and Assessment for Part 23 Airplanes

**AC 25-16** Electrical Fault and Fire Prevention and Protection

**AC 25.869-1()** Electrical System Fire and Smoke Protection

**AC 25.981-1()** Fuel Tank Ignition Source Prevention Guidelines

**AC 25.1353-1()** Electrical Equipment and Installations

**AC 25.1357-1()** Circuit Protective Device Accessibility

**AC 27-1B** Certification of Normal Category Rotorcraft

**AC 29-2C** Certification of Transport Category Rotorcraft

**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:<sup>5</sup>

**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

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

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>4</sup> 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>.

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

**ARP 1308** Preferred Electrical Connectors for Aerospace Vehicles and Associated Equipment

**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:<sup>4</sup>

**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<sup>6</sup>  
**EIA 471** Symbol & Label for Electrostatic Sensitive Devices<sup>7</sup>

**National Electrical Manufacturers Association (NEMA) WC 27500** Standards for Aerospace and Industrial Electric Cable (replaces MIL-DTL-27500H)<sup>8</sup>  
**ICAO Annex 5** Units of Measurement to be used in Air and Ground Operations<sup>9</sup>

### 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

<sup>6</sup> Available from RTCA, Inc., 1828 L St., NW, Suite 805, Washington, DC 20036.

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

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

<sup>9</sup> Available from ICAO, Document Sales Unit, 999 University St., Montreal, Quebec H3C 5H7, Canada.



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.

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 *polyvinylidene 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 *FMS*—Flight Manual Supplement
- 3.3.14 *ID*—identification
- 3.3.15 *NiCad*—nickel cadmium
- 3.3.16 *NiMH*—nickel metal hydride
- 3.3.17 *OD*—outside diameter
- 3.3.18 *ODA*—Organization Designation Authorization
- 3.3.19 *OEM*—original equipment manufacturer
- 3.3.20 *PI*—polyimide
- 3.3.21 *RCCB*—remote-controlled circuit breaker
- 3.3.22 *RFI*—radio frequency interference
- 3.3.23 *RFM*—Rotorcraft Flight Manual
- 3.3.24 *RFMS*—Rotorcraft Flight Manual Supplement
- 3.3.25 *SOF*—safety of flight
- 3.3.26 *SSPC*—solid-state power controller
- 3.3.27 *SWAMP*—severe wind and moisture problems
- 3.3.28 *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.

**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

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 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:

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

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

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

(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



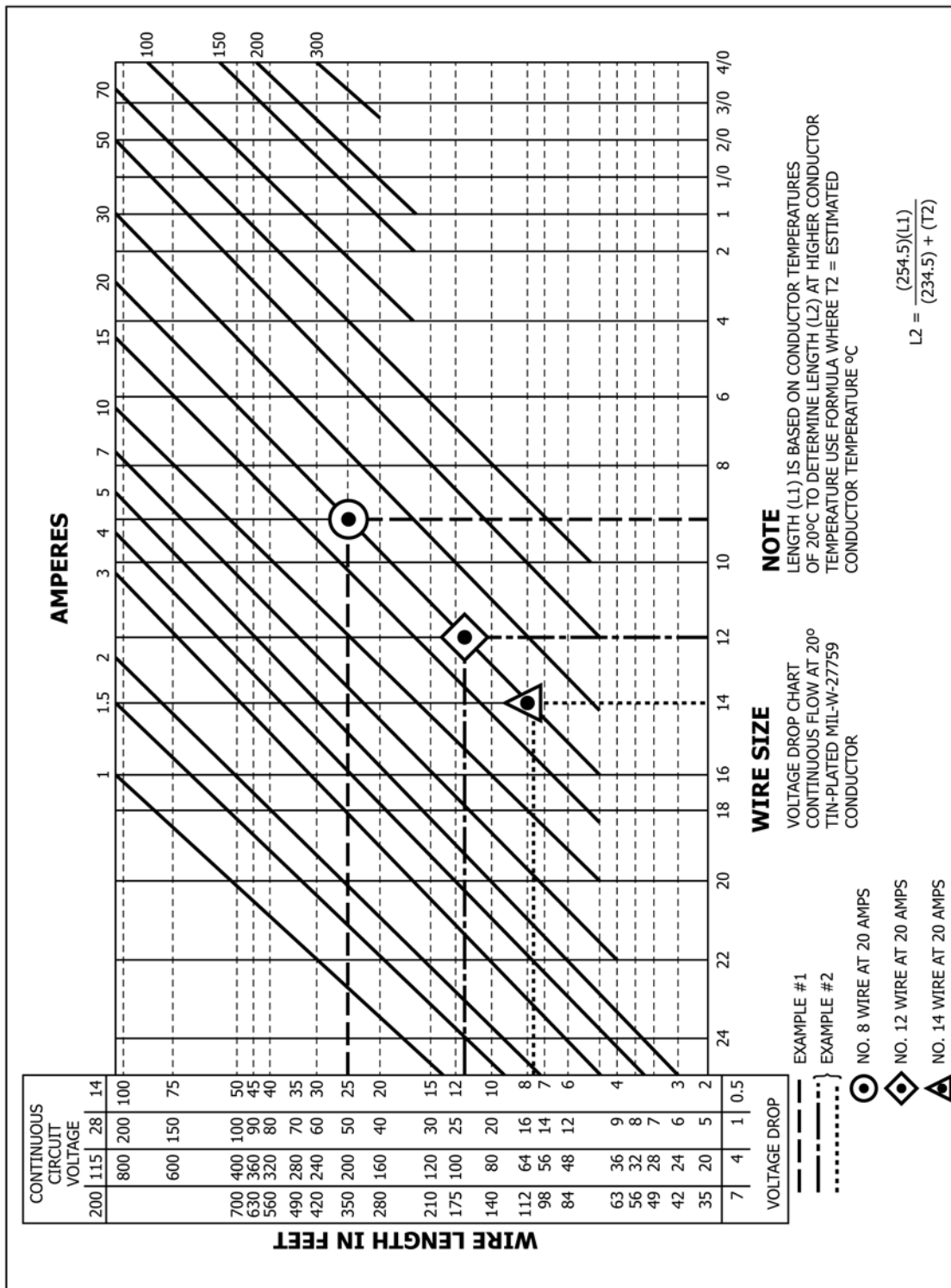


FIG. 1 Conductor Chart, Continuous Flow

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),

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,

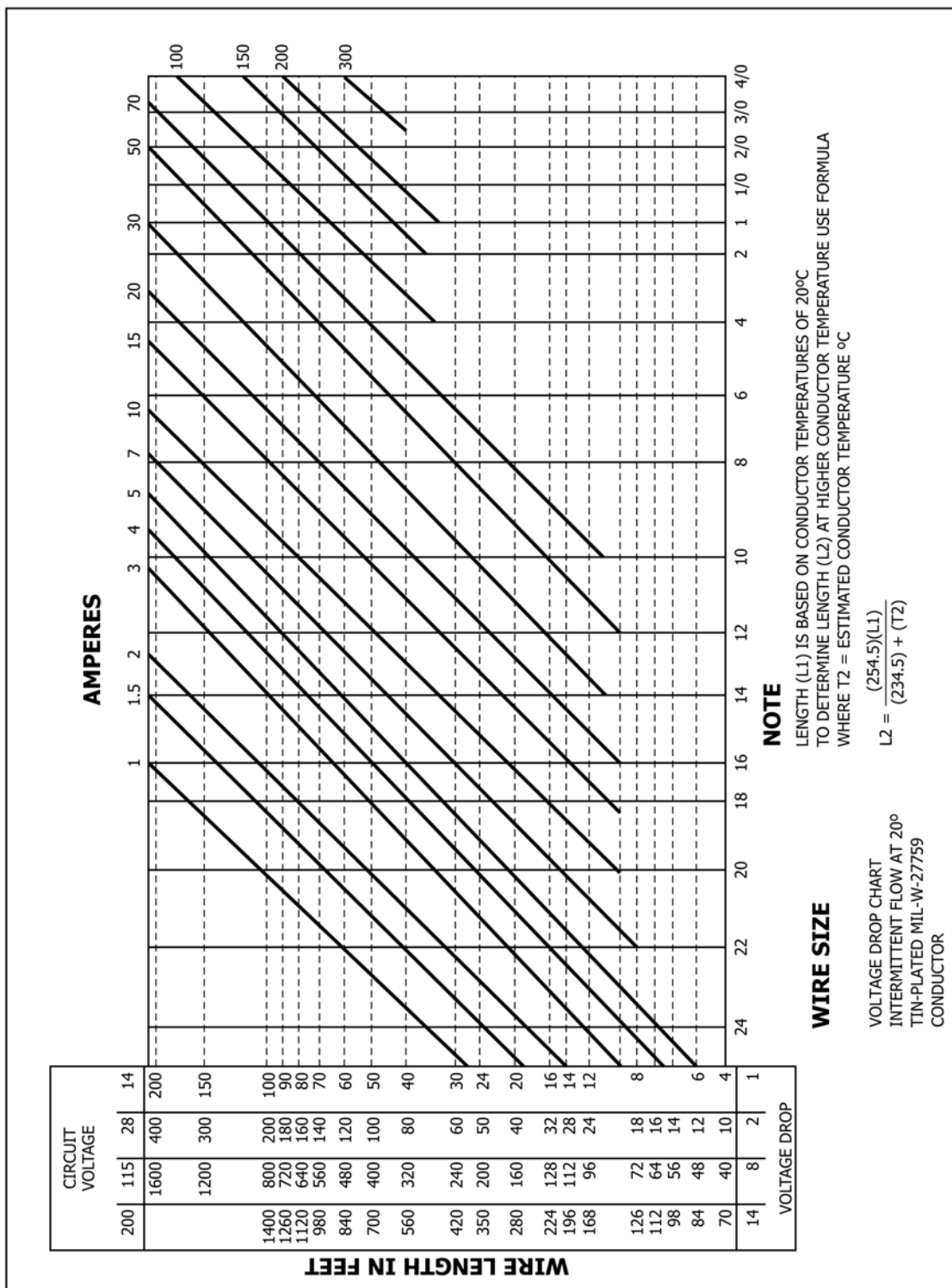


FIG. 2 Conductor Chart, Intermittent Flow

- 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
- 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: