

CHAPTER 11. AIRCRAFT ELECTRICAL SYSTEMS

SECTION 1. INSPECTION AND CARE OF ELECTRICAL SYSTEMS

11-1. GENERAL. The term “electrical system” as used in this AC means those parts of the aircraft that generate, distribute, and use electrical energy, including their support and attachments. The satisfactory performance of an aircraft is dependent upon the continued reliability of the electrical system. Damaged wiring or equipment in an aircraft, regardless of how minor it may appear to be, cannot be tolerated. Reliability of the system is proportional to the amount of maintenance received and the knowledge of those who perform such maintenance. It is, therefore, important that maintenance be accomplished using the best techniques and practices to minimize the possibility of failure. This chapter is not intended to supersede or replace any government specification or specific manufacturer’s instruction regarding electrical system inspection and repair.

11-2. INSPECTION AND OPERATION CHECKS. Inspect equipment, electrical assemblies, and wiring installations for damage, general condition, and proper functioning to ensure the continued satisfactory operation of the electrical system. Adjust, repair, overhaul, and test electrical equipment and systems in accordance with the recommendations and procedures in the aircraft and/or component manufacturer’s maintenance instructions. Replace components of the electrical system that are damaged or defective with identical parts, with aircraft manufacturer’s approved equipment, or its equivalent to the original in operating characteristics, mechanical strength, and environmental specifications. A list of suggested problems to look for and checks (Refer to the glossary for a description of the check types) to be performed are:

- a. **Damaged**, discolored, or overheated equipment, connections, wiring, and installations.
- b. **Excessive heat** or discoloration at high current carrying connections.
- c. **Misalignment** of electrically driven equipment.
- d. **Poor electrical bonding** (broken, disconnected or corroded bonding strap) and grounding, including evidence of corrosion.
- e. **Dirty equipment** and connections.
- f. **Improper, broken**, inadequately supported wiring and conduit, loose connections of terminals, and loose ferrules.
- g. **Poor mechanical** or cold solder joints.
- h. **Condition of circuit breaker** and fuses.
- i. **Insufficient clearance** between exposed current carrying parts and ground or poor insulation of exposed terminals.
- j. **Broken or missing safety wire**, broken bundle lacing, cotter pins, etc.
- k. **Operational check** of electrically operated equipment such as motors, inverters, generators, batteries, lights, protective devices, etc.
- l. **Ensure** that ventilation and cooling air passages are clear and unobstructed.

m. Voltage check of electrical system with portable precision voltmeter.

n. Condition of electric lamps.

o. Missing safety shields on exposed high-voltage terminals (i.e., 115/200V ac).

11-3. FUNCTIONAL CHECK OF STAND-BY OR EMERGENCY EQUIPMENT. An aircraft should have functional tests performed at regular intervals as prescribed by the manufacturer. The inspections or functional check periods should be clearly stated in the aircraft maintenance manual, along with the overhaul intervals.

11-4. CLEANING AND PRESERVATION. Annual cleaning of electrical equipment to remove dust, dirt, and grime is recommended. Suitable solvents or fine abrasives that will not score the surface or remove the plating may be used to clean the terminals and mating surfaces if they are corroded or dirty. Only cleaning agents that do not leave any type of residue must be used. Components must be cleaned and preserved in accordance with the aircraft handbooks or manufacturer's instructions. Avoid using emery cloth to polish commutators or slip rings because particles may cause shorting and burning. Be sure that protective finishes are not scored or damaged when cleaning. Ensure that metal-to-metal electrically bonded surfaces are treated at the interface with a suitable anti-corrosive conductive coating, and that the joint is sealed around the edges by restoring the original primer and paint finish. Connections that must withstand a highly corrosive environment may be encapsulated with an approved sealant in order to prevent corrosion.

CAUTION: Turn power off before cleaning.

11-5. BATTERY ELECTROLYTE CORROSION. Corrosion found on or near lead-acid batteries can be removed mechanically with a stiff bristle brush and then chemically neutralized with a 10 percent sodium bicarbonate and water solution. For Nickel Cadmium (NiCad) batteries, a 3 percent solution of acetic acid can be used to neutralize the electrolyte. After neutralizing, the battery should be washed with clean water and thoroughly dried.

11-6. ADJUSTMENT AND REPAIR. Accomplish adjustments to items of equipment such as regulators, alternators, generators, contactors, control devices, inverters, and relays at a location outside the aircraft, and on a test stand or test bench where all necessary instruments and test equipment are at hand. Follow the adjustment and repair procedures outlined by the equipment or aircraft manufacturer. Replacement or repair must be accomplished as a part of routine maintenance. Adjustment of a replacement voltage regulator is likely since there will always be a difference in impedance between the manufacturer's test equipment and the aircraft's electrical system.

11-7. INSULATION OF ELECTRICAL EQUIPMENT. In some cases, electrical equipment is connected into a heavy current circuit, perhaps as a control device or relay. 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. Stranded 18 or 20 AWG wire should be used as a grounding strap to avoid shock hazard to equipment and personnel. If the end connection is used for shock hazard, the ground wire must be large enough to carry the highest possible current (0.1 to 0.2 ohms max.).

11-8. BUS BARS. Annually check bus bars for general condition, cleanliness, and security of all attachments and terminals. Grease, corrosion, or dirt on any electrical junction may cause the connections to overheat and eventually fail. Bus bars that exhibit corrosion, even in limited amounts, should be disassembled, cleaned and brightened, and reinstalled.

11-9.—11-14. [RESERVED.]

SECTION 2. STORAGE BATTERIES

11-15. GENERAL. Aircraft batteries may be used for many functions, e.g., 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 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.

a. Storage batteries are usually identified by the material used for the plates. All battery types possess different characteristics and, therefore, must 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 Ni-Cad and vice-versa.

11-16. BATTERY CHARGING. 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 volts. In the case of NiCad batteries, the charging voltage limit varies with design and construction. Values of

1.4 and 1.5 volts per cell are generally used. In all cases, follow the recommendations of the battery manufacturer.

11-17. BATTERY FREEZING. Discharged lead-acid batteries exposed to cold temperatures are subject to plate damage due to freezing of the electrolyte. To prevent freezing damage, maintain each cell's specific gravity at 1.275, or for sealed lead-acid batteries check "open" circuit voltage. (See table 11-1.) Ni-Cad battery electrolyte is not as susceptible to freezing because no appreciable chemical change takes place between the charged and discharged states. However, the electrolyte will freeze at approximately minus 75 °F.

NOTE: Only a load check will determine overall battery condition.

TABLE 11-1. Lead-acid battery electrolyte freezing points.

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			

11-18. TEMPERATURE CORRECTION. U.S. manufactured lead-acid batteries are considered fully charged when the specific gravity reading is between 1.275 and 1.300. A 1/3 discharged battery reads about 1.240 and a 2/3 discharged battery will show a specific gravity reading of about 1.200, when tested by a hydrometer and the electrolyte temperature is 80 °F. However, to determine precise specific gravity readings, a temperature correction (see table 11-2) should be applied to the

hydrometer indication. As an example, a hydrometer reading of 1.260 and the temperature of the electrolyte at 40 °F, the corrected specific gravity reading of the electrolyte is 1.244.

TABLE 11-2. Sulfuric acid temperature correction.

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

11-19. BATTERY MAINTENANCE.

Battery inspection and maintenance procedures vary with the type of chemical technology and the type of physical construction. Always follow the battery manufacturer's approved procedures. Battery performance at any time in a given application will depend upon the battery's age, state of health, state of charge, and mechanical integrity.

a. Age. To determine the life and age of the battery, record the install date of the battery on the battery. During normal battery maintenance, battery age must be documented either in the aircraft maintenance log or in the shop maintenance log.

b. State of Health. Lead-acid battery state of health may be determined by duration of service interval (in the case of vented batteries), by environmental factors (such as excessive heat or cold), and by observed electrolyte leakage (as evidenced by corrosion of

wiring and connectors or accumulation of powdered salts). If the battery needs to be re-filled often, with no evidence of external leakage, this may indicate a poor state of the battery, the battery charging system, or an over charge condition.

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

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

c. State of Charge. Battery state of charge will be determined by the cumulative effect of charging and discharging the battery. In a normal electrical charging system the battery's generator or alternator restores a battery to full charge during a flight of one hour to ninety minutes.

d. Mechanical Integrity. Proper mechanical integrity involves the absence of any physical damage as well as assurance that hardware is correctly installed and the battery is properly connected. Battery and battery compartment venting system tubes, nipples and attachments, when required, provide a means of avoiding the potential buildup of explosive gases, and should be checked periodically to ensure that they are securely connected and oriented in accordance with the maintenance manual's installation procedures. Always follow procedures approved for the specific aircraft and battery system to ensure that the battery system is capable of delivering specified performance.

e. Battery and Charger Characteristics. The following information is provided to acquaint the user with characteristics of the more common aircraft battery and battery charger types. Products may vary from these descriptions due to different applications of available technology. Consult the manufacturer for specific performance data.

NOTE: Under no circumstances connect a lead-acid battery to a charger, unless properly serviced.

(1) Lead-acid vented batteries have a two volt nominal cell voltage. Batteries are constructed so that individual cells cannot be removed. Occasional addition of water is required to replace water loss due to overcharging in normal service. Batteries that become fully discharged may not accept recharge.

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

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

(4) Do not use high amperage automotive battery chargers to charge aircraft batteries.

(5) NiCad vented batteries have a 1.2 volt nominal cell voltage. Occasional addition of distilled water is required to replace water loss due to overcharging in normal service. Cause of failure is usually shorting or

weakening of a cell. After replacing the bad cell with a good cell, the battery's life can be extended for five or more years. Full discharge is not harmful to this type of battery.

(6) 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 zero volts) may cause irreversible damage to one or more cells, leading to eventual battery failure due to low capacity.

(7) The state of charge of a NiCad battery cannot be determined by measuring the specific gravity of the potassium hydroxide electrolyte. The electrolyte specific gravity does not change with the state of charge. The only accurate way to determine the state of charge of a NiCad battery is by a measured discharge with a NiCad battery charger and following the manufacturer's instructions. After the battery has been fully charged and allowed to stand for at least two 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.

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

(9) Constant-current battery chargers are usually provided for NiCad batteries because the NiCad cell voltage has a negative temperature coefficient. With a constant-voltage charging source, a NiCad battery

having a shorted cell might overheat due to excessive overcharge and undergo a thermal runaway, destroying the battery and creating a possible safety hazard to the aircraft.

DEFINITION: Thermal runaway can result in a chemical fire and/or explosion of the NiCad battery under recharge by a constant-voltage source, and is due to cyclical, ever-increasing temperature and charging current. One or more shorted cells or an existing high temperature and low charge can produce the cyclical sequence of events: (1) excessive current, (2) increased temperature, (3) decreased cell(s) resistance, (4) further increased current, and (5) further increased temperature. This will not become a self-sustaining thermal-chemical action if the constant-voltage charging source is removed before the battery temperature is in excess of 160 °F.

(10) Pulsed-current battery chargers are sometimes provided for NiCad batteries.

CAUTION: It is important to use the proper charging procedures for batteries under test and maintenance. These charging regimes for reconditioning and charging cycles are defined by the aircraft manufacturer and should be closely followed.

f. Shop-Level Maintenance Procedures. Shop procedures must follow the manufacturer's recommendations. Careful examination of sealed batteries and proper reconditioning of vented batteries will ensure the longest possible service life.

g. Aircraft Battery Inspection.

(1) Inspect battery sump jar and lines for condition and security.

(2) Inspect battery terminals and quick-disconnect plugs and pins for evidence of corrosion, pitting, arcing, and burns. Clean as required.

(3) Inspect battery drain and vent lines for restriction, deterioration, and security.

(4) Routine pre-flight and post-flight inspection procedures should include observation for evidence of physical damage, loose connections, and electrolyte loss.

11-20. ELECTROLYTE SPILLAGE.

Spillage or leakage of electrolyte may result in serious corrosion of the nearby structure or control elements as both sulfuric acid and potassium hydroxide are actively corrosive. Electrolyte may be spilled during ground servicing, leaked when cell case rupture occurs, or sprayed from cell vents due to excessive charging rates. If the battery is not case enclosed, properly treat structural parts near the battery that may be affected by acid fumes. Treat all case and drain surfaces, that have been affected by electrolyte, with a solution of sodium bicarbonate (for acid electrolyte) or boric acid, vinegar, or a 3 percent solution of acetic acid (for potassium hydroxide electrolyte).

CAUTION: Serious burns will result if the electrolyte comes in contact with any part of the body. Use rubber gloves, rubber apron, and protective goggles when handling electrolyte. If sulfuric acid is splashed on the body,

neutralize with a solution of baking soda and water, and shower or flush the affected area with water. For the eyes, use an eye fountain and flush with an abundance of water. If potassium hydroxide contacts the skin, neutralize with 9 percent acetic acid, vinegar, or lemon juice and wash with water. For the eyes, wash with a weak solution of boric acid or a weak solution of vinegar and flush with water.

11-21. NOXIOUS FUMES. When charging rates are excessive, the electrolyte may boil to the extent that fumes containing droplets of the electrolyte are emitted through the cell vents. These fumes from lead-acid batteries may become noxious to the crew members and passengers; therefore, thoroughly check the venting system. NiCad batteries will emit gas near the end of the charging process and during overcharge. The battery vent system in the aircraft should have sufficient air flow to prevent this explosive mixture from accumulating. It is often advantageous to install a jar in the battery vent discharge system serviced with an agent to neutralize the corrosive effect of battery vapors.

11-22. INSTALLATION PRACTICES.

a. External Surface. Clean the external surface of the battery prior to installation in the aircraft.

b. Replacing Lead-Acid Batteries. When replacing lead-acid batteries with NiCad batteries, a battery temperature or current monitoring system must be installed. Neutralize the battery box or compartment and thoroughly flush with water and dry. A flight manual supplement must 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.

c. Battery Venting. Battery fumes and gases may cause an explosive mixture or contaminated compartments and should 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 should always be positive, and remain between recommended minimum and maximum values. Line runs should not permit battery overflow fluids or condensation to be trapped and prevent free airflow.

d. Battery Sump Jars. A battery sump jar installation may be incorporated in the venting system to dispose of battery electrolyte overflow. The sump jar should be of adequate design and the proper neutralizing agent used. The sump jar must be located only on the discharge side of the battery venting system. (See figure 11-1.)

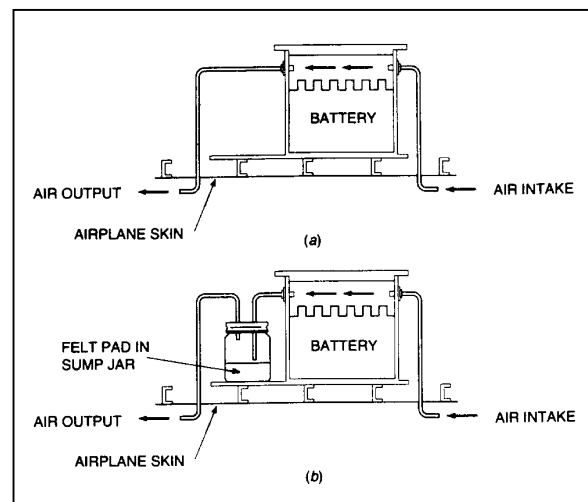


FIGURE 11-1. Battery ventilating systems.

e. Installing Batteries. When installing batteries in an aircraft, exercise care to prevent inadvertent shorting of the battery terminals. Serious damage to the aircraft structure (frame, skin and other subsystems, avionics, wire, fuel etc.) 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.

f. 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.

g. Quick-Disconnect Type Battery. If a quick-disconnect type of battery connector, that prohibits crossing the battery lead is not employed, 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.

11-23.—11-29. [RESERVED.]

SECTION 3. INSPECTION OF EQUIPMENT INSTALLATION

11-30. GENERAL. When installing equipment which consumes electrical power in an aircraft, it should be determined that the total electrical load can be safely controlled or managed within the rated limits of the affected components of the aircraft's electrical power supply system. Addition of most electrical utilization equipment is a major alteration and requires appropriate FAA approval. The electrical load analysis must be prepared in general accordance with good engineering practices. Additionally, an addendum to the flight manual is generally required.

11-31. INSTALLATION CLEARANCE PROVISIONS. All electrical equipment should be installed so that inspection and maintenance may be performed and that the installation does not interfere with other systems, such as engine or flight controls.

11-32. WIRES, WIRE BUNDLES, AND CIRCUIT PROTECTIVE DEVICES. Before any aircraft electrical load is increased, the new total electrical load (previous maximum load plus added load) must be checked to determine if the design levels are being exceeded. Where necessary, wires, wire bundles, and circuit protective devices having the correct ratings should be added or replaced.

11-33. ALTERNATOR DIODES. Alternators employ diodes for the purpose of converting the alternating current to direct current. These diodes are solid-state electronic devices and are easily damaged by rough handling, abuse, over heating, or reversing the battery connections. A voltage surge in the line, if it exceeds the design value, may destroy the di-

ode. The best protection against diode destruction by voltage surges is to make certain that the battery is never disconnected from the aircraft's electrical system when the alternator is in operation. The battery acts as a large capacitor and tends to damp out voltage surges. The battery must never be connected with reversed polarity as this may subject the diodes to a forward bias condition, allowing very high current conduction that will generally destroy them instantly.

11-34. STATIC ELECTRICAL POWER CONVERTERS. Static power converters employ 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.

a. Location of static converters should be carefully chosen to ensure adequate ventilation for cooling purposes. Heat-radiating fins should be kept clean of dirt and other foreign matter that may impair their cooling properties.

b. 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.

CAUTION: Do not load converters beyond their rated capacity.

11-35. ACCEPTABLE MEANS OF CONTROLLING OR MONITORING THE ELECTRICAL LOAD.

a. Output Rating. The generator or alternator output ratings and limits prescribed by the manufacturer must be checked against the electrical loads that can be imposed on the affected generator or alternator by installed equipment. When electrical load calculations show that the total continuous electrical load can exceed 80 percent output load limits of the generator or alternator, and where special placards or monitoring devices are not installed, the electrical load must be reduced or the generating capacity of the charging system must be increased. (This is strictly a “rule of thumb” method and should not be confused with an electrical load analysis, which is a complete and accurate analysis, which is a complete and accurate of the composite aircraft power sources and all electrical loads) When a storage battery is part of the electrical power system, the battery will be continuously charged in flight.

b. The use of placards is recommended to inform the pilot and/or crew members of the combination(s) of loads that may be connected to each power source. Warning lights can be installed that will be triggered if the battery bus voltage drops below 13 volts on a 14-volt system or 26 volts on a 28-volt system.

c. For installations where 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. As long as the ammeter never reads “discharge” (except for short intermittent loads such as operating the gear and flaps) and the voltmeter remains at “system voltage,” the generator or alternator will not be overloaded.

d. In installations where 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 percent of the generator or alternator rating. If the ammeter reading is never allowed to exceed the red line, except for short intermittent loads, the generator or alternator will not be overloaded.

e. Where the use of placards or monitoring devices is not practical or desired, and where assurance is needed that the battery will be charged in flight, the total continuous connected electrical load should be held to approximately 80 percent 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.

f. 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 should 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 should 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.

11-36. ELECTRICAL LOAD DETERMINATION. The connected load of an aircraft’s electrical system may be determined by any one or a combination of several acceptable methods, techniques, or practices. However, those with a need to know the status of a particular aircraft’s electrical system should have accurate and up-to-date data concerning the capacity of the installed electrical power source(s) and the load(s) imposed by installed electrical power-consuming devices. Such

data should provide a true picture of the status of the electrical system. New or additional electrical devices should not be installed in an aircraft, nor the capacity changed of any power source, until the status of the electrical system in the aircraft has been determined accurately and found not to adversely affect the integrity of the electrical system.

11-37. JUNCTION BOX CONSTRUCTION. Replacement junction boxes should be fabricated using the same material as the original or 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 should be provided in the lowest portion of the box. Cases of electrical power equipment must be insulated from metallic structure to avoid ground fault related fires. (See paragraph 11-7.)

a. Internal Arrangement. The junction box arrangement should permit easy access to any installed items of equipment, terminals, and wires. Where marginal clearances are unavoidable, an insulating material should 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.

b. Installation. Junction boxes should 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.

c. Wiring. Junction box layouts should take into consideration the necessity for adequate wiring space and possible future additions. Electrical wire bundles should 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 should be protected against chafing by using grommets or other suitable means.

11-38.—11-46. [RESERVED.]

SECTION 4. INSPECTION OF CIRCUIT-PROTECTION DEVICES

11-47. GENERAL. All electrical wires must be provided with some means of circuit protection. Electrical wire should 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.

11-48. DETERMINATION OF CIRCUIT BREAKER RATINGS. Circuit protection devices must be sized to supply open circuit capability. A circuit breaker must 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. A circuit breaker must always open before any component downstream can overheat and generate smoke or fire. Wires must 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 section 5 for wire rating methods.

11-49. DC CIRCUIT PROTECTOR CHART. Table 11-3 may be used as a guide for the selection of circuit breaker and fuse rating to protect copper conductor wire. This chart 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.

TABLE 11-3. DC wire and circuit protector chart.

Wire AN gauge 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. ambient and altitudes up to 30,000 feet.
- (2) Wire bundles of 15 or more wires, with wires carrying no more than 20 percent of the total current carrying capacity of the bundle as given in Specification MIL-W-5088 (ASG).
- (3) Protectors in 75 to 85 °F. ambient.
- (4) Copper wire Specification MIL-W-5088.
- (5) Circuit breakers to Specification MIL-C-5809 or equivalent.
- (6) Fuses to Specification MIL-F-15160 or equivalent.

11-50. RESETTABLE CIRCUIT PROTECTION DEVICES.

a. All resettable type circuit breakers must 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.”

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

11-51. CIRCUIT BREAKER USAGE. Circuit breakers are designed as circuit protection for the wire (see paragraph 11-48 and 11-49), 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.

11-52. CIRCUIT BREAKER MAINTENANCE. Circuit breakers should be periodically cycled with no load to enhance contact performance by cleaning contaminants from the contact surfaces.

11-53. SWITCHES. In all circuits where a switch malfunction can be hazardous, a switch specifically designed for aircraft service should be used. These switches are of rugged construction and have sufficient contact capacity to break, make, and continuously carry the connected load current. The position of the switch should be checked with an electrical meter.

a. Electrical Switch Inspection. Special attention should be given to electrical circuit switches, especially the spring-loaded type, during the course of normal airworthiness inspection. An internal failure of the spring-loaded type may allow the switch to remain closed even though the toggle or button returns to the "off" position. During inspection, attention should also be given to the possibility that improper switch substitution may have been made.

(1) With the power off suspect aircraft electrical switches should be checked in the ON position for opens (high resistance) and in The OFF position for shorts (low resistance), with an ohmmeter.

(2) Any abnormal side to side movement of the switch should be an alert to imminent failure even if the switch tested was shown to be acceptable with an ohmmeter.

b. Electromechanical Switches.

Switches have electrical contacts and various types of switch actuators (i.e., toggle, plunger, push-button, knob, rocker).

(1) Contacts designed for high-level loads must not be subsequently used for low-level applications, unless testing has been performed to establish this capability.

(2) Switches are specifically selected based on the design for the aircraft service current ratings for lamp loads, inductive loads, and motor loads and must be replaced with identical make and model switches.

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

d. 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 should 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) Direct-current 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.

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

f. Derating Factors. Table 11-4 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.

TABLE 11-4. Switch derating factors.

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

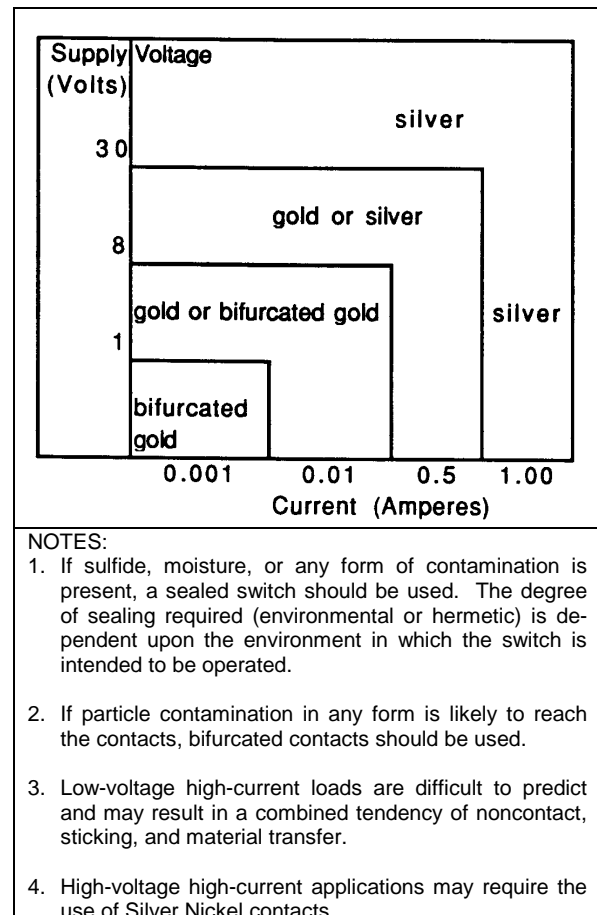
NOTES:

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.
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.

g. Low Energy Loads. Switches rated for use at 28 VDC or more, and at 1.0 amp or more, generally have silver contacts. In general, silver contacts should not be used to control devices which have either a voltage less than 8 volts or a continuous current less than 0.5 amps unless the switch is specifically rated for use with low-energy loads. Table 11-5 provides general guidelines for selecting contact materials for low-energy loads, but is not applicable to hermetically sealed switches.

(1) Typical logic load devices have a voltage of 0.5 volts to 28 volts and a continuous current of less than 0.5 amps. A suitable method of rating switches for use on logic load devices is specified in ANSI/EIA 5200000. (General specification for special use electro-mechanical switches of certified quality.)

TABLE 11-5. Selection of contact material.



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

h. Shock and Vibration.

(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 microseconds and that closing of open contacts in excess of 1 microsecond 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.

(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 should reflect the applicable environment. Note that the mounting of both the proximity sensor and its target must be rigid enough to withstand shock or vibration to avoid creating false responses.

i. Electromagnetic/Radio Frequency Interference (EMI/RFI).

(1) DC operated electromechanical switches are usually not susceptible to EMI/RFI. Proximity switches are susceptible to an EMI/RFI environment and must be evaluated in the application. Twisting lead wires, metal overbraids, lead wire routing, and the design of the proximity switch can minimize susceptibility.

(2) 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. 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.

b. Temperature.

(1) Electromechanical switches can withstand wide temperature ranges and rapid gradient shifts without damage. Most aircraft switches operate between -55 °C and 85 °C with designs available from -185 °C to 260 °C or more. Higher temperatures require more exotic materials, which can increase costs and limit life. It should be noted 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.

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

c. Sealing.

NOTE: The materials used for sealing (o-rings, potting materials, etc.) should be compatible with any aircraft fluids to which the switch may be exposed.

(1) 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.

(2) Proximity switches for aircraft applications typically have a metal face and potting material surrounding any electronics and lead wire exits. The potting material should 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 should be protected.

d. Switch Installation. Hazardous errors in switch operation may be avoided by logical and consistent installation. "On-off" two-position switches should 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 should move in the same direction as the desired motion. Inadvertent operation of switches can be prevented by mounting suitable guards over the switches.

11-48. RELAYS. A relay is an electrically controlled device that opens and closes electrical contacts to effect the operation of other devices in the same or in another electrical circuit. The relay converts electrical energy into mechanical energy through various means, and through mechanical linkages, actuates electrical conductors (contacts) that control electrical circuits. Solid-state relays may also be used in electrical switching applications.

a. Use of Relays. Most relays are used as a switching device where 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.

b. 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 should be followed to ensure proper operation of the relay.

c. Repair. Relays are complicated electromechanical assemblies and most are not repairable.

d. Relay Selection.

(1) 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. (Ref. MIL-PRF-39016, MIL-PRF-5757, MIL-PRF-6016, MIL-PRF-835836.)

(2) Operating a relay at less than nominal coil voltage may compromise its performance and should never be done without written manufacturer approval.

e. Relay Installation and Maintenance. For installation and maintenance, care should be taken to ensure proper placement of hardware, especially at electrical connections. The use of properly calibrated torque wrenches and following the manufacturer's installation procedures is strongly recommended. This is especially important with hermetically sealed relays, since the glass-to-metal seal (used for

insulation of the electrically “live” components) is especially vulnerable to catastrophic failure as a result of overtorquing.

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

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

11-49. LOAD CONSIDERATIONS.

When switches or relays are to be used in applications where current or voltage is substantially lower than rated conditions, additional intermediate testing should be performed to ensure reliable operation. Contact the manufacturer on applications different from the rated conditions.

11-50. OPERATING CONDITIONS FOR SWITCHES AND RELAYS.

Switches and relays should 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 or relay is to be installed.

11-57.—11-65. [RESERVED.]

SECTION 5. ELECTRICAL WIRE RATING

11-66. GENERAL. Wires must 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.

a. Mechanical Strength of Wires. If it is desirable to use wire sizes smaller than #20, particular attention should be given to the mechanical strength and installation handling of these wires, e.g., vibration, flexing, and termination. Wire containing less than 19 strands must not be used. Consideration should be given to the use of high-strength alloy conductors in small gauge wires to increase mechanical strength. As a general practice, wires smaller than size #20 should be provided with additional clamps and be grouped with at least three other wires. They should also have additional support at terminations, such as connector grommets, strain relief clamps, shrinkable sleeving, or telescoping bushings. They should not be used in applications where they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw termination.

b. Voltage Drop in Wires. The voltage drop in the main power wires from the generation source or the battery to the bus should not exceed 2 percent of the regulated voltage when the generator is carrying rated current or the battery is being discharged at the 5-minute rate. The tabulation shown in table 11-6 defines the maximum acceptable voltage drop in the load circuits between the bus and the utilization equipment ground.

c. 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

TABLE 11-6. 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

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 should be maintained at a constant value. Tables 11-7 and 11-8 show formulas that may be used to determine electrical resistance in wires and some typical examples.

d. Resistance Calculation Methods. Figures 11-2 and 11-3 provide a convenient means of calculating maximum wire length for the given circuit current.

(1) Values in tables 11-7 and 11-8 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. Figures 11-2 and 11-3 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.

TABLE 11-7. Examples of determining required tin-plated copper wire size and checking voltage drop using figure 11-2

Voltage drop	Run Lengths (Feet)	Circuit Current (Amps)	Wire Size From Chart	Check-calculated voltage drop (VD)= (Resistance/Ft) (Length) (Current)
1	107	20	No. 6	VD= (.00044 ohms/ft) (107)(20)= 0.942
0.5	90	20	No. 4	VD= (.00028 ohms/ft) (90)(20)= 0.504
4	88	20	No. 12	VD= (.00202 ohms/ft) (88)(20)= 3.60
7	100	20	No. 14	VD= (.00306 ohms/ft) (100)(20)= 6.12

TABLE 11-8. Examples of determining maximum tin-plated copper wire length and checking voltage drop using figure 11-2.

Maximum Voltage drop	Wire Size	Circuit Current (Amps)	Maximum Wire Run Length (Feet)	Check-calculated voltage drop (VD)= (Resistance/Ft) (Length) (Current)
1	No. 10	20	39	VD= (.00126 ohms/ft) (39)(20)= .98
0.5	----		19.5	VD= (.00126 ohms/ft) (19.5)(20)= .366
4	----		156	VD= (.00126 ohms/ft) (156)(20)= 3.93
7	----		273	VD= (.00126 ohms/ft) (273)(20)= 6.88

(2) As an alternative method or a means of checking results from figure 11-2, continuous flow resistance for a given wire size can be read from table 11-9 and multiplied by the wire run length and the circuit current. For intermittent flow, use figure 11-3.

(3) Voltage drop calculations for aluminum wires can be accomplished by multiplying the resistance for a given wire size, defined in table 11-10, by the wire run length and circuit current.

(4) When the estimated or measured conductor temperature (T₂) exceeds 20 °C, such as in areas having elevated ambient temperatures or in fully loaded power-feed wires, the maximum allowable run length (L₂), must be shortened from L₁ (the 20 °C value) using the following formula for copper conductor wire:

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

For aluminum conductor wire, the formula is:

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

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

(5) To determine T₂ 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 should be run at anticipated worse case ambient temperature and maximum current-loading combinations.

(6) Approximate T₂ can be estimated using the following formula:

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

Where:

- T_1 = Ambient Temperature
 T_2 = Estimated Conductor Temperature
 T_R = Conductor Temperature Rating
 I_2 = Circuit Current (A=Amps)
 I_{max} = Maximum Allowable Current
 (A=Amps) at T_R

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

Note: Aluminum wire-From Table 11-9 and 11-10 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 11-9 can be used when it is desired to substitute aluminum wire and the proper size can be selected by reducing the copper wire size by two numbers and referring to Table 11-10. The use of aluminum wire size smaller than No. 8 is not recommended.

TABLE 11-9. Current carrying capacity and resistance of copper wire.

Wire Size	Continuous duty current (amps)-Wires in bundles, groups, harnesses, or conduits. (See Note #1)			Max. resistance ohms/1000ft@20 °C tin plated conductor (See Note #2)	Nominal conductor area - circ.mils
	Wire Conductor Temperature Rating				
	105 °C	150 °C	200 °C		
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

Note #1: 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 percent of harness current carrying capacity being used, at an operating altitude of 60,000 feet. For rating of wires under other conditions or configurations see paragraph 11-69.

Note #2: For resistance of silver or nickel-plated conductors see wire specifications.

TABLE 11-10. Current carrying capacity and resistance of aluminum wire.

Wire Size	Continuous duty current (amps) Wires in bundles, groups or harnesses or conduits (See table 11-9 Note #1)		Max. resistance ohms/1000ft
Wire conductor temperature rating			@ 20 °C
	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
Note: Observe design practices described in paragraph 11-67 for aluminum conductor			

11-67. METHODS FOR DETERMINING CURRENT CARRYING CAPACITY OF WIRES. This paragraph 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. 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 gauge may need to be used to fit within the crimp range of connector contacts that are adequately rated for the current being carried. Figure 11-5 gives a family of curves whereby the bundle derating factor may be obtained.

a. 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 due either to high ambient temperatures, high-current loading, or a combination of the two, selection should be made on the basis of satisfactory performance under the most severe operating conditions.

b. Maximum Operating Temperature. The current that causes a temperature steady state condition equal to the rated temperature of the wire should 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.

c. 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 figures 11-4a and 11-4b.)

d. Wires in a Harness. When wires are bundled into harnesses, the current derived for a single wire must be reduced as shown in figure 11-5. 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.

e. Harness at Altitude. Since heat loss from the bundle is reduced with increased altitude, the amount of current should be derated. Figure 11-6 gives a curve whereby the altitude-derating factor may be obtained.

f. Aluminum Conductor Wire. When aluminum conductor wire is used, sizes should be selected on the basis of current ratings shown in table 11-10. The use of sizes smaller than #8 is discouraged (Ref. AS50881A). Aluminum wire should 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 feet (AS50991A). Termination hardware should be of the type specifically designed for use with aluminum conductor wiring.

11-68. INSTRUCTIONS FOR USE OF ELECTRICAL WIRE CHART.

a. Correct Size. To select the correct size of electrical wire, two major requirements must be met:

(1) The wire size should be sufficient to prevent an excessive voltage drop while carrying the required current over the required distance. (See table 11-6, Tabulation Chart, for allowable voltage drops.)

(2) The size should be sufficient to prevent overheating of the wire carrying the required current. (See paragraph 11-69 for allowable current carrying calculation methods.)

b. Two Requirements. To meet the two requirements (see paragraph 11-66b) in selecting the correct wire size using figure 11-2 or figure 11-3, 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 and/or bundle?
- (7) Is the wire to be installed as a single wire in free air?

c. Example No. 1. Find the wire size in figure 11-2 using the following known information:

- (1) The wire run is 50 feet long, including the ground wire.
- (2) Current load is 20 amps.
- (3) The voltage source is 28 volts from bus to equipment.

(4) The circuit has continuous operation.

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

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 (e.g., 14V, 28V, 115V, 200V). 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 gauge.

STEP 1: From the left scale find the wire length, 50 feet under the 28V source column.

STEP 2: Follow the corresponding horizontal line to the right until it intersects the slanted line for the 20-amp load.

STEP 3: At this point, drop vertically to the bottom of the chart. The value falls between No. 8 and No. 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, figure 11-2. Use figure 11-2 for continuous flow and figure 11-3 for intermittent flow.

d. Procedures in Example No. 1 paragraph 11-68c, can be used to find the wire size for any continuous or intermittent operation (maximum two minutes). Voltage (e.g. 14 volts, 28 volts, 115 volts, 200 volts) as indicated on the left scale of the wire chart in figure 11-2 and 11-3.

e. Example No. 2. Using figure 11-2, find the wire size required to meet the allowable voltage drop in table 11-6 for a wire carrying

current at an elevated conductor temperature using the following information:

(1) The wire run is 15.5 feet long, including the ground wire.

(2) Circuit current (I_2) is 20 amps, continuous.

(3) The voltage source is 28 volts.

(4) The wire type used has a 200 °C conductor rating and it is intended to use this thermal rating to minimize the wire gauge. Assume that the method described in paragraph 11-66d(6) was used and the minimum wire size to carry the required current is #14.

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

f. Procedures in example No. 2.

STEP 1: Assuming that the recommended load bank testing described in paragraph 11-66d(5) is unable to be conducted, then the estimated calculation methods outlined in paragraph 11-66d(6) may be used to determine the estimated maximum current (I_{max}). The #14 gauge wire mentioned above can carry the required current at 50 °C ambient (allowing for altitude and bundle derating).

(1) Use figure 11-4a to calculate the I_{max} a #14 gauge wire can carry.

Where:

T_2 = estimated conductor temperature

T_1 = 50 °C ambient temperature

T_R = 200 °C maximum conductor rated temperature

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

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

(4) Use figure 11-5, left side of chart reads 0.91 for 20,000 feet, multiple $0.91 \times 47 \text{ Amps} = 42.77 \text{ Amps}$.

(5) Use figure 11-6, find the derate factor for 8 wires in a bundle at 60 percent. First find the number of wires in the bundle (8) at bottom of graph and intersect with the 60 percent curve meet. Read derating factor, (left side of graph) which is 0.6. Multiply $0.6 \times 42.77 \text{ Amps} = 26 \text{ Amps}$.

$I_{max} = 26 \text{ amps}$ (this is the maximum current the #14 gauge wire could carry at 50 °C ambient)

$L_1 = 15.5$ feet maximum run length for size #14 wire carrying 20 amps from figure 11-2

STEP 2: From paragraph 11-66d (5) and (6), determine the T_2 and the resultant maximum wire length when the increased resistance of the higher temperature conductor is taken into account.

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

$$T_2 = 50^\circ\text{C} + (200^\circ\text{C} - 50^\circ\text{C}) (\sqrt{20\text{A} / 26\text{A}})$$

$$= 50^\circ\text{C} + (150^\circ\text{C}) (.877)$$

$$T_2 = 182^\circ\text{C}$$

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

$$L_2 = \frac{(254.5^\circ\text{C})(15.5\text{ft})}{(234.5^\circ\text{C}) + (182^\circ\text{C})}$$

$$L_2 = 9.5 \text{ ft}$$

The size #14 wire selected using the methods outlined in paragraph 11-66d is too small to meet the voltage drop limits from figure 11-2 for a 15.5 feet long wire run.

STEP 3: Select the next larger wire (size #12) and repeat the calculations as follows:

$L_1 = 24$ feet maximum run length for 12 gauge wire carrying 20 amps from figure 11-2.

$I_{\max} = 37$ amps (this is the maximum current the size #12 wire can carry at 50 °C ambient. Use calculation methods outlined in paragraph 11-69 and figure 11-4a.

$$T_2 = 50\text{ °C} + (200\text{ °C} - 50\text{ °C}) \left(\sqrt{20A/37A} \right) = 50\text{ °C} + (150\text{ °C})(.540) = 131\text{ °C}$$

$$L_2 = \frac{254.5\text{ °C}(L_1)}{234.5\text{ °C} + (T_2)}$$

$$L_2 = \frac{(254.5\text{ °C})(24\text{ft})}{(234.5\text{ °C}) + (131\text{ °C})} = \frac{6108}{366}$$

$$L_2 = \frac{(254.5\text{ °C})(24\text{ft})}{366} = 16.7\text{ ft}$$

The resultant maximum wire length, after adjusting downward for the added resistance associated with running the wire at a higher temperature, is 15.4 feet, which will meet the original 15.5 foot wire run length requirement without exceeding the voltage drop limit expressed in figure 11-2.

11-69. COMPUTING CURRENT CARRYING CAPACITY.

a. 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 where the ambient temperature is 60 °C and the vehicle is capable of operating at a 60,000-foot altitude. Circuit analysis reveals that 7 of the 35 wires in the bundle

(7/35 = 20 percent) will be carrying power currents nearly at or up to capacity.

STEP 1: Refer to the “single wire in free air” curves in figure 11-4a. Determine the change of temperature of the wire to determine free air ratings. Since the wire will be in an ambient of 60 °C and rated at 200 °C, the change of temperature is 200 °C - 60 °C = 140 °C. Follow the 140 °C temperature difference horizontally until it intersects with wire size line on figure 11-4a. The free air rating for size #20 is 21.5 amps, and the free air rating for size #22 is 16.2 amps.

STEP 2: Refer to the “bundle derating curves” in figure 11-5, the 20 percent curve is selected since circuit analysis indicate that 20 percent or less of the wire in the harness would be carrying power currents and less than 20 percent 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 percent curve.

STEP 3: Derate the size #22 free air rating by multiplying 16.2 by 0.52 to get 8.4 amps in-harness rating. Derate the size #20 free air rating by multiplying 21.5 by 0.52 to get 11.2 amps in-harness rating.

STEP 4: Refer to the “altitude derating curve” of figure 11-6, look for 60,000 feet (on the abscissa) since that is the altitude at which the vehicle will be operating. Note that the wire must be derated by a factor of 0.79 (found on the ordinate). Derate the size #22 harness rating by multiplying 8.4 amps by 0.79 to get 6.6 amps. Derate the size #20 harness rating by multiplying 11.2 amps by 0.79 to get 8.8 amps.

STEP 5: To find the total harness capacity, multiply the total number of size #22 wires by the derated capacity (25 x 6.6 = 165.0 amps) and add to that the number of size #20 wires

multiplied by the derated capacity ($10 \times 8.8 = 88$ amps) and multiply the sum by the 20 percent harness capacity factor. Thus, the total harness capacity is $(165.0 + 88.0) \times 0.20 = 50.6$ amps. It has been determined that the total harness current should not exceed 50.6 A, size #22 wire should not carry more than 6.6 amps and size #20 wire should not carry more than 8.8 amps.

STEP 6: Determine the actual circuit current for each wire in the bundle and for the whole bundle. If the values calculated in step #5 are exceeded, select the next larger size wire and repeat the calculations.

b. Example 2. Assume a harness (open or braided), consisting of 12, 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-foot altitude. All 12 wires will be operated at or near their maximum capacity.

STEP 1: Refer to the “single wire in free air” curve in figure 11-4a, determine the temperature difference of the wire to determine free air ratings. Since the wire will be in ambient of 25 °C and 60 °C and is rated at 200 °C, the temperature differences are $200\text{ °C} - 25\text{ °C} = 175\text{ °C}$ and $200\text{ °C} - 60\text{ °C} = 140\text{ °C}$ respectively. Follow the 175 °C and the 140 °C temperature difference lines on figure 11-4a until each intersects wire size line, the free air ratings of size #12 are 68 amps and 61 amps, respectively.

STEP 2: Refer to the “bundling derating curves” in figure 11-5, the 100 percent curve is

selected because we know all 12 wires will be carrying full load. Find 12 (on the abscissa) since there are 12 wires in the bundle and determine a derating factor of 0.43 (on the ordinate) from the 100 percent curve.

STEP 3: Derate the size #12 free air ratings by multiplying 68 amps and 61 amps by 0.43 to get 29.2 amps and 26.2 amps, respectively.

STEP 4: Refer to the “altitude derating curve” of figure 11-6, look for sea level and 20,000 feet (on the abscissa) since these are the conditions at which the load will be carried. The wire must 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 amps at sea level and 26.6 amps at 20,000 feet by 1.0 and 0.91, respectively, to obtain 29.2 amps and 23.8 amps. The total bundle capacity at sea level and 25 °C ambient is $29.2 \times 12 = 350.4$ amps. At 20,000 feet and 60 °C ambient the bundle capacity is $23.8 \times 12 = 285.6$ amps. Each size #12 wire can carry 29.2 amps at sea level, 25 °C ambient or 23.8 amps at 20,000 feet, 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.

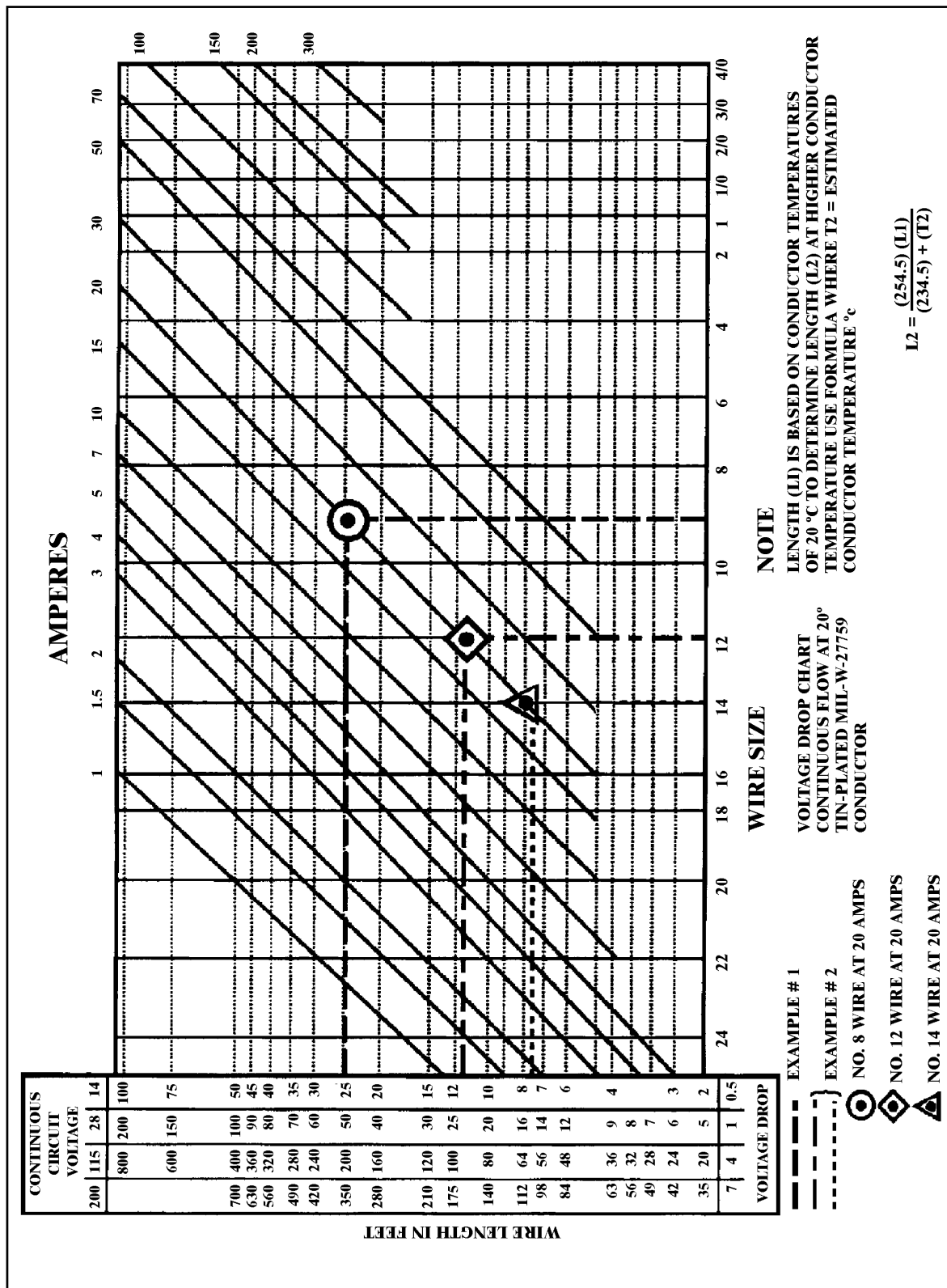


FIGURE 11-2. Conductor chart, continuous flow.

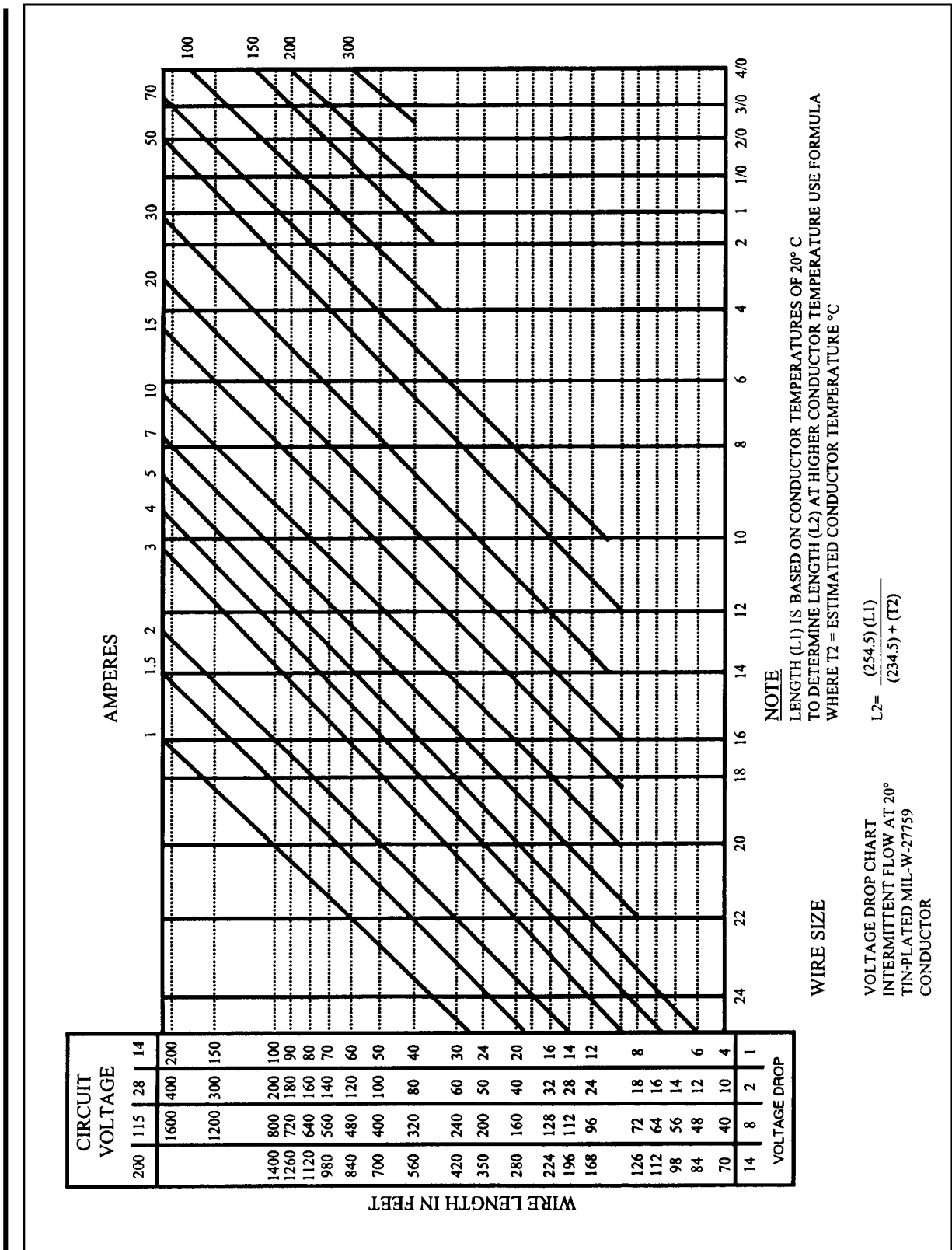


FIGURE 11-3. Conductor chart, intermittent flow.

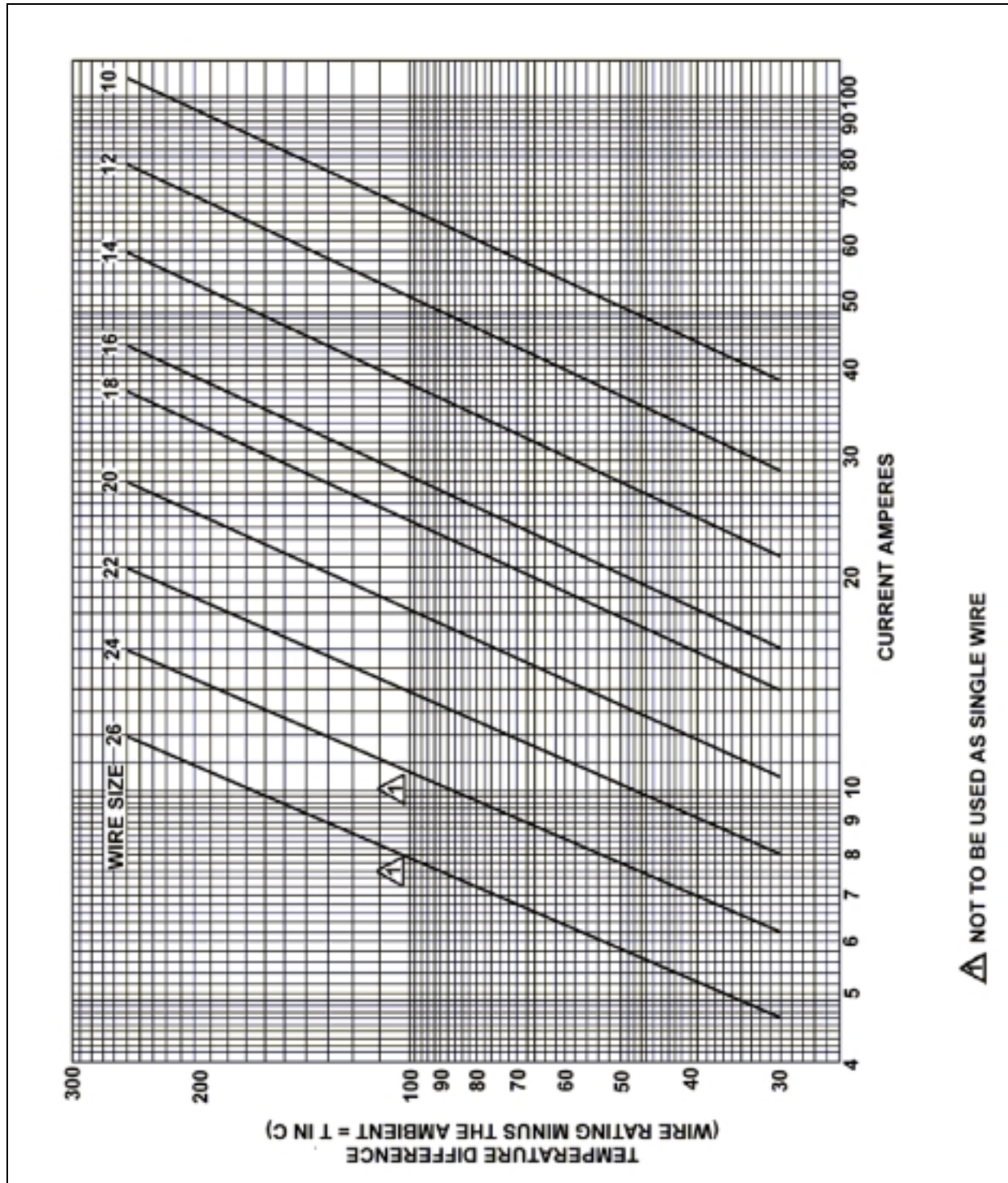


FIGURE 11-4a. Single copper wire in free air.

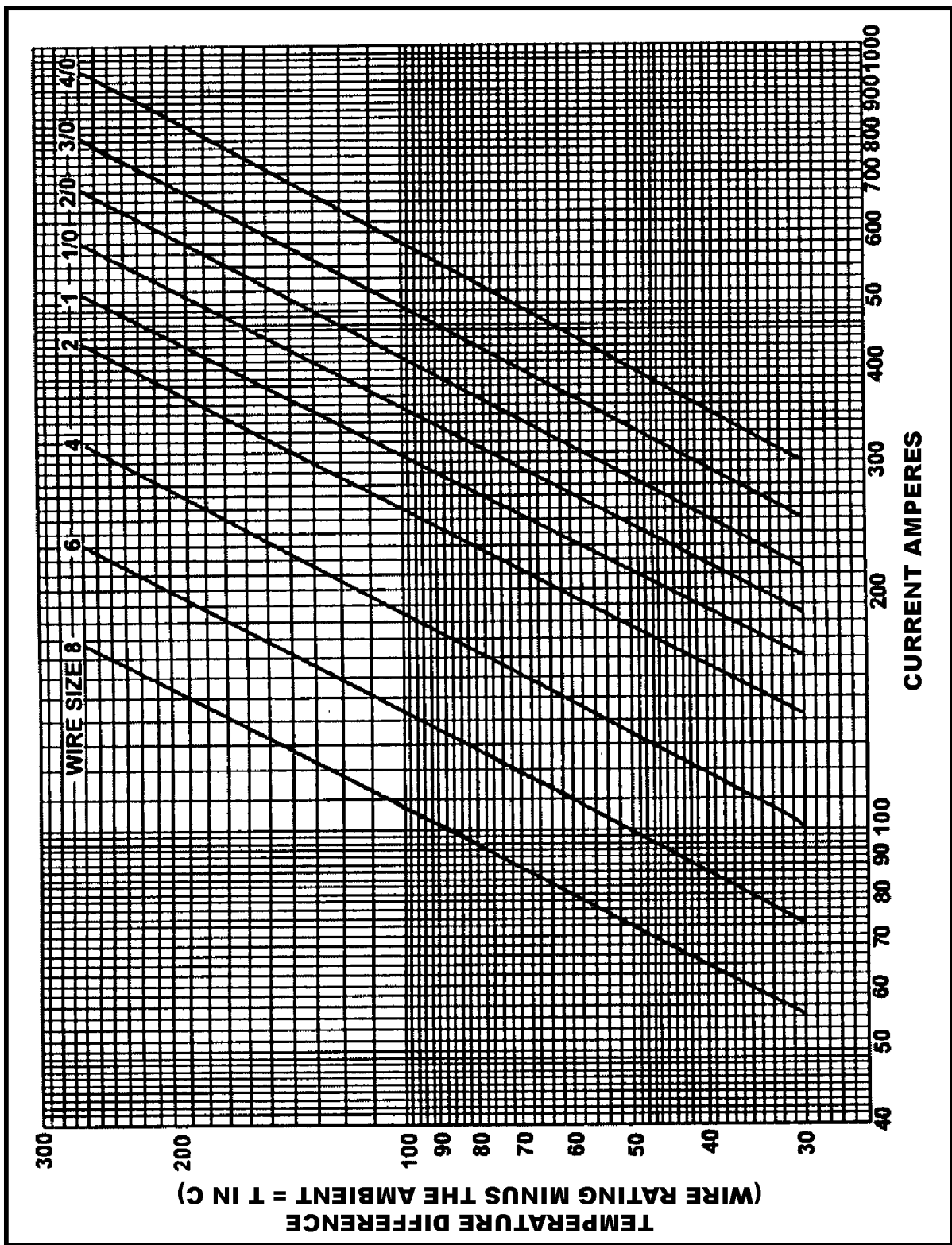


FIGURE 11-4b. Single copper wire in free air.

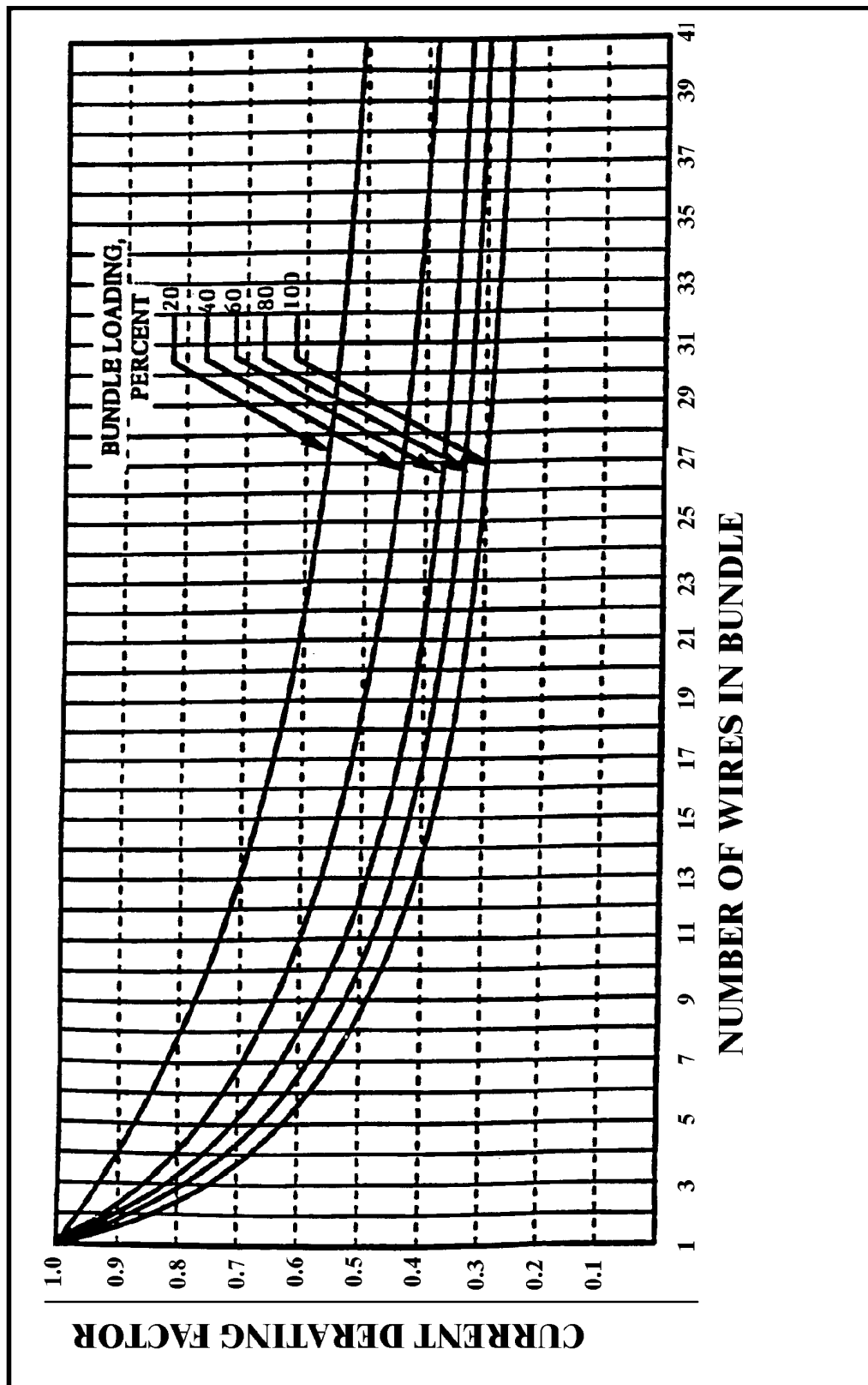


FIGURE 11-5. Bundle derating curves.

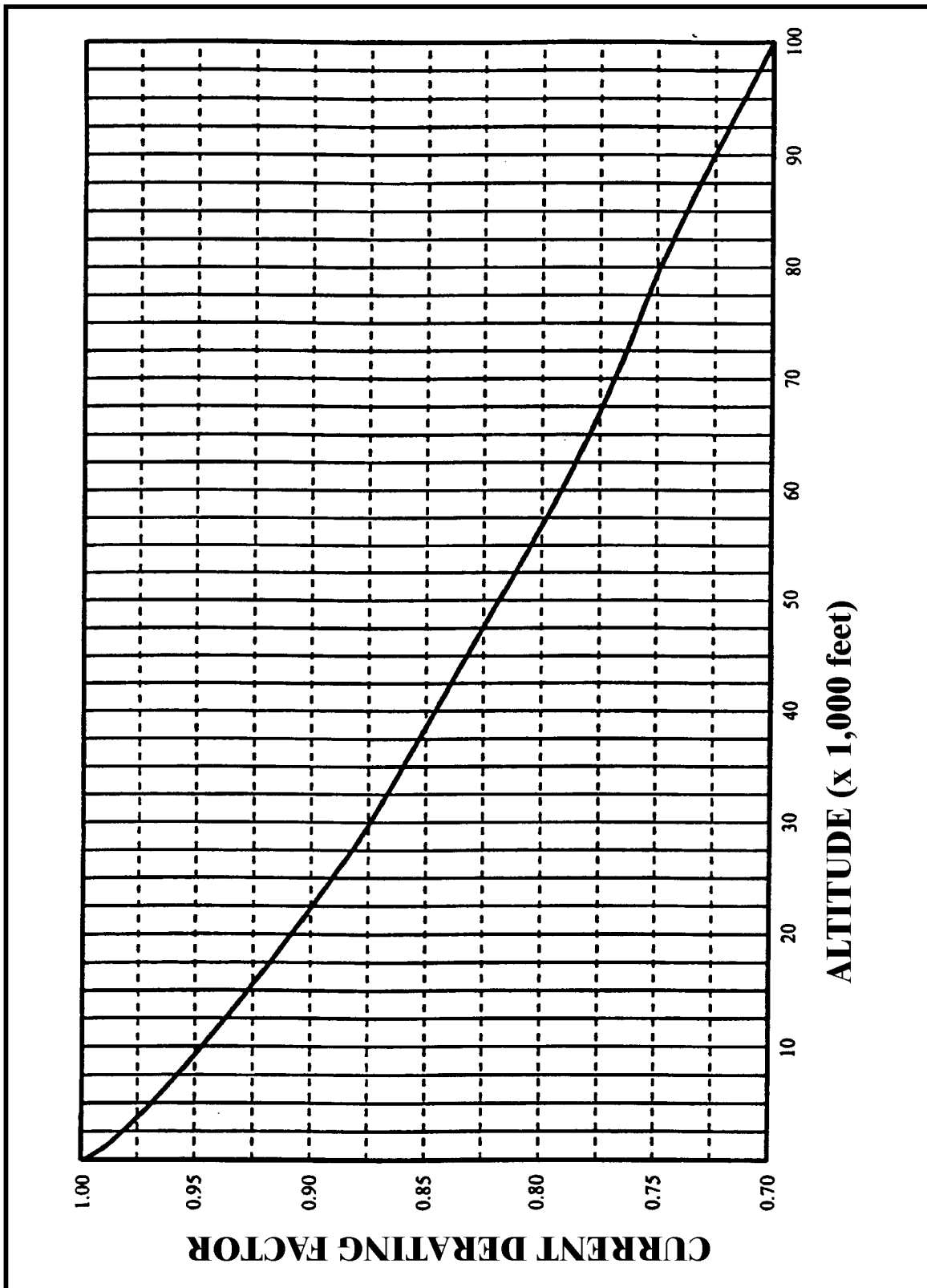


FIGURE 11-6. Altitude derating curve.

11-70. – 11-75. [RESERVED.]

SECTION 6. AIRCRAFT ELECTRICAL WIRE SELECTION

11-76. GENERAL. Aircraft service imposes severe environmental condition on electrical wire. To ensure satisfactory service, inspect wire annually for abrasions, defective insulation, condition of terminations, and potential corrosion. Grounding connections for power, distribution equipment, and electromagnetic shielding must be given particular attention to ensure that electrical bonding resistance has not been significantly increased by the loosening of connections or corrosion.

a. Wire Size. Wires must have sufficient mechanical strength to allow for service conditions. Do not exceed allowable voltage drop levels. 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 should be given to the mechanical strength and installation handling of these wires, e.g. vibration, flexing, and termination. When used in interconnecting airframe application, #24 gauge wire must be made of high strength alloy.

b. 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 should not be used in applications where they will be subjected to excessive vibration, repeated bending, or frequent disconnection from screw terminations.

c. Identification. All wire used on aircraft must have its type identification imprinted along its length. It is common practice to follow this part number with the five digit/letter Commercial and Government Entity (C.A.G.E). code identifying the wire

manufacturer. Existing installed wire that needs replacement can thereby be identified as to its performance capabilities, and the inadvertent use of a lower performance and unsuitable replacement wire avoided.

(1) In addition to the type identification imprinted by the original wire manufacturer, aircraft wire also contains its unique circuit identification coding that is put on at the time of harness assembly. The traditional "Hot Stamp" method has not been totally satisfactory in recent years when used on modern, ultra-thin-walled installations. Fracture of the insulation wall and penetration to the conductor of these materials by the stamping dies have occurred. Later in service, when these openings have been wetted by various fluids, serious arcing and surface tracking have damaged wire bundles.

(2) Extreme care must be taken during circuit identification by a hot stamp machine on wire with a 10 mil wall or thinner. Alternative identification methods, such as "Laser Printing" and "Ink Jet," are coming into increasing use by the industry. When such modern equipment is not available, the use of stamped identification sleeving should be considered on thin-walled wire, especially when insulation wall thickness falls below 10 mils.

11-77. AIRCRAFT WIRE MATERIALS. Only wire, specifically designed for airborne use, must be installed in aircraft.

a. Authentic Aircraft Wire. Most aircraft wire designs are to specifications that require manufacturers to pass rigorous testing of wires before being added to a Qualified Products List (QPL) and being permitted to produce the wire. Aircraft manufacturers who maintain their own wire specifications invariably exercise close control on their approved

sources. Such military or original equipment manufacturer (OEM) wire used on aircraft should only have originated from these defined wire mills. Aircraft wire from other unauthorized firms, and fraudulently marked with the specified identification, must be regarded as “unapproved wire,” and usually will be of inferior quality with little or no process control testing. Efforts must be taken to ensure obtaining authentic, fully tested aircraft wire.

b. 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, that have far slower oxidation rates.

(1) 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.

(2) Silver-coated wire is used where temperatures do not exceed 200 °C (392 °F).

(3) 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.

c. Conductor Stranding. Because of flight vibration and flexing, conductor round wire should be stranded to minimize fatigue breakage.

d. Wire Construction Versus Application. The most important consideration in the selection of aircraft wire is properly matching the wire’s construction to the application envi-

ronment. Wire construction that is suitable for the most severe environmental condition to be encountered should be selected. Wires are typically categorized as being suitable for either “open wiring” or “protected wiring” applications. MIL-W-5088L, replaced by AS50881A, wiring aerospace vehicle, Appendix A table A-I lists wires considered to have sufficient abrasion and cut-through resistance to be suitable for open-harness construction. MIL-W-5088L, replaced by AS50881A, wiring aerospace vehicle, Appendix A table A-II 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 ability to withstand the combination of ambient temperature and current related conductor temperature rise.

e. Insulation. There are many insulation materials and combinations used on aircraft electrical wire. Characteristics should be chosen based on environment; such as abrasion resistance, arc resistance, corrosion resistance, cut-through strength, dielectric strength, flame resistant, mechanical strength, smoke emission, fluid resistance, and heat distortion. An explanation of many of the abbreviations is identified in the glossary.

11-78. SUBSTITUTIONS. In the repair and modification of existing aircraft, when a replacement wire is required, the maintenance manual for that aircraft must first be reviewed to determine if the original aircraft manufacturer (OAM) has approved any substitution. If not, then the OAM must be contacted for an acceptable replacement.

a. MIL-W-5088L, replaced by AS50881A, wiring aerospace vehicle, Appendix A lists wire types that have been approved for military

aerospace applications in open and protected wiring applications. These wires could potentially be used for substitution when approved by the OAM.

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

c. The use of current military specification, multi-conductor cables in place of OEM installed constructions may create problems such as color sequence. Some civilian aircraft are wired with the older color sequence employing "Red-Blue-Yellow" as the first three colors. Current military specification, multi-conductor cables, in accordance with MIL-C-27500, use "White-Blue-Orange" for the initial three colors. Use of an alternative color code during modification without adequate notation on wiring diagrams could severely complicate subsequent servicing of the aircraft. At the time of this writing, MIL-C-27500 is being revised to include the older color sequence and could eliminate this problem in the future.

11-79.—11-84. [RESERVED.]

Table 11-2b. Comparable properties of wire insulation systems.

	Most desirable → Least			
<u>Relative Ranking</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
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

SECTION 7. TABLE OF ACCEPTABLE WIRES

11-85. AIRCRAFT WIRE TABLE. Tables 11-11 and 11-12 list wires used for the transmission of signal and power currents in aircraft. It does 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.

a. **All wires** in tables 11-11 and 11-12 have been determined to meet the flammability requirements of Title 14 of the Code of Federal Regulation (14 CFR) part 25, section 25.869(a)(4) and the applicable portion of part 1 of Appendix F of part 25.

b. **The absence of any wire** from tables 11-11 and 11-12 are 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.

c. **Explanations** of the various insulation materials mentioned in table 11-11, by abbreviations, can be found in the glossary.

11-86. 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 11-11.) 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.

11-87. 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 11-12.)

11-88. SEVERE WIND AND MOISTURE PROBLEMS (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 MIL-W-22759 shall be used in these applications. (See table 11-11.)

Suitable wire types selected from MIL-W-22759 are preferred for areas that require repeated bending and flexing of the wire. Consideration should be made to areas that require frequent component removal or repair. (See table 11-11.)

11-89. 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 MIL-DTL-27500, Cable, Power, Electrical and Cable Special Purpose, Electrical Shielded and Unshielded General Specifications.

TABLE 11-11. Open Wiring.

Document	Voltage rating (maximum)	Rated wire temperature (°C)	Insulation Type	Conductor type
MIL-W-22759/1	600	200	Fluoropolymer insulated TFE and TFE coated glass	Silver coated copper
MIL-W-22759/2	600	260	Fluoropolymer insulated TFE and TFE coated glass	Nickel coated copper
MIL-W-22759/3	600	260	Fluoropolymer insulated TFE -glass-TFE	Nickel coated copper
MIL-W-22759/4	600	200	Fluoropolymer insulated TFE -glass-FEP	Silver coated copper
MIL-W-22759/5	600	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/6	600	260	Fluoropolymer insulated extruded TFE	Nickel coated copper
MIL-W-22759/7	600	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/8	600	260	Fluoropolymer insulated extruded TFE	Nickel coated copper
MIL-W-22759/9	1000	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/10	1000	260	Fluoropolymer insulated extruded TFE	Nickel coated copper
MIL-W-22759/13	600	135	Fluoropolymer insulated FEP PVF2	Tin coated copper,
MIL-W-22759/16	600	150	Fluoropolymer insulated extruded ETFE	<u>Tin coated copper,</u>
MIL-W-22759/17	600	150	Fluoropolymer insulated extruded ETFE	Silver coated high strength copper alloy
MIL-W-22759/20	1000	200	Fluoropolymer insulated extruded TFE	Silver coated high strength copper alloy
MIL-W-22759/21	1000	260	Fluoropolymer insulated extruded TFE	Nickel coated high strength copper alloy
MIL-W-22759/34	600	150	Fluoropolymer insulated crosslinked modified ETFE	Tin coated copper
MIL-W-22759/35	600	200	Fluoropolymer insulated crosslinked modified ETFE	Silver coated high strength copper alloy
MIL-W-22759/41	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated copper
MIL-W-22759/42	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated high strength copper alloy
MIL-W-22759/43	600	200	Fluoropolymer insulated crosslinked modified ETFE	Silver coated copper
MIL-W-25038/3/2/	600	260	See specification sheet *	See specification sheet
MIL-W-81044/6	600	150	Crosslinked polyalkene	Tin coated copper
MIL-W-81044/7	600	150	Crosslinked polyalkene	Silver coated high strength copper alloy
MIL-W-81044/9	600	150	Crosslinked polyalkene	Tin coated copper
MIL-W-81044/10	600	150	Crosslinked polyalkene	Silver coated high strength copper alloy

* Inorganic Fibers - Glass - TFE

TABLE 11-12. Protected wiring.

Document	Voltage rating (maximum)	Rated wire temperature (°C)	Insulation Type	Conductor type
MIL-W-22759/11	600	200	Fluoropolymer insulated extruded TFE	Silver coated copper
MIL-W-22759/12	600	260	Fluoropolymer insulated extruded TFE	Nickel coated copper
MIL-W-22759/14	600	135	Fluoropolymer insulated FEP-PVF2	Tin coated copper
MIL-W-22759/15	600	135	Fluoropolymer insulated FEP-PVF2	Silver plated high strength copper alloy
MIL-W-22759/18	600	150	Fluoropolymer insulated extruded ETFE	Tin coated copper
MIL-W-22759/19	600	150	Fluoropolymer insulated extruded ETFE	Silver coated high strength copper alloy
MIL-W-22759/22	600	200	Fluoropolymer insulated extruded TFE	Silver coated high strength copper alloy
MIL-W-22759/23	600	260	Fluoropolymer insulated extruded TFE	Nickel coated high strength copper alloy
MIL-W-22759/32	600	150	Fluoropolymer insulated crosslinked modified ETFE	Tin coated copper
MIL-W-22759/33	600	200	Fluoropolymer insulated crosslinked modified ETFE	Silver coated high strength copper alloy
MIL-W-22759/44	600	200	Fluoropolymer insulated crosslinked modified ETFE	Silver coated copper
MIL-W-22759/45	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated copper
MIL-W-22759/46	600	200	Fluoropolymer insulated crosslinked modified ETFE	Nickel coated high strength copper alloy
MIL-W-81044/12	600	150	Crosslinked polyalkene - PVF2	Tin coated copper
MIL-W-81044/13	600	150	Crosslinked polyalkene - PVF2	Silver coated high strength copper alloy
MIL-W-81381/17	600	200	Fluorocarbon polyimide	Silver coated copper
MIL-W-81381/18	600	200	Fluorocarbon polyimide	Nickel coated copper
MIL-W-81381/19	600	200	Fluorocarbon polyimide	Silver coated high strength copper alloy
MIL-W-81381/20	600	200	Fluorocarbon polyimide	Nickel coated high strength copper alloy
MIL-W-81381/21	600	150	Fluorocarbon polyimide	Tin coated copper

11-90.—11-95. [RESERVED.]

SECTION 8. WIRING INSTALLATION INSPECTION REQUIREMENTS

11-96. GENERAL. Wires and cables should be inspected for adequacy of support, protection, and general condition throughout. The desirable and undesirable features in aircraft wiring installations are listed below and indicate conditions that may or may not exist. Accordingly, aircraft wiring must be visually inspected for the following requirements:

CAUTION: For personal safety, and to avoid the possibility of fire, turn off all electrical power prior to starting an inspection of the aircraft electrical system or performing maintenance.

a. Wires and cables are supported by suitable clamps, grommets, or other devices at intervals of not more than 24 inches, except when contained in troughs, ducts, or conduits. The supporting devices should be of a suitable size and type, with the wires and cables held securely in place without damage to the insulation.

b. Metal stand-offs must be used to maintain clearance between wires and structure. Employing tape or tubing is not acceptable as an alternative to stand-offs for maintaining clearance.

c. Phenolic blocks, plastic liners, or rubber grommets are 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.

d. Wires and cables in junction boxes, panels, and bundles are properly supported and laced to provide proper grouping and routing.

e. Clamp retaining screws are 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.

f. Wire and cables are properly supported and bound so that there is no interference with other wires, cables, and equipment.

g. Wires and cables are adequately supported to prevent excessive movement in areas of high vibration.

h. Insulating tubing is secured by tying, tie straps or with clamps.

i. Continuous lacing (spaced 6 inches apart) is not used, except in panels and junction boxes where this practice is optional. When lacing is installed in this manner, outside junction boxes should be removed and replaced with individual loops.

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

k. Insulating tubing must be kept at a minimum and must be used to protect wire and cable from abrasion, chafing, exposure to fluid, and other conditions which could affect the cable insulation. However; the use of insulating tubing for support of wires and cable in lieu of stand-offs is prohibited.

l. Do not use moisture-absorbent material as "fill" for clamps or adapters.

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

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

o. Do not use tape, tie straps, or cord for primary support.

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

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

r. 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.

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

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

u. Ensure that wires and cables are routed so that there is not a possibility of damage from battery electrolytes or other corrosive fluids.

v. Ensure that wires and cables are adequately protected in wheel wells and other areas where they may be exposed to damage from impact of rocks, ice, mud, etc. (If re-routing of wires or cables is not practical, protective jacketing may be installed). This type of installation must be held to a minimum.

w. Where practical, route electrical wires and cables above fluid lines and provide a 6 inch separation from any flammable liquid,

fuel, or oxygen line, fuel tank wall, or other low voltage wiring that enters a fuel tank and requires electrical isolation to prevent an ignition hazard. Where 6 inch spacing cannot practically be provided, a minimum of 2 inches must be maintained between wiring and such lines, related equipment, fuel tank walls and low voltage wiring that enters a fuel tank. Such wiring should be closely clamped and rigidly supported and tied at intervals such that contact between such lines, related equipment, fuel tank walls or other wires, would not occur, assuming a broken wire and a missing wire tie or clamp.

x. 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.

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

z. Separate wires from high-temperature equipment, such as resistors, exhaust stacks, heating ducts, etc., 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 polyethylene, because these materials are subject to deterioration and deformation at elevated temperatures. Many coaxial cables have this type of insulation.

aa. The minimum radius of bends in wire groups or bundles must not be less than 10 times the outside diameter of the largest wire or cable, except that at the terminal strips where wires break out at terminations or re-

verse direction in a bundle. Where the wire is suitably supported, the radius may be 3 times the diameter of the wire or cable. Where it is not practical to install wiring or cables within the radius requirements, the bend should be enclosed in insulating tubing. The radius for thermocouple wire should be done in accordance with the manufacturer's recommendation and shall be sufficient to avoid excess losses or damage to the cable.

bb. Ensure that RF cables, e.g., coaxial and triaxial are bent at a radius of no less than 6 times the outside diameter of the cable.

cc. 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.

dd. Ensure that wires and electrical cables are separated from mechanical control cables. In no instance should wire be able to come closer than 1/2 inch to such controls when light hand pressure is applied to wires or controls. In cases where clearance is less than this, adequate support must be provided to prevent chafing.

ee. Ensure that wires and cables are provided with enough slack to meet the following requirements:

- (1) Permit ease of maintenance.
- (2) Prevent mechanical strain on the wires, cables, junctions, and supports.
- (3) Permit free movement of shock and vibration mounted equipment.

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

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

gg. Ensure that all wires and cables are identified properly at intervals of not more than 15 inches. Coaxial cables are identified at both equipment ends.

11-97. WIRING REPLACEMENT. Wiring must be replaced with equivalent wire (see paragraph 11-78) when found to have any of the following defects:

a. Wiring that has been subjected to chafing or fraying, that has been severely damaged, or that primary insulation is suspected of being penetrated.

b. Wiring on which the outer insulation is brittle to the point that slight flexing causes it to crack.

c. Wiring having weather-cracked outer insulation.

d. Wiring that is known to have been exposed to electrolyte or on which the insulation appears to be, or is suspected of being, in an initial stage of deterioration due to the effects of electrolyte.

e. Check wiring that shows evidence of overheating (even if only to a minor degree) for the cause of the overheating.

f. Wiring on which the insulation has become saturated with engine oil, hydraulic fluid, or another lubricant.

g. Wiring that bears evidence of having been crushed or severely kinked.

h. Shielded wiring on which the metallic shield is frayed and/or corroded. Cleaning agents or preservatives should not be used to minimize the effects of corrosion or deterioration of wire shields.

i. Wiring showing evidence of breaks, cracks, dirt, or moisture in the plastic sleeves placed over wire splices or terminal lugs.

j. Sections of wire in which splices occur at less than 10-foot intervals, unless specifically authorized, due to parallel connections, locations, or inaccessibility.

k. When replacing wiring or coaxial cables, identify them properly at both equipment and power source ends.

l. Wire substitution-In the repair and modification of existing aircraft, when a replacement wire is required, the maintenance manual for that aircraft should first be reviewed to determine if the original aircraft manufacturer (OAM) has approved any substitution. If not, then the OAM should be contacted for an acceptable replacement.

m. Testing of the electrical and chemical integrity of the insulation of sample wires taken from areas of the aircraft that have experienced wiring problems in the past, can be used to supplement visual examination of the wire. The test for chemical integrity should be

specific for the degradation mode of the insulation. If the samples fail either the electrical or chemical integrity tests, then the wiring in the area surrounding the sampling area is a candidate for replacement.

11-98. TERMINALS AND TERMINAL BLOCKS. Inspect to ensure that the following installation requirements are met:

a. 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.

b. 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.

c. Terminal connections to terminal module block studs and nuts on unused studs are tight.

d. Evidence of overheating and corrosion is not present on connections to terminal module block studs.

e. Physical damage to studs, stud threads, and terminal module blocks is not evident. Replace cracked terminal strips and those studs with stripped threads.

f. The number of terminal connections to a terminal block stud does not exceed four, unless specifically authorized.

g. Shielding should be dead-ended with suitable insulated terminals.

h. All wires, terminal blocks, and individual studs are clearly identified to correspond to aircraft wiring manuals.

i. **Terminations** should be made using terminals of the proper size and the appropriate terminal crimping tools.

11-99. FUSES AND FUSE HOLDERS.

Inspect as follows:

a. **Check security** of connections to fuse holders.

b. **Inspect for the presence of corrosion** and evidence of overheating on fuses and fuse holders. Replace corroded fuses and clean fuse holders. If evidence of overheating is found, check for correct rating of fuse.

c. **Check mounting security** of fuse holder.

d. **Inspect for replenishment** of spare fuses used in flight. Replace with fuses of appropriate current rating only.

e. **Inspect for exposed fuses** susceptible to shorting. Install cover of nonconducting material if required.

11-100. CONNECTORS. Ensure reliability of connectors by verifying that the following conditions are met or that repairs are effected as required.

a. **Inspect connectors** for security and evidence of overheating (cause of overheating must be corrected), and exteriors for corrosion and cracks. Also, wires leading to connectors must be inspected for deterioration due to overheating. Replace corroded connections and overheated connectors.

b. **Ensure installation** of cable clamp (reference MIL-C-85049) adapters on applicable MS connectors, except those that are moisture-proof.

c. **See that silicone tape** is wrapped around wires in MS3057 cable clamp adapters

so that tightening of the cable clamp adapter cap provides sufficient grip on the wires to keep tension from being applied to the connector pins.

d. **Make sure unused plugs and receptacles** are covered to prevent inclusion of dust and moisture. Receptacles should 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 should be visible behind the connector or a tag should be attached identifying the associated circuit or attaching equipment. The connector should be attached to structure by its normal mounting means or by the use of appropriate clamps.

e. **Ensure that connectors** are fully mated by checking position and tightness of coupling ring or its alignment with fully mated indicator line on receptacle, if applicable.

f. **Ensure that the coupling nut** of MS connectors is safetied, by wire or other mechanical locking means, as required by applicable aircraft instructional manuals.

g. **Ensure that moisture-absorbent material** is not used as "fill" for MS3057 clamps or adapters.

h. **Ensure that there is no evidence of deterioration** such as cracking, missing, or disintegration of the potting material.

i. **Identical connectors** in adjacent locations can lead to incorrect connections. When such installations are unavoidable, the attached

wiring must be clearly identified and must be routed and clamped so that it cannot be mismatched.

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

11-101. JUNCTION BOXES, PANELS, SHIELDS, AND MICROSWITCH HOUSINGS. Examine housing assemblies to ascertain the following:

a. Verify that one or more suitable holes, about 3/8-inch diameter, but not less than 1/8-inch diameter, are provided at the lowest point of the box, except vapor-tight boxes, to allow for drainage with the aircraft on the ground or in level flight.

b. Verify that vapor tight or explosion proof boxes are externally labeled **VAPOR-TIGHT or EXPLOSION PROOF.**

c. Verify that boxes are securely mounted.

d. Verify that boxes are clean internally and free of foreign objects.

e. Verify that safety wiring is installed on all lid fasteners on J-boxes, panels, shields, or microswitch housings which are installed in areas not accessible for inspection in flight, unless the fasteners incorporate self-locking devices.

f. Verify that box wiring is properly aligned.

g. Verify that there are no unplugged, unused holes (except drainage holes) in boxes.

11-102. CONDUIT - RIGID METALLIC,

FLEXIBLE METALLIC AND RIGID NONMETALLIC. Inspection of conduit assemblies should ascertain that:

a. Conduit is relieved of strain and flexing of ferrules.

b. Conduit is not collapsed or flattened from excessive bending.

c. Conduits will not trap fluids or condensed moisture. Suitable drain holes should be provided at the low points.

d. Bonding clamps do not cause damage to the conduit.

e. Weatherproof shields on flexible conduits of the nose and main landing gear and in wheel wells are not broken; that metallic braid of weatherproof conduit is not exposed; and that conduit nuts, ferrules, and conduit fittings are installed securely.

f. Ends of open conduits are flared or routed to avoid sharp edges that could chafe wires exiting from the conduit.

11-103. JUNCTIONS. 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. Inspect for the provisions outlined below:

a. Electrical junctions should be protected from short circuits resulting from movement of personnel, cargo, cases, and other loose or stored materials. Protection should 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, etc.

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

c. Electrical junctions should be mechanically and electrically secure. They should not be subject to mechanical strain or used as a support for insulating materials, except for insulation on terminals.

11-104. CIRCUIT BREAKERS. Note those circuit breakers which have a tendency to open circuits frequently, require resetting more than normal, or are subject to nuisance tripping. Before considering their replacement, investigate the reason.

11-105. SYSTEM SEPARATION. Wires of redundant aircraft systems should be routed in separate bundles and through separate connectors to prevent a single fault from disabling multiple systems. Wires not protected by a circuit-protective device, such as a circuit breaker or fuse, should be routed separately from all other wiring. Power feeders from separate sources should be routed in separate bundles from each other and from other aircraft wiring, in order to prevent a single fault from disabling more than one power source. The ground wires from aircraft power sources should be attached to the airframe at separate points so that a single failure will not disable multiple sources. Wiring that is part of electro-explosive subsystems, such as cartridge-actuated fire extinguishers, rescue hoist shear, and emergency jettison devices, should be routed in shielded and jacketed twisted-pair cables, shielded without discontinuities, and kept separate from other wiring at connectors. To facilitate identification of specific separated system bundles, use of colored plastic cable ties or lacing tape is allowed. During aircraft maintenance, colored plastic cable straps or lacing tape should be replaced with the same type and color of tying materials.

11-106. ELECTROMAGNETIC INTERFERENCE (EMI). Wiring of sensitive circuits that may be affected by EMI must 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 which is a source of EMI increases in proportion to the length of parallel runs and decreases with greater separation. EMI should be limited to negligible levels in wiring related to critical systems, that is, the function of the critical system should not be affected by the EMI generated by the adjacent wire. Use of shielding with 85 percent coverage or greater is recommended. Coaxial, triaxial, twinaxial, or quadraxial cables should be used, wherever appropriate, with their shields connected to ground at a single point or multiple points, depending upon the purpose of the shielding. The airframe grounded structure may also be used as an EMI shield.

11-107. INTERFERENCE TESTS. Perform an interference test for installed equipment and electrical connections as follow:

a. The equipment must be installed in accordance with manufacturer's installation instructions. Visually inspect all the installed equipment to determine that industry standard workmanship and engineering practices were used. Verify that all mechanical and electrical connections have been properly made and that the equipment has been located and installed in accordance with the manufacturer's recommendations. The wire insulation temperature rating should also be considered.

b. Power input tests must be conducted with the equipment powered by the airplane's electrical power generating system, unless otherwise specified.

c. All associated electrically operated equipment and systems on the airplane must be on and operating before conducting interference tests, unless otherwise specified.

d. The effects on interference must be evaluated as follows:

(1) The equipment shall not be the source of harmful conducted or radiated interference or adversely affect other equipment or systems installed in the airplane.

(2) With the equipment energized on the ground, individually operate other electrically operated equipment and systems on the airplane to determine that no significant conducted or radiated interference exists. Evaluate all reasonable combinations of control settings and operating modes. Operate communication and navigation equipment on at least one low, high and mid-band frequency. Make note of systems or modes of operation that should also be evaluated during flight.

(3) For airplane equipment and systems that can be checked only in flight, determine that no operationally significant conducted or radiated interference exists. Evaluate all reasonable combinations of control settings and operating modes. Operate communications and navigation equipment on at least one low, high and mid-band frequency.

NOTE: Electromagnetic compatibility problems which develop after installation of this equipment may result from such factors as design characteristics of previously installed systems or equipment, and the physical installation itself. It is not intended that

the equipment manufacturer should design for all installation environments. The installing facility will be responsible for resolving any incompatibility between this equipment and previously installed equipment in the airplane. The various factors contributing to the incompatibility should be considered.

NOTE: Ground EMI test have consistently been found adequate for follow-on approvals of like or identical equipment types, irrespective of the airplane model used for the initial approval. Radio frequency transmission devices, such as wireless telephones, must also be tested with respect to their transmission frequencies and harmonics.

11-108. IDENTIFICATION STENCILS AND PLACARDS ON ELECTRICAL EQUIPMENT. Replace worn stencils and missing placards.

11-109.—11-114. [RESERVED.]

SECTION 9. ENVIRONMENTAL PROTECTION AND INSPECTION

11-115. MAINTENANCE AND OPERATIONS. Wire bundles must be routed in accessible areas that are protected from damage from personnel, cargo, and maintenance activity. They should not be routed in areas in where they are likely to be used as handholds or as support for personal equipment or where they could become damaged during removal of aircraft equipment. Wiring must 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, etc., should be provided. Protective grommets must be used, wherever wires cannot be clamped, in a way that ensures at least a 3/8-inch clearance from structure at penetrations. Wire must not have a preload against the corners or edges of chafing strips or grommets. Wiring must be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Protective flexible conduits should be made of a material and design that eliminates the potential of chafing between their internal wiring and the conduit internal walls. Wiring that must be routed across hinged panels, must be routed and clamped so that the bundle will twist, rather than bend, when the panel is moved.

11-116. 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 figure 11-7.) 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 figure 11-8, may be made from any suitable insulating material, taking care to

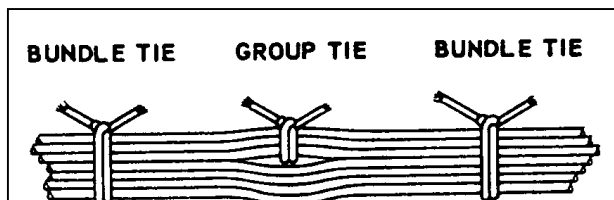


FIGURE 11-7. Group and bundle ties.

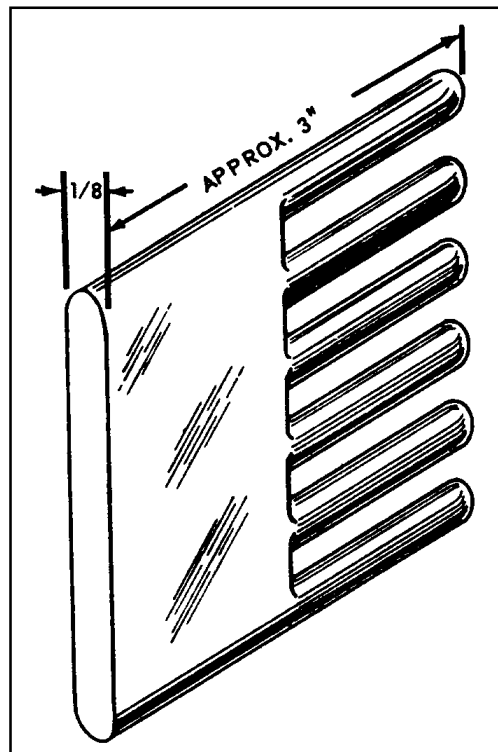


FIGURE 11-8. Comb for straightening wires in bundles.

ensure all edges are rounded to protect the wire insulation.

11-117. MINIMUM WIRE BEND RADII. The minimum radii for bends in wire groups or bundles must not be less than 10 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.

a. RF cables should not bend on a radius of less than six times the outside diameter of the cable.

b. Care should be taken to avoid sharp bends in wires that have been marked with the hot stamping process.

11-118. SLACK. Wiring should be installed with sufficient slack so that bundles and individual wires are not under tension. Wires connected to movable or shock-mounted equipment should have sufficient length to allow full travel without tension on the bundle. Wiring at terminal lugs or connectors should have sufficient slack to allow two reterminations without replacement of wires. This slack should be in addition to the drip loop and the allowance for movable equipment. Normally, wire groups or bundles should not exceed 1/2-inch deflection between support points, as shown in figure 11-9a. 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 should be provided at each end to:

- a. Permit** replacement of terminals.
- b. Prevent** mechanical strain on wires.
- c. Permit** shifting of equipment for maintenance purposes.

11-118A. DRIP LOOP IN WIRE BUNDLE.

A drip loop is an area where 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 Figure 11-9b) Wires or groups of wires should enter a junction box or piece of equipment in an upward direction where practicable. Where wires must be routed downwards to a junction box or unit of electric equipment, the entry should be sealed or adequate slack should be provided to form a trap or drip loop to prevent liquid from running down the wires in the box or electric unit.

11-119. POWER FEEDERS. The power feeder wires should be routed so that they can be easily inspected or replaced. They must be given special protection to prevent potential chafing against other wiring, aircraft structure, or components.

11-120. RF CABLE. All wiring needs to be protected from damage. However, coaxial and triaxial cables are particularly vulnerable to certain types of damage. Personnel should exercise care while handling or working around coaxial. 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. Coaxial cables with solid center conductors should not be used. Stranded center coaxial cables can be used as a direct replacement for solid center coaxial.

11-121. PRECAUTIONS.

- a. Never kink** coaxial cable.
- b. Never drop** anything on coaxial cable.
- c. Never step** on coaxial cable.
- d. Never bend** coaxial cable sharply.
- e. Never loop** coaxial cable tighter than the allowable bend radius.
- f. Never pull** on coaxial cable except in a straight line.
- g. Never use** coaxial cable for a handle, lean on it, or hang things on it (or any other wire).

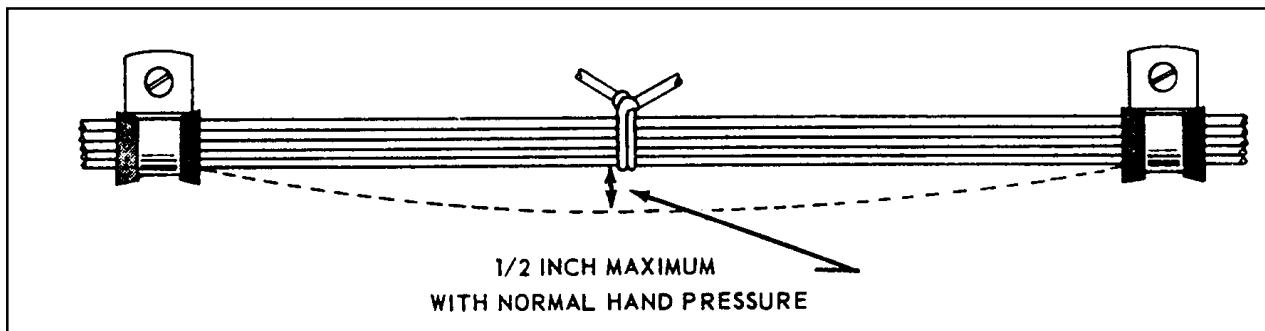


FIGURE 11-9a. Slack between supports

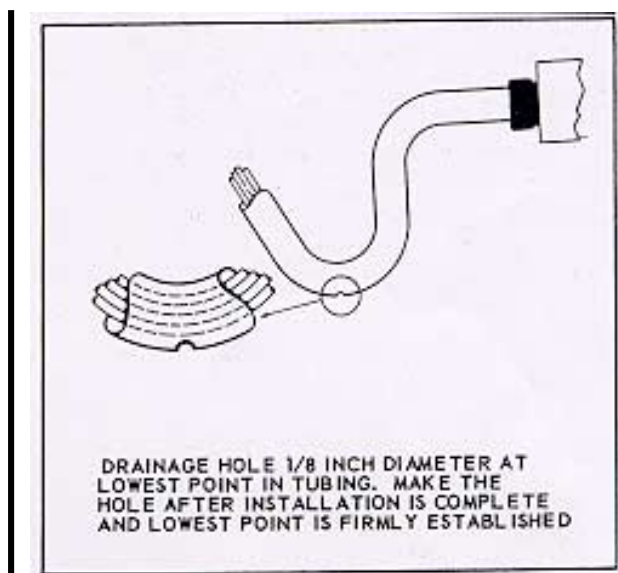


FIGURE 11-9b. Drainage hole in low point of tubing.

11-122. MOISTURE PROTECTION, WHEEL WELLS, AND LANDING GEAR AREAS.

a. **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 must not be any strain on attachments or excessive slack when parts are fully extended or retracted. The wiring and protective tubing must be inspected frequently and replaced at the first sign of wear.

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

11-123. PROTECTION AGAINST PERSONNEL AND CARGO. Wiring must 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 must be used, or a suitable mechanical guard must be provided.

11-124. HEAT PRECAUTIONS. Wiring must be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Wires must be rated (reference paragraph 11-66 and 11-67) 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 should 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, must 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 resistance shielding or insulation.

11-125. MOVABLE CONTROLS WIRING PRECAUTIONS. Clamping of wires routed near movable flight controls must be attached with steel hardware and must be spaced so that failure of a single attachment point can not result in interference with controls. The minimum separation between wiring and movable controls must be at least 1/2 inch when the bundle is displaced by light hand pressure in the direction of the controls.

11-126. 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 must be made to avoid this hazard by physical separation of the wire from lines and equipment containing oxygen, oil, fuel, hydraulic fluid, or alcohol. Wiring must be routed above these lines and equipment with a minimum separation of 6 inches or more whenever possible. When such an arrangement is not practicable, wiring must be routed so that it does not run parallel to the fluid lines. A minimum of 2 inches must be maintained between wiring and such lines and equipment, except when the wiring is positively clamped to maintain at least 1/2-inch separation, or when it must be connected

directly to the fluid-carrying equipment. Install clamps as shown in figure 11-10. These clamps should not be used as a means of supporting the wire bundle. Additional clamps should 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.

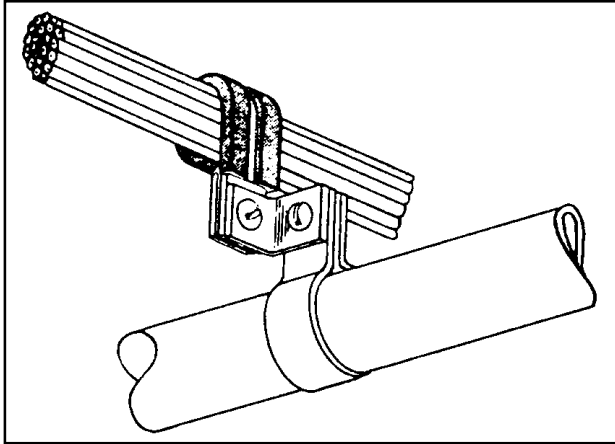


FIGURE 11-10. Separation of wires from plumbing lines.

11-127.—11-134. [RESERVED.]

SECTION 10. SERVICE LOOP HARNESSES (Plastic Tie Strips)

11-135. 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.

11-136. SUPPORT. Only string ties or plastic cable straps in accordance with paragraph 11-158 should be used on service loop harnesses. A 90° or "Y" type spot tie should be installed at the harness breakout point on the harness bundle. Ties should be installed on service loop harnesses at 4 to 6-inch intervals.

11-137. ANTI-CHAFING MATERIAL. When service loops are likely to be in contact with each other, expandable sleeving or equivalent chafe protection jacket material must be installed over service loop harnesses to prevent harness-to-harness chafing. The sleeve should be held in place with string ties at 6 to 8-inch intervals. Harness identification labels should be installed, with string tie, within 3 inches of the service loop harness installation.

11-138. STRAIN RELIEF. 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 should be installed. The heat-shrinkable boots will provide preselected angles of wire harness termination when heat is applied. Heat-shrinkable tubing should be held at the desired angle until cool.

11-139. "SERVICE LOOP." Primary support for service loop harness(es) should be a cushion clamp and a connector at the harness termination. Service loop harnesses should be inspected for the following:

a. Adequate Length. Components should 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 inches, with all other components installed, should be sufficient.

b. Bundle BreakOut Point.

(1) Bundle breakout point should be adequately supported with string tie.

(2) Service loop must maintain a minimum bend radius of 3 times the harness diameter.

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

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

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

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

11-140.—11-145. [RESERVED.]

SECTION 11. CLAMPING

11-146. GENERAL. Wires and wire bundles must be supported by using clamps meeting Specification MS-21919, or plastic cable straps in accessible areas if correctly applied within the restrictions of paragraph 11-158. Clamps and other primary support devices must be constructed of materials that are compatible with their installation and environment, in terms of temperature, fluid resistance, exposure to ultraviolet (UV) light, and wire bundle mechanical loads. They should be spaced at intervals not exceeding 24 inches. Clamps on wire bundles should be selected so that they have a snug fit without pinching wires, as shown in figure 11-11 through figure 11-13.

CAUTION: The use of metal clamps on coaxial RF cables may cause problems if clamp fit is such that RF cable's original cross-section is distorted.

a. Clamps on wire bundles should not allow the bundle to move through the clamp when a slight axial pull is applied. Clamps on RF cables must fit without crushing and must be snug enough to prevent the cable from moving freely through the clamp, but may allow the cable to slide through the clamp when a light axial pull is applied. The cable or wire bundle may be wrapped with one or more turns of electrical tape when required to achieve this fit. Plastic clamps or cable ties must not be used where their failure could result in interference with movable controls, wire bundle contact with movable equipment, or chafing damage to essential or unprotected wiring. They must not be used on vertical runs where inadvertent slack migration could result in chafing or other damage. Clamps must 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 figure 11-11.).

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

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

d. When wire bundle is clamped into position, if there is less than 3/8-inch clearance between the bulkhead cutout and the wire bundle, a suitable grommet should be installed as indicated in figure 11-14. The grommet may be cut at a 45 degree angle to facilitate installation, provided it is cemented in place and the slot is located at the top of the cutout.

11-147. WIRE AND CABLE CLAMPS INSPECTION. Inspect wire and cable clamps for proper tightness. Where cables pass through structure or bulkheads, inspect for proper clamping and grommets. Inspect for sufficient slack between the last clamp and the electronic equipment to prevent strain at the cable terminals and to minimize adverse effects on shock-mounted equipment.

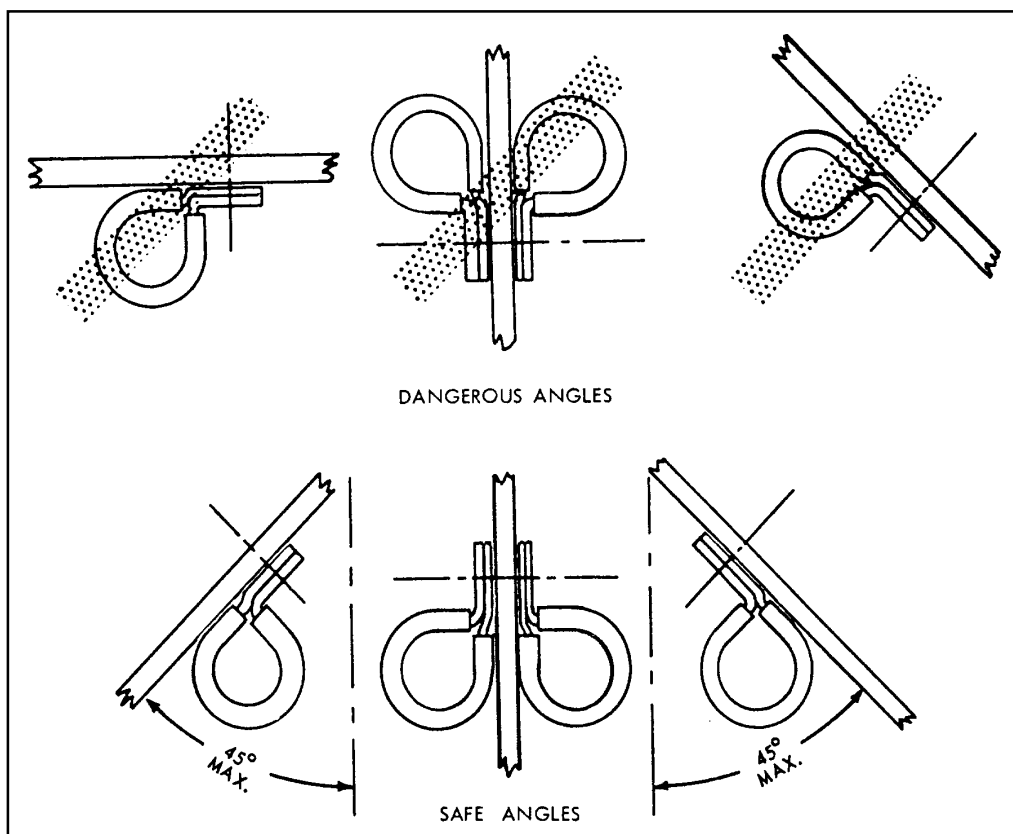


FIGURE 11-11. Safe angle for cable clamps.

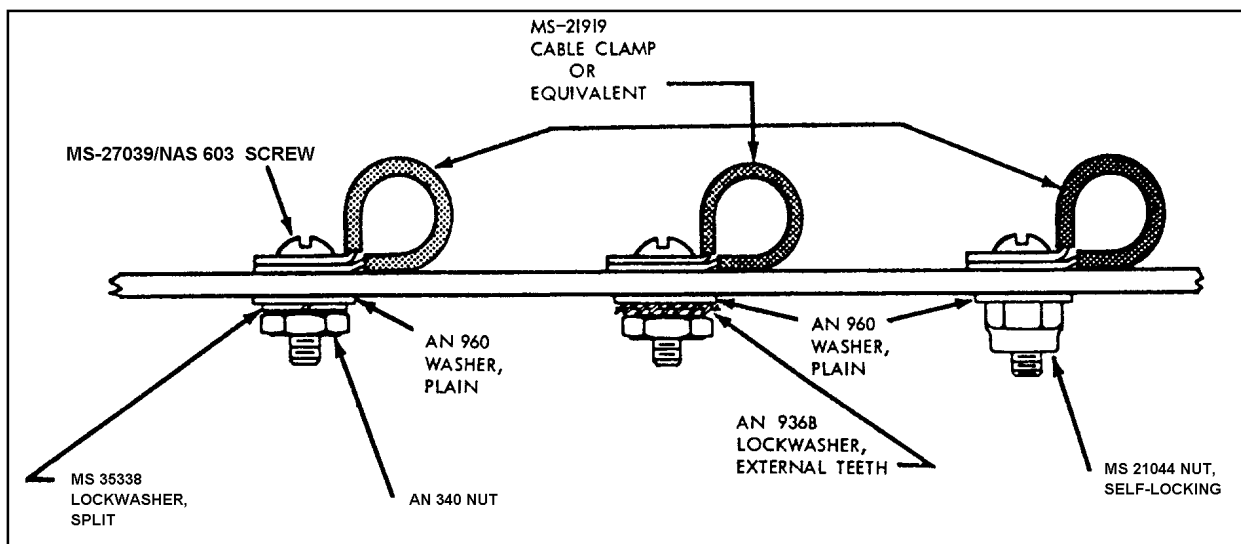


FIGURE 11-12. Typical mounting hardware for MS-21919 cable clamps.

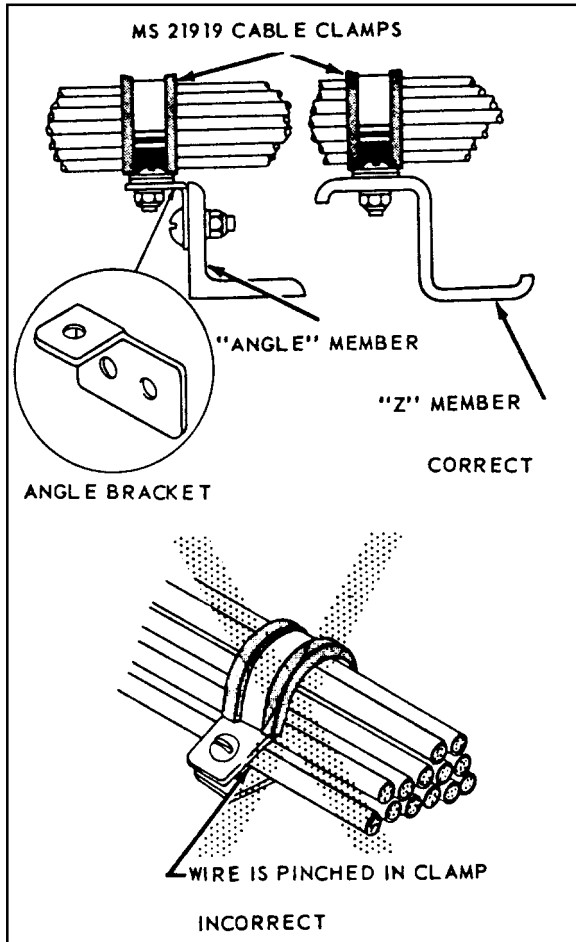


FIGURE 11-13. Installing cable clamp to structure.

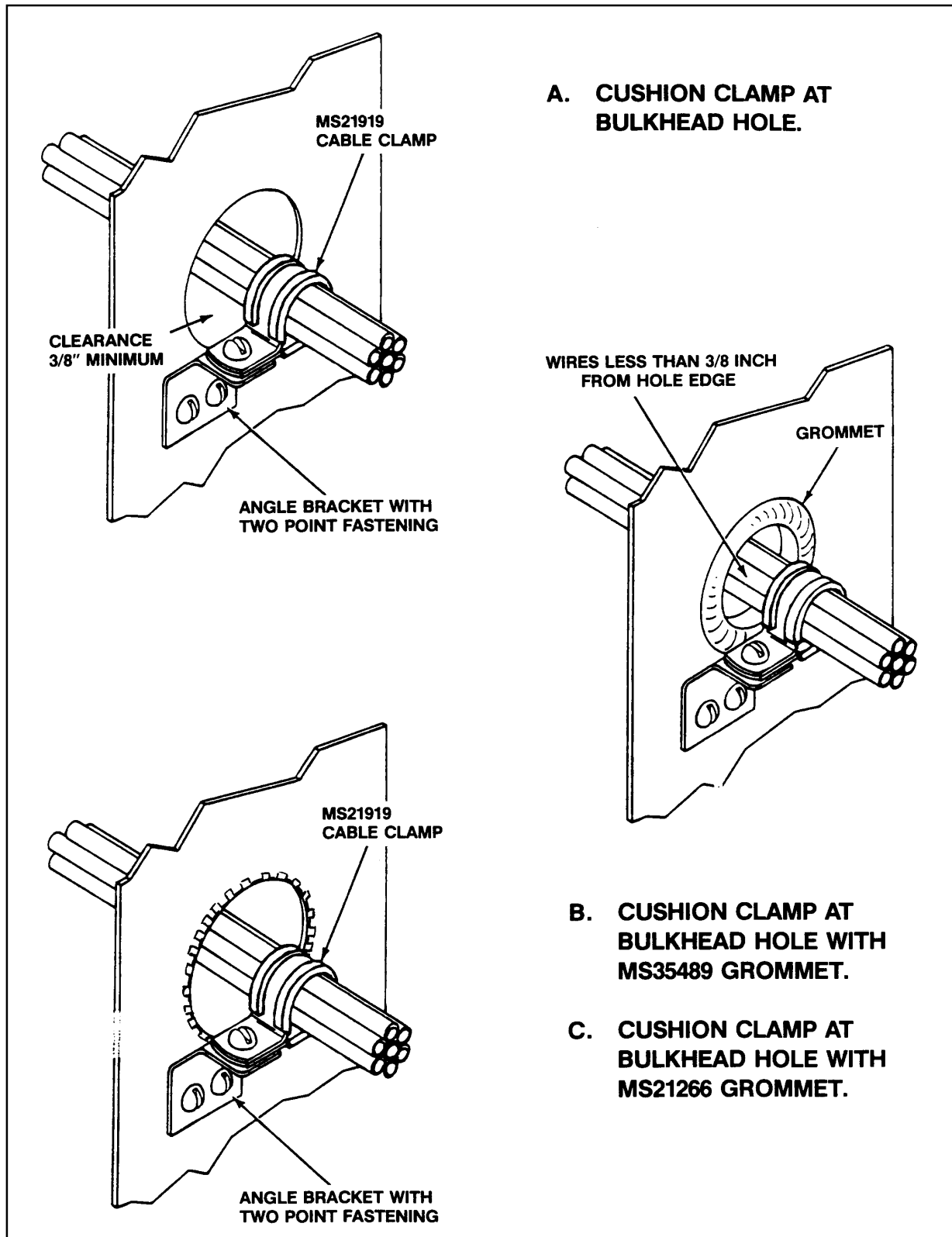


FIGURE 11-14. Clamping at a bulkhead hole.

11-148.—11-154. [RESERVED.]

SECTION 12. WIRE INSULATION AND LACING STRING TIE

11-155. GENERAL. Insulation of wires should be appropriately chosen in accordance with the environmental characteristics of wire routing areas. Routing of wires with dissimilar insulation, within the same bundle, is not recommended, particularly when relative motion and abrasion between wires having dissimilar insulation can occur. Soft insulating tubing (spaghetti) cannot be considered as mechanical protection against external abrasion of wire; since at best, it provides only a delaying action. Conduit or ducting should be used when mechanical protection is needed.

11-156. INSULATION MATERIALS. Insulating materials should be selected for the best combination of characteristics in the following categories:

- a. Abrasion resistance.
- b. Arc resistance (noncarbon tracking).
- c. Corrosion resistance.
- d. Cut-through strength.
- e. Dielectric strength.
- f. Flame resistance.
- g. Heat distortion temperature.
- h. Impact strength.
- i. Mechanical strength.
- j. Resistance to fluids.
- k. Resistance to notch propagation.
- l. Smoke emission.

m. Special properties unique to the aircraft.

n. For a more complete selection of insulated wires refer to SAE AS 4372 Aerospace Wire Performance Requirement and SAE AS 4373 Test Methods for Aerospace Wire.

11-157. STRIPPING INSULATION.

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

a. Make sure all cutting tools used for stripping are sharp.

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

c. Damage to wires should not exceed the limits specified in table 11-13.

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

11-158. LACING AND TIES. Ties, lacing, and straps are used to secure wire groups or bundles to provide ease of maintenance, inspection, and installation. Braided lacing tape per MIL-T-43435 is suitable for lacing and tying wires. In lieu of applying ties, straps meeting Specification MS17821 or MS17822 may be used in areas where the temperature does not exceed 120 °C. Straps may not be used in areas of SWAMP such as wheel wells, near wing flaps or wing folds. They may not be used in high vibration areas, where failure

TABLE 11-13. 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 or Copper Alloy	19	2 nicked, none broken
12-10		37	4 nicked, none broken
8-4		133	6 nicked, 6 broken
2-1		665-817	6 nicked, 6 broken
0-00		1,045-1,330	6 nicked, 6 broken
000		1,665-	6 nicked, 6 broken
0000		2,109-	6 nicked, 6 broken
8-000	Aluminum	All numbers of strands	None, None

of the strap would permit wiring to move against parts which could damage the insulation and foul mechanical linkages or other moving mechanical parts. They also may not be used where they could be exposed to UV light, unless the straps are resistant to such exposure.

a. Lacing. Lace wire groups or bundles inside junction boxes or other enclosures. Single cord-lacing method, shown in figure 11-15, and tying tape, meeting specification MIL-T-43435, may be used for wire groups of bundles 1-inch 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 figure 11-15, step a. Use the double cord-lacing method on wire bundles 1-inch in diameter or larger as shown in figure 11-16. When using the double cord-lacing method, employ a bowline on a bight as the starting knot.

b. Tying. Use wire group or bundle ties where the supports for the wire are more than

12 inches apart. A tie consists of a clove hitch, around the wire group or bundle, secured by a square knot as shown in figure 11-17.

c. Plastic Ties. Refer to Paragraph 11-220 and table 11-21.

11-159. INSULATION TAPE. Insulation tape should be of a type suitable for the application, or as specified for that particular use. Insulation tape should be used primarily as a filler under clamps and as secondary support. Nonadhesive tape may be used to wrap around wiring for additional protection, such as in wheel wells. All tape should have the ends tied or otherwise suitably secured to prevent unwinding. Tape used for protection should be applied so that overlapping layers shed liquids. Drainage holes should be provided at all trap points and at each low point between clamps. Plastic tapes, that absorb moisture or have volatile plasticizers that produce chemical reactions with other wiring, should not be used. (Reference MIL-W-5088.)

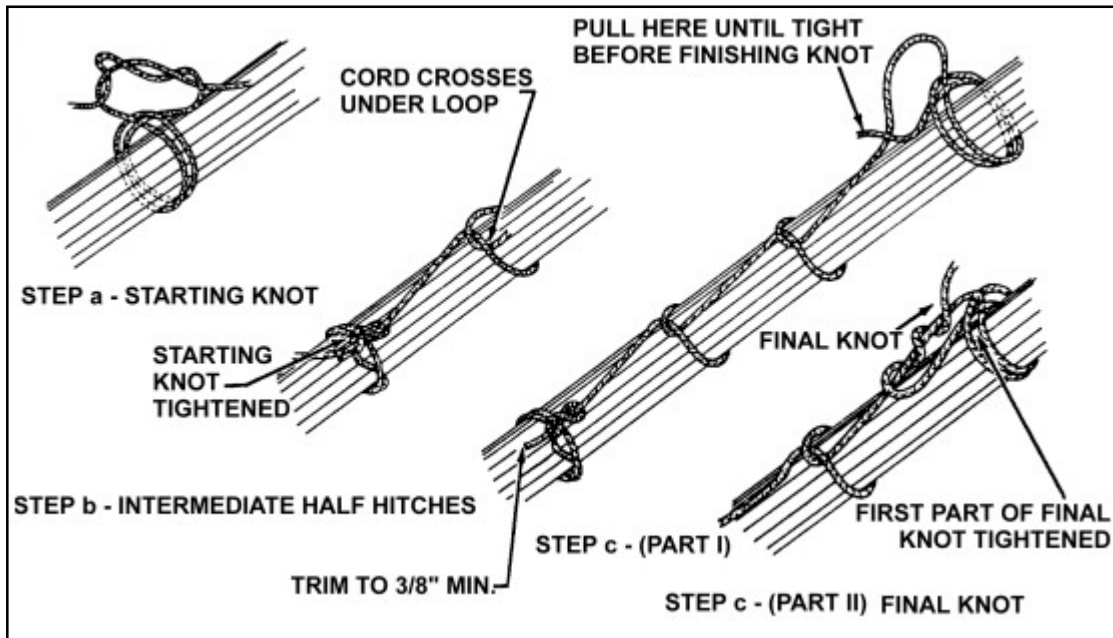


FIGURE 11-15. Single cord lacing.

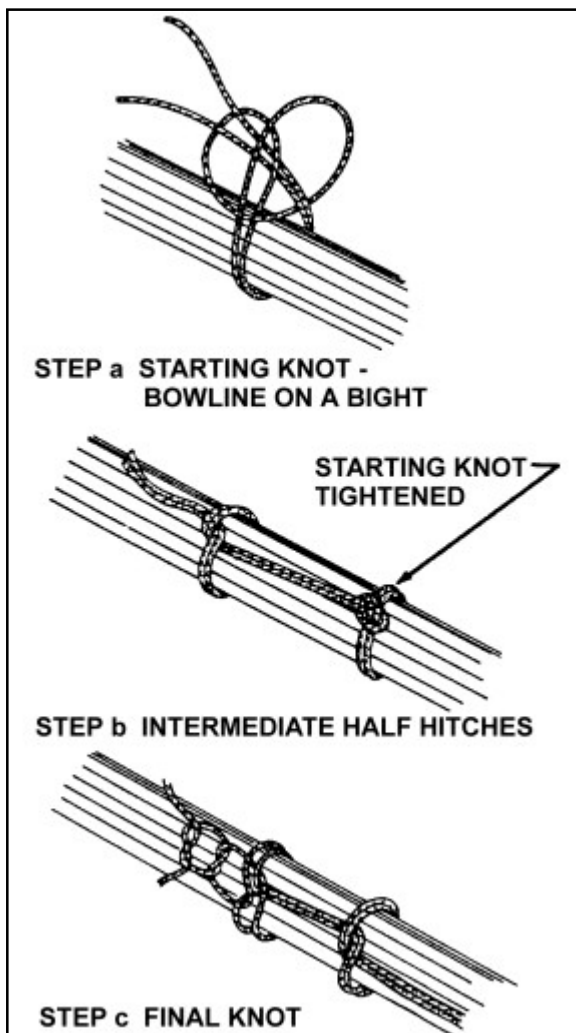


FIGURE 11-16. Double cord lacing.

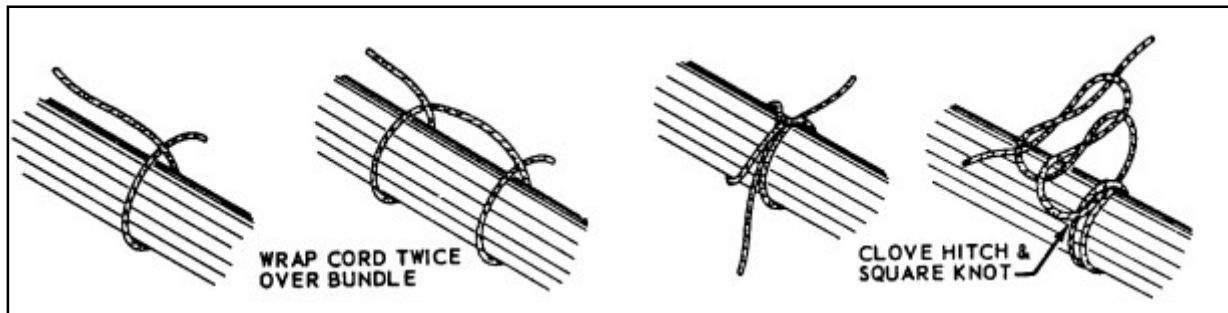


FIGURE 11-17. Making ties.

11-160.—11-166. [RESERVED.]

SECTION 13. SPLICING.

11-167. 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 must have approved data.

a. Splicing of electrical wire should be kept to a minimum and avoided entirely in locations subject to extreme vibrations. Splicing of individual wires in a group or bundle should have engineering approval and the splice(s) should be located to allow periodic inspection.

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

c. There should not be more than one splice in any one wire segment between any two connectors or other disconnect points, except; when attaching to the spare pigtail lead of a potted connector, 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 MIL-W-5088, now AS50881A, and NAVAIR 01-1A-505.)

d. Splices in bundles must 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 figure 11-18.)

e. Splices should not be used within 12 inches of a termination device, except for paragraph f below.

f. Splices may be used within 12 inches of a termination device when attaching to the pigtail spare lead of a potted termination device, or 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.

g. Selection of proper crimping tool, refer to paragraph 11-178.

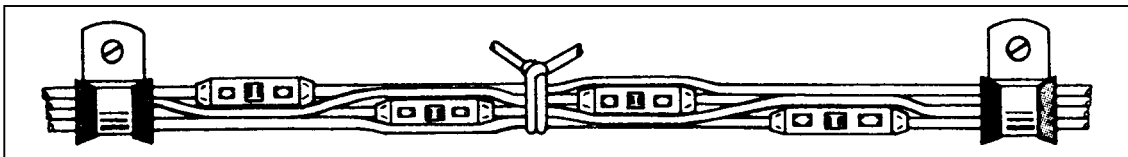


FIGURE 11-18. Staggered splices in wire bundle.

11-168.—11-173. [RESERVED.]

SECTION 14. TERMINAL REPAIRS

11-174. GENERAL. Terminals are attached to the ends of electrical wires to facilitate connection of the wires to terminal strips or items of equipment. The tensile strength of the wire-to-terminal joint should be at least equivalent to the tensile strength of the wire itself, and its resistance negligible relative to the normal resistance of the wire.

a. Selection of Wire Terminals. The following should be considered in the selection of wire terminals.

- (1) Current rating.
- (2) Wire size (gauge) and insulation diameter.
- (3) Conductor material compatibility.
- (4) Stud size.
- (5) Insulation material compatibility.
- (6) Application environment.
- (7) Solder/solderless.

Pre-insulated crimp-type ring-tongue terminals are preferred. The strength, size, and supporting means of studs and binding posts, as well as the wire size, should be considered when determining the number of terminals to be attached to any one post. In high-temperature applications, the terminal temperature rating must be greater than the ambient temperature plus current related temperature rise. Use of nickel-plated terminals and of uninsulated terminals with high-temperature insulating sleeves should be considered. Terminal blocks should be provided with adequate electrical clearance or insulation strips between mounting hardware and conductive parts.

b. Terminal Strips. Wires are usually joined at terminal strips. A terminal strip fitted with barriers should be used to prevent the terminals on adjacent studs from contacting each other. Studs should be anchored against rotation. When more than four terminals are to be connected together, a small metal bus should be mounted across two or more adjacent studs. In all cases, the current should be carried by the terminal contact surfaces and not by the stud itself. Defective studs should be replaced with studs of the same size and material since terminal strip studs of the smaller sizes may shear due to overtightening the nut. The replacement stud should be securely mounted in the terminal strip and the terminal securing nut should be tight. Terminal strips should be mounted in such a manner that loose metallic objects cannot fall across the terminals or studs. It is good practice to provide at least one spare stud for future circuit expansion or in case a stud is broken. Terminal strips that provide connection of radio and electronic systems to the aircraft electrical system should be inspected for loose connections, metallic objects that may have fallen across the terminal strip, dirt and grease accumulation, etc. These type conditions can cause arcing which may result in a fire, or system failures.

c. Terminal Lugs. Wire terminal lugs should 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 should be connected to any one stud. Total number of terminal lugs per stud includes a common bus bar joining adjacent studs. Four terminal lugs plus a common bus bar thus are not permitted on one stud. Terminal lugs should be selected with a stud hole diameter that matches the diameter of the stud. However, when the terminal lugs attached to a stud vary in diameter, the greatest

diameter should be placed on the bottom and the smallest diameter on top. Tightening terminal connections should not deform the terminal lugs or the studs. Terminal lugs should be so positioned that bending of the terminal lug is not required to remove the fastening screw or nut, and movement of the terminal lugs will tend to tighten the connection.

d. Copper Terminal Lugs. Solderless crimp style, copper wire, terminal lugs should be used and conform to MIL-T-7928. Spacers or washers should not be used between the tongues of terminal lugs.

e. Aluminum Terminal Lugs. The aluminum terminal lugs conforming to MIL-T-7099 (MS-25435, MS-25436, MS-25437, and MS-25438) should be crimped to aluminum wire only. The tongue of the aluminum terminal lugs or the total number of tongues of aluminum terminal lugs when stacked, should be sandwiched between two MS-25440 flat washers when terminated on terminal studs. Spacers or washers should not be used between the tongues of terminal lugs. Special attention should be given to aluminum wire and cable installations to guard against conditions that would result in excessive voltage drop and high resistance at junctions that may ultimately lead to failure of the junction. Examples of such conditions are improper installation of terminals and washers, improper torsion ("torquing" of nuts), and inadequate terminal contact areas.

f. 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 should be the insulated type, unless the conductor temperature exceeds 105 °C. In that case uninsulated terminal lugs should be used. Parts' lists should indicate the appropriate

Class 1 terminal lugs to be used for service replacement of any Class 2 terminal lugs installed.

g. Termination of Shielded Wire. For termination of shielded wire refer to MIL-DTL-27500.

11-175. 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, due to misinstallation, poor maintenance, and service life, should 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 paragraph 11-178)

11-176. STUDS AND INSULATORS. The following recommendations concerning studs also apply to other feed-through conductors.

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

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

c. Support for Studs. The main stud support in the feed-through insulation should be independent of the attachment of the lugs to the stud. Therefore, loosening of the insulation support of the stud will not affect the

electric contact efficiency. In other words, the contact pressure on the wire lugs should not in any way be affected by the loosening of the stud in the insulator.

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

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

11-177. WIRE TERMINALS AND BINDING POSTS. All wire terminals in or on electrical equipment, except case ground, must be firmly held together with two nuts or suitable locking provisions, or should be secured in a positive manner to equipment in such a way that no insulation material is involved in maintaining physical pressure between the various current carrying members of an electrical connection. Terminal studs or binding posts should be of a size that is entirely adequate for the current requirements of the equipment and have sufficient mechanical strength to withstand the torque required to attach the cable to the equipment. All terminals on equipment should have barriers and covers provided by equipment manufacturers.

11-178. CRIMP ON TERMINAL LUGS AND SPLICES (pre-insulated crimp type). The crimp on terminal lugs and splices must be installed using a high quality ratchet-type, crimping tool. We recommend the use of the proper calibrated tool. 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 due to corrosion build-up between the crimped terminal and the wire. MIL-C22520/2 or MIL-T-DTI2250G specification covers in detail the general requirement for crimp tools, inspection gages and tool kits.

a. 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.

b. Crimp tools must be carefully inspected:

(1) Insure that the full cycle ratchet mechanism is tamper-proof so that it cannot be disengaged prior to or during the crimp cycle.

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

(3) The tool calibration and adjustments are made only by the manufacturer or an approved calibration laboratory.

(4) Suitable gages of the Go/No Go type are available and shall be used prior to

any crimping operation and whenever possible during operation to ensure crimp dimensions.

11-179. LOCK WASHERS FOR TERMINALS ON EQUIPMENT. Where locknuts are used to ensure binding and locking of electrical terminals, they should be of the all metal type. In addition, a spring lock washer of suitable thickness may be installed under the nut to ensure good contact pressure. A plain washer should be used between the spring washer and the terminal to prevent galling. A plain nut with a spring lock washer and a plain washer may be used to provide binding and contact pressure.

11-180.—11-184. [RESERVED.]

SECTION 15. GROUNDING AND BONDING

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

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

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

ground return should be labeled "ac Right". The return currents for the left generator should be connected to a ground point labeled "ac Left"

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

c. Heavy-Current Grounds. Power ground connections, for generators, transformer rectifiers, batteries, external power receptacles, and other heavy-current, loads must be attached to individual grounding brackets that are attached to aircraft structure with a proper metal-to-metal bonding attachment. This attachment and the surrounding structure must provide adequate conductivity to accommodate normal and fault currents of the system without creating excessive voltage drop or damage to the structure. At least three fasteners, located in a triangular or rectangular pattern, must be used to secure such brackets

in order to minimize susceptibility to loosening under vibration. If the structure is fabricated of a material such as carbon fiber composite (CFC), which has a higher resistivity than aluminum or copper, it will be necessary to provide an alternative ground path(s) for power return current. Special attention should be considered for composite aircraft.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

b. Metallic Surface Bonding. All conducting objects on the exterior of the airframe must be electrically connected to the airframe through mechanical joints, conductive hinges, or bond straps capable of conducting static charges and lightning strikes. Exceptions may

be necessary for some objects such as antenna elements, whose function requires them to be electrically isolated from the airframe. Such items should be provided with an alternative means to conduct static charges and/or lightning currents, as appropriate.

c. Static Bonds. All isolated conducting parts inside and outside the aircraft, having an area greater than 3 in² and a linear dimension over 3 inches, that are subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion, should have a mechanically secure electrical connection to the aircraft structure of sufficient conductivity to dissipate possible static charges. A resistance of less than 1 ohm when clean and dry will generally ensure such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.

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

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

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

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

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

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

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

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

h. Bonds must be installed to ensure that the structure and equipment are electrically stable and free from the hazards of lightning, static discharge, electrical shock, etc. To

ensure proper operation and suppression of radio interference from hazards, electrical bonding of equipment must conform to the manufacturer's specifications.

i. Use of bonding testers is strongly recommended.

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

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

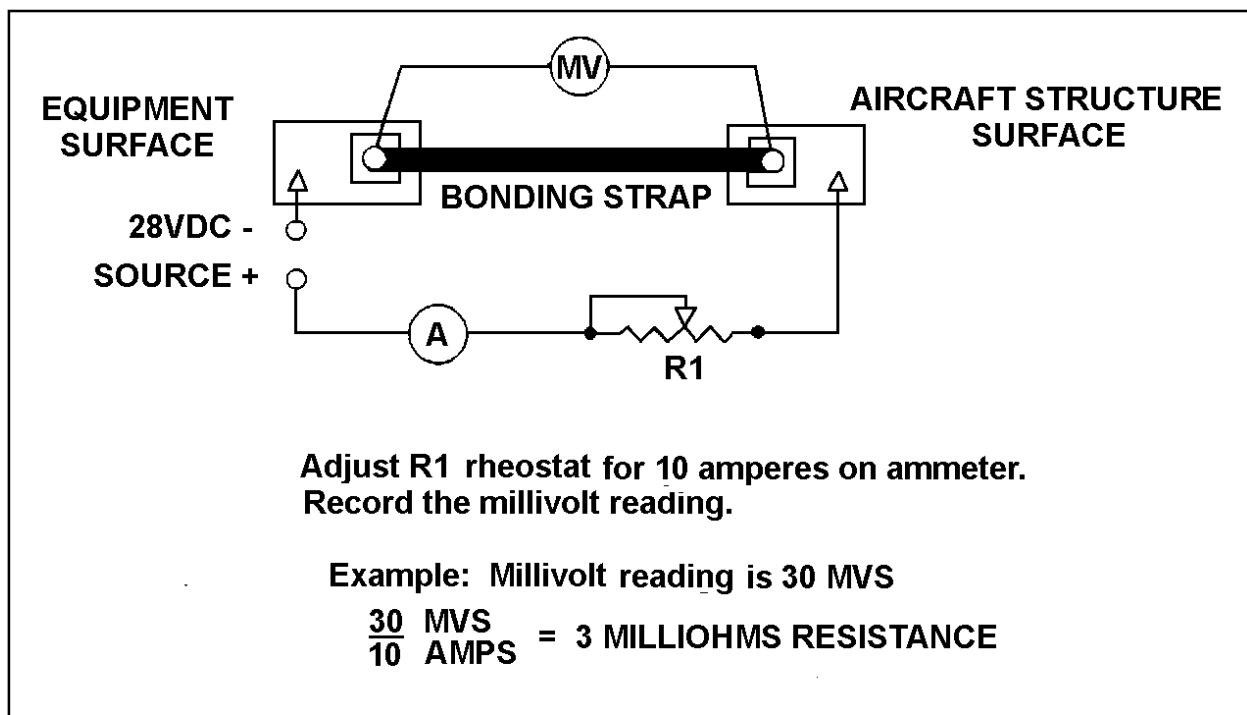


Figure 11-19. Millivolt drop test.

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

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

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

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

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

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

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

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

<p>The diagram illustrates a stud bonding assembly. A screw or bolt passes through a structure. Washers A, B, C, D, E, and F are positioned around the bolt. Lockwashers E and F are also shown. A plain nut is used to secure the assembly. A terminal (limit to 4) is attached to the bolt. A locknut is also shown.</p>							
Aluminum Terminal and Jumper							
Structure	Screw or Bolt and Lock nut	Plain nut	Washer A	Washer B	Washer C & D	Lock washer E	Lock washer F
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	Cadmium Plated Steel	Cadmium Plated Steel	Aluminum Alloy	Aluminum Alloy	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum
Magnesium Alloys ¹							
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	None	None	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel
Steel, Corrosion Resisting	Corrosion Resisting Steel	Corrosion Resisting Steel	None	None	Cadmium Plated Steel	Corrosion Resisting Steel	Corrosion Resisting Steel

¹ Avoid connecting copper to magnesium.

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

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

¹ Avoid connecting copper to magnesium.

² Use washers having a conductive finished treated to prevent corrosion, suggest AN960JD10L

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

<p>The diagram shows a cross-section of a bolt and nut assembly. A screw or bolt passes through a terminal plate (labeled 'TERMINAL LIMITED TO 4'). On the top side of the terminal plate is 'WASHER A'. Below the terminal plate is 'WASHER B'. Under 'WASHER B' is a 'LOCKWASHER'. Below the lockwasher is a 'LOCKNUT'. At the bottom of the assembly is 'WASHER C'.</p>					
Aluminum Terminal and Jumper					
Structure	Screw or bolt and nut plate	Lock-nut	Washer A	Washer B	Washer C
Aluminum Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum	None	Cadmium Plated Steel or Aluminum
Magnesium Alloys	Cadmium Plated Steel	Cadmium Plated Steel	Magnesium Alloy	None or Magnesium alloy	Cadmium Plated Steel or Aluminum
Steel, Cadmium Plated	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel or Aluminum
Steel, Corrosion 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	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	Aluminum ² Alloy	Cadmium Plated Steel
Magnesium Alloy ¹	Cadmium Plated Steel	Cadmium Plated Steel	Cadmium Plated Steel	None	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
¹ Avoid connecting copper to magnesium.					
² Use washers having a conductive finished treated to prevent corrosion, suggest AN960JD10L					

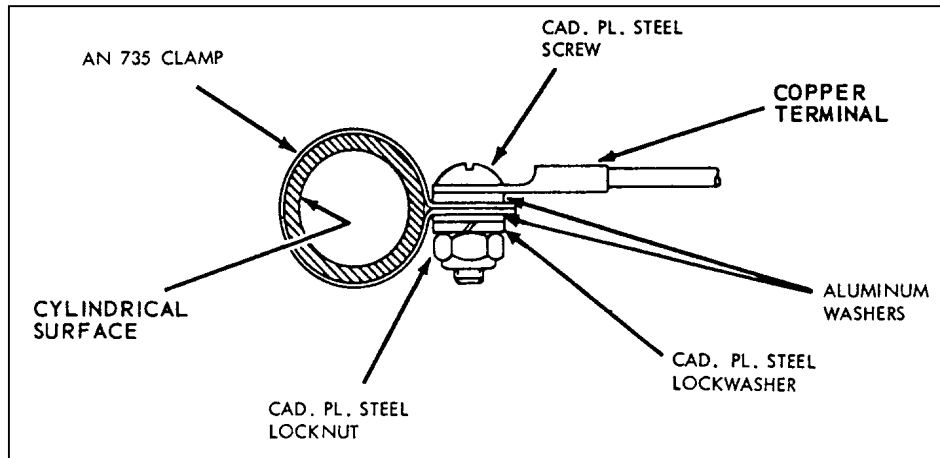


FIGURE 11-20. Copper jumper connector to tubular structure.

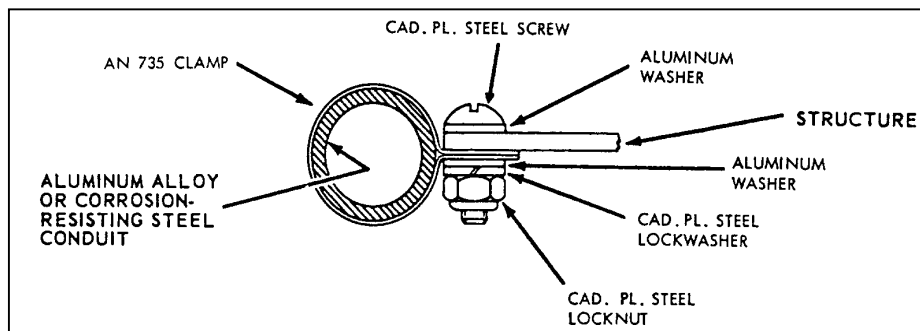


FIGURE 11-21. Bonding conduit to structure.

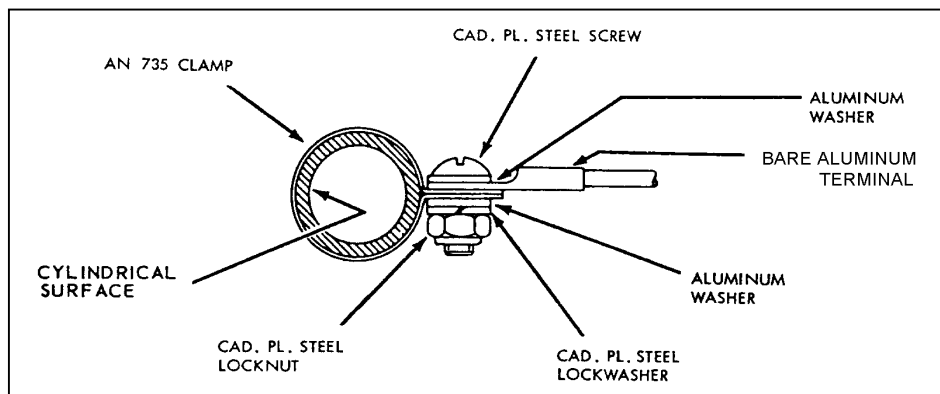


FIGURE 11-22. Aluminum jumper connection to tubular structure.

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

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

11-193. LIGHTNING PROTECTION

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

a. Control Surface Lightning Protection Bonding. Control surface bonding is intended to prevent the burning of hinges on a surface that receives a lightning strike; thus causing possible loss of control. To accomplish this bonding, control surfaces and flaps should have at least one 6500 circular mil area copper (e.g. 7 by 37 AWG size 36 strands) jumper

across each hinge. In any case, not less than two 6500 circular mil jumpers should be used on each control surface. The installation location of these jumpers should be carefully chosen to provide a low-impedance shunt for lightning current across the hinge to the structure. When jumpers may be subjected to arcing, substantially larger wire sizes of 40,000 circular mils or a larger cross section are required to provide protection against multiple strikes. Sharp bends and loops in such jumpers can create susceptibility to breakage when subjected to the inductive forces created by lightning current, and should be avoided.

b. Control Cable Lightning Protection

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

11-194. LIGHTNING PROTECTION FOR ANTENNAS AND AIR DATA PROBES.

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

11-195. STATIC-DISCHARGE DEVICE.

Means should be provided to bleed accumulated static charges from aircraft prior to

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

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

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

11-198.—11-204. [RESERVED.]

SECTION 16. WIRE MARKING

11-205. 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.

a. Each wire and cable should be marked with a part number. It is common practice for wire manufacturers to follow the wire material part number with the five digit/letter C.A.G.E. code identifying the wire manufacturer. Existing installed wire that needs replacement can thereby be identified as to its performance capabilities, and the inadvertent use of a lower performance and unsuitable replacement wire avoided.

b. The method of identification should not impair the characteristics of the wiring.

CAUTION: 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.

11-206. WIRE IDENTIFICATION. To facilitate installation and maintenance, original wire-marking identification is to be retained. The wire identification marks should consist of a combination of letters and numbers that identify the wire, the circuit it belongs to, its gauge size, and any other information to relate the wire to a wiring diagram. All markings should be legible in size, type, and color.

11-207. IDENTIFICATION AND INFORMATION RELATED TO THE WIRE AND WIRING DIAGRAMS. The wire identification marking should consist of similar information to relate the wire to a wiring diagram.

11-208. PLACEMENT OF IDENTIFICATION MARKINGS. Identification markings should be placed at each end of the wire and at 15-inch maximum intervals along the length of the wire. Wires less than 3 inches long need not be identified. Wires 3 to 7 inches in length should be identified approximately at the center. Added identification marker sleeves should be so located that ties, clamps, or supporting devices need not be removed in order to read the identification.

The wire identification code must be printed to read horizontally (from left to right) or vertically (from top to bottom). The two methods of marking wire or cable are as follows:

a. Direct marking is accomplished by printing the cable's outer covering. (See figure 11-23.)

b. Indirect marking is accomplished by printing a heat-shrinkable sleeve and installing the printed sleeve on the wire or cables outer covering. Indirect-marked wire or cable should be identified with printed sleeves at each end and at intervals not longer than 6 feet. The individual wires inside a cable should be identified within 3 inches of their termination. (See figure 11-24.)

11-209. TYPES OF WIRE MARKINGS. The preferred method is to mark directly on the wire. A successful requirement qualification should produce markings that meet the marking characteristics specified in MIL-W-5088 or AS50881A without causing insulation degradation. Teflon coated wires, shielded wiring, multi-conductor cable, and thermocouple wires usually require special sleeves to carry identification marks. There are some wire marking machines in the market that can be used to stamp directly on the type wires mentioned above. Whatever method of marking is used, the marking should be legible and

the color should contrast with the wire insulation or sleeve.

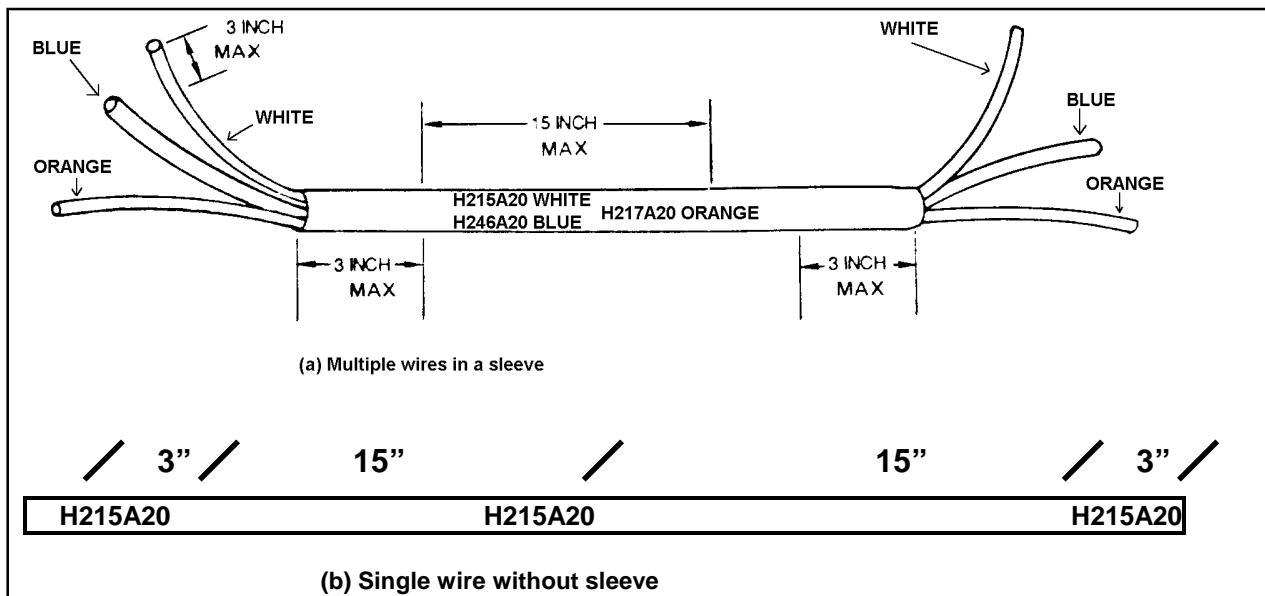


FIGURE 11-23. Spacing of printed identification marks (direct marking).

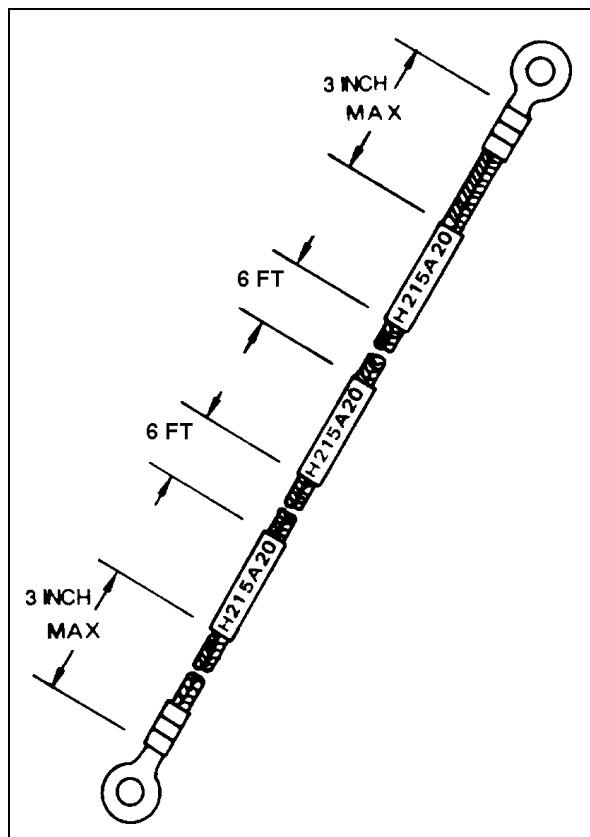


FIGURE 11-24. Spacing of printed identification marks (indirect marking).

a. Extreme care must, therefore, be taken during circuit identification by a hot stamp machine on insulation wall 10 mils or thinner.

b. Alternative identification methods such as "Laser Printing", "Ink Jet", and "Dot Matrix" are preferred. When such modern equipment is not available, the use of stamped identification sleeving should be considered on insulation wall thickness of 10 mils or less.

11-210. HOT STAMP MARKING. Due to widespread use of hot stamp wire marking, personnel should refer to SAE ARP5369, Guidelines for Wire Identification Marking using the Hot Stamp Process, for guidance on minimizing insulation damage. 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. The heat of the type set characters transfers the ink from the marking foil onto the wire.

a. Good marking is obtained only by the proper combination of temperature, pressure, and dwelling. Hot stamp will mark wire with an outside diameter of 0.038 to 0.25-inch.

b. Before producing hot stamp wire, it must be assured that the marking machine is properly adjusted to provide the best wire marking with the least wire insulation deterioration. The marking should never create an indent greater than 10 percent of the insulation wall.

CAUTION: The traditional Hot Stamp method is not recommended for use on wire with outside diameters of less than 0.035. (REF. SAE ARP5369). Stamping dies may cause fracture of the insulation wall and penetration to the conductor of these materials. When various fluids wet these opening in service, arcing and surface tracking damage wire bundles. Later in service, when various fluids have wet these openings, serious arcing and surface tracking will have damaged wire bundles.

11-211. DOT MATRIX MARKING. The dot matrix marking is imprinted onto the wire or cable very similar to that of a dot matrix computer printer. The wire must 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. De

pending on equipment configuration, dot matrix can mark wire from 0.037 to 0.5-inch outside diameter. Multi-conductor cable can also be marked.

11-212. INK JET MARKING. This is a “non-impact” 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.

a. Thermal cure inks must 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.

b. Ink jet marks the wire on the fly and makes a reasonably durable and legible mark without damaging the insulation. Ink jets normally mark wire from 0.030 to 0.25-inch outside diameter. Multiconductor cable can also be marked.

11-213. LASER MARKING. Of the variety of laser marking machines, UV lasers are proving to be the best. This method marks into the surface of the wire’s insulation without degradation to its performance. One common type of UV laser is referred to as an excimer laser marker. UV laser produces the most durable marks because it marks into the insulation instead of on the surface. However, excimer laser will only mark insulation that contain appropriate percentages of titanium dioxide (TiO₂). The wire can be marked on the fly. UV can mark from 0.030 to 0.25-inch outside diameter. The UV laser makes only gray marks and they appear more legible on white or pastel-colored insulation.

11-214. 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 should

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 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 alumel, chromel, iron, constantan, and copper constantan.

c. Coaxial cable should not be hot stamped directly. When marking coaxial cable, care should be taken not to deform the cable as this may change the electrical characteristics of the cable. When cables cannot be printed directly, they should 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 should be identified with printed sleeves at each end and at intervals not longer than 3 feet. Individual wires within a cable should be identified within 3 inches from their termination.

d. Multiconductor cable normally use identification sleeves for identifying unshielded, unjacketed cable.

e. High-temperature wire with insulation is difficult to mark (such as Teflon and fiberglass).

11-215. IDENTIFICATION TAPE. Identification tape can be used in place of sleeving, in most cases (i.e. polyvinylfluoride).

11-216. OPERATING CONDITIONS. For sleeving exposed to high temperatures (over 400 °F), materials such as silicone fiberglass should be used.

11-217. INSTALLATION OF PRINTED SLEEVES. Polyolefin sleeving should be used in areas where 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 11-17.

Table 11-17. Recommended size of identification sleeving.

Wire Size		Sleeving Size	
AN	AL	No.	Nominal ID (inches)
#24		12	.085
#22		11	.095
#20		10	.106
#18		9	.118
#16		8	.113
#14		7	.148
#12		6	.166
#10		4	.208
#8	#8	2	.263
#6	#6	0	.330
#4	#4	3/8 inch	.375
#2	#2	1/2 inch	.500
#1	#1	1/2 inch	.500
#0	#0	5/8 inch	.625
#00	#00	5/8 inch	.625
#000	#000	3/4 inch	.750
#0000	#0000	3/4 inch	.750

11-218. IDENTIFICATION OF WIRE BUNDLES AND HARNESSSES. The identification of wire bundles and harnesses is becoming a common practice and may be accomplished by the use of a marked sleeve tied in place or by the use of pressure-sensitive tape as indicated in figure 11-25.

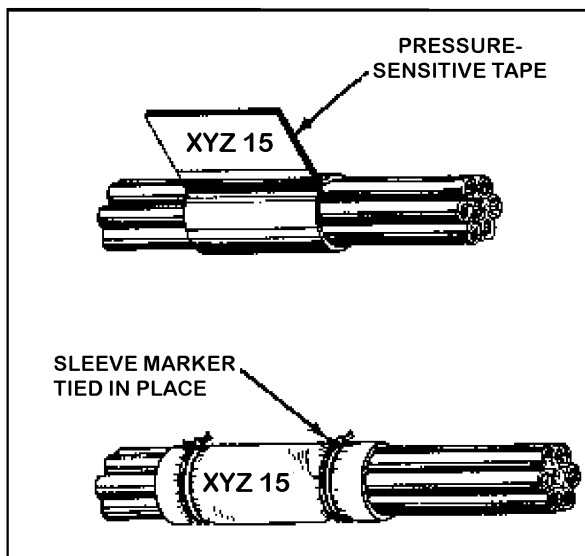


FIGURE 11-25. Identification of wire bundles and harnesses.

a. Wires for which identifications are reassigned after installation, may be remarked on sleeves at the termination of each wire segment. It may be necessary to reidentify such wires throughout their lengths to facilitate ease of maintenance.

b. For high-density harnesses, shielded, and jacketed multiconductor cables and when using nonsignificant wire identification, color coding or its alphanumeric equivalent may be interchanged within the same harnesses. The alphanumeric equivalent of the color code should be as set forth in MIL-STD-681.

11-219. 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 should be inserted over the proper wire or cable and heat-shrunk using the proper manufacturer recommended heating tool. (See figures 11-26 and 11-27.)

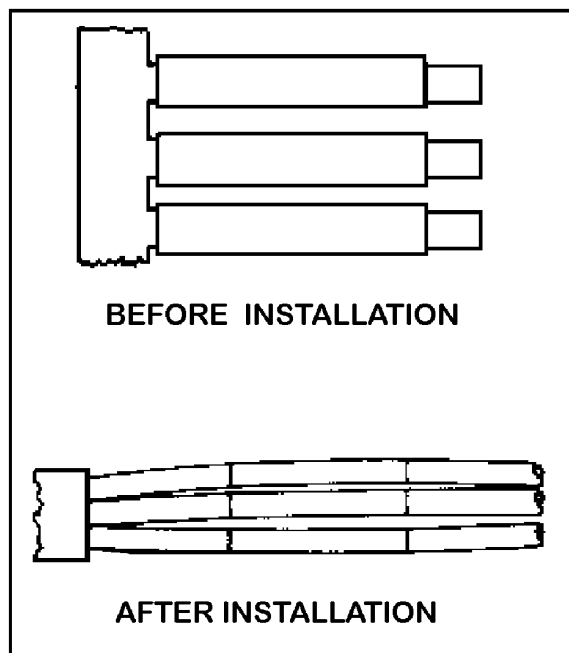


FIGURE 11-26. Standard sleeves (135 °C).

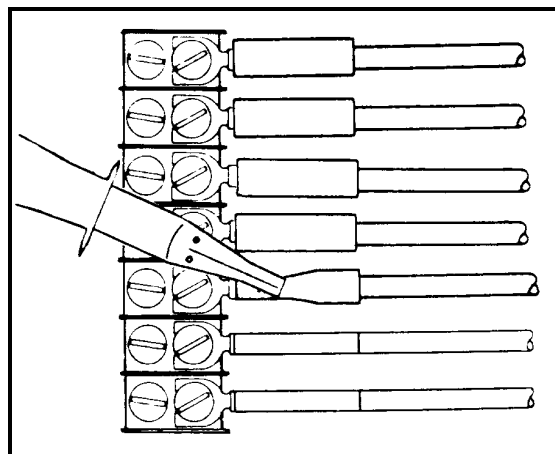


FIGURE 11-27. Installation of heat-shrinkable insulation sleeves.

11-220. SLEEVES AND CABLE MARKERS SELECTION. Sleeves and cable markers must be selected by cable size and operating conditions. (See tables 11-18 through 11-21).

a. 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 ban-

doliers, 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.

b. Markers are normally installed using the following procedure:

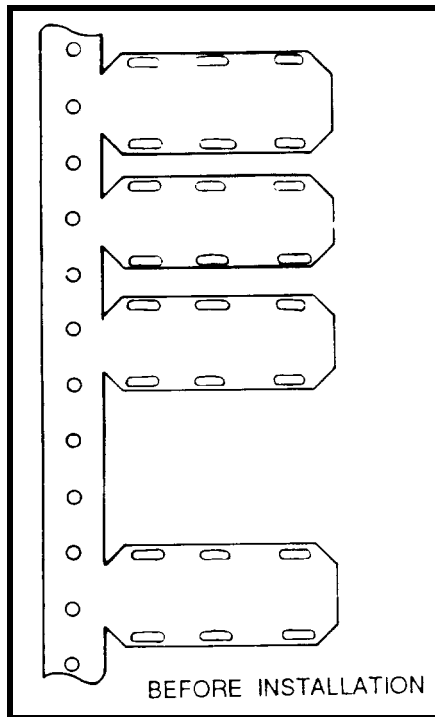


FIGURE 11-28. Cable markers.

(1) Select the smallest tie-down strap that will accommodate the outside diameter of the cable. (See table 11-22.)

(2) Cut the marking plate from the bandolier. (See figure 11-28.)

(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 figure 11-29.) Pull tip until strap is snug around cable.

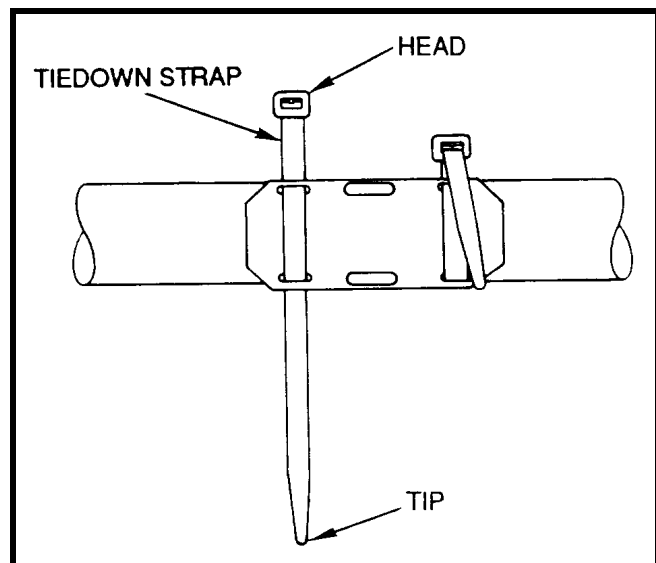


FIGURE 11-29. Tie-down strap installation.

TABLE 11-18. Selection table for standard sleeves.

Wire or Cable Diameter Range. (inches)		Markable Length *	Installed Sleeve Length (nom) (inches)	Installed Wall Thickness (max inches)	As-supplied Inside Diameter (min inches)
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

* Based on 12 characters per inch

TABLE 11-19. Selection table for thin-wall sleeves.

Wire or Cable Diameter Range (inches)		Markable Length *	Installed Sleeve Length (nom)	Installed Wall Thickness	As-supplied Inside Diameter
Min.	Max.	(inches)	(inches)	(max inches)	(min inches)
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
* Based on 12 characters per inch					

TABLE 11-20. Selection table for high-temperature sleeves.

Wire or Cable Diameter Range (inches)		Markable Length *	Installed Sleeve Length (nom)	Installed Wall Thickness	As-supplied Inside Diameter (min inches)
Min.	Max.	(inches)	(inches)	(max inches)	
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
* Based on 12 characters per inch					

TABLE 11-21. Selection table for cable markers.

Cable Diameter Range (inches)	Type of Cable Marker	Number of Attachment Holes	Number of Lines of Type	Marker Thickness (nom) (inches)
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

TABLE 11-22. Plastic tie-down straps (MS3367, Type I, Class 1).

Cable Diameter (inches)		Tie-down Strap MS3367-	Strap Identification *	Installation Tool	Tension Setting
Min	Max				
1/16	5/8	4-9	Miniature (MIN)	MS90387-1	2
1/16	1 1/4	5-9	Intermediate (INT)	MS90387-1	4
1/16	4	2-9	Standard (STD)	MS90387-1	6
3/16	8	6-9	Heavy (HVV)	MS90387-2	6
* The specified tool tension settings are for typical cable application. Settings less than or greater than those specified may be required for special applications.					

(4) Select the applicable installation tool and move the tension setting to the correct position. (See figure 11-30.)

(5) Slide tip of strap into opening in the installation tool nose piece. (See figure 11-30.)

(6) Keeping tool against head of tie-down strap, ensure gripper engages tie-down strap, and squeeze trigger of installation tool until strap installation is completed as shown in figure 11-31.

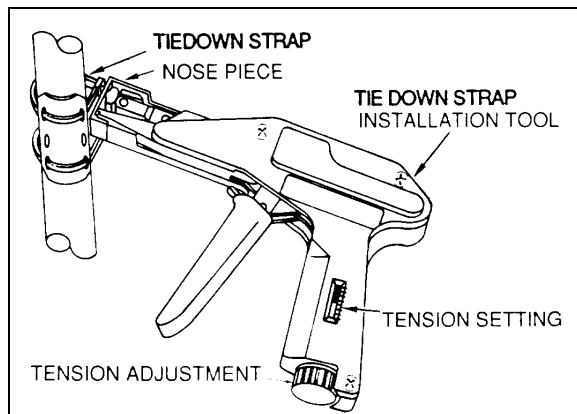


FIGURE 11-30. Tie-down strap installation tool.

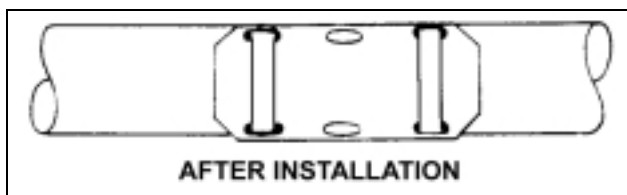


FIGURE 11-31. Completed installation.

11-221. TEMPORARY WIRE AND CABLE MARKING PROCEDURE. A temporary wire marking procedure follows but should be used only with caution and with plans for future permanence. (See figure 11-32.)

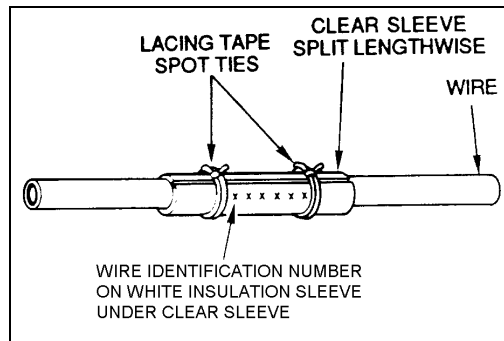


FIGURE 11-32. Temporary wire identification marker.

a. With a pen or a typewriter, write wire number on good quality white split insulation sleeve.

b. Trim excess white insulation sleeve, leaving just enough for one wrap around wire to be marked, with number fully visible.

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

d. Obtain clear plastic sleeve that is long enough to extend 1/4 inch past white insulation sleeve marker edges and wide enough to overlap itself when wrapped around white insulation and wire.

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

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

11-222. MARKER SLEEVE INSTALLATION AFTER PRINTING. The following general procedures apply:

a. Hold marker, printed side up, and press end of wire on lip of sleeve to open sleeve. (See figure 11-33.)

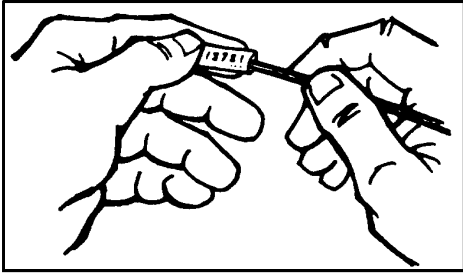


FIGURE 11-33. Inserting wire into marker.

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

c. Push sleeve onto wire with a gentle twisting motion.

d. Shrink marker sleeve, using heat gun with shrink tubing attachment. (See figure 11-34.)

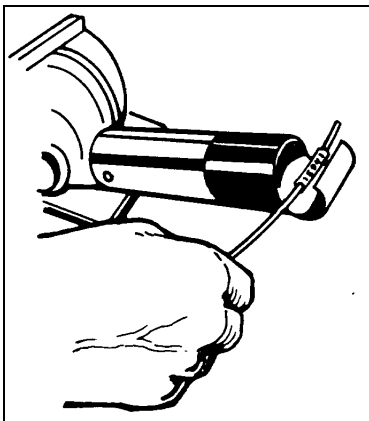


FIGURE 11-34. Shrinking marker on wire.

11-223.—11-229. [RESERVED.]

SECTION 17. CONNECTORS

11-230. GENERAL. There is a multitude of types of connectors. Crimped contacts are generally used. Some of the more common are the round cannon type, the rectangular, and the module blocks. Environmental-resistant connectors should be used in applications subject to fluids, vibration, thermal, mechanical shock, and/or corrosive elements. When HIRF/Lightning protection is required, special attention should be given to the terminations of individual or overall shields. 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 must 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 must be followed.

11-231. SELECTION. . Connectors should 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 an hermetic seal. (Reference SAE ARP 1308, Preferred Electrical Connectors For Aerospace Vehicles and Associated Equipment.) A replacement connector of the same basic type and design as the connector it replaces should be used. With a crimp type connector for any electrical connection, the proper insertion, or extraction tool must 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 un-

intentional grounding. Connectors that are susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly.

11-232. TYPES OF CONNECTORS. Connectors must be identified by an original identification number derived from MIL Specification (MS) or OAM specification. Figure 11-35 provides some examples of MS connector types. Several different types are shown in figures 11-36 and 11-37.

a. Environmental Classes. Environment-resistant connectors are used in applications where they will probably be subjected to fluids, vibration, thermal, mechanical shock, corrosive elements, etc. Firewall class connectors incorporating these same features should, 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 should 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.

b. Rectangular Connectors. The rectangular connectors are typically used in applications where 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 which 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.

c. 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 where a number of wires are connected for power or signal distribution.

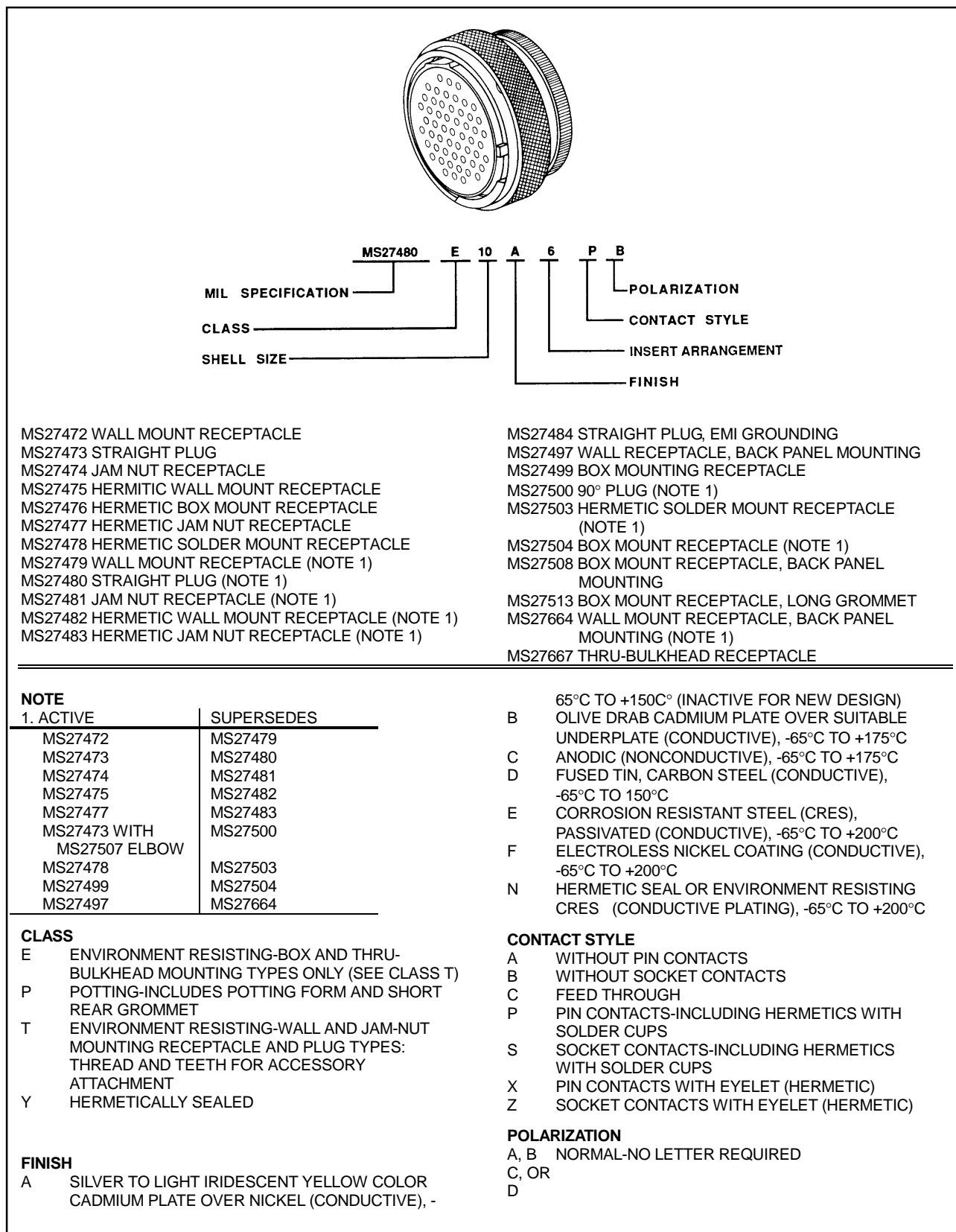


FIGURE 11-35. Connector information example.

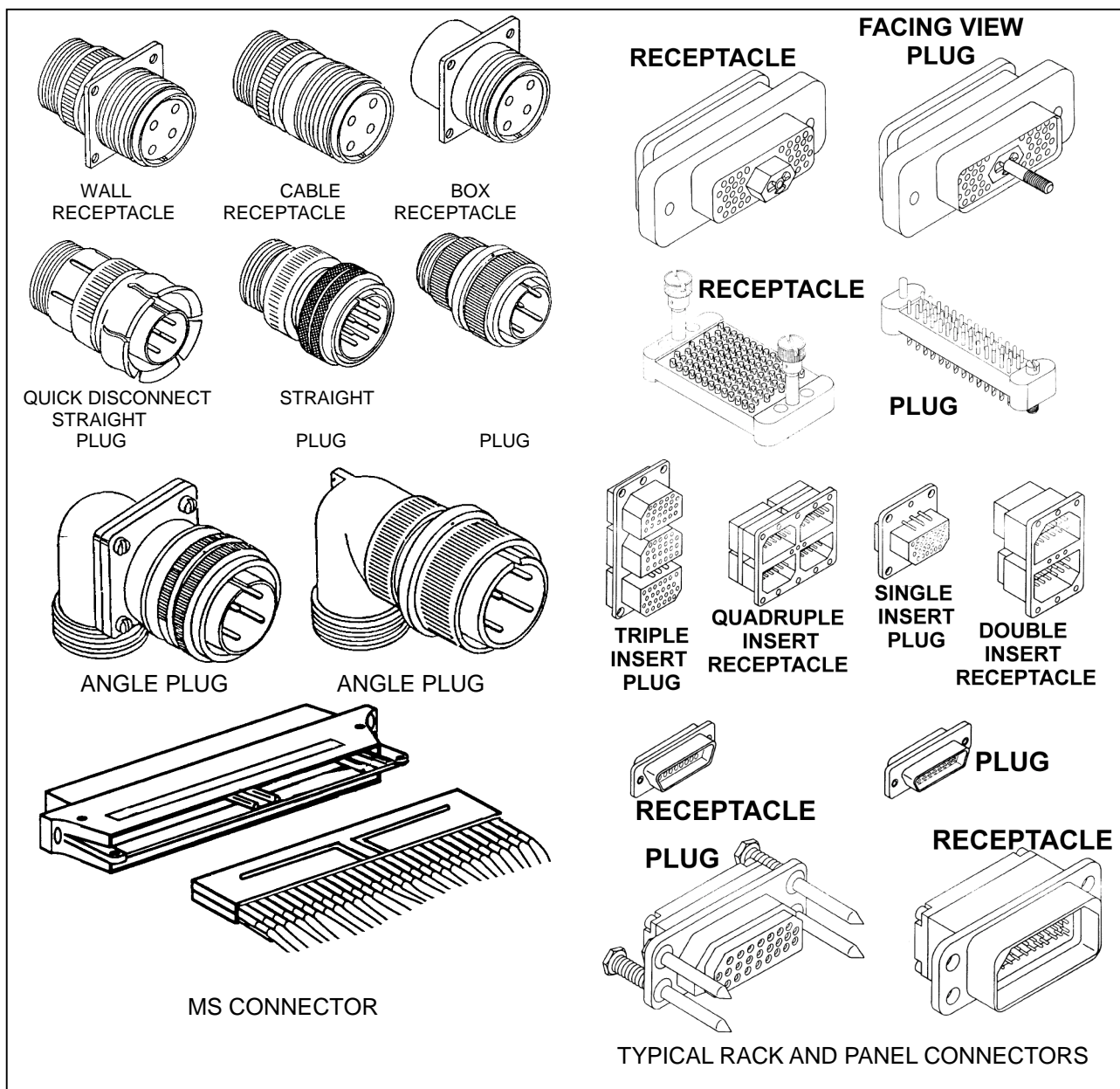


FIGURE 11-36. Different types of connectors.

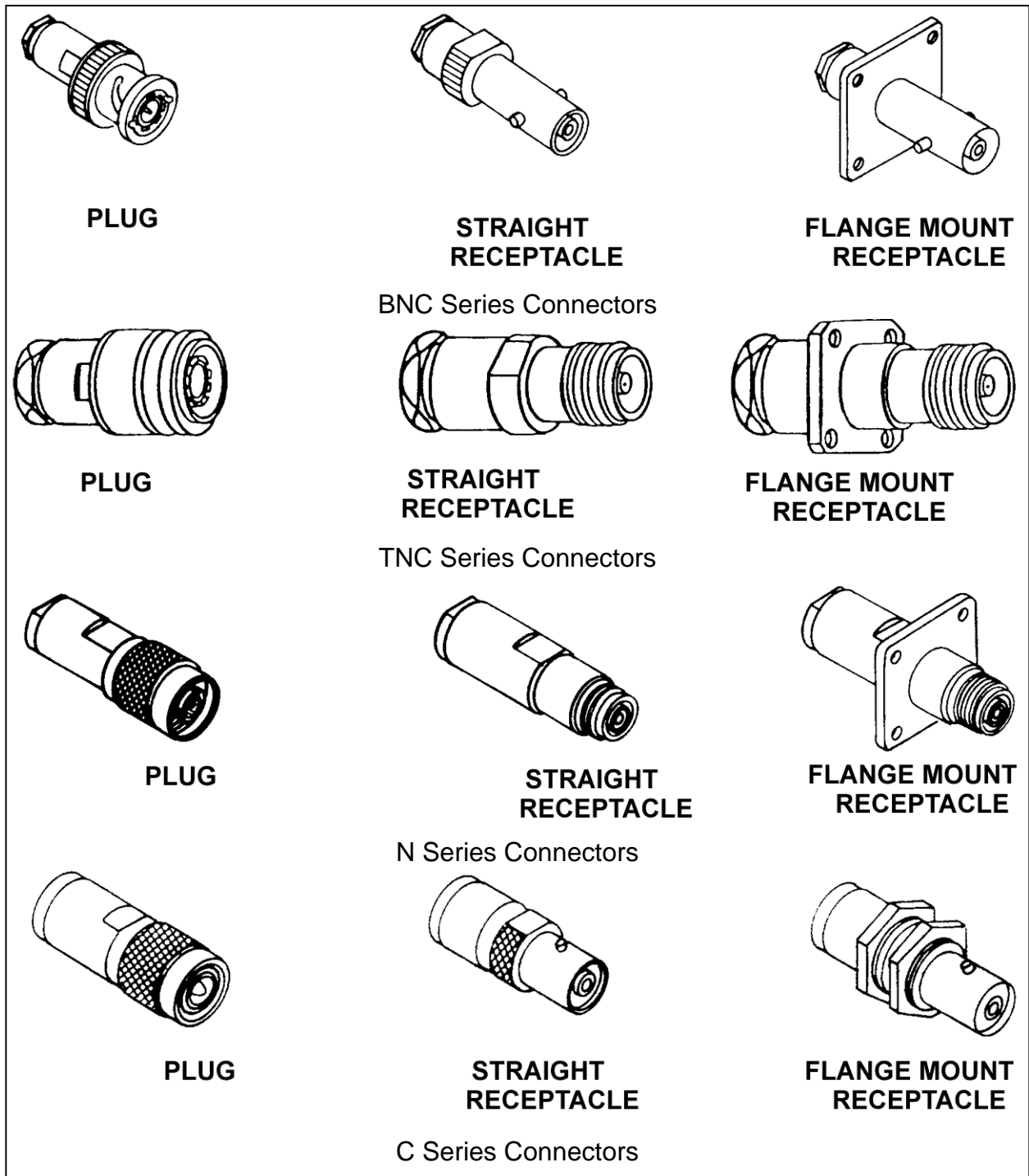


FIGURE 11-37. Coax cable connectors.

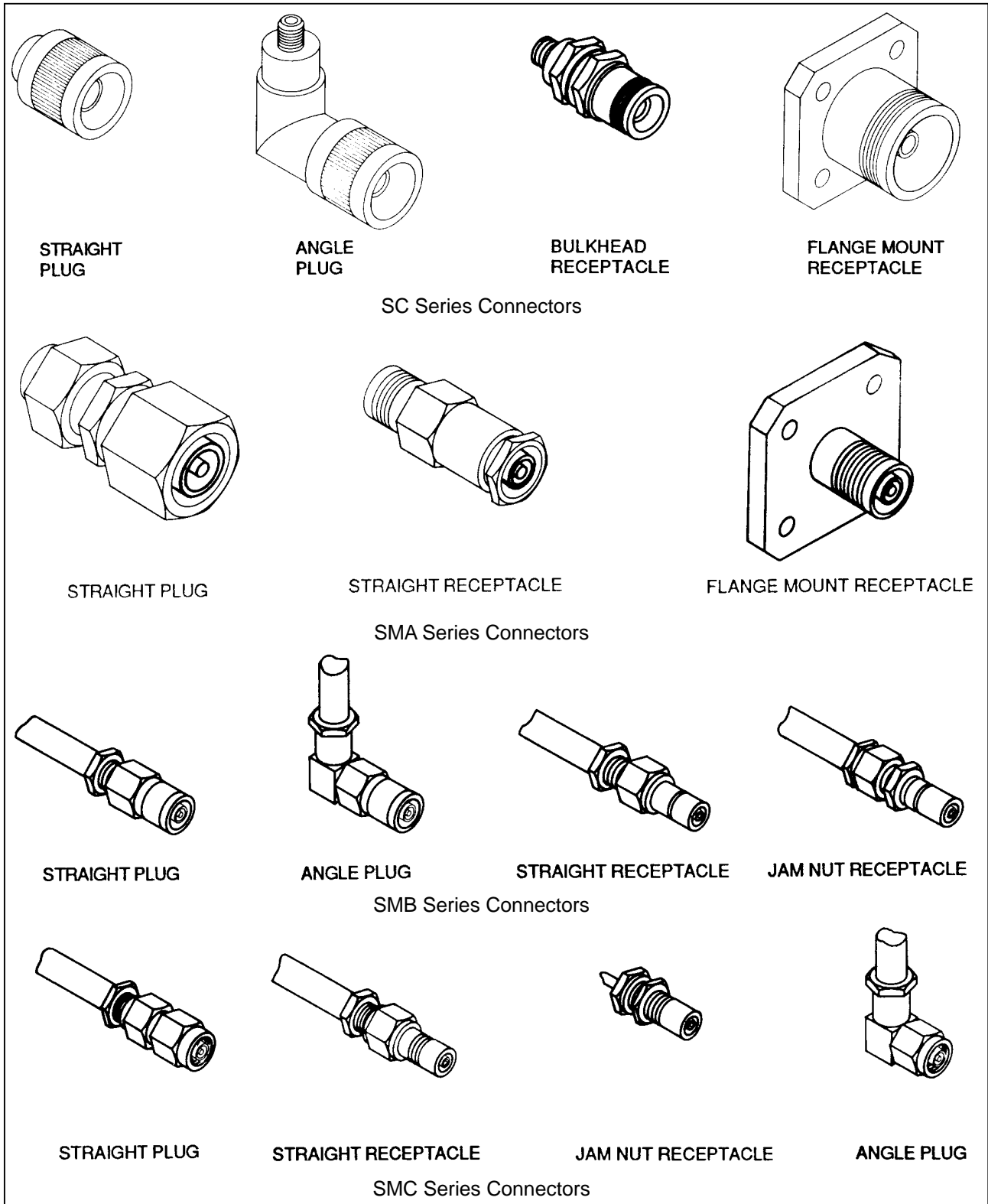


FIGURE 11-37. Coax cable connectors (continued).

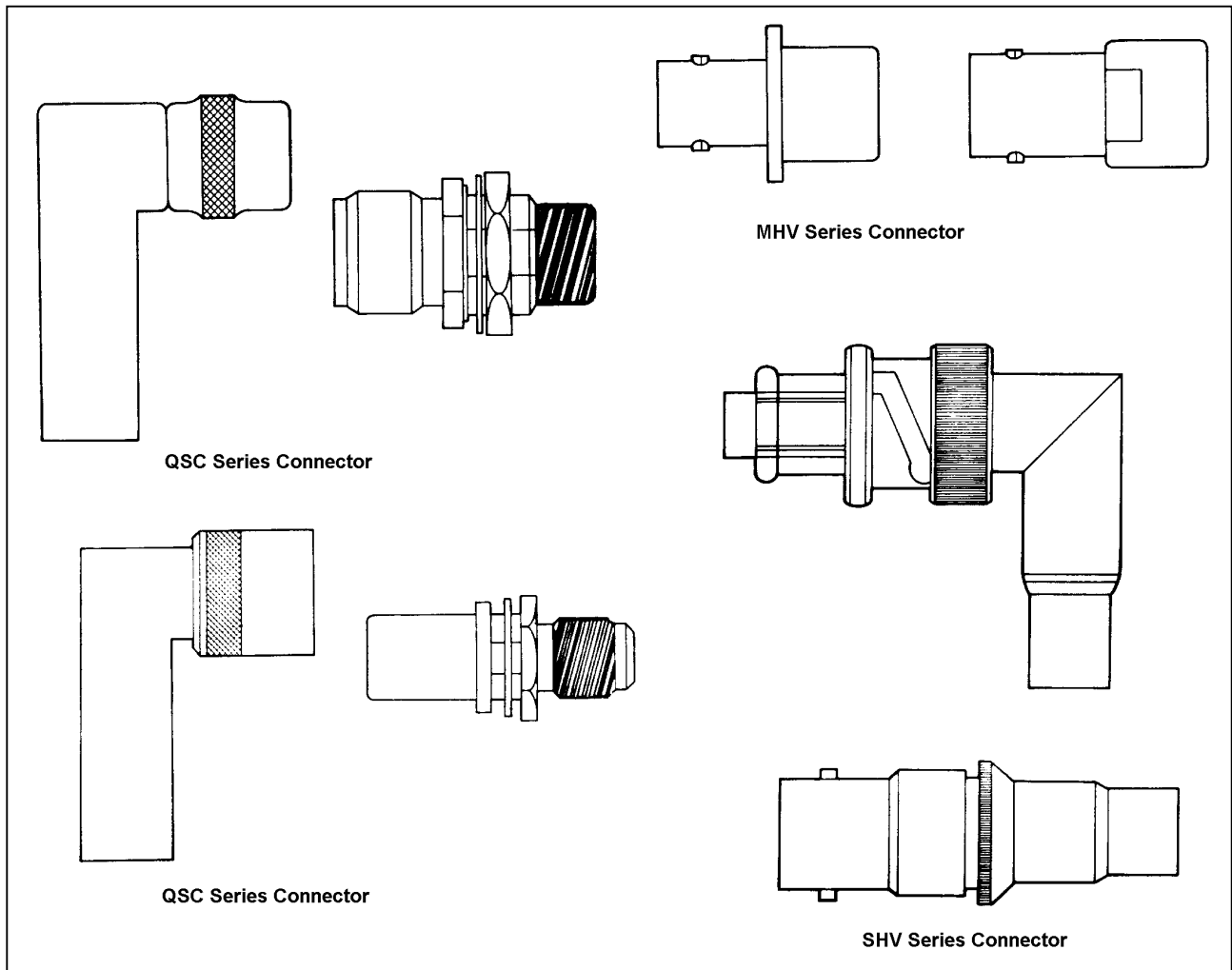


FIGURE 11-37. Coax cable connectors (continued).

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 environment-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 when the ability to disconnect the wires is desired. The in-line terminal junction is environment-resistant. The terminal junction splice is small and may be tied to the surface of a wire bundle when approved by the OAM.

11-233. VOLTAGE AND CURRENT RATING. Selected connectors must 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 should be derated. It is good engineering practice to conduct preliminary testing in any situation where 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 should 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 should be covered in the specifications.

11-234. 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. Connectors must have all available contact cavities filled with wired or unwired contacts. Unwired contacts should be provided with a plastic grommet sealing plug.

11-235. INSTALLATION.

a. Redundancy. Wires that perform the same function in redundant systems must be routed through separate connectors. On systems critical to flight safety, system operation wiring should 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 practicable. These steps can reduce an aircraft's susceptibility to incidents that might result from connector failures.

b. Adjacent Locations. Mating of adjacent connectors should not be possible. In order to ensure this, adjacent connector pairs must be different in shell size, coupling means, insert arrangement, or keying arrangement. When such means are impractical, wires should 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.

c. Sealing. Connectors must be of a type that exclude moisture entry through the use of peripheral and interfacial seal that are compressed when the connector is mated. Moisture entry through the rear of the connector must 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 should be considered only where other means cannot be used. Unwired spare contacts should have a correctly sized plastic plug installed. (See section 19.)

d. Drainage. Connectors must be installed in a manner which ensures that moisture and fluids will drain out of and not into the connector when unmated. Wiring must be routed so that moisture accumulated on the bundle will drain away from connectors. When connectors must be mounted in a vertical position, as through a shelf or floor, the connectors must 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.

e. Wire Support. A rear accessory backshell must be used on connectors that are not enclosed. Connectors having very small size wiring, or are subject to frequent maintenance activity, or located in high-vibration areas must be provided with a strain-relief-type backshell. The wire bundle should be protected from mechanical damage with suitable cushion 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 should not impart tension on wires between the clamp and contact.

f. Slack. Sufficient wire length must 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.

g. Identification. Each connector should have a reference identification that is legible throughout the expected life of the aircraft.

11-236. FEED-THROUGH BULKHEAD WIRE PROTECTION. Feed-through bushing protection should be given to wire bundles which pass through bulkheads, frames, and other similar structure. 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.

11-237. 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 where 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.

11-238. 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 should 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 must not revert to liquid or become gummy or sticky due to high humidity or contact with chemical fluids.

a. 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.

b. Potting compounds normally cure at temperatures of 70 °F to 76 °F. If the mixed compound is not used at once, the working pot life (normally 90 minutes) can be prolonged by storing in a deep freeze at -20 °F 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.

c. Mixed compounds that are not to be used immediately should be cooled and thawed quickly to avoid wasting the short working life. Chilled compounds should be thawed by blowing compressed air over the outside of the container. Normally the compound will be ready for use in 5 to 10 minutes.

CAUTION: Do not use heat or blow compressed air into the container when restoring the compound to the working temperature.

11-239. 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 due to vibration.

a. Connectors specifically designed for potting compounds should be potted to provide environment resistance. An o-ring or sealed gasket should 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, should also be considered. To facilitate circuit changes, spare wires may be installed to all unused contacts prior to filling the connector with potting compound.

b. Connect wires to all contacts of the connector prior to the application of the potting compound. Wires that are not to be used should be long enough to permit splicing at a later date. Unused wires should be as shown in figure 11-38 and the cut ends capped with heat-shrinkable caps or crimped insulated end caps such as the MS 25274 prior to 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 °F to 75 °F or carefully placed in a drying oven at 100 °F for 3 to 4 hours. In all cases follow manufacturer's instructions.

11-240. THROUGH BOLTS. Through bolts are sometimes used to make feeder connections through bulkheads, fuselage skin, or firewalls. Mounting plates for through bolts must be a material that provides the necessary fire barrier, insulation, and thermal properties for the application. Sufficient cross section should 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.

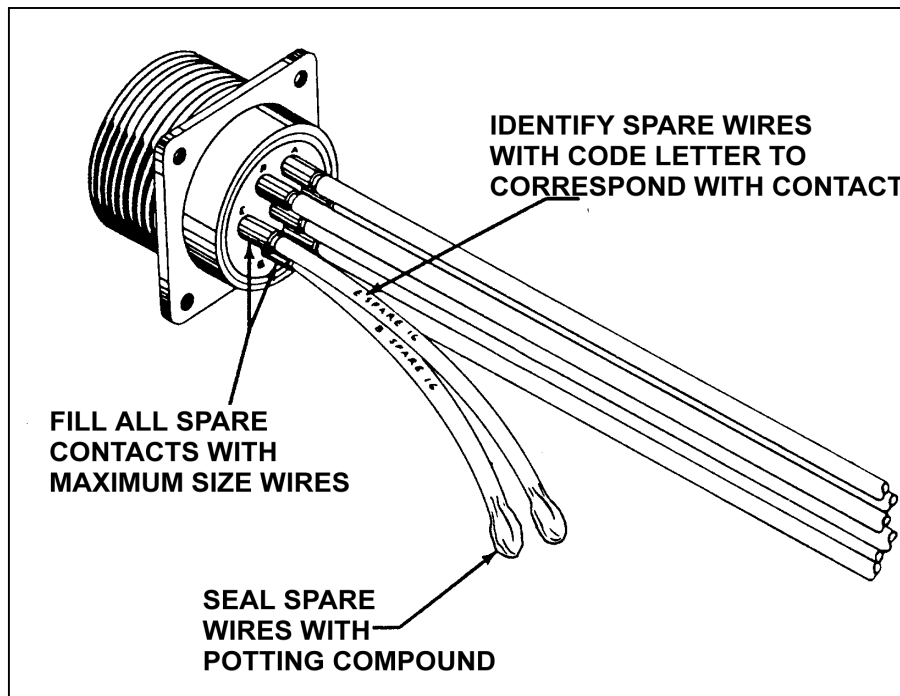


FIGURE 11-38. Spare wires for potting connector.

11-241.—11-247. [RESERVED.]

SECTION 18. CONDUITS

11-248. 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. Conduit should be inspected for: proper end fittings; absence of abrasion at the end fittings; proper clamping; distortion; adequate drain points which are free of dirt, grease, or other obstructions; and freedom from abrasion or damage due to moving objects, such as aircraft control cables or shifting cargo.

11-249. SIZE OF CONDUIT. Conduit size should 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 (I.D.) about 25 percent larger than the maximum diameter of the wire bundle.

11-250. CONDUIT FITTINGS. Wire is vulnerable to abrasion at conduit ends. Suitable fittings should 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 should be flared to prevent wire insulation damage. Conduit should be supported by use of clamps along the conduit run.

11-251. CONDUIT INSTALLATION. Conduit problems can be avoided by following these guidelines:

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

b. Provide drainholes at the lowest point in a conduit run. Drilling burrs should be carefully removed.

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

11-252. RIGID CONDUIT. Conduit sections that have been damaged should be repaired to preclude injury to the wires or wire bundle which may consume as much as 80 percent of the tube area. Minimum acceptable tube bend radii for rigid conduit are shown in table 11-23. Kinked or wrinkled bends in rigid conduits are not recommended and should be replaced. Tubing bends that have been flattened into an ellipse and the minor diameter is less than 75 percent of the nominal tubing diameter should be replaced because the tube area will have been reduced by at least 10 percent. Tubing that has been formed and cut to final length should be deburred to prevent wire insulation damage. When installing replacement tube sections with fittings at both ends, care should be taken to eliminate mechanical strain.

TABLE 11-23. Bend radii for rigid conduit.

Nominal Tube O.D. (inches)	Minimum Bend Radii (inches)
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

11-253. FLEXIBLE CONDUIT. Flexible aluminum conduit conforming to Specification 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 MIL-C-7931 is available and normally used instead of flexible aluminum where necessary to minimize radio interference. Also available is a plastic flexible tubing. (Reference MIL-T-8191A.) 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 should be centered over the cutting reference mark with the saw

cutting through the tape. After cutting the flexible conduit, the transparent tape should 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 11-24.

TABLE 11-24. Minimum bending radii for flexible aluminum or brass conduit.

Nominal I.D. of conduit (inches)	Minimum bending radius inside (inches)
3/16	2 1/4
1/4	2 3/4
3/8	3 3/4
1/2	3 3/4
5/8	3 3/4
3/4	4 1/4
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

11-254.—11-259. [RESERVED.]

SECTION 19. UNUSED CONNECTORS AND UNUSED WIRES

11-260. 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 pre-insulated closed end connector or 1 inch piece of insulating tubing folded and tied back.

11-261. QUICK REFERENCE CHART. A quick reference chart of unused connector contact cavity requirements is given in table 11-25. These requirements apply to harness manufacturing or connector replacement only.

11-262. UNPRESSURIZED AREA CONNECTORS. Connectors may be installed in unpressurized areas of the aircraft. Unused connector contact cavities installed in unpressurized areas should be properly sealed as follows:

a. Firewall Connectors Installations.

Firewall unused connector contact cavities should be filled with spare contacts and stub wires. (See figure 11-39.)

(1) Construct stub wires using high temperature wire (260 °C). Ensure that stub wires are of the same type of wires in the bundle.

(2) Crimp the proper contact, for the connector and cavity being used, onto the wire. Install the crimped contact into the unused cavity.

(3) Extend stub wires beyond the back of the connector clamp from 1.5 to 6 inches. Feather trim stub wires to taper wire bundle.

(4) Secure wire ends with high tem

perature (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.

b. Non-firewall Connector Installations.

In this type of installation all unused connector cavities must 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 Teflon sealing plugs or rods. (See figure 11-40.) Rods shall be cut so that they extend 1/8 to 1/4 inch beyond the surface of the grommet when bottomed against the end of the spare contact. (See table 11-26 for dimensions.)

11-263. PRESSURIZED AREAS. Connectors installed in pressurized areas of the aircraft may be divided into two main installation categories, sealed and unsealed.

a. Sealed connector installations. Sealed connectors installed in pressurized areas must have their unused contact cavities filled with Teflon sealing plugs or rods. (See figure 11-40.) Installation of spare contacts is optional, except for future wiring addition requirements. (See paragraph 11-234). No stub wires are required.

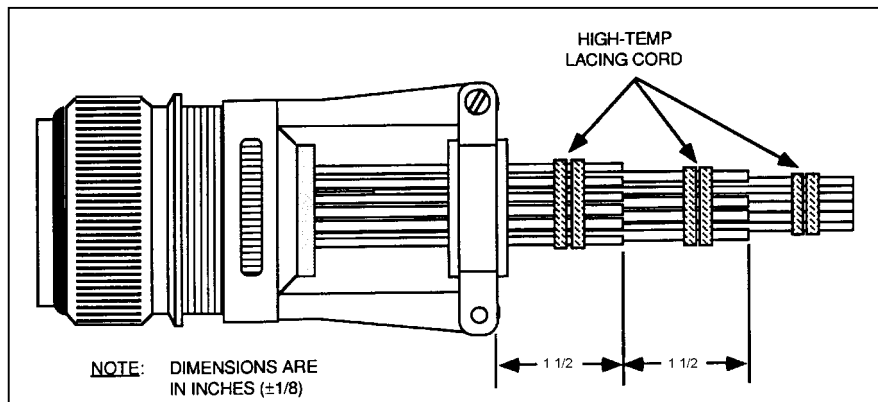
b. Unsealed Connector Installations. It is not required to fill unused contact cavities of unsealed connectors installed in pressurized areas with Teflon sealing plugs or rods. Installation of spare contacts is optional, except for future wiring addition requirements. (See paragraph 11-234.)

TABLE 11-25. Contact cavity sealing-quick reference.

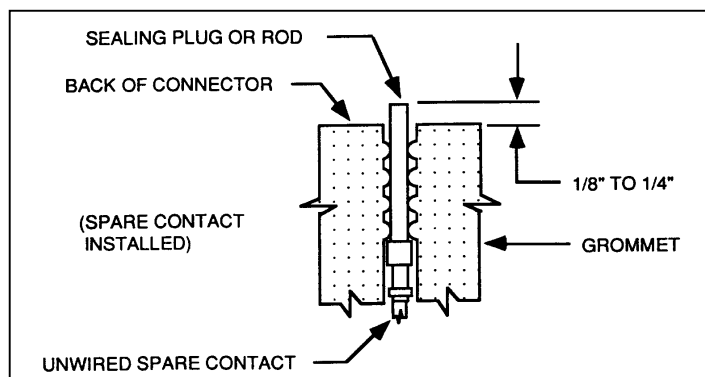
Sealing Means	Connector Installation Types	
	Unpressurized Area	
	Firewall	Non-Firewall
Sealing Plugs or Teflon Sealing Rods	No	Yes
Stub Wires (Note 2)	Yes	No
Spare Contacts	Yes	Yes

NOTE 1: 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 11-26 for sealing rod dimensions.)

NOTE 2: Stub wires must be of the same type as the other wires of the bundle.

**FIGURE 11-39.** Stub wire installation.**TABLE 11-26.** Sealing rod dimensions.

CONTACT SIZE (AWG)	DIAMETER (INCHES)	ROD LENGTH (INCHES)	
		MIN	MAX
20	1/16	5/8"	3/4"
16	3/32	7/8"	1"
12	1/8	7/8"	1"

**FIGURE 11-40.** Sealing unused contact cavities-unpressurized areas-(cut-away view).**11-264.—11-270. [RESERVED.]**

SECTION 20. ELECTRICAL AND ELECTRONIC SYMBOLS

11-271. GENERAL. The electrical and electronic symbols shown here are those that are likely to be encountered by the aviation maintenance technician. They are in accordance with ANSI-Y32.2-1975.

11-272. SYMBOLS. Only those symbols associated with aircraft electrical and electronic wiring have been listed in general. Refer to ANSI-Y32.2-1975 for more specific detail on each symbol.

TABLE 11-27. Electronic/Electrical Symbols.

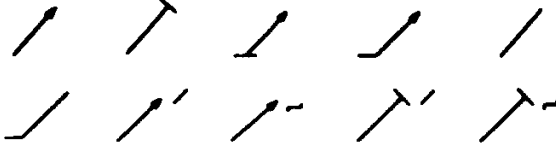




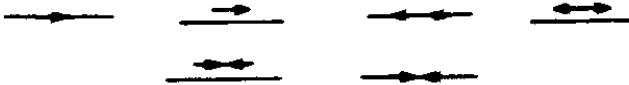




Symbol	Meaning
	Adjustability Variability
	Radiation Indicators
	Physical State Recognition
	Test-Point Recognition
	Polarity Markings
	Direction of Flow of Power, Signal, or Information
	Kind of Current
	Envelope Enclosure
	Shield Shielding
	Special Connector or Cable Indicator

TABLE 11-27. Electronic/Electrical Symbols (continued).


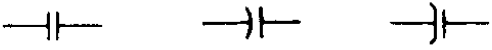
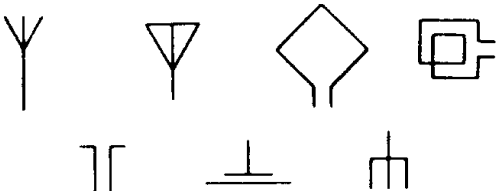




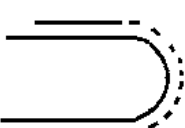

Symbol	Meaning
	Resistor
	Capacitor
	Antenna
	Battery
	Thermal Element Thermomechanical Transducer
	Thermocouple
	Spark Gap Ignitor Gap
	Continuous Loop Fire Detector (Temperature Sensor)
	Ignitor Plug

TABLE 11-27. Electronic/Electrical Symbols (continued).

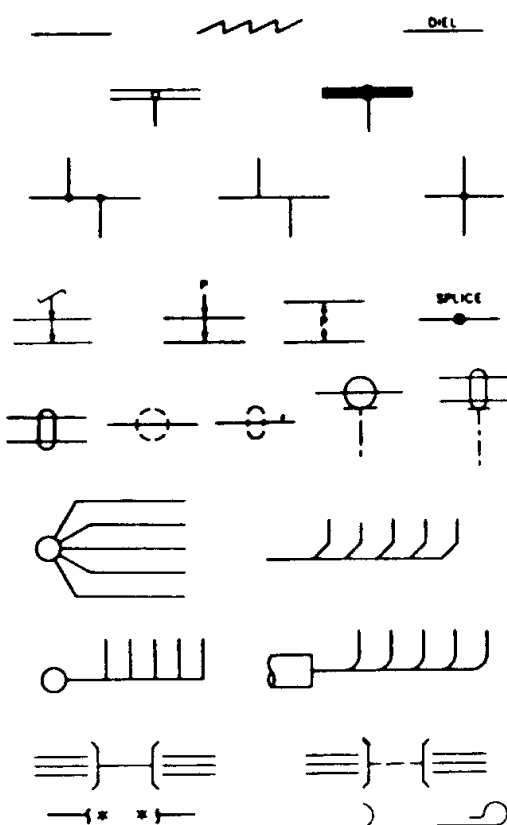
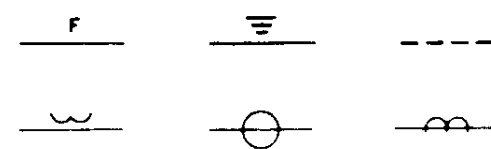
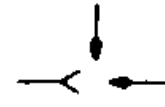

Symbol	Meaning
	<p>Transmission Patch Conductor Cable Wiring</p>
<p>F S T V</p> 	<p>Distribution Lines Transmission Lines</p>
	<p>Alternative or Conditioned Wiring</p>
	<p>Associated or Future</p>

TABLE 11-27. Electronic/Electrical Symbols (continued).

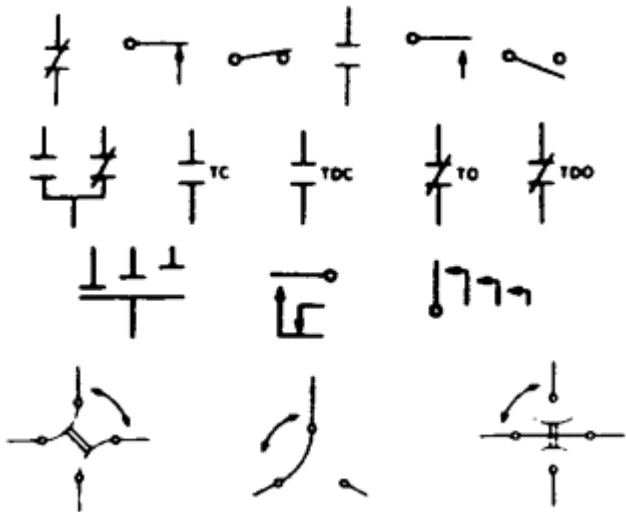
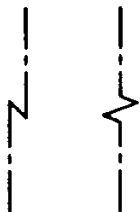
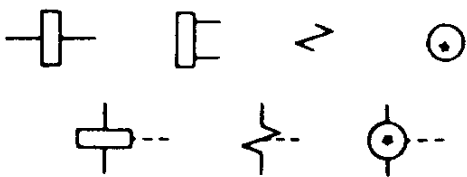
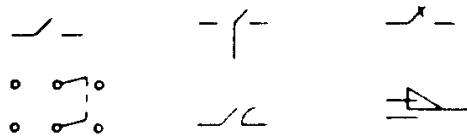

Symbol	Meaning
	Basic Contact Assemblies
	Magnetic Blowout Coil
	Operating Coil Relay Coil
	Switch
	Pushbutton, Momentary, or Spring- Return

TABLE 11-27. Electronic/Electrical Symbols (continued).

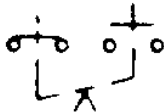
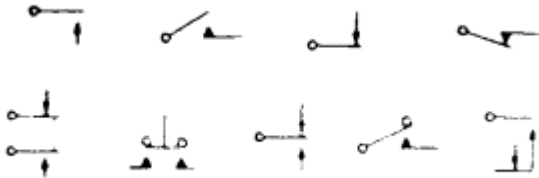
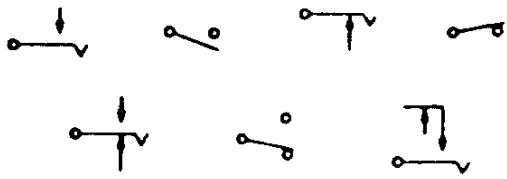

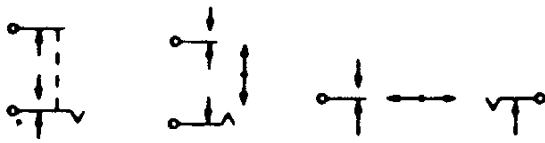
Symbol	Meaning
	Two-Circuit, Maintained, or Not Spring-Return
	Nonlocking Switching, Momentary, or Spring-Return
	Locking Switch
	Combination Locking and Nonlocking Switch
	Key-Type Switch Lever Switch

TABLE 11-27. Electronic/Electrical Symbols (continued).

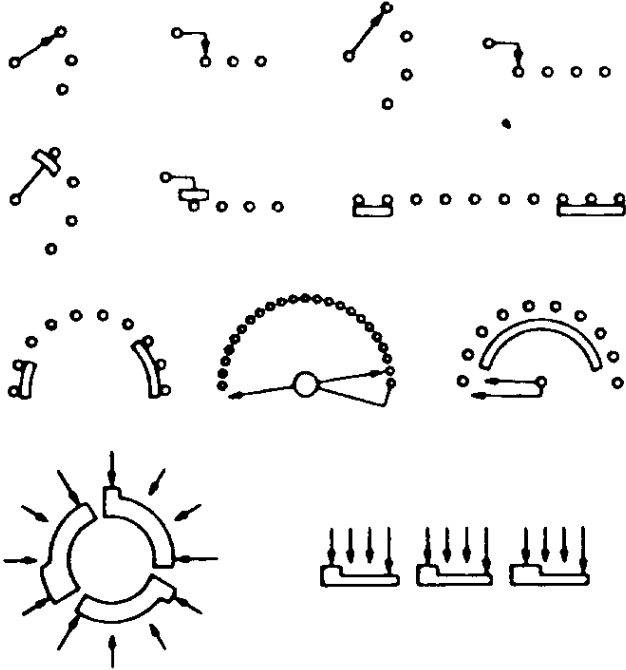

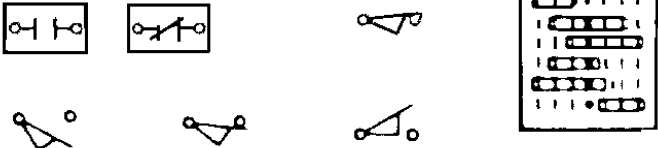
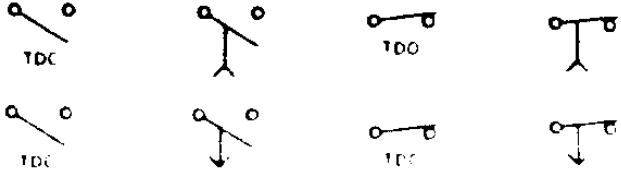

Symbol	Meaning
	Selector or Multiposition Switch
	Safety Interlock
	Limit Switch Sensitive Switch
	Switches with Time-Delay Feature
	Flow-Actuated Switch

TABLE 11-27. Electronic/Electrical Symbols (continued).







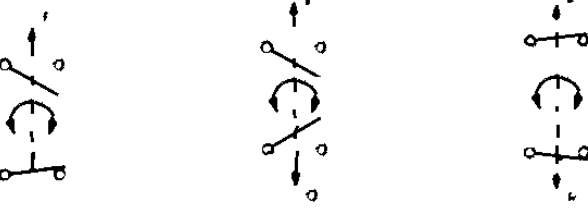
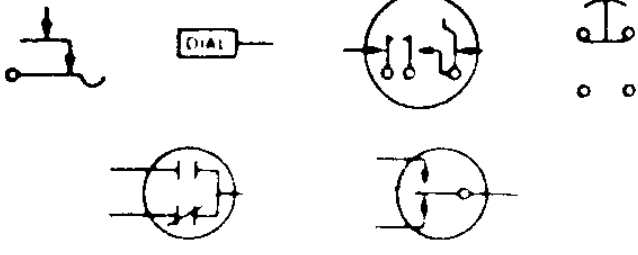
Symbol	Meaning
	Liquid-Level Actuated Switch
	Pressure- or Vacuum-Actuated Switch
	Temperature-Actuated Switch
	Thermostat
	Flasher Self-Interrupting Switch
	Foot-Operated Switch Foot Switch
	Switch Operated by Shaft Rotation and Responsive to Speed or Direction
	Switches with Specific Features

TABLE 11-27. Electronic/Electrical Symbols (continued).







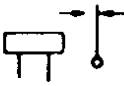
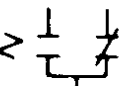
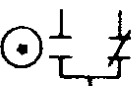
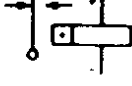
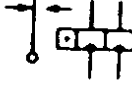
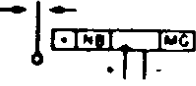











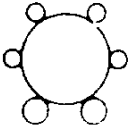




Symbol	Meaning
	Governor Speed Regulator
<div style="display: flex; flex-wrap: wrap;"> <div style="width: 50%;"> <p>  AC  P  SO  SR </p> </div> <div style="width: 50%;"> <p> D DB SA L </p> </div> <div style="width: 50%;"> <p> DP EP SW ML </p> </div> <div style="width: 50%;"> <p> MG NB NR FO FR </p> </div> </div> <p>     </p> <p>    </p> <p>     </p>	Relay
	Inertia Switch
  	Mercur Switch
  	Terminals
 	
  	

TABLE 11-27. Electronic/Electrical Symbols (continued).


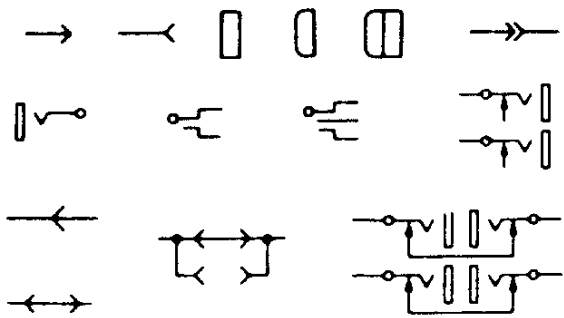
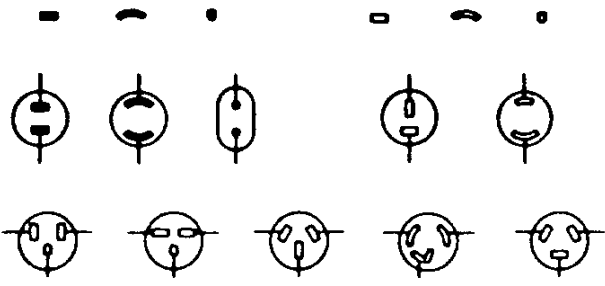

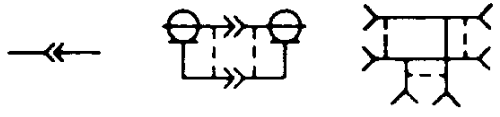
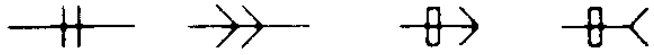
Symbol	Meaning
	Cable Termination
	Connector Disconnecting Device
	Connectors of the Type Commonly Used for Power-Supply Purposes
	Test Blocks
	Coaxial Connector
	Waveguide Flanges Waveguide Junction

TABLE 11-27. Electronic/Electrical Symbols (continued).

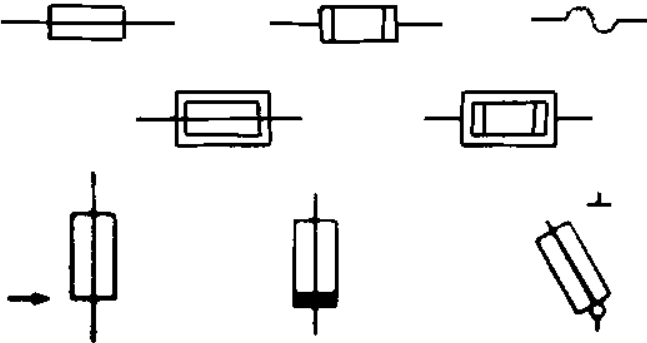

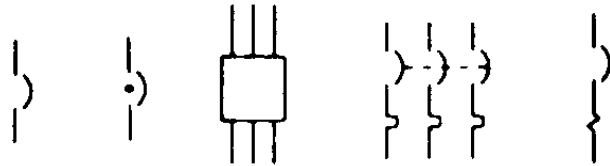
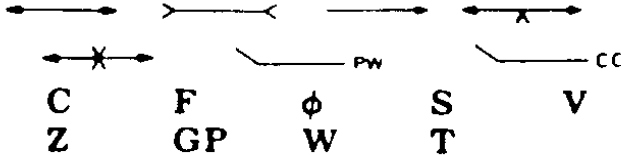
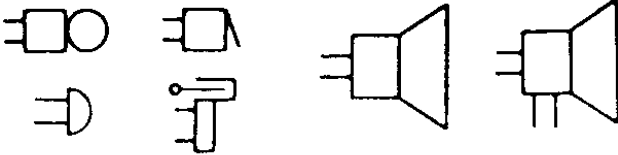

Symbol	Meaning
	Fuse
	Lightning Arrester Arrester Gap
	Circuit Breaker
	Protective Relay
	Audible-Signaling Device
	Microphone

TABLE 11-27. Electronic/Electrical Symbols (continued).

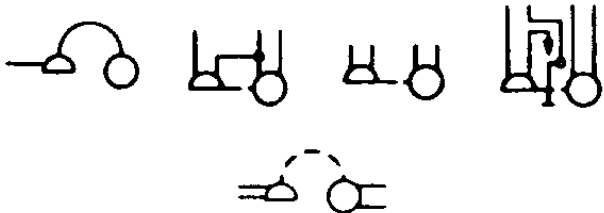
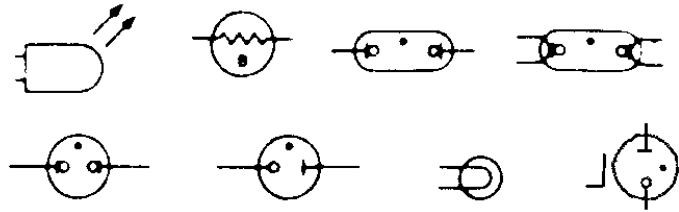
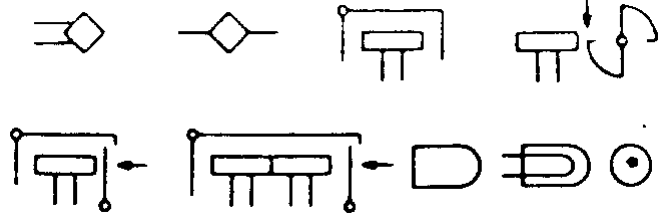

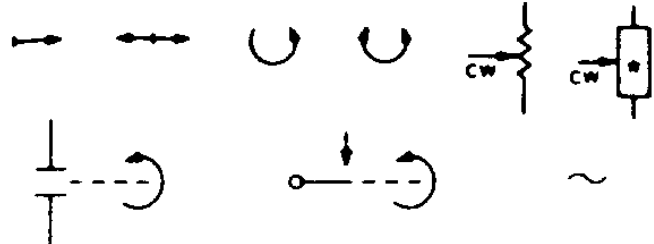
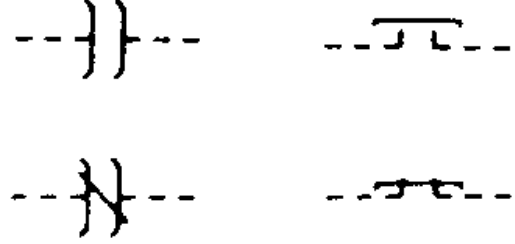



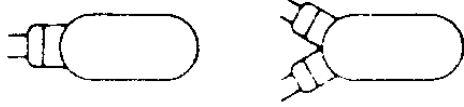
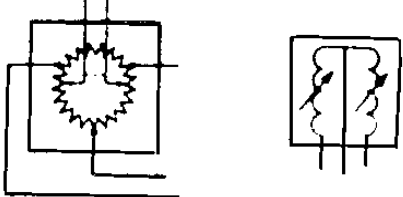
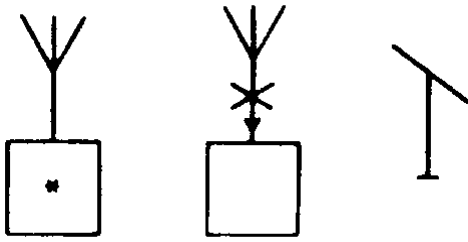
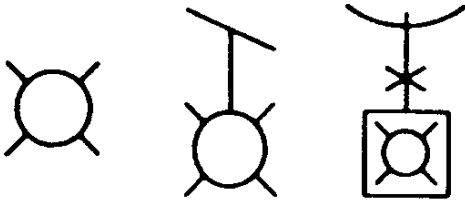
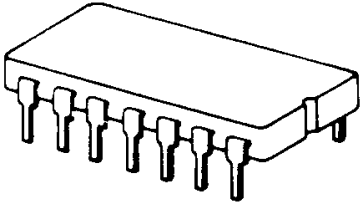
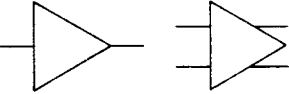
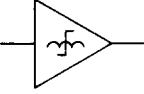

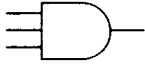
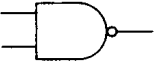




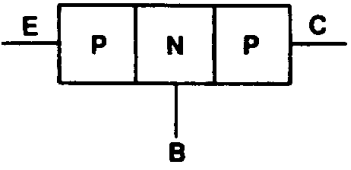
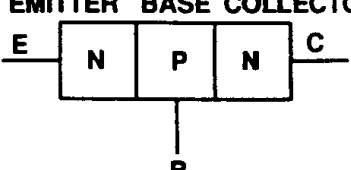
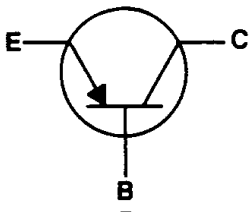
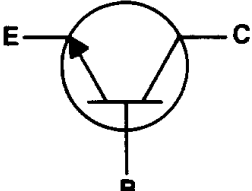
Symbol	Meaning
	Handset Operator's Set
	Lamp
	Visual-Signaling Device
	Mechanical Connection Mechanical Interlock
	Mechanical Motion
	Clutch Brake

TABLE 11-27. Electronic/Electrical Symbols (continued).

Symbol	Meaning
	Manual Control
	Gyro Gyroscope Gyrocompass
	Position Indicator
	Fire Extinguisher Actuator Head
	Position Transmitter
	Radio Station
	Space Station

	Integrated Circuit
 <p>GENERAL SYMBOLS</p>  <p>MAGNETIC AMPLIFIER</p>	Amplifiers
 <p>INVERTOR OR NOT GATE</p>  <p>AND GATE WITH THREE INPUTS</p>  <p>NAND (NOT AND) GATE</p>  <p>OR GATE</p>  <p>NOR (NOT OR) GATE</p>  <p>EXCLUSIVE OR GATE</p>	Logic Gates
	Diode
<p>EMITTER BASE COLLECTOR</p>  <p>EMITTER BASE COLLECTOR</p>   	Transistor Symbols

11-273.—11-283. [RESERVED.]