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AIRCRAFT ELECTRICAL INSTALLATIONS

FOREWORD

The acceptability of the electric wiring system for a transport aircraft depends to a large degree on the consideration, in the preliminary design stages, given to such factors as electrical load analysis, generating equipment characteristics, location of centers of load distribution, and general wire routing. Good detail electrical design, including proper equipment and wire selection and installation, coupled with the proper evaluation of the reliability of circuitry to be used, are necessary steps in assuring a good system.

In general, the material in this document applies specifically to 28 V DC and 115/200 V AC electric systems. It is recognized that detail design considerations must vary with each type of aircraft. With the development of improved techniques, there will be differences within given types. Therefore, this document has been prepared on the basis of a general guide, and no attempt has been made to cover exact details of installation. It is believed that this method of presentation will allow the designers maximum opportunity to exercise their best judgment and ingenuity to make the system in their aircraft as simple, safe, and reliable as possible.

The various phases of transport aircraft electrical design, as related to reliability of operation and reduction of hazards, are set forth on the following pages. These factors should be considered throughout the design stages from preliminary design to the completed aircraft. It is felt that the application of the principles in this guide will provide a safe and satisfactory electric system installation for transport type aircraft.

ACKNOWLEDGMENT

A Handbook was first published by the Aerospace Industries Association (AIA) on February 1, 1950, and a revision was published on May 1, 1952. Its preparation was accomplished by project groups of experienced electrical design engineers from various interested aircraft manufacturers, at the request of the Airworthiness Requirements Committee, an activity of the Aircraft Technical Committee of the AIA. These editions were widely used for guidance by many organizations throughout the world in the manufacturing, operating, and educational fields of air transport. It was revised again in June 1958.

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1. SCOPE:

It is the purpose of this document to present design recommendations that will provide a basis for satisfactory and safe electrical wiring installations in transport aircraft. This document is not intended to be a complete electrical installation design handbook. However, the requirements for safety extend so thoroughly throughout the electric systems that few areas of the installation are untouched by the document. It is recognized that individual circumstances may alter the details of any design. It is, therefore, important that this document not be considered mandatory but be used as a guide to good electrical application and installation design.

Transport aircraft electric systems have rapidly increased in importance over a number of years until they are now used for many functions necessary to the successful operation of the aircraft. An ever increasing number of these functions are critical to the safety of the aircraft and its occupants. The greatly increased power available in electric systems is another factor in aircraft safety. These considerations make it essential that aircraft electrical design practices be carefully considered from the standpoint of safety and reliability. It is believed that this document will be of value in pointing out potential difficulties and in solving many of the problems.

2. APPLICABLE DOCUMENTS:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS486	Aircraft Circuit Breaker and Fuse Arrangement
ARP1199	Selection, Application, and Inspection of Electrical Overcurrent Protection Devices (DOD Adopted)
AIR1263	Tin Plated Solderless Terminal Lugs and Splices on Nickel Coated High Temperature Wire
ARP1308	Preferred Electrical Connectors for Aerospace Vehicles and Associated Equipment
AIR1329	Electrical Connectors and Wiring, Compatibility of
AIR1350	Installation and Mounting of Single Hole Mount, Cylindrical, Electrical Connectors, Procedure for
AIR1402	Common Termination Method, Electrical Wiring System, Application of
AIR1557	High and Extended Vibration Environment
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP1928	Torque Recommendations for Attaching Electrical Wiring Devices to Terminal Boards of Blocks, Studs, Posts, etc.
ARP1931	Glossary of Terms with Specific Reference to Electrical Wire and Cable
ARP4043	Flight Line Grounding and Bonding of Aircraft
ARP4101/5	Aircraft Circuit Breakers and Fuse Arrangement
AS4372	Performance Requirements for Wire
AS4373	Test Methods for Insulated Electric Wire
AS8011	Minimum Performance Standards for AC Generators and Associated Regulators
AS8020	Minimum Performance Standards for Engine Driven DC Generators/Starter Generators and Associated Voltage Regulators

2.1 (Continued):

AS8023	Minimum Performance Standards for Airborne Static Electric Power Inverters
AS8028	Power Plant Fire Protection Instruments Thermal and Flame Contact Types (Reciprocating and Turbine Engine Powered Aircraft)
SAE J554	Electric Fuses, Cartridge Type Standard

2.2 Military Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-HDBK-221	Fire Protection Design Handbook for US Navy Aircraft Powered by Turbine Engines
MIL-STD-461	Electromagnetic Emission and Susceptability Requirements for the Control of Electromagnetic Interference
MIL-STD-704	Electric Power, Aircraft, Characteristics of
MIL-STD-705	Generator Sets, Engine and Driven, Methods of Tests and Instructions
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-889	Dissimilar Metals
MIL-STD-1353	Electrical Connectors, Plug in Sockets and Associated Hardware, Selection and Use of
MIL-C-5015	Connector, Electrical, Circular, AN Type - General Specification for
MIL-B-5087	Bonding, Electrical, and Lightning Protection for Aerospace Systems
MIL-W-5088	Wiring, Aerospace Vehicle
MIL-F-5372	Fuse, Current Limiter Type, Aircraft
MIL-F-5373	Fuse Holder, Block Type, Aircraft
MIL-C-5809	Circuit-Breaker, Trip-Free, Aircraft, General Specification for
MIL-E-7016	Electric Load and Power Source Capacity, Aircraft, Analysis of
MIL-G-7017	Electric Load Analysis, Method for Aircraft DC
MIL-E-7080	Electric Equipment, Aircraft, Selection and Installation of
AND 10439	Receptable Installation - Fuel Nozzle Grounding
MIL-F-15160	Fuse, Instrument, Power, and Telephone
MS 21919	Clamp, Loop Type, Cushioned, Support
MS 24000	Fuse Holder, Block-Type, 1-, 2-, and 3-Pole, 1- to 30-Ampere, Aircraft
MS 24001	Fuse Holder, Block-Type, 1-, 2-, and 3-Pole, 35- to 60-Ampere, Aircraft
MIL-W-22759	Wire, Electric, Fluoropolymer Insulated, Copper or Copper Alloy
MIL-W-25038	Wire, Electrical, High Temperature and Fire Resistant, General Specification for
MIL-C-27500	Cable, Electrical, Shielded and Unshielded, Aerospace
MIL-W-81044	Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkane-imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy
MIL-W-81381	Wire, Electric, Polyimide-Insulated, Copper and Copper Alloy
MIL-C-85485	Cable, Electric, Filter Line, Radio Frequency Absorptive

2.3 Other Documents:

IEEE 135	Recommended Practice for Aircraft, Missile and Space Equipment Electrical Insulation Tests
IEEE 816	Guide for Determining the Smoke Generation of Solid Materials Used for Insulations and Coverings of Electrical Wire and Cable
Handbook H6.1	Federal Item Identification Guides for Supply Cataloging
CAA No. 259	Safety Regulation Release No. 259, Compliance of Equipment and Materials Used in Air-Carrier Aircraft with Fire Prevention Requirements
NRL Report 442	Current Rating Tables for Bundled Aircraft Cables Carrying Continuous DC Currents (This document is available through NTIS as document number AD 625901.)
NAS 557	Grommet, Plastic - Split (DOD Adopted)
NAF 1357	Fuse Holder - Cartridge, Extractor Post (15 Amperes, 250 Volts)
ASTM D 3032	Standard Test Methods for Hookup Wire Insulation

3. CIRCUIT PROTECTION:

3.1 Definitions, Principles, and General Recommendations:

Circuit protection is broadly defined as automatic protection of a consequence limiting nature used to minimize the danger of fire and/or smoke as well as the disturbance to the rest of the system, which may result from electrical faults or prolonged electrical overload. With regard to faults, however, it should be remembered that no automatic protection scheme or device can assure complete protection against fire when the device operates only after the fault has created an arc or spark. Preventive measures for the physical protection of electric circuits, with the aim of eliminating circuit faults, go hand in hand with automatic protective devices to provide the desired and necessary reliability and safety.

3.1.1 Circuit Protectors: Circuit protectors are devices that respond to excess current by opening the circuit, generally after some time delay. They are primarily intended to protect electric wires rather than electric equipment. The protector should be selected so that it will interrupt the fault or overload current by disconnecting the affected wire from the power system before the wire insulation begins to burn or emit objectionable smoke. It should not be so sensitive as to cause nuisance trips.

3.1.2 Scope of Protection: It is desirable that all circuits, including emergency circuits, be equipped with an appropriate protective device. The "burning clear", a self-clearing characteristic of aircraft wire, is not a desirable or reliable method of protection. A circuit protector should be used at all points in a circuit where a change in electric conductor size occurs, unless a preceding protector still provides adequate protection. Caution is emphasized for the cases where more than one wire is fed from a single circuit protector. The protector size required to handle the total current should not be larger than that capable of providing adequate protection for the individual wires. Since circuit protectors are not generally "explosion-proof aeronautical equipment", extreme care should be exercised to ensure against locating protectors in vapor areas.

3.1.3 Equipment Protection: Equipment protection, although related to circuit protection, is actually a separate problem and should receive separate consideration. Maximum safe equipment utilization is particularly important in emergency circuits (circuits the failure of which may result in the inability of the aircraft to maintain controlled flight). It is desirable that any equipment protection, which is found to be necessary, be provided by protection incorporated in the equipment itself, rather than by a circuit protector. The wire for such a circuit should be properly selected to permit maximum utilization of the equipment, and a protector of suitable rating can then be selected to protect the wire.

3.1.4 Dual Protection: Although both circuit and equipment protection are sometimes achieved by the use of a single device (i.e., a circuit protector), it should be recognized that the characteristics of circuit protectors together with the requirements for their installation generally result in a large discrepancy between their current-time-to-trip characteristics and those that would be required for both protection and maximum utilization of electric equipment. In particular, an attempt to achieve automatic protection of emergency equipment by circuit protectors should be carefully reviewed to assure that no hazard is involved. Equipment that must function in order to maintain a controlled flight should not be removed from the immediate control of the pilot or crew. However, protection of nonemergency equipment, where maximum utilization is not a requirement, may be acceptably accomplished by circuit protectors, provided this dual function is not allowed to conflict with the basic requirement of affording protection to the wire associated with the equipment.

3.2 Circuit Breakers:

3.2.1 Definitions, Principles, and General Recommendations: Circuit breakers, as used here and as distinguished from fuses, are automatic circuit interrupting devices which are capable of repeatedly performing their function to the prescribed set of conditions. Circuit breakers are generally preferred to fuses from a convenience standpoint in that a fuse must be replaced when blown. Also, for the present aircraft types of fuses, there is the possibility of replacement with an improper size or type.

3.2.1.1 Function of Circuit Breakers: A circuit breaker's basic function is to protect the aircraft wire. To do so it should be selected so that the thermal characteristics of the aircraft wire are not exceeded, making due allowance for differences in ambient temperature between the circuit breaker and wire locations.

3.2.1.2 Application of Circuit Breakers: Circuit breakers are designed to match the thermal characteristics of aircraft wire. Therefore, the application of such breakers for equipment protection will generally not be satisfactory. The utilization and protection of equipment usually are achieved more reliably when the protection is built into the equipment. Such protection can be designed to match the thermal characteristics of the equipment being protected and will not be affected by differences in ambient temperatures that otherwise occurs where the equipment and the protector are at different locations in the aircraft.

3.2.1.3 Effect of Ambient Temperature on Circuit Breakers: Circuit breakers are generally uncompensated thermal devices influenced by ambient temperature variations. Ambient temperature changes will affect the circuit breaker minimum trip current as well as its trip time at higher currents. This characteristic, as well as the wide variation in trip times, as allowed by MIL-C-5809, must be given consideration in the application of circuit breakers. Although circuit breakers are designed for compliance to a given specification, there is a lack of uniformity in the characteristics comparing a circuit breaker made by a particular manufacturer with those made by other manufacturers. Designing to the characteristics of a single manufacturer's circuit breakers should generally be avoided unless precautions are taken to guard against service replacement being made with other than specified equipment. Consideration should also be given to the effects of mutual heating of adjacent circuit breakers.

3.2.1.4 Selection of Circuit Breakers (See also 3.2.1.5): In general, circuit breakers should be selected on the basis of the lowest rating that will not result in nuisance outages. For emergency circuits (circuits the failure of which may result in inability of the aircraft to maintain controlled flight and affect a safe landing), it is essential that the circuit breaker be of the highest rating possible consistent with wire protection. For these circuits, it is especially necessary that the wire and breaker combination supplying the power be carefully engineered, taking into account short time transients (e.g., motor starting, abnormally high current due to low temperature operation, etc.) in order to insure maximum utilization of the vital equipment without circuit interruption. AS486, ARP1199, and ARP4101/5 provide information on selection and arrangement of circuit breakers. Circuit breakers used on circuits that do not have individual switches should be of a type that will permit disconnecting the circuit manually (i.e., toggle type or push-pull type).

3.2.1.5 Nonemergency Circuit Breaker Selection: For nonemergency circuits it is desirable to select the circuit breaker, or other protector, on the basis of the lowest rating consistent with reliable equipment operation. Careful engineering, or testing, or both, is recommended to demonstrate the effectiveness of such protection under service conditions, since circuit protectors are not generally applicable as equipment protectors.

3.2.1.6 Location of Circuit Breakers: Control of circuit breakers whose operation could affect safety of flight should be readily accessible to the crew during aircraft operation. Circuit breakers generally should be located so they are accessible for resetting in flight and should be located as close to the bus as possible so that there is a minimum of unprotected wiring. There will be instances where circuit breaker locations other than accessible in flight will result in the minimum of unprotected wiring (provided that operation of the aircraft is not prejudiced, such locations are considered satisfactory). MIL-E-7080 may be used as a guide for electrical equipment installation design.

3.2.1.6.1 Circuit Breaker Connection to Buses: When it is necessary to connect loads of less than 50 A to large capacity buses, the circuit protectors should not be rigidly tied to the bus for the following reasons:

a. The characteristics of the circuit protectors are changed when they are attached directly to a large bus because of the high rate of heat transfer from the protector to the bus.

b. The calibration of some circut breakers is changed when a heavy mechanical load is applied to the terminals of the circuit breaker.

c. A short jumper between the bus and the circuit breaker will tend to limit the short-circuit current that the breaker may have to interrupt in high current DC systems.

3.2.2 Interrupting Capacity of Circuit Breakers: In selecting circuit breakers for various applications, it is important that the interrupting capacity be given careful consideration with respect to both current and recovery voltage. Failure of a circuit breaker to isolate a fault presents a definite electrical fire hazard from overheated wiring and equipment and increases the possibility of electrical arcing. A burnout of the circuit breaker would be less hazardous provided no flames, sparks, or molten metal escape from the breaker case. However, re-establishment of the circuit in flight after such an opening would almost certainly be impossible. The use of an adequate fuse in such a case would have been preferable. In view of the facts, circuit breakers with adequate interrupting capacity should be selected for high capacity buses of large systems, which may be capable of 5000 to 10 000 A under short-circuit conditions. When anticipated, lead lengths from the bus to the circuit breakers are less than 6 ft, Tests for interrupting capacity should be conducted with wires selected from Table 1. The actual length of wire to be used with the breakers should be used in the precalibrated circuit. It is highly desirable that the breakers selected be capable of clearing the maximum possible short-circuit current several times without suffering an appreciable change in calibration.

3.2.2.1 Special Circuit Applications: For circuits where voltage or current may exceed normal aircraft circuit breaker ratings, special attention should be given to the circuit breaker selection and the application should be substantiated by test. Examples of such applications are generator fields, variable frequency systems, and high voltage DC systems.

3.2.3 Trip-Free Circuit Breakers: A trip-free circuit breaker is one which cannot be maintained closed while a tripping condition persists (i.e., manual overriding of the trip mechanism is impossible).

3.2.3.1 Recommendations for Trip-Free Circuit Breakers: Circuit breakers are intended to provide circuit protection. Being able to hold a circuit breaker closed against a high fault current is not in the interest of aircraft safety. To obtain maximum equipment utilization in emergency circuits (circuits the failure of which may result in the inability of the aircraft to maintain controlled flight and affect a safe landing), the circuit breaker should be trip-free (nonoverride) and of the highest rating consistent with wire protection. It is recommended that all circuit breakers be trip-free (nonoverride).

3.2.4 Non-Trip-Free Circuit Breakers: A non-trip-free circuit breaker is one that can be maintained closed by manual override action while a tripping condition persists.

3.2.4.1 Recommendations for Non-Trip-Free Circuit Breakers: There appears to be no reason for requiring non-trip-free (override) circuit breakers in the emergency circuits. Proper and careful application of trip-free (nonoverride) circuit breakers with appropriate wire sizes can provide any degree of equipment utilization desired. For extremely vital aircraft functions, consideration may be given to the use of parallel or alternate circuits, using duplicate circuit breakers and possibly duplicate equipment. In the interest of aircraft safety, it is recommended that non-trip-free (override) circuit breakers not be used.

3.2.5 Automatic Reset Circuit Breakers: Automatic reset circuit breakers are generally of the thermal type and have no provisions for manual operation either in opening or closing. They are, therefore, trip-free (nonoverride) in opening and are arranged to reclose as soon as cooling reduces the temperature of the trip element to a value that is usually well below the tripping temperature but considerably above ambient.

3.2.5.1 Recommendations for Automatic Reset Circuit Breakers: In general, automatic reset circuit breakers should not be used for circuit protection. Any use should be justified by analysis and test.

3.2.6 Remote Circuit Breakers: Remote circuit breakers comprise a solenoid operated contactor having its solenoid circuit controlled by a current sensitive element plus a manual switching and trip indicating device. This latter device often consists of a manually operated circuit breaker arranged to trip whenever the remote breaker trips. Opening of the contactor due to low circuit voltage, possibly without overcurrent, is an undesirable feature of this type of breaker. This undesirable feature should be considered in any application of these breakers. In any event, the contactor should be selected on the basis of safe opening under maximum short-circuit current.

3.2.6.1 Low Voltage Operation of Remote Circuit Breakers: In order to avoid circuit interruption due to low voltage, remote circuit breakers used for circuit protection should employ a latch or other suitable arrangement, which will hold it down to 0 V. Special consideration should be given to the tripping of latch type circuit breakers under low voltage conditions.

3.2.6.2 Rating and Type of Remote Circuit Breakers: Where a circuit breaker is used for the trip indicating device mentioned, it is recommended that it be of the trip-free type. Using a non-trip-free circuit breaker allows overloading the control circuit wire when an attempt is made to reset it before the remote breaker current sensitive element has recycled. This situation is to be avoided. In general, the circuit breaker should be the lowest current rating available, consistent with its continuous load, so as to give the earliest possible indication that the remote breaker has tripped. Consideration should also be given to the difference between the tripping time of the indicating breaker and the recycling time of the current sensitive element of the remote breaker. For these reasons, a low tripping time should be used for the indicating device.

3.2.6.3 Connections for Remote Circuit Breakers: The remote breakers presently available can be connected in any of several methods so as to provide trip-free, non-trip-free, or automatic recycling operation. It is recommended that all remote breakers be connected so as to provide trip-free action.

3.2.7 Magnetic Circuit Breakers: Magnetic circuit breakers make use of a trip mechanism that functions in response to the magnetic effect rather than the heating effect of the current carried by the thermal circuit breaker. Magnetic trip mechanisms are substantially independent of ambient temperature and can be effective in opening a circuit in a matter of milliseconds although some means of slowing down the action is usually incorporated. This feature tends to avoid nuisance outages due to current surges of short duration, which may occur frequently without doing any harm. Since the trip characteristics of magnetic circuit breakers may be affected by mounting position or vibration, the location chosen for such breakers should be thoroughly analyzed to ensure proper operation.

3.2.7.1 Application of Magnetic Breakers: General use of magnetic circuit breakers is discouraged since their characteristics are less standardized than thermal circuit breakers. If they are used, the same principles of application apply. Due to lack of standardization, more individual study is generally needed for the application of the magnetic type. Because of the diverse time-current characteristics of magnetic circuit breakers, their application and coordination with other protection should be carefully investigated.

3.2.7.2 AC-DC Tripping Characteristics of Magnetic Breakers: Magnetic breakers generally have different tripping characteristics for AC and DC. Depending upon the degree of time delay offered, they may trip upon the peak or average AC currents rather than the rms value. Thermal breakers, in contrast, operate mainly on a heating principle and, therefore, their AC and DC characteristics are essentially the same.

3.2.8 High Voltage Applications of Circuit Breakers: The selection of circuit breakers for high voltage circuit protection requires careful evaluation and should be substantiated by test wherever satisfactory data are lacking. As circuit breaker operating voltages increase, close attention must be given to possible changes in operating characteristics stated for lower voltages. Additional possible failure modes change in interrupting capacity at altitude, arcing at altitude, and personnel protection.

3.2.8.1 Selection, Installation, and Testing of High Voltage Circuit Breakers: Voltages in excess of 115/200 V applications should utilize specially designed breakers. The installation procedures should be determined and be tested to prove their adequacy under all anticipated operating conditions.

3.2.8.2 Safety Considerations for High Voltage Circuit Breakers: Breakers used on systems operating at voltages considered hazardous to personnel should include safety considerations such as terminal protection and insulated handles or buttons.

3.2.9 Multiple-Pole Circuit Breakers: Circuit breakers in which a single actuation controls more than one pole are called multiple-pole breakers. A major application of this type of circuit breaker is in three phase AC systems. The following are the two major types of multiple-pole circuit breakers:

a. Trip-free
b. Companion trip

3.2.9.1 Trip-Free Multiple-Pole Circuit Breakers: A trip-free multiple-pole breaker is one in which no pole may be maintained closed while a tripping condition persists on any pole or combination of poles.

3.2.9.2 Companion-Trip Multiple-Pole Circuit Breakers: A companion-trip multiple-pole circuit breaker is one in which the unfaulted poles may be maintained closed while a tripping condition persists on one pole or combination of poles; however, the faulted pole(s) is trip-free. This device is essentially three single pole circuit breakers mechanically tied together so that when one circuit is faulted all trip simultaneously.

3.2.9.3 Application of Multiple-Pole Circuit Breakers: Multiple-pole circuit breakers should be used where the opening of one phase may result in an unsafe condition. The calibration of the trip-free multiple-pole circuit breakers may be affected by unsymmetrical loading. In addition, the operating mechanisms of this type unit tend to be somewhat complex. Consideration may be given to the use of companion-trip multiple-pole circuit breakers if the complete trip-free feature is not required by the application. Operating forces of multiple-pole circuit breakers may be somewhat higher than single pole units thereby limiting the location of such units.

3.2.9.4 Use of Single-Pole Circuit Breakers in Multiple-Pole Circuits: Single-pole circuit breakers may be used to protect multiple-pole circuits if there exists no requirement for companion tripping. The single-pole units should be grouped for the convenience of the operating personnel and their association identified.

3.3 Fuses:

3.3.1 Definitions, Principles, and General Recommendations: A fuse is an overcurrent protective device with a circuit opening fusible member directly heated and destroyed by the passage of overcurrent. Being a thermal device it will be influenced by ambient temperature variations. These variations affect to some extent the fuse minimum "blowing" current as well as its "blowing" time at higher currents. This characteristic should not be overlooked in applying fuses. Normally a fuse is used to provide circuit protection, but the equipment and system protection aspects should not be overlooked. Many times consideration of the latter can result in greater aircraft safety. To perform the circuit protection function, fuses should be selected to match, insofar as practicable, the thermal characteristics of aircraft wire.

3.3.1.1 Overload Characteristics of Fuses: The inverse-time or overload characteristics of fuses generally differ from the thermal or overload characteristics of electric equipment. Because fuses are seldom located or designed to respond ideally to changes in the ambient temperature of the electric equipment, they do not provide good equipment protection. Generally they can provide only short-circuit protection. If some degree of equipment protection is desired, they will be selected to overprotect the electric wire.

3.3.1.2 Selection of Fuses (See also 3.3.1.3): In general, fuses should be selected on the basis of the lowest rating that will adequately protect the wire and not result in nuisance outages. For emergency circuits (circuits the failure of which may result in the inability of the aircraft to maintain controlled flight and affect a safe landing), it is essential that the fuse be of the highest rating possible consistent with wire protection. For these circuits it is especially necessary that the wire and fuse combination supplying the power be carefully engineered. Short time transients (e.g., motor starting, abnormally high current due to low temperature operation, etc.) should be considered in order to ensure maximum utilization of the vital equipment without circuit interruption.

3.3.1.3 Nonemergency Circuit Fuses: For nonemergency circuits it is desirable to select the fuse on the basis of the lowest rating consistent with reliable equipment operation. Careful engineering and/or testing are recommended to demonstrate the effectiveness of such protection under service conditions.

3.3.1.4 Location of Fuses: Fuses should be located so that they are accessible for replacement in flight. They should be located as close to the bus as possible to achieve the minimum of unprotected wiring. In providing the minimum of unprotected wiring, there will be instances where fuses are located in areas other than accessible in flight. Such locations are considered satisfactory provided that operation of the aircraft is not compromised.

3.3.1.5 Ventilation of Fuses: Fuses, particularly high capacity units, dissipate considerable energy, and their installation should allow for heat rejection so that the temperature rise of the fuse(s) does not exceed that of the wire and so that the mutual heating of two or more fuses does not adversely affect the desired time-current curve or continuous rating of the fuse. Also, care should be taken to ensure that the rejected heat does not cause an overheat condition on adjacent equipment coupled to the bus in the vicinity of the fuses.

3.3.2 Application of Fuses: Either fuses or circuit breakers may be used for circuit protection except that circuit breakers are preferable on any circuit whose failure endangers safety of flight. This preference is primarily due to the fact that resetting a circuit breaker is believed to be safer and quicker than changing a fuse. The hazard of replacing a fuse with one of the wrong current rating or of creating an accidental short-circuit in an open fuse panel is increased during the stress of flight emergencies. Circuit breakers also provide more positive trip indication than do fuses. However, presently available fuses provide a much wider range of ratings and trip characteristics than are now available with circuit breakers. In particular, the nonavailability of circuit breakers rated at 1 A or less has led to the general practice of protecting equipment such as instruments, small transformers, etc. with low current fuses. When the nature of a circuit requires mixing different types of circuit protective devices in series, extreme care should be used to ensure proper coordination. In addition, fuses may be affected by vibration or shock; therefore, care should be exercised in the selection of type and location so that satisfactory performance will result.

3.3.3 Fuse Specifications and Designations: The general specification covering nonrenewable AC and DC instrument and power fuses is MIL-F-15160. The specification and the Military Standard drawings describe the physical and electrical properties of the various fuses. Due to the wide tolerance in blowing time allowed by the military specification, it may be necessary to establish closer tolerances for particular applications.

3.3.4 Fuse Types: Fuses are generally classified by their physical dimensions, materials of construction, and their electrical properties. AS486, ARP1199, ARP4101/5, and SAE J554 provide information on selection and arrangement of fuses. The following paragraphs list some of the Military Standard fuses considered applicable for commercial aircraft use.

3.3.4.1 Cartridge Type Fuses - Ferrule Connections - Glass, Plastic, or Ceramic Case Material: See MIL-F-15160/1 through /5, and NAF 1357.

3.3.4.2 Cartridge Type Fuses - Bolt On Connections - Fiber, Plastic, or Paper Sheet Case Material: See MIL-F-15160/36 through /39.

3.3.5 Fuse Materials: Fuses should be fabricated of fracture-proof material and be specially constructed to withstand aircraft vibration. They should have firmly attached ends and a convenient means of extraction.

3.3.6 Connections for Fuses: Fuse clips, when used, should be beryllium copper, suitably plated for environment protection. Bolted connections are preferable to spring clips for high current applications. Loose or high resistance fuse connections cause excessive heating with danger of nuisance circuit opening and possible arcing. Any substitute methods of attachment not conforming to these recommendations should be thoroughly investigated and proved by test. It should be especially noted that dirty contacts and heating of the fuse clip tend to draw the temper of the spring material and further weaken its contact pressure. The blowing characteristics of a fuse directly bolted to a high capacity bus may be affected by heat transfer through the bolted connection. Specification tolerances on fuse blowing

3.3.6 (Continued):

characteristic are so broad that the effect is probably negligible except for special cases where close coordination is being attempted on the basis of a particular manufacturer's product and special tolerances.

3.3.7 Fuse Time-Current Characteristics: Figure 1 shows some generalized inverse time-current curves for fuses and AC and DC limiters.

3.3.7.1 Normal Fuses: In general, normal fuses are designed to do the following:

a. Carry 100 to 110% rated current continuously.
b. Blow at 135% of rated current in 1 h or less.
c. Have interrupting capacities up to 10 000 A.

3.3.7.2 Slow-Blow Fuses: In general, slow-blow fuses exhibit the following characteristics:

a. Carry 110% of rated current continuously.
b. Blow at 135% of rated current in 2 h or less depending on the size.
c. Blow at 300% of rated current in 6, 15, or 30 s minimum depending on the type and time-current characteristic.
d. Have interrupting capacities up to 10 000 A.

3.4 Limiters:

3.4.1 Definitions, Principles, and General Recommendations: A limiter is an overcurrent protective device whose fusible element is specifically designed with a considerably higher temperature melting point than the usual fuse. It is usually used in distribution systems and on large utilization feeders to provide system or short-circuit protection. Circuit breakers are preferable to limiters in emergency circuits, or any circuit whose failure might jeopardize the safety of flight, and because of their more satisfactory inverse time-current characteristics and ease with which they can be reclosed.

3.4.1.1 Effect of Ambient Temperatures on Limiters: Limiters are not appreciably affected by changes in ambient temperature normally encountered in aircraft. This is due to the high melting temperatures of the fusible link used in the limiter construction.

3.4.1.2 Wire Protection with Limiters: Limiters are not designed to match the thermal characteristics of aircraft electric wire. A limiter chosen to provide complete wire protection will have less short time (high current) overload capacity than either a circuit breaker or a slow-blow fuse, thereby overprotecting the wire and preventing the wire from being used to the full extent of its short time-current capacity.

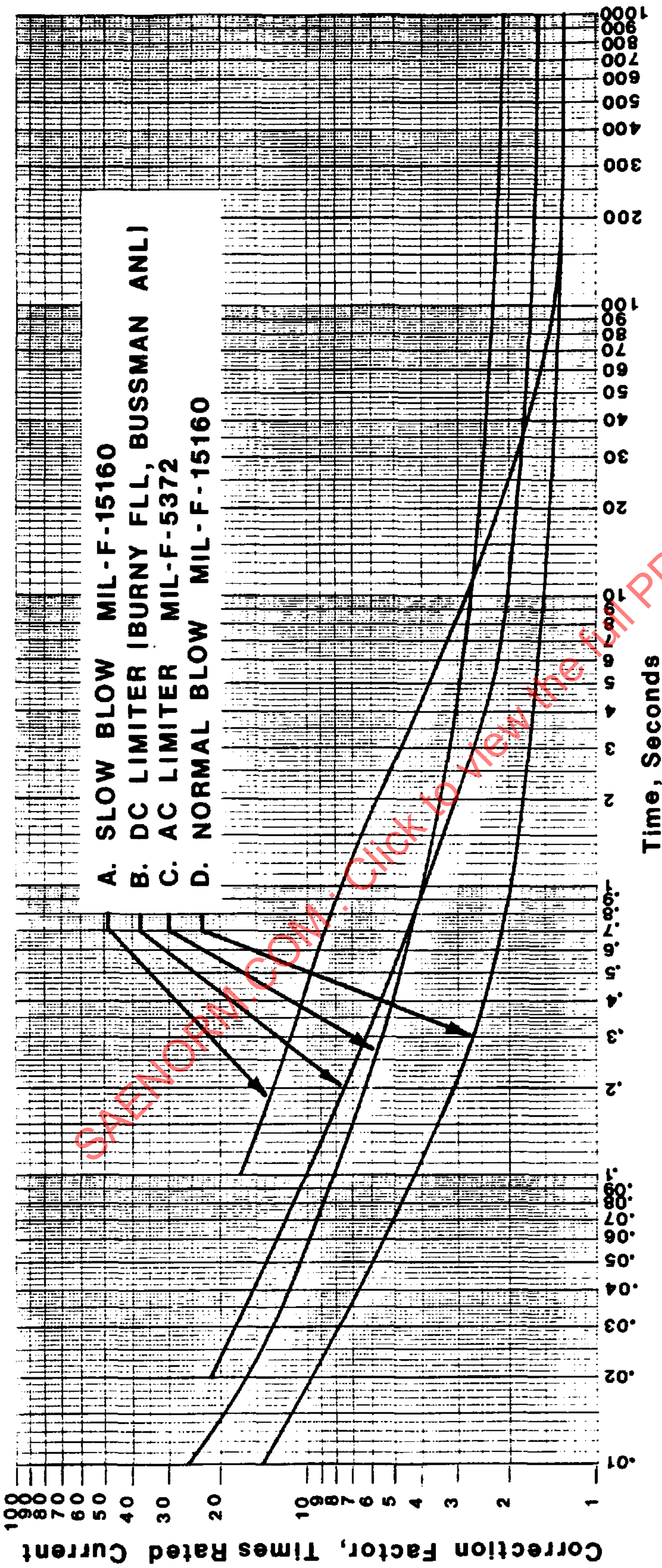

FIGURE 1 - Fuse and Limiter Typical Time - Current Characteristics

3.4.1.3 System Protection with Limiters: Limiters are designed specifically to isolate any portion of an electric power distribution system that may be drawing fault current quickly enough to prevent voltage collapse or damage to the generating system. The difference between fuse and limiter applications may be illustrated by two examples as follows:

a. Power leads from the bus to the engine starter are normally subjected to severe overloading for a short time only. Proper protection of such a wire, still allowing for maximum utilization of a small light wire, can best be achieved by a slow-blow fuse or other protector designed with a current-time characteristic conforming closely to that of the wire.

b. In contrast, the power leads from a main bus to a sub-bus usually carry current continuously. Voltage drop limitations and the nature of the loads usually result in conditions in which maximum utilization of the wire is not required. There is, however, the need for isolating this feeder should it or the sub-bus become grounded or short-circuited. This can be accomplished very well by a limiter. Under short-circuit conditions this limiter will open and relieve the main bus and generating system more quickly than a slow-blow fuse.

3.4.1.4 Application of Limiters: In summary, limiters are useful for isolating high capacity wires whose short-circuit current might collapse or damage the generating system if protection were based on maximum utilization of the wire, while slow-blow fuses or circuit breakers are best for realizing maximum wire utilization. High capacity limiters, in general, need not be accessible for replacement in flight. The nature of the faults to be cleared generally makes it undesirable to be able to replace such devices during flight, and their usual location at a main bus would usually make it difficult and unsafe to attempt replacement until power could be removed from the bus. Limiters should be installed to allow for proper heat rejection. Although excessive heat transfer to a high capacity bus should be avoided, particular care should be taken to prevent installing high rating fuses or limiters in such a way that this rejected heat may cause an overheat condition to develop in adjacent equipment or equipment to which the limiter may attach. Limiter installations should be arranged in such a way that undue mechanical strain will not be imposed in the limiter link or case. When the nature of a circuit requires using circuit breakers and limiters in a series arrangement, extreme care should be used to ensure proper protector coordination.

3.4.2 Types of Limiters: Limiters are available in two types as follows:

a. For 28 V DC systems
b. For 200/115 V, three phase 400 Hz systems

Neither of these types is entirely suitable for 120 V DC systems and, therefore, their use in this application should be given special consideration.

3.4.2.1 AC Limiters (Fuses): AC limiters and their holders are covered by MIL-F-5372 (ASG), MIL-F-5373 (ASG), and MS24000 and MS24001 (AC Limiters). The specification and the Military Standard drawings describe the physical and electrical properties of the various limiters. Due to the wide tolerance in blowing time allowed by the military specifications, it may be necessary to establish closer tolerances for particular applications.

3.4.2.2 DC Limiters: DC limiters and their bases are not covered by military specifications.

3.4.3 Limiter Time-Current Characteristics: Limiters in general exhibit inverse time-current characteristics somewhat similar to fuses. The similarity and differences can readily be seen in Figure 1.

3.4.3.1 AC Limiters: AC limiters are generally designed to do the following:

a. Carry approximately 200% rated current for at least 5 min.
b. Blow at 240% rated current in some time less than 5 min.
c. Have interrupting capacities of 4000 and 2500 A when applied at 120 and 208 V, respectively

3.4.3.2 DC Limiters: DC limiters are designed for a maximum voltage of 32 V and will generally carry from 140 to 200% rated current continuously. The small ampere rated DC limiters will continuously carry 200% current, but the larger exhibit characteristics which indicate that the higher the current rating the smaller the percentage of overcurrent that can be carried continuously. A typical characteristic is shown by Curve B of Figure 1. Because of the fact that a military specification does not exist, it is suggested that all applications of the DC limiters take into account the data published by manufacturers, or that laboratory tests be used to determine the suitability of the limiter application.

3.5 Aircraft Wire and Circuit Protector Coordination:

3.5.1 Protection and Wire Utilization: The problem of protecting electric wire involves limiting the duration of any current, which may be imposed upon the wire to such a time interval that the temperature reached by the wire insulation is not hazardous. This is generally 20 °C above the stated wire temperature rating. Well coordinated protection should be aimed at providing maximum wire utilization by permiting current durations, which cause the temperature rise to approach the design limit. The consideration of utilization is, however, secondary to the necessity for avoidance of hazard.

3.5.2 This document presents examples based upon wire designed for continuous operation at a maximum conductor temperature of 105 °C (221 °F). Within other military specifications MIL-W-22759, MIL-W-81044, and MIL-W-81381 one finds wires designed for 135 °C (275 °F), 150 °C (302 °F), 200 °C (392 °F), and 220 °C (428 °F) maximum conductor temperature. Experience has shown that a 105 °C wire will withstand 110 °C (230 °F) for a minimum of 1 h without smoking. It will safely withstand other temperatures in excess of 105 °C for limited periods of time. The relationship between time, temperature, and the electrical and mechanical deterioration of the insulation (which occurs as a result of temperatures above the working

3.5.2 (Continued):

level) constitutes one criterion for establishing a protection requirement. The evolution of smoke or fumes constitutes a second and very practical operational limit, which can be expressed as a graph of time versus temperature (Reference AIEE paper 46-145). Based on these considerations, the following design conductor temperatures are recommended for 105 °C (221 °F) rated wire:

a. Working Temperatures: 105 °C (221 °F) maximum continuous temperature 125 °C (257 °F) maximum short time temperature.

b. Protection Temperatures: 125 °C (257 °F) maximum long time temperature (approximately 15.0 s or more). 150 °C (302 °F) maximum short time temperatures (approximately 0.01 s or less).

c. Wires with working and protection temperatures higher than the limits should be adequately tested for any applications utilizing these higher temperatures.

Circuits protected within the limits could suffer an abnormal condition leading to a conductor temperature approaching 125 °C (257 °F) and theoretically be unrelieved by the operation of the protective devices. Practically, the condition would be discovered on the basis of other abnormalities before any significant damage to the installation could occur. In fact, tests have shown that 105 °C (221 °F) rated wire maintained at 125 °C (257 °F) for over 400 h was still safe for a further limited period of normal operation, and it must be recognized that a very great deal of aircraft operating time would be required, even theoretically, in order to accumulate 400 h under just the right combination of ambient temperature, circuit loading, etc. to produce a wire temperature approaching but not exceeding the protection design value of 125 °C (257 °F). The limits are, therefore, considered safe, and their use provides a spread of 20 to 25 °C between working and maximum protection values, which allows for tolerances in the operating characteristics of circuit protectors.

3.5.3 Short Time-Current (Time Relationships for Bundles and Single Wires): Based on the temperature limits and an assumed ambient temperature of 57.2 °C (135 °F), a limiting current-time relationship for each size of a single electric wire can be determined (Reference AIEE paper 46-145). Factors such as ambients, installations in conduits, and currents in other wires in a bundle (see 9.3) may affect these current-time relationships from a maximum under a continuous duty condition to a negligible amount for every short time. Tests and experience have shown that for normal bundles and installations where only a small percentage (20%) of wires are simultaneously carrying currents and times are short, current time relationships may be safely predicted on the performance of a single conductor in free air. For heavily loaded bundles, bundles containing large differences in wire gages and times that are relatively long, the effects of an overload on wire temperatures should be adequately investigated (see Appendix D).

3.5.4 Protector Selection for Wires: A comparison between the protection curves described in 3.5.2 and the current trip curves for various protectors has been made. The ambient temperature of the protector was conservatively assumed as 25 °C (77 °F) as against a wire ambient of 57.2 °C (135 °F). Protectors for each wire size were selected with a view to the protector opening under any given current prior to the wire reaching its limiting temperature under that current loading. The method outlined for matching wire and protector characteristics is believed sound although there is still an acute lack of comprehensive data on which to establish firm numerical values. Therefore, it has been necessary to make the final protector selections based on analysis tempered by service experience. The protector values thus selected and tabulated necessarily depend on many assumptions relative to operating conditions, etc. but they are recommended as a conservative guide suitable for general aircraft use. For any specific case where individual evaluation of all the pertinent factors appears justified, it is not unlikely that higher utilizations obtained by selecting a higher rated protector can be shown to be safe for the restricted set of circumstances involved. The following is a brief resume of the factors to be considered when making an analysis or conducting laboratory tests to arrive at a special wire protector combination for the wire:

a. Maximum safe long and short time temperatures for the particular wire insulation, considering both smoke, electrical, and mechanical deterioration.

b. Maximum wire ambient recognizing that this may be the working temperature of the bundle of wires in which this wire runs.

c. Maximum altitude of operation recognizing the difference between cooling with sea level air density and altitude air density.

d. Maximum amount of current and number of wires carrying current that are bundled with the wire being protected.

3.5.4.1 For the Protector:

a. Range of ambient temperature allowing for possible temperature rise at the protector location due to I^2R loss of electric wires and equipment in the vicinity and heat loss due to type of protector mounting

b. Current trip time characteristic of the particular protector, allowing for tolerance between different units of the rating and type specified at the ambient temperature and altitude conditions to be encountered.

3.5.5 Aircraft Wire and Circuit Protector Coordination Chart:

3.5.5.1 Basis of Chart:

a. Wire bundles of 15 or more wires, with wires carrying no more than 20% of the total current carrying capacity of the bundle (see 9.3 and MIL-W-5088).

b. Wires at 135 °F ambient

c. Altitudes up to 30 000 ft (see 3.5.7)

d. Protectors in 75 to 85 °F ambient

e. Copper wire, 105 °C rated

f. Aluminum wire

g. Circuit breakers to MIL-C-5809 or with similar time-current characteristics

h. Fuses to MIL-F-15160

i. AC limiters to MIL-F-5372

j. DC limiters per characteristics furnished by the limiter manufacturer

The protector ratings listed in Table 1 have been selected to protect 105 °C rated wire used as noted. Moderate overcurrent (115 to 140% of the protector rating) has generally been the determining factor. Overcurrent of higher magnitude (exceeding 200% of the protector rating) will cause the protector to open the circuit before the wire conductor temperature has time to approach its maximum safe limit. For motor in rush currents and other large overloads of very short duration, these protectors do not permit utilization of the wire to the full extent of its safe short time capacity. This is more pronounced using fuses to MIL-F-15160 and especially in the case of the limiters. Broad tolerances in the specifications covering protectors further contribute toward overprotection of the wire under many circumstances. The use of wire other than as noted, or use of protectors held to closer tolerances, or other pertinent factors, should be justified by analysis or test.

3.5.6 Opening Versus Load for Protectors: For the protector ratings listed or any others that may be suitably selected, it is recommended that the circuit opening characteristics of the protector be compared with the load to be carried in order to avoid nuisance openings. This comparison should consider any contemplated combination of ambient temperature and pressure and allowance for manufacturing tolerances in the protector. When it is necessary to increase the protector rating in order to ensure reliable service, the wire size should be correspondingly increased unless it can be shown that under the circumstances of the application the smaller wire is given adequate protection by the protector with higher rating.

TABLE 1 - Wire Sizes and Circuit Protectors

Aluminum Wire Size	Copper Wire Size	Circuit Breaker Amp.	Fuse Amp. See 3.3.3	Limiter 115/208 V AC See 3.4.2.1	Limiter 28 V DC
	22	5	5		
	20	7.5	5		
	18	10	10	10	
	16	15	10	10	
	14	20	15	10	
	12	25(30)	20	20	
8	10	35(40)	30	30	
6	8	50	50	40	
4	6	80	70	50	ANL50
2	4	100	70	60	ANL80
1	2	125	100		ANL130
0	1		150		ANL150
2/0	0		150		ANL175

NOTE: Figures in parentheses may be safely used where protectors of the indicated rating are available. Protector selection from this Table should not be considered complete without reference to 3.3.3, 3.4.2.1, 3.5.5.1, 3.5.6, and 3.5.7.

3.5.7 Discussion: There is one additional factor that may require consideration. For pressurized aircraft, altitude operation tends to modify the coordinating of wire and protector ratings. An electrical overload will affect wire in a 30 000 ft unpressurized area more quickly than protectors in a cabin pressurized to an altitude of 8000 ft. If the wire ambient is to remain at 135 °F at 30 000 ft (with the protectors in an 8000 ft cabin), a reduction of 20% in the circuit breaker rating should be considered (e.g., use of a 20 A rather than a 25 A circuit breaker). However, if the wire ambient is not over 135 °F at sea level, a reduction to 90 °F (or lower) is not unlikely at 30 000 ft altitude. Under these circumstances (in relation to, wire at 30 000 ft and 90 °F ambient, protectors at 8000 ft and approximately 80 °F ambient), coordination would be unaffected although the current rating of both the wire and the protector would be reduced to approximately 92% of its sea level value.

3.5.7 (Continued):

For the unpressurized aircraft without a heated cabin, the reduction in temperature at altitude will affect both the protector and wire so that coordination will not be changed. The current rating will not be greatly affected since the reduction in ambient temperature will almost completely compensate for the reduction in air density up to 30 000 ft altitude. With a heated but unpressurized cabin the protectors will tend to overprotect (i.e., coordination is affected, but in a safe direction). Here the designer's principle concern should be with the reduction in the ultimate trip current of the protectors, especially circuit breakers for which the current rating at 30 000 ft may be reduced to approximately 75% of its sea level value. For the protector ratings listed, or any others that may be suitably selected, it is recommended that the circuit opening characteristics of the protector be compared with the load to be carried in order to avoid nuisance openings under any contemplated combination of ambient temperature and pressure, also allowing for manufacturing tolerances in the protector.

3.6 Power System Protection:

3.6.1 Definitions, Principles, and General Recommendations:

3.6.1.1 Power Systems: The aircraft electric power system will be treated in the ensuing discussion as four separate parts: 1) The generation system(s), 2) the distribution system, 3) the utilization system(s), and 4) the conversion system(s).

a. The generation part of the electric system includes that portion from the generators up to and including the bus contactors. It also includes the batteries and all control and protection for these parts of the electric system. It may also include gearboxes and the constant speed drives used in controlled frequency systems. AS8011 and AS8020 provide minimum performance requirements for AC and DC generators, respectively.

b. The distribution part of the electric system performs the function of transmitting the generated power to the utilization equipment or systems. It includes the main bus or buses, the contactors, the distribution feeders and their protective devices as well as the several sub-buses from which the power is distributed to the loads.

c. The utilization part of the electric system includes all of the many electrically operated devices or systems, the load circuits from the power using equipment to its load bus, and whatever circuit breakers, or protective devices that may be employed.

d. The conversion part of the electric system includes the transformers, rectifiers, converters, etc., which might reasonably be classified in the first three groups but will be considered as a separate category. AS8023 provides minimum performance requirements for power inverters.

3.6.1.2 Objectives of Protection: Protection, as applied to the electric power systems, has the following objectives:

a. A reliable, uninterrupted supply of adequately regulated power available at the utilization system(s) both normally and in event of malfunction.

b. The prevention of fire and smoke of electrical origin.

c. The reduction of maintenance cost. (This factor, though important, must be considered secondary to the other two.)

3.6.1.3 Protection Afforded by Careful Design: Ensuring generator circuit and bus protection, electrical integrity, and the prevention of fire and smoke are the most important considerations in preventing electrical faults. No device, or protective scheme, that operates only after a failure that may have created an arc or perhaps just a faint spark, even though promptly cleared, can assure complete protection against fire. A large part of electrical fire protection is fault prevention. Complete fault elimination is, of course, unlikely. However, designs should be thoroughly reviewed and improved as necessary to make them as fault-proof as practicable. Definite reduction in the number of faults occurring can be assured by careful selection of materials and equipment by proper installation and by adequate inspection and maintenance in service (see MIL-E-7080).

3.6.1.3.1 Bus Locations: Main buses should be located in enclosures designed to minimize the probability that loose foreign objects will fall across the buses or exposed power terminals. Inverted mounting of terminals (and equipment bearing terminals) usually is desirable in accomplishing the objective.

3.6.1.3.2 Bus Enclosures: The mounting of buses in completely insulated enclosures, if properly designed and maintained, minimizes the probability of faults to ground, except possibly through the miscellaneous ground leads required for operation of control equipment. Such leads may be arranged to create little hazard. Care should be exercised that proper facility for heat dissipation as well as for inspection and maintenance shall not be compromised. Where feasible, buses between which a significant electric potential exists should be separated by substantial, solid, dielectric barriers.

3.6.1.3.3 Bus Bar Insulation: Application of fire resistant insulation to bus bars and bus attaching parts may be used to avoid bare metal exposure to possible short circuits and accidental contact by mechanics and inspectors, however, bus cooling must not be unduly compromised.

3.6.1.3.4 Exposed Terminal Insulation: Exposed terminals on power equipment should be enclosed or protected with insulating materials. Equipment located entirely within enclosures containing only electrical equipment is not considered as exposed.

3.6.1.3.5 Power Control Equipment Insulation: Devices such as contactors, circuit protectors, reverse current relays, etc. connected directly to a power source without intervening protection and having grounded metal cases should be mounted on insulated bases. Any ground connection required for control (or EMI protection) should be made through jumpers routed separately from the wires at positive potential.

3.6.1.3.6 Bus Extension Protection: Bus extensions (including any conductor directly attached to a bus) should be considered as part of the bus and given corresponding protection. Such extensions should be as short as practical. Physical protection by enclosure within a reliable insulating material (e.g., a fiber glass duct) is recommended. Such enclosure should not interfere with frequent and complete inspection or heat dissipation.

3.6.1.3.7 Interchange of Phase Leads: In three phase systems the installation should be designed to prevent cross connection of phase leads at all connection points. Where possibility exists that such leads could be inadvertently interchanged, it should be determined that any resulting malfunction will not be hazardous or will be detected during preflight check.

3.6.1.4 Automatic Protection: Inevitable faults in power system circuits are to be expected in spite of the best efforts of prevention. Automatic protective devices to limit the magnitude and duration of the fault currents are required to reduce the hazard of fire. This function naturally combines with and is accomplished by the same devices provided to avoid damage to equipment and maintain system reliability. Such devices limit the energy developed at the fault and the time during which associated control and wiring are exposed to excessive overload and possible dangerous overheating. Thus, the likelihood of smoke, possibly followed by fire, due to prolonged overheating is reduced. For systems in which an automatic transfer arrangement connects an alternate source of power to a dead bus, sensing should be provided so that, in the event of a bus fault, the alternate source will be locked out and the reconnection of the normal source prevented.

3.6.1.5 Coordination of Protection: A thorough analysis should be made of each power system to achieve minimum fire hazard. Such an analysis should take into account the short-circuit capacity of the various buses when supplied by ground power sources, as well as aircraft generators over the expected range of aircraft engine speeds. Protection coordination, sensitivity, selectivity, operating characteristics, and interrupting capacity should be analyzed for all probable combinations of voltage, altitude, and temperature. All action to minimize fire hazard should further be conditioned by evaluation of the overheating and burning characteristics of the equipment and material involved.

3.6.1.6 Wire Protection: All wires should be provided with some means of circuit protection. This protection should preferably be electrical, using circuit protectors. But if electrical protection is impractical, physical protection relying on preventive measures such as enclosures may be adequate. The effect of enclosures on wire and bus rating should be carefully checked.

3.6.2 Generation System Protection: Generation system protection should protect the aircraft from hazard, and protect the generation system against damage due to faults, without materially detracting from the ability of the system to reliably supply electric power. First consideration should be given to the prevention of circuit faults as discussed. Generator feeders should be separated from miscellaneous control wiring insofar as practicable, and carefully routed to minimize exposure to damage. Protection against faults in associated control, instrument, and indicator circuits is also required to minimize fire hazards. This protection may be provided by the use of small individual circuit breakers (preferred) or fuses.

3.6.2.1 Items Common to Both AC and DC Systems:

3.6.2.1.1 Generator Overvoltage Protection: Generator overvoltage protection should be provided.

3.6.2.1.2 Generator Overheat Indication: Generator overheat indication should be considered; however, its limitations should be recognized:

a. A temperature detector will not reliably warn of bearing failure in time to prevent physical damage to laminations and windings. (Bearing failure detectors, which do not rely on temperature measurement, are available.)

b. It is not usually possible to locate the overheat detector so that it will sense the most critical overtemperature under all conditions of operation.

3.6.2.1.3 Generator Cooling Provisions: Provisions for generator cooling (and generator drive, where applicable) should be checked at all operation altitudes to ensure that under the least favorable conditions, the generator rating is adequate.

3.6.2.2 DC Generation System Protection: DC generator circuit protection basically starts with some form of reverse-current protection. This type of protection is required because of the varying speed of the aircraft engines and because the generator design is optimized over a narrower range of speed than the engine. This device prevents excessive bus current, from the battery or other generators, from motoring a generator at low speeds or feeding into faults, which may develop in the generator or generator feeders. It does not prevent the generator from feeding a fault between it and the bus; such protection requires some method such as generator and feeder differential (balanced) current protection. Generator overheat indication provides additional means for warning of a dangerous condition and should offer possibilities of detecting and cutting off a fault of a slowly developing nature. Generator feeders and connections should be installed with due consideration to physical protection. In addition, other means, such as differential protection, to prevent the generator from supplying a feeder fault should be provided. Overvoltage protection is recommended as an automatic function. Monitoring of generator load should usually be a crew function, except in special circumstances when the short-term generator load capacity allows insufficient time for crew action. No simple, generally applicable automatic monitoring device is available. Generator "reverse polarity" protection is recommended and is usually provided as a

3.6.2.2 (Continued):

part of the reverse-current protection device. Protection against faults in associated control, instrument, and indicator circuits may be used to minimize fire hazards. This protection may be provided by the use of small individual circuit breakers (preferred) or fuses.

NOTE: In DC power systems, if a solid fault is on the generator output and the shunt field is open, series field effects in the generator may cause a hazardous buildup of voltage and current.

3.6.2.3 AC Generation System Protection: Table 2 shows the types of protection for AC generator systems that are available. The amount of protection to be installed must be chosen to suit the application; however, the magnitude and importance of the loads connected to AC power systems of modern aircraft usually justify a comprehensive protective system.

Protection against faults in associated control, instrument and indicator circuits should be used to minimize fire hazards. The protection may be provided by the use of small individual circuits breakers (preferred) or fuses.

TABLE 2 - Suggested Protection Methods

Problem	Suggested Protection Method
Faulted generator	Differential current
Faulted generator feeder	Differential current
Underfrequency	Underspeed switch (underfrequency switch)
[1]Overfrequency	Overspeed switch (overfrequency relay)
Reverse power flow	Overrunning clutch
Armature stoppage	Shear section (gen. or drive)
Reversed phase sequence	Phase sequence relay
Out-of-phase paralleling	Auto-paralleling relay
Overload and/or bearing failure	Overheat warning
Overload	Exciter ceiling protection
Overvoltage	Overvoltage relay
Undervoltage	Undervoltage relay
Over and under excitation	Diff. reactive current sensing relays
Cooling system malfunction	Overheat indicator

[1]May not be necessary in nonparalleled systems designed for wide frequency. Although the table suggests the feasibility of protection against generator overload, it is recommended in the interest of simplicity and reliability that the automatic overload protection be designed only for protection against gross overloads and that correction of overloads tolerable for a few minutes be accomplished manually.

3.6.2.4 Generator Drive Protection: When used, generator drive units should be installed in such a way that the generator and drive combination will meet the requirements of this document relative to installation of generator systems.

3.6.2.4 (Continued):

The installation of protective devices and warning devices should be carefully considered. Devices considered appropriate for one type of hydraulic-mechanical drive include: low oil pressure warning, differential (in/out) temperature indication, drive disconnect, and a shear section in the input shaft. Careful coordination of generator and drive characteristics is required to ensure that faults are cleared properly without damage to the drive.

3.6.3 Conversion System Protection: The nature and extent of protection required is a function of the equipment served by the conversion system (e.g., a rectifier for a shaver outlet may require only a circuit breaker or fuse in the input circuit whereas an inverter supplying power to flight instruments may require circuit protection in input and output circuits, failure warning, or automatic switching device, etc.)

3.6.3.1 Rectifiers, Transformer Rectifiers, and Transformers: Rectifiers, when used to supply an item of utilization equipment, should usually be protected by a circuit breaker or fuse on the power input side. A rectifier used as a control element (such as a blocking rectifier in a battery charging circuit), usually needs no protection in excess of that already provided for the wire feeding it. Inverters, transformers, and transformer rectifiers should usually have circuit breakers or fuses of appropriate rating both in the input and output circuits. If the output circuit is capable of passing, without hazard, a current sufficient to cause the input protector to open, an output circuit protector may be unnecessary. Overvoltage protection of transformers-rectifiers and inverters should be considered if they utilize voltage regulators capable of producing hazardous voltages as a result of probable malfunction.

3.6.4 Distribution System Protection: The principles of protection by careful design listed in 3.6.1.3 are generally applicable, irrespective of type of system (AC or DC).

3.6.4.1 Main Bus Protection: A main bus is a vital part of the electrical system and generally serves as a point of connection of the generator to loads and to other generators. A fault on this bus will result in the loss of service to loads connected directly to it, may cause large amounts of power to be dissipated locally, and will affect the ability of the system to function properly. Dependent upon the nature of the system in which it is used, power failure warning or automatic switching may be desirable.

3.6.4.1.1 DC Main Bus Protection: No completely satisfactory means of clearing an actual main bus fault has been developed and generally applied. Centralizing the bus in a protected location, reducing it to the smallest practical size, and providing means for fast sectionalizing in the event of a fault constitute possible methods for reducing fire hazards. Methods for disconnecting all power sources on a faulted bus, requiring discrimination between faults and legitimate overloads, must be carefully analyzed and tested. Backup protection for reverse current relays should be considered. It would be further desirable to take account of possible feedback currents from high inertia motors

3.6.4.1.1 (Continued):

that may be connected and running at the time of a fault. Feeders to other buses and to utilization systems should be connected to the main bus only through appropriate circuit breakers or fuses.

3.6.4.1.2 AC Main Bus Protection: The system should be such that when a fault occurs on a main bus, the bus will be isolated from its generator(s), and (if paralleled) from the remainder of the system. Protection of the bus from faults in the generator and its feeders may be accomplished by the same fault protection afforded the generator and its feeders. Isolation of a faulted main bus from the balance of the system should be provided by a means compatible with the overall system protection. The protection for the main bus should disconnect all phases for single phase, two phase, or three phase faults to prevent improper operation or damage to three phase equipment connected to the bus. Feeders to distribution buses should be protected with devices of adequate rupture capacity at or near the main bus.

3.6.4.2 Distribution Bus Protection: The distribution bus should be mechanically protected from faults by proper design (see 3.6.1.3).

Feeders should be protected with circuit breakers or current limiters of adequate interrupting capacity at or near the main bus. Special care should be exercised to assure coordination between bus feeder protection and the protective devices, which are connected to the distribution bus.

Load circuits should be connected to the distribution bus by means of circuit breakers or fuses. When the importance of the distribution bus or the exposure to faults of the feeder justifies, reliability of electrical service may be improved by use of multiple feeders. Each conductor of such a multiple feeder should be connected to the bus at each end by means of a limiter or circuit breaker chosen to provide discrimination between faulted and serviceable circuits.

3.6.5 Utilization System Protection: As discussed earlier (3.2 and 3.3), power wires to utilization systems should be protected by means of circuit breakers or fuses. These circuit protectors may afford some protection to the equipment but will usually be found marginal or inadequate if smoke from overheated equipment must be prevented. Thermal protection tailored to the requirements of the load device can usually be made effective for the latter purpose and should be provided if a probable malfunction could result in hazard due to fire or smoke.

The electric power system output characteristics should be compatible with the load equipment. MIL-STD-704 may be used as a guide for this purpose.

Choice of circuit protectors for three phase loads should be in accordance with 3.2.9 in order to achieve maximum equipment reliability and protection in addition to adequate wire protection.

3.6.6 External Power Circuit Protection: Feeders from the external power receptacle to the aircraft power system should be protected and isolated so that any probable malfunction will not adversely affect any system required for flight. The external power contactor should be located close to the aircraft bus so that a minimum of feeder is left connected to the power system when ground power is not being used. A means of preventing connection of electric power of reversed polarity or reversed phase sequence should be considered.

4. FAIL-SAFE FEATURES IN ELECTRIC CIRCUITS:

4.1 General Probability Consideration for Failure Analysis:

The installation of electric equipment and wiring in aircraft should consider a probable failure or malfunction with its attendant results on overall performance, safety of flight, and takeoff or landing. For example, dual navigation instruments are provided because the failure of one instrument would preclude the possibility of proper navigation during normal flight conditions.

4.1.1 Wiring Failures: During the service life of an aircraft it can be expected that wiring might fail for various reasons.

4.1.1.1 Wiring Opens: Consideration should be given to provide systems in which an open wire will not cause loss of control of the aircraft.

4.1.1.2 Wiring Grounds: Because wiring to equipment could suffer grounds or, under rare conditions, shorts to other wires, the design should prevent loss of control of the aircraft. In addition, appropriate circuit protection should be provided to reduce the hazard of smoke, fire, etc.

4.1.1.3 Loss of Phase: On three phase systems, consideration should be given to the possible loss of one or more phases resulting in erratic operation. Warning and protective devices should be provided if safety of flight could be jeopardized.

4.1.2 Equipment Failures: Occasional equipment failures are to be expected. Systems should be designed to minimize hazards that might result from such failures.

4.1.2.1 Relay Malfunction: Where relays are required, consideration should be given to the possibility of malfunction in completing the desired action or a return to its original state. Careful design and circuit analysis should be made to ascertain effects on overall aircraft performance.

4.1.2.2 Power System Malfunction: The electric power system can malfunction due to engine failure, generator malfunction, or a generator control system failure. Provisions should be incorporated in the system so that malfunction of one or more generators will not cause malfunction of other generators. In the event generator loading is excessive, provisions for monitoring should be provided in accordance with 17.6.

4.1.3 Design Considerations: Wiring and equipment may be exposed to physical abuse, foreign objects, dirt, moisture, etc., which could result in cross connections, grounds, shorts, or open circuits. Careful design and application will help to preclude these possibilities.

4.1.3.1 Continuous Wiring: Continuous wiring from a source to a unit, or wiring properly isolated and protected at splice points, can be considered as minimizing the probability of shorting or grounding except at its terminations.

4.1.3.2 Separation of Wires: For special considerations, the separation of wires of the same system by location in separate harnesses and separate connectors further reduces the probability of shorting together.

4.1.3.3 Critical Circuits: Critical circuits such as reverse pitch, fire extinguisher, etc., which complete their circuit by grounding, can be considered as having no probability of false operation if both ends of the circuit are grounded or isolated when normally in the nonoperate condition. Maximum protection can be achieved by providing grounding or isolating with a minimum of wire between isolation or grounding point and the equipment involved.

4.2 Definitions, Principles, and General Recommendations:

Safety and reliability should be prime considerations for all the circuits and components of an aircraft electrical installation. An inoperative or malfunctioning condition is, however, more potentially hazardous in certain circuits than it is in others. Here special design consideration should be given and measures taken, even at the expense of adding weight where necessary, in order to minimize the probabilities of failure. Basic principles for securing reliability are listed as follows:

a. Careful selection of equipment allowing for the full range of environmental and operational conditions for which reliable operation is desired

b. Particular care in routing and installation of wire and components, segregating them where possible from other installations, and providing maximum practical mechanical protection

c. Power supply from a source, or sources, of maximum reliability

d. Duplication of circuits and equipment

In spite of all design precautions, however, it is impossible to absolutely assure freedom from power failure and from shorted or open circuits. Recognizing this situation, the application of "fail-safe" principles to circuit and equipment design may nevertheless make it possible to minimize fire hazard and avoid false operation or indication. An ideal "fail-safe" design as applied to a control circuit would leave the actuator in a safe position for continued aircraft operation and, as applied to an indicator, would notify the crew that the indicator had suffered a failure and was no longer reliable.

4.2.1 Definition: A fail-safe circuit may be defined as a circuit that has characteristics such that any probable malfunction will not adversely affect the safe operation of the aircraft or the safety of the passengers.

4.2.2 Circuit Analysis: Every circuit and system being considered for installation in an aircraft should be analyzed, by actual test where necessary, for its effect on the aircraft operation as well as its effect on other equipment or systems. Such analysis should include all system components.

4.2.2.1 Circuit Malfunctions: Evaluation of circuit failures should include all probable malfunctions with particular attention to the following:

a. Short-circuit to ground

b. Short-circuit to adjacent leads or terminals

c. Open circuit, especially open bridge or amplifier circuits

d. Faulted or malfunctioning relays, vacuum tubes, transformers, etc. particularly in bridge circuits

e. Open or high resistance ground connections, especially where common to more than one system or component

f. Undesirable feedback where one or more elements are common to two or more circuits

4.3 Fire Detection Circuits:

4.3.1 Integrity of Fire Detector Circuits: The need for accurate performance of fire detection circuits cannot be overemphasized. Judicious use of fire extinguishing agents is to be made. The design of the fire detection equipment should reduce needless concern of the pilot as well as unwarranted shutdown of engines, heaters, etc. from faulty fire signals. AS8028 provides information on fire detection instruments.

4.3.2 Selection of Components for Fire Detector Circuits: It is recommended that all components of the circuit, including wire, be carefully selected for the utmost in reliability and that the installation receive due attention particularly in zones where damage is most likely to occur.

4.3.3 Shorted or Open Wire Effects on Fire Detector Circuits: A shorted or open wire in the circuit should not produce a fire signal. A simple method of checking the circuit, suitable for crew use, both on the ground and in flight, should be provided.

4.3.4 Coordination and Interconnection of Fire Detector Circuits: The fire detection circuits should be carefully coordinated with fire protection (i.e., a number of detectors should be installed in an area covered by a given charge of fire fighting agent). Fire detection circuits should not be so interconnected that a failure of any component or wire will make other fire detection circuits inoperative. For example, a circuit failure in one nacelle should not trip the circuit breaker for, or otherwise interfere with, the fire detection circuit of another nacelle.

4.4 Propeller Circuits:

4.4.1 Interconnection of Propeller Control Circuits: Circuits to control various propeller functions, such as feathering, reversing, and pitch change within the governed range should not be unnecessarily interconnected so that a failure of control for one function would make other functions inoperative. No single failure should result in the hazardous malfunctioning of more than one propeller.

4.4.2 Failure of Propeller Control Circuits: Failure of control circuits for a particular function should not permit the propeller to attain an unselected position. For example, failure of propeller governed range control should not allow the propeller to go into feathered or reverse position but should preferably hold either fixed pitch or fixed rpm. Conversely, the propeller should remain in a feathered position if it has been selected prior to failure. Particular attention should be paid to automatic or interdependent control circuits, such as turboprop engine automatic propeller controls.

4.5 Thermal Anti-Icing and Deicing Circuits:

4.5.1 Overheat Control in Thermal Anti-Icing and Deicing Circuits: The circuitry for anti-icing and deicing systems should provide a means for protecting against overheat conditions that would be hazardous to aircraft structure or present a fire hazard. Where anti-icing or defogging is provided for windshields, etc. special consideration is necessary to prevent distortion or crazing, which affects visibility as well as structural strength. Low heat signals should also be included. This may be provided by temperature indicators and selector switches. Overheat controls should have low thermal inertia so that the signal or correction will not lag behind the temperature rise.

4.5.2 Symmetrical Anti-Icing and Deicing Control: Depending on the particular application, consideration may be given to maintaining a symmetrical anti-icing pattern regardless of individual circuit or heater component failures. For example, failure of a section of left inboard wing anti-icing might require that the corresponding anti-icing for the right wing be shut down. In addition, the failure of an ice removal or prevention system on helicopter or propeller blades may require similar control to prevent unsymmetrical deicing.

4.6 Fire Extinguishing Control Circuits:

4.6.1 Selection and Protection of Fire Extinguishing Control Components: In view of the importance of assuring reliable operation of fire extinguisher circuits, it is recommended that all switches and control elements be judiciously selected for maximum reliability and that all electric components and wires be carefully installed so as to provide the best practicable degree of physical protection. Segregation and separate routing from other wiring is suggested with extra precautions to be taken in zones where damage is most likely to occur. Also as a design objective, the circuits for a fire extinguishing system should be arranged to permit the operator, possibly by means of duplicate circuitry and control equipment, to operate the system by bypassing shorted or broken wires.

4.6.2 Circuit Connection for Fire Extinguishing Control Components: The circuitry for a fire extinguishing system should be arranged to avoid discharge of the extinguishing agent into a "closed line" (i.e., the direction valve(s) should be operated prior to release of the agent). The circuit should also avoid dependence on the fire detection system for actuation of the direction valves since some fires, not picked up by the detection system, are discovered by the crew. Fire extinguishing circuits should not be so interconnected that a failure of any component or wire will make other fire extinguishing circuits inoperative. For example, a circuit failure in one nacelle should not trip the circuit breaker for, or otherwise interfere with, the fire extinguishing circuit of another nacelle.

4.7 Fluid Shutoff Valve Circuits:

4.7.1 Selection of Fluid Shutoff Valves: In order to provide "fail-safe" features in fluid shutoff control circuits, it is recommended that normally closed solenoid valves for fuel and oil lines be used in all cases where automatic closure of the valve, due to a failure in the valve itself or its electric circuit, would not create a hazardous flight condition (e.g., a solenoid valve should be used in a cabin heater circuit but not in the fuel line to an engine). For the latter application, the valve should remain in its last selected position in case of low voltage. In order to avoid having overheated valves under no-flow condition, continuously energized solenoid valves should be checked for temperature rise under actual operating conditions.

4.7.2 Engine Oil Valve Control: Consideration should be given to the possibility of engine seizure resulting from arrangements in which engine oil is shut off prior to completion of feathering. Fuel valves, however, should close as soon as possible in fighting a fire. It should be impossible to turn the fuel on for an engine without also turning the oil on.

4.8 Other Circuits:

4.8.1 Circuits Recommended for Fail-Safe Consideration: Consideration should be given to fail-safe characteristics for the following circuits:

a. Auto pilot
b. Fuel control
c. Turbo control
d. Control system boost
e. Flight control systems including trim and artificial feel systems
f. Flight instruments
g. Heating, ventilating, and pressurization systems including combustion heaters
h. Fluid shutoff valve control
i. Automatic brake control
j. Reverse thrust controls
k. Electric flare release
l. Engine controls, especially automatic turbine engine controls
m. Landing gear control

5. CIRCUITS FOR ESSENTIAL EQUIPMENT:

5.1 Definitions and General Principles:

In order to provide the most safety and reliability of operation of an aircraft electric system and its components, it is necessary that each circuit be given design consideration commensurate with the importance of the circuit involved. The type of power to be used, type of wire required, wire routing, wire protection, etc. are prime considerations in the design of all circuits. They should be given special attention in circuits for essential equipment.

5.1.1 Essential Circuits: Essential circuits are defined as those necessary to accomplish the mission of the aircraft under the most adverse environmental conditions for which the aircraft was designed.

5.1.2 Emergency Circuits: Emergency circuits are defined as those essential circuits, the failure of which may result in the inability of the aircraft to maintain controlled flight and affect a safe landing.

5.2 Dual Power Sources:

For emergency circuits, alternate sources of power should be provided.

5.2.1 Selection of Alternate Power Supplies: The source of power for emergency circuits should be of the highest reliability. This is generally the primary power generating system. Some of the considerations in the selection of an emergency power supply are as follows:

a. The source should be adequate to supply the required power until a safe landing is made under all probable initial conditions (e.g., a battery not fully charged).

b. The source should have sufficient capacity to start and operate emergency systems (e.g., starting of gyro instruments, fuel pumps, or inverters).

c. The source should have a means of being checked prior to flight and, preferably, during flight as well. The capacity of the supply should not be compromised by this testing.

d. The emergency supply circuitry should be arranged so that the supply will not be detrimentally affected by normal operation of the main system (e.g., where a battery is used as an alternative source of power, it cannot be relied upon to perform this function unless means are provided to immediately warn the crew of an abnormal discharge condition so that the battery may be disconnected from the main bus before the normal electrical power requirements seriously discharge the battery).

5.2.1.1 Recommendation: It is recommended that, if possible, the primary generating system be designed to fulfill the requirements for the dual emergency power sources.

5.2.2 Types of Self-Contained Emergency Power Supplies: Emergency load requirements are gradually increasing and becoming AC, rather than DC, so that a battery source may be uneconomical for many applications. Various solid fuel, liquid fuel, and ram air turbine driven generator units are available. These units are usually complex mechanisms and require extreme care in application.

5.2.3 Use of Main Engines: If the main engines are considered for the source of emergency power, consideration should be given to problems arising from engine failures in flight.

5.3 Electrical Isolation:

5.3.1 Individual Circuit Protection for Essential Circuits: Circuits for essential equipment, including emergency circuits, should have individual circuit protection.

5.3.2 Emergency Circuit Power Sources: Emergency circuits should be fed from the most reliable bus of the aircraft. The reliability of this bus can be improved by designing so that it can be connected to an alternate source or sources of power and so that it can be isolated from other buses by sectionalizing means.

5.3.2.1 Essential Load Grouping: Special consideration should be given to ensure against the loss of more than one group of instruments or control units due to opening of a single circuit protector (e.g., instruments or control units for one engine should not be connected to the protector used for the corresponding equipment of another engine). Similarly, duplicate systems used to improve reliability, should not be operated from a common protector (i.e., duplicate fire extinguishers or flight instrument systems should be provided with separate protectors).

5.3.2.2 Secondary Load Grouping: Consideration should be given to grouping the controls for loads (not classified as essential or emergency) so that they can be conveniently and quickly disconnected in the event of critical reduction of available electric power.

5.4 Types of Circuit Protection:

5.4.1 Protection for Essential Circuits: Circuit breakers should be used for essential circuits in order to take advantage of the ease with which they can be reclosed in flight. Where the required rating is such that only a fuse is available, special consideration should be given to assuring ease and safety in making a replacement during flight. Ready availability of a spare fuse of proper rating (and a fuse extractor if required) is very important. All circuit breakers or fuses used in essential or emergency circuits should be of the indicating type. Remote circuit breakers should be of a type that will give an indication of a tripped condition. The indicator should be at or near the control point.

5.5 Sequence Operation:

5.5.1 Sequence Operation of Relays and Switches: Where it is necessary to design essential circuits in such a way that two or more sets of contacts must operate in a given sequence, positive interlocking means should be provided to assure the proper sequence of operation.

5.6 Special Consideration in Wire Routing:

5.6.1 High Temperature Area Wire Routing: As a design objective, wires for essential equipment should be routed only through locations that are not subjected to extremes in temperature. In areas where high temperatures are encountered such as engine compartments, high temperature wire should be used. If conduit is required for mechanical protection on emergency circuits, fireproof rigid or flexible conduit should be used. Wiring from an outboard engine should be protected from fire where it passes an inboard engine.

5.6.2 Low Temperature Area Wire Routing: The majority of aircraft wire is designed to withstand flexing at low temperatures. However, various materials such as tubing, hose, etc., which are used to protect wiring, may not withstand low temperature flexing. Their use should be carefully considered in applications where flexing takes place. Cracking of these materials may damage the conductors or cause shorts in adjacent wires. If cracking is severe, pieces may fall from the wiring and interfere with mechanical parts.

5.6.3 Deterioration Hazards Due to Wire Routing: Wires should be routed away from heated equipment, fuel, oil, and hydraulic lines, oxygen tanks, etc. to prevent wire insulation deterioration and minimize hazard caused by failure of the equipment or lines. When proximity to such items is unavoidable, the wiring should be adequately protected. (See also 9.2.2.)

5.6.4 Mechanical Damage Due to Wire Routing: Wires should be routed and protected in such a manner that they will not be damaged by personnel moving within or working on the aircraft and from cargo stowage or shifting.

5.6.5 Alternate Circuit Wire Routing: Where essential equipment and wiring are duplicated, the advantages can best be realized by routing the two circuits separately from each other. Grounds for such circuits should be attached to separate points on the airframe. One or both may be routed with bundles from other equipment where there is a need to reduce the total number of bundles.

5.6.6 Protection and Support of Wires: Where practicable, wires should be routed in areas easily accessible for periodic inspection. Wires should be supported securely to prevent chafing, and to reduce vibration and mechanical strain. In areas where severe vibration is encountered, wires in junction and pull boxes may require supporting clamps within the boxes to prevent chafing against conduit fittings. Heavy wire bundles should be supported so the bundle does not press against the edges of conduit fittings or nylon grommet. A short length of flexible dielectric tubing

5.6.6 (Continued):

slipped over and secured to the bundle, and extending through the fitting, may suffice for single wires or small bundles where a special clamp does not appear justified.

5.6.7 Fire Zone Wire Routing: To minimize the potential danger from fires that occur, circuits such as ignition, propeller, fire detection, and fire extinguishing control should receive very special treatment. For that part of a wire run, which is within a fire zone, fire zone wire should be used (see MIL-W-25038).

5.7 Special Considerations in Fire Areas:

5.7.1 Fire Wall and Fire Seal Connections: Steel plugs and receptacles with fireproof inserts used in engine fire walls and baffles will comply with pertinent FAA regulations by preventing fires in one area from spreading to the adjacent area. In addition, circuits may be maintained through the connector by using contacts that do not melt under the test conditions prescribed by FAA test requirements. These contacts may be attached to the wires by mechanical means. Conduit fittings on fire walls should either be shrouded or preferably manufactured from steel or titanium. Die cast aluminum fittings melt in approximately 2 min during an engine fire and allow the flames to penetrate to the adjacent zone. The requirement for 2000 °F flame in MIL-HDBK-221 dates to CAA safety regulations release No. 259 dated 26 August 1947.

5.7.2 Fire Detector Circuits: Use of a fireproof plug together with a proper wire is recommended for fire detector circuits in order to maintain a circuit functionally for as long as practical during the occurrence of a fire. Conduit, if used to protect the wire, should be fireproof, preferably employing stainless steel. Conduit, however, is not necessarily required in order to maintain a working circuit; fire detector wires in fire areas may be installed open and supported by steel clamps. Means should be provided to prevent abrasion of the wire by the clamps. The use of infrared type fire detecting devices mounted through engine fire walls can minimize the exposure of related connectors and wire to engine compartment fires.

5.7.3 Fairleads on Fire Walls: Fairleads, grommets, and feed-throughs in fire walls and in the engine sections should be manufactured from fireproof insulation materials. Because of the many different characteristics of these materials, it is recommended that tests be conducted for strength, vibration, moisture resistance, and conformance with pertinent regulations.

5.7.4 Dielectric Materials: Certain insulators, used because of their resistance to damage by fire, become conductors during and after exposure to fire. Tests should be performed to determine if such results will adversely affect the performance. IEEE 135 lists tests for electrical insulation for aircraft.

5.7.5 Electric Equipment: Electric equipment required to operate during a fire should be fire-resistant.

5.8 Flight Instruments:

5.8.1 Multipower Sources for Flight Instruments: Where duplicate flight instruments are required, the system, including power sources, should be such that no single failure can cause the loss of both sets of instruments. (See also 5.6.)

5.8.1.1 Flight Instrument Power Indication: Consideration should be given to providing indication of the failure to supply satisfactory power to one or more phases of the instruments.

6. MULTI-ENGINE RELIABILITY:

6.1 General Principles and Recommendations:

The proper operation and, in many cases, the safety of modern aircraft depends on a completely reliable electric system. Even with up to 50% of the main engines out, there should be enough electric power available to operate fire fighting equipment, flight instruments, essential radio, emergency lighting, etc. Therefore, as long as the main engines are to be used as a power source to drive generators, it is very important that the generators be distributed among the engines in such a way that electric power will be available under all conditions under which level flight can be maintained after any probable engine failure.

6.2 Power Source (Generators):

6.2.1 Low Engine Revolutions Per Minute Operation of Generators: On some aircraft, electric power requirements are such that two generators are mounted on one engine. When this is necessary, the engines normally used for taxi purposes should be considered for mounting the extra generators. In this way, maximum electric power is made available during ground operations that normally are performed under low engine rpm conditions.

6.2.2 Capacity of Generators: The installed capacity of the generation system should be at least 100% in excess of the amount required for operation of all essential loads under any flight condition. As used herein, installed generation system capacity means the actual available capacity of all generators under the particular altitude and cooling conditions prevailing during the various flight conditions. In paralleled generator systems, due to paralleling tolerances, the electric load, as indicated by the load analysis, should not exceed 85%[1] of the continuous or short time capacity of the generation system under the specified conditions of ground or flight operation. (See MIL-E-7016 or MIL-E-7017 for a method of making load analysis.) The electric power available in excess of essential requirements may be used for convenience or passenger comfort items such as reading lights, electric shavers, water heaters, etc. In the event that one or more generators are lost, passenger comfort items may be disconnected as required by the reduced generator capacity. Consideration should generally be given to means for disconnection of convenience loads by manual or automatic monitoring, in order not to exceed the short time capacities of the generators. (See also 14.2 for growth capacity.)

[1] The 85% allows for imperfect paralleling as well as generator feeder losses. A higher value is permissible if it can be justified.

6.3 Separate Routing of Wiring:

6.3.1 Instrument Wire Routing: Instrument wires should be so routed that any probable damage to any wire bundle will not affect the operation of more than one group of instruments. A fire in any single wire bundle should not affect the operation of instruments for more than one engine or set of flight instruments. Separate routing should be considered for the wire bundles from each engine all the way to the instrument panel. (See also 5.6.)

6.3.2 Generator Feeder and Control Wiring: In multiple generator installations, generator wiring should be installed to minimize the probability of damage, which would render more than one generator inoperative. (See also 5.6.)

7. CONNECTORS AND OTHER TERMINATIONS:

7.1 General Recommendation:

Connectors and terminals in aircraft require special attention to assure a safe and satisfactory installation. Every possibility of short-circuits due to misinstallation, poor maintenance, and service life should be eliminated in the design.

7.2 Studs and Insulators:

Recommendations concerning studs also apply to other feed-through conductors.

7.2.1 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. The stud should not be hotter than the wire. (See also 9.5.1.)

7.2.2 Size of Studs: In designing the stud for a feed-through connection, attention should be given to the higher resistivity of brass, etc. 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 compensated for the difference of resistivity of the metals. Consideration should also be given to mechanical strength.

7.2.3 Support for Studs: The main stud support in the feed-through insulation should be independent of the attachment of the lugs to the stud, so that a loosening of the insulation support of the stud will in no way 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.

7.2.4 Support of Wire at Studs: Unless some other positive locking action is provided, the lug or wire should be supported next to the stud to prevent loosening the connection with a side pull on the wire. Torque recommendations for attaching electrical wiring devices to terminal boards or blocks, studs, posts, etc. are found in ARP1928. (See also 9.5.2.)

7.2.5 Feed-Through Insulator and Stud Design: Feed-through insulator design should be such as to prevent a loose insulator from failing to provide circuit isolation. It should not be able to move from between the stud and the structure thus allowing the two to come into contact. The assembly should be so designed that it is impossible to 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.

7.3 Electrical Connectors:

7.3.1 General: The number and complexity of wiring systems has resulted in increased utilization of electrical connectors in modern aircraft. The proper choice and application of connectors is a significant part of the design of any new aircraft wiring system.

7.3.2 Design Objective: Connectors should be selected and installed in a manner, which provides the maximum degree of safety and reliability to the aircraft and its occupants. It must be recognized that achievement of this goal can be more readily accomplished if the use of connectors is kept to a minimum consistent with efficient manufacturing and maintenance.

7.3.3 Selection: The connector used for each application should be selected only after a careful determination of the electrical and environmental requirements. Size, weight, tooling, logistic and maintenance support, and compatibility with standardization programs should be considered. For ease of assembly and maintenance, connectors using crimped contacts are generally chosen for all applications except those requiring an hermetic seal. ARP1308 may be used as a selection guide for commercial applications and MIL-STD-1353 for military applications. Connectors not listed in these selection guides may also be used when the application dictates.

7.3.4 Connector Types:

7.3.4.1 Environmental Classes: Environment resistant connectors are used in applications where they will probably be subjected to fluids, vibration, thermal and mechanical shock, corrosive elements, etc. Fire wall class connectors incorporating these same features must, in addition, be able to prevent the penetration of fire through the aircraft fire wall connector opening and must 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 must be given to the termination of individual and overall shields. Backshell adapters designed for shield termination, connectors with conductive finishes, and EMC grounding fingers are available for this purpose. On installations where limited space and visibility are a problem, "scoop proof" connectors can be used to avoid pin damage caused by mishandling during the mating operation. The use of nonenvironmental connectors is limited to areas where exposure to elements, which might induce connector failure, can be positively avoided. Guidance for selecting connector types for SWAMP (severe wind and moisture problem) locations is provided by AIR1557.

7.3.4.2 Rectangular Connectors: Rectangular connectors are typically used in applications where a very large number of circuits must be 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 thath assure 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.

7.3.4.3 Module Blocks: These junctions accept crimped contacts similar to those on connectors. Some utilize internal bussing to provide a variety of circuit arrangements. They are useful where a number of wires must be connected for power or signal distribution. When used as grounding modules, they save space 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.

7.3.5 Rating: Connectors should be selected, which are 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 must 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 chosen, which are 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 purchase specifications.

7.3.6 Spare Contacts: In order to accommodate future wiring additions, spare contacts are normally provided. Locating these unwired contacts along the outer part of the connector facilitates future access. A good practice is to provide a minimum of 10% spares (2 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 for components that are unlikely to have added wiring. Connectors should have all available contact cavities filled with wired or unwired contacts. Unwired contacts should be provided with a plastic grommet sealing plug. Spare contacts removed at a future date should not be used to wire the connector. New contacts should be used.

7.3.7 Redundancy: Wires that perform the same function in redundant systems should 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 will considerably reduce an aircraft's susceptibility to incidents that might result from connector failures.

7.3.8 Adjacent Locations: It should not be possible to incorrectly mate adjacent connectors. In order to avoid this, adjacent connector pairs, which are different in shell size, coupling means, insert arrangement, or keying should be used. When such means are impractical, wires should be routed and clamped such that incorrectly matched pairs cannot reach each other. Reliance on markings or color stripes are not recommended as they are likely to deteriorate with age.

7.3.9 Sealing: Connectors should be of a type that exclude moisture entry through the use of peripheral and interfacial seals, which are compressed when the connector is mated. Moisture entry through the rear of the connector should be avoided by correctly matching the wire outside diameter with the connector rear grommet's 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 and the application of potting to the wire entry area are additional means of providing a rear seal. Step stripping wire insulation to a smaller diameter to provide compatibility with the rear grommet is not recommended. These extra means have inherent penalties and should only be considered where other means cannot be used. Unwired spare contacts should have a correctly sized plastic plug installed. AIR1329 provides detailed information on connector/wire sealing compatibility, proper matching of connectors, wire, and contact insert/removal tools.

7.3.10 Drainage: Connectors should be installed in a manner, which assures that moisture and fluids will drain out of and not into the connector. Wiring should 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 should 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. AIR1350 provides detailed guidelines for receptacle mounting.

7.3.11 Wire Support: A rear accessory backshell, which compresses the connector rear grommet when tightened, should be used on connectors that are not located inside of enclosures. Connectors having very small size wiring, or are subject to frequent maintenance activity, or located in high vibration areas should 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.

7.3.12 Slack: Sufficient wire length should be provided at connectors to assure a proper drip loop and no strain on terminations exist after a complete replacement of the connector and its contacts.

7.3.13 Identification: Reference identification shall be provided for each connector. The identification shall remain legible throughout the expected life of the aircraft.

NOTE: AIR1329, AIR1350, AIR1402, AIR1557, and ARP1308 are available from the Society of Automotive Engineers, Inc., Warrendale, PA 15096.

7.4 Feed-Through Bulkhead Wire Protection:

7.4.1 Feed-Through Bushings for Wire Bundles: Consideration should be given to means of protecting wire bundles, which pass through bulkheads, frames, and other similar structure. Feed-through bushings of hard dielectric material, affording a minimum of 1/16 in mechanical separation between wire bundles and any metal edges, are satisfactory. The use of NAS557 split plastic grommets (nylon) is recommended in lieu of rubber grommets, as they eliminate the unsatisfactory features of rubber grommets and are resistant to fluids usually encountered in aircraft.

7.4.2 Wire Clamps: MS21919 cushion type clamps are considered to be satisfactory if a minimum 1/8 in air separation is maintained from the metal structure. Supports should be positively secured against rotation.

8. GROUNDING AND BONDING:

8.1 General and Definitions:

One of the most commonly overlooked factors in good aircraft electrical design is proper grounding and bonding of equipment. Such oversights lead to poor and unsafe operation of the equipment and to radio noise. MIL-B-5087, ARP1870, and ARP4043 provide information on bonding and grounding.

8.1.1 Bonding (Definition): "Bonding" is a general term applied to the process of electrically connecting two or more conducting objects. In aircraft, the purpose of bonding (except as applied to individual connections in the wiring and grounding system) is to provide conducting paths for frequencies ranging from DC to beyond UHF. This is accomplished by suitably low, nonvarying impedance connections joining parts to the aircraft structure. Another purpose of bonding is to ensure the safe passage of current caused by lightning or static electricity to aircraft structure.

8.1.2 Grounding (Definition): The term "grounding" is usually applied to a particular form of bonding that is the process of electrically connecting conducting objects to basic metal structure for the purpose of safely completing either a normal or fault circuit at power frequency. (An additional requirement on the ground connection is that impedance must be essentially constant, that is, it must not introduce noise.) Several bonds may be involved in completing a ground.

8.2 Grounding:

8.2.1 Current Return Paths: Ground return circuits should have a current rating adequate for satisfactory operation of the electric and electronic equipment connected thereto. The current carrying capacity and voltage drop requirements of Section 9 should be met. The design of the ground return circuit for a device should be given just as much attention as the other leads. Special care should be exercised to eliminate the possibility of maintenance personnel not replacing ground return leads because of the erroneous understanding that the device is grounded by means of its mounting. The use of numbered insulated wire leads instead of bare grounding jumpers may aid in this respect. In general, where heavy current devices are used the unit should have a ground terminal, even though internally grounded. This will permit ground lead connections. Direct mechanical connection to magnesium structure should not be used for ground return.

8.2.1.1 Current Return Paths for Internally Grounded Equipment: Internally grounded equipment should be avoided if possible and carefully installed when used. The finishes should be removed from the structure and equipment attachment points to ensure adequate current carrying capacity of the grounding path to primary structure. In particular, internally grounded devices utilized in fuel and similar systems should be carefully examined for adequacy of the grounding path. Omission of a grounding jumper, failure to clean mating surfaces, faulted equipment, or cross connection of the power, and/or ground leads should not result in sparking or undue heating of any part exposed to flammable mixtures. The effects of transient conditions should be considered in determining freedom from this hazard.

8.2.1.2 Grounding for Fault Protection: All metallic conduit and junction boxes should be grounded to structure with a resistance of 1/10 Ω or less to assure proper operation of the circuit protectors in the event of shorts inside of the conduit or junction boxes. (See also 8.3.4.)

8.2.1.3 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 the malfunctions, which might be caused by a loose or improperly made connection, affecting more than one circuit will not result in a hazardous condition. The effect of the interconnection of the circuits when ungrounded should be considered. Bonds to thermally or vibration isolated structure require special consideration to avoid single ground return to primary structure.

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

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

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

8.3 Bonding:

The following bonding requirements should be considered from a safety standpoint:

8.3.1 Equipment Bonding: Low impedance paths to aircraft structure are required for radio and radar equipment to provide radio frequency return circuits and for most electric equipment to facilitate radio noise reduction.

8.3.2 Metallic Surface Bonding: Homogeneous ground or counterpoise should be provided for radio antenna systems. All large external metallic surfaces such as wing, empennage, nacelles, doors, etc. should have mechanically secure electric connections to basic structure. A resistance to structure of less than 1 Ω is desirable and in no instance should the resistance be variable.

8.3.3 Parts to be Bonded: All isolated conducting parts inside and outside the aircraft having an area greater than 3 in² and a linear dimension over 3 in, which are subjected to appreciable electrostatic charging due to precipitation, to fluid or to air in motion, should have a mechanically secure electrical connection to the aircraft structure having a resistance of less than 1/2 MΩ when clean and dry.

8.3.4 Electric Shock Prevention Bonding: Electric shock to personnel should be prevented by providing a low resistance path of 1/10 Ω or less between structure and metallic conduits or equipment containing circuits of 50 V or above. 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 will provide adequate bonding if metal-to-metal contacts are maintained.

8.3.5 Lightning Discharge Systems for Antenna: Antenna lightning discharge systems should be installed on external antenna lead-ins together with suitable isolating devices to prevent lightning voltages and currents from being passed into the interior of the aircraft where they may produce sparking, damage radio equipment, or result in fire or smoke from excessive heat. The use of discharge devices without isolating devices such as capacitors is usually not effective. Discharge gaps and isolating means should be designed to permit normal operation of the radio equipment. A suitable system might consist of the following, all connected as close as possible to the antenna lead-in point:

a. A lightning discharge gap between antenna and ground adjusted to afford maximum protection and still not fail electrically at transmitter voltages.

b. A 1 MΩ resistor, connected between antenna and ground, of suitable voltage rating and impedance to withstand full voltage output of the radio transmitter.

8.3.5 (Continued):

c. An 0.0015 μF capacitor having a suitable radio frequency voltage and current rating for full transmitter output connected in series with the lead to the transmitter

8.3.6 Static Discharge Devices: Static grounding provisions should be made for the discharge of accumulated static electricity by automatically bringing the aircraft to ground potential on landing. Fuel nozzle grounding should be in accordance with AND 10439.

8.3.7 Lightning Protection Bonding: Special bonding should be applied (except on antenna systems) to achieve a lightning protection system such that a lightning discharge current may be carried between any two extremities of the aircraft without risk of damaging flight controls or of producing voltages within the aircraft that are in excess of 500 V. The design of this bonding should be based on a current surge crest of 100 000 A at 10 μs and dropping to 50 000 A at 20 μs.

8.3.7.1 Control Surface Lightning Protection Bonding: To accomplish the above, control surfaces and flaps should have at least one 6500 circular mil area copper 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. Loops in the copper jumper should be avoided. This is to prevent burning of hinges resulting in possible loss of control on the surface that receives a lightning strike.

8.3.7.2 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.

9. WIRE SELECTION AND ROUTING:

9.1 General:

The selection of the proper type and size of wire for any aircraft circuit is as important as selecting the proper protector for the wire. Improper wire selection either as to type, size, or poor wire routing can make an otherwise good electric system unsafe.

MIL-W-5088 covers aspects of wire selection for military aerospace vehicles and is normally used as a guide for many commercial programs. This document is maintained on a current basis through coordinated industry and military activities and should be used as a reference. Detail data is included for current ratings, altitude derating, corona considerations, and list of approved wire types.

9.2 Wire Type Selection:

SAE AS4372 and SAE AS4373 are recommended for the evaluation and proposed selection of wire constructions not listed in MIL-W-5088.

The following factors are of particular importance in the selection of types of electric wire with regard to the avoidance of hazards. The tests in the following are suggested for use when comparing types of wire.

9.2.1 Abrasion Resistance of Wire Insulation: Aircraft wire may be subjected to three different types of abrasion as follows:

a. A longitudinal rubbing or scraping during installation or maintenance operations.

b. A cross or circular rubbing due to vibration of wires in contact with each other or with supports and enclosures.

c. A beating effect due to vibration against supports and enclosures.

In determining the adequacy of wire insulation for aircraft use, tests should be made to determine the ability of the wire insulation to withstand all three types of abrasion. Different insulation constructions may show a marked difference in their susceptibility to the different types of damage. Resistance to cross or circular rubbing should be emphasized as being of the most importance in installed wire. The more commonly applied abrasion tests are only for longitudinal rubbing or scraping.

NOTE: Exposure to liquids, vapors, or combinations thereof may seriously affect the abrasion resistance of the insulation and should not be overlooked.

9.2.1.1 If wire with low abrasion resistant insulation is used, special installation methods should be employed to prevent chafing.

9.2.2 Effects of Fluids on Wire Insulation: Fluids that come in contact with electric wiring may create a hazardous condition either by increasing the flammability or by causing deterioration of the insulating materials. The military wire specifications specify tests with various fluids. Where the wire may come in contact with other liquids, similar tests should be conducted. Tests for fluid resistance should be made at the most adverse temperature encountered in the application. Particular attention should be given to "nonflammable" hydraulic fluids and special types of fuels, as the effects of such fluids have not been considered in the design of standard aircraft wire. The aircraft may also be subjected to low pH cleaning fluids, anti-icing fluids, paint removers, etc., which may contact the aircraft wiring. Sanitary fluids dripping on wire bundles should be avoided. Insulation that has degraded, which causes a circuit breaker to trip, may cause a fire in the wet bundle when the circuit breaker is reset. Judicious wire routing can eliminate such problems.

9.2.3 Effects of Aging on Wire Insulation: Since electric wire may be installed in areas in the aircraft where inspection is infrequent over extended periods of time, it is necessary to give special consideration to the aging characteristics in selection of the wire.

9.2.4 Heat Resistance of Wire Insulation: Resistance to heat is of primary importance in the selection of wire for aircraft use as it is the basic factor in wire rating. Wire ratings are based on either a maximum continuous conductor temperature or a maximum continuous wire insulation temperature. Where wire may be required to operate at higher temperatures, due either to high ambient temperatures or high current loadings or a combination of the two, selection should be made on the basis of tests for satisfactory operation and life under the worst conditions which may be anticipated. Test of wire under simulated operating conditions must be prolonged to be of value in determining the wire life, but shorter tests at elevated temperatures may be of value in determining whether smoke, fumes, or other rapid deterioration will result. Thermal characteristics of the wire insulation can be evaluated using test methods in ASTM D 3032.

9.2.5 Flame Resistance of Wire Insulation: Part 25, "Airworthiness Standards: Transport Category Airplanes", paragraph 25.1359 (d) requires that insulation on wires installed in any area of the fuselage be "self-extinguishing" when tested in accordance with Appendix F of Part 25. The test is performed with the wire at a 60° angle. MIL-W-22759, MIL-W-81044, and MIL-W-81381 all have flammability requirements based upon the 60° angle for the wire position. ASTM F 777 is also a wire insulation flammability test procedure which uses the 60° angle for the wire. These test procedures are more definitive than those in Part 25. The flammability test in ASTM D 3032, Section 18, uses a vertical wire position. In addition to the usual requirements in the flammability test procedures, consideration should be given to insulation constructions which minimize short-circuits between adjacent wires when the wires are subjected to overheating, but not otherwise damaged by fire.

9.3 Wire Size Selection:

9.3.1 Current Carrying Capacity of Copper Wires: Copper wire rated for 105 °C (221 °F) application should be selected for current carrying capability in accordance with Table 3. For applications above 105 °C, MIL-W-5088 should be used. MIL-W-5088 is more conservative at 105 °C than this document. Table 3 shows allowable currents for single wires and wires in bundles where the wire is rated for 105 °C (221 °F) and the ambient is 57.2 °C (135 °F). Bundles of 15 or more wires carrying in excess of 20% of the total carrying capacity of the bundle or containing large gage wires in a predominately small gage bundle may require derating of the wires. In smaller bundles the allowable percentage of total current may be increased as the bundle approaches the single wire condition. Continuous current carrying capacity may also be limited by a low current protector being utilized for particular design conditions. For short time ratings of copper wire, refer to curves of Figure 2. The current rating curves of Figure 2 are based on a maximum conductor temperature of 125 °C for time intervals of less than 0.04 s, and of 105 °C for time intervals of more than 9.0 s. This maximum temperature is graduated from 125 °C to 105 °C between the 0.04 s and 9.0 s. The method followed is based on AIEE Paper 46-145, and the protection limits for both long and short times are

9.3.1 (Continued):

selected to be approximately 25 °C higher than the working temperatures noted. The 25 °C spread between working and protection temperatures is intended to minimize the protector coordination problem as covered in Section 3.

TABLE 3 - Current Carrying Capacity of Copper Wires (Maximum Wire Temperature 105 °C (221 °F) with Ambient Temperature of 57.2 °C (135 °F))

Wire Size	Single Wire in Free Air	Wires in Conduit or Bundles See text in 9.3.1
22	9	5
20	11	7.5
18	16	10
16	22	13
14	32	17
12	41	23
10	55	33
8	73	46
6	101	60
4	135	80
2	181	100
1	211	125
0	245	150
00	283	175
000	328	200
0000	380	225

9.3.1.1 Calculating Allowable Current For Wires: The information on "current-temperature" relationships from MIL-W-5088 is also included herein in Appendix D. Bundle and altitude derating curves are also shown. The examples in Appendix D show how to use the curves, which are conservative and/or the "fail safe" side of the design. It is a good method for determining the size wire to use but may tend to underutilize the wire's temperature capability. In critical applications, the harness should be tested in its actual use environment to utilize it to its full and safe capability.

9.3.2 Specific Current Capacities for Copper Wire: In all bundles, the currents being carried by other wires in the bundle affect the capacity of each wire. In special cases such as power feeders or areas where bundle wire sizes or currents are known, it is possible to calculate wire capacities in lieu of using Table 3. This method is covered in detail by NRL Memorandum Report 442. The method allows the calculation of a specific current for each wire size in a bundle and may result in weight savings in lightly loaded bundles and prevent wire overheating in heavily loaded bundles.

9.3.3 High Temperature Wire Selection: Where ambient temperatures higher than 57.2 °C (135 °F) are encountered, the wire should be derated or wire with a high allowable temperature should be used (see Equation 1 for derating wires). High temperature wire may be uprated when used for lower ambient temperatures if the uprating does not cause the wire operating temperature to exceed the rated temperature of the wire. Restrictions may be imposed by the resistance of the conductor material used in high temperature wire or by the heat dissipation characteristics of the insulation used on such wire. Increased ratings should be based on adequate testing, information, and data.

$$I_D = I_R \left[(T_M - T_D)/(T_M - T_R)\right]^{1/2} \qquad \text{(Eq.1)}$$

where:

I_D = Derated value of current
I_R = Normal current rating from Table 3
T_M = Maximum rated wire temperature
T_R = Design ambient temperature for rated current (= 57.2 °C when I_R is taken from Table 3)
T_D = Actual ambient temperature between T_R and T_M

9.3.4 Aluminum Wire Selection: Aluminum wire should be selected on the basis of current ratings shown in Table 4. Where protectors are selected from Table 1 additional limitations may be imposed by the rating of the protector. For short time ratings of aluminum wire see Figure 3. Figure 3 was developed in the same manner as Figure 2 for copper wire except that it is for 100 °C (212 °F) rated wire temperature.

TABLE 4 - Current Carrying Capacity of Aluminum Wires

Wire Size	Maximum Current Amperes 57.2 °C Ambient Temperature Single Wire	Maximum Current Amperes 57.2 °C Ambient Temperature Bundled
8	60	36
6	83	50
4	108	66
2	152	82
1	174	105
0	202	123
00	235	145
000	266	162
0000	303	190

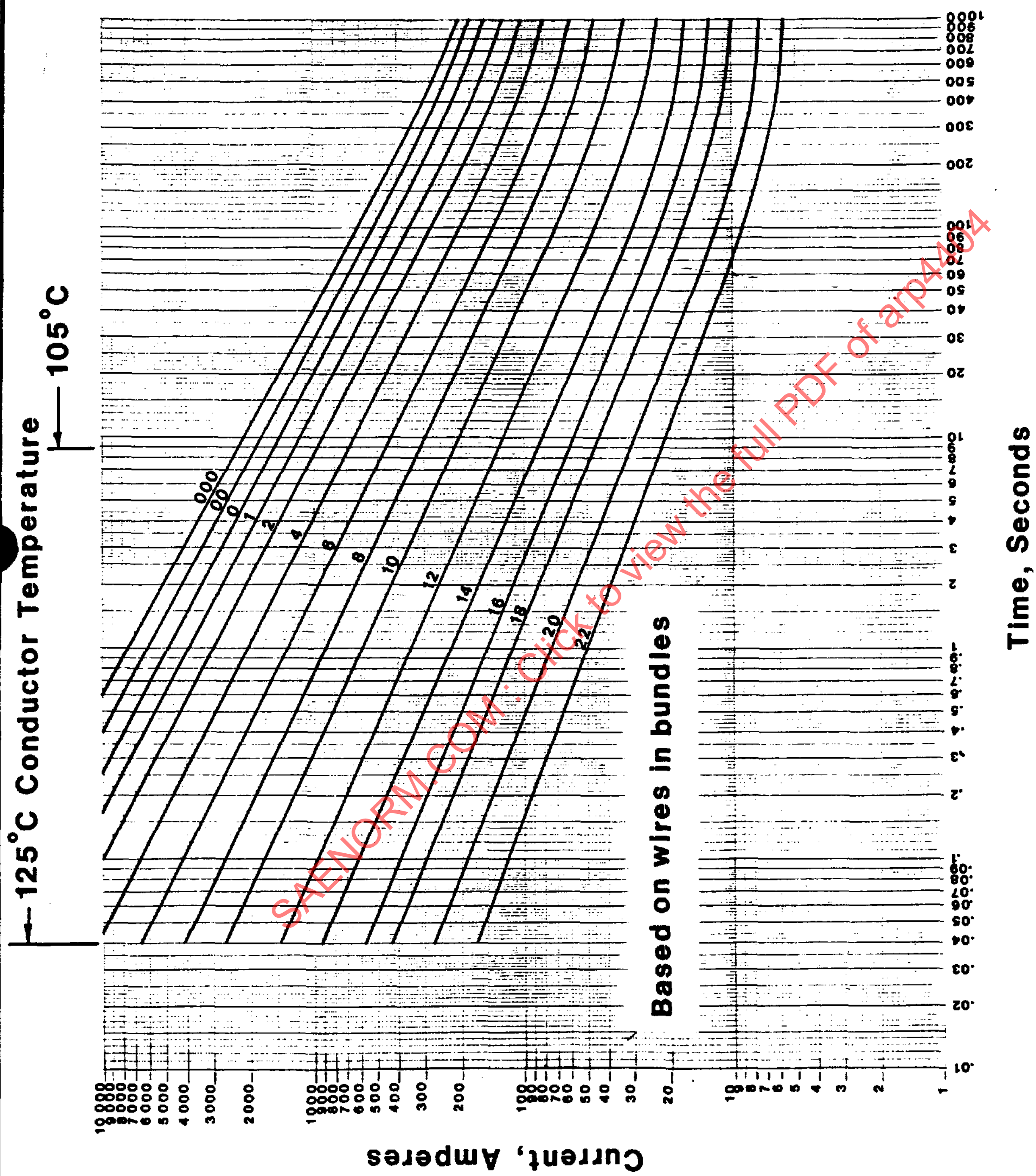

FIGURE 2 - Current - Time Characteristics, Copper Wire, 57.2 °C Ambient

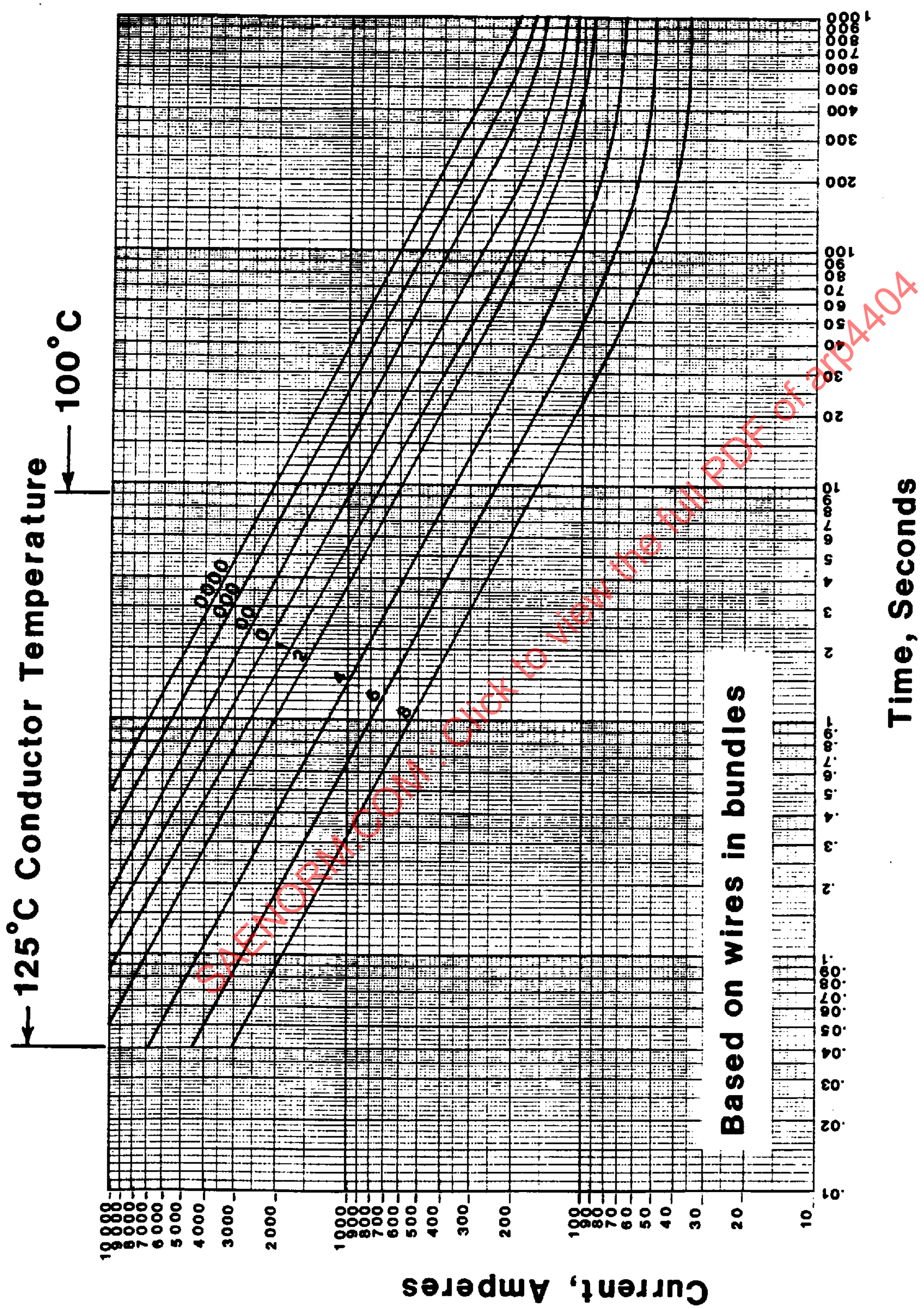

FIGURE 3 - Current - Time Characteristics, Aluminum Wire, 57.2 °C Ambient

9.3.5 Protective Devices for Wires: The protective devices should be as described in Table 1. In most cases, protective devices do not follow the same current-time curves as the wire. For this reason, the allowable current under some conditions may be limited by the protective device rather than by the heating of the wire. Care should be taken to select a protective device of the correct rating to avoid any nuisance tripping. Particular attention should be given to inrush and surge currents for motor starting, lamp starting, etc. and allowance should be made for the most adverse tolerances on the current-time cure of the protective device, as well as differences between protector and wire ambients not covered by Table 1.

9.3.6 Voltage Drop in Wires: Wire size will frequently be selected for voltage drop considerations rather than for current carrying capacity. Satisfactory operating voltage of the equipment should be provided under all required conditions. The increase in resistance due to the wire operating temperature may require special consideration when calculating voltage drops, particularly when using high strength copper alloy wire. To afford a greater degree of protection when wire sizes are selected for voltage drop reasons, lower rating protection than indicated for the wire size shown in Table 1, may be used. MIL-STD-704 can be used as a guide for required voltage levels for operation of aircraft electrical equipment.

9.3.7 Mechanical Strength of Wires: If it is desirable to use wire sizes smaller than listed in Tables 3 and 4, particular attention should be given to the mechanical strength and installation handling of these wires, i.e., vibration, flexing, and termination. Wire containing less than 19 strands should not be used unless a means for increasing mechanical strengths is provided. Consideration should be given to the use of copper covered steel wire or the use of high strength alloys in small gage wires to increase strength. Care should be exercised in choosing copper covered steel conductors in low frequency and DC applications as the conductivity of the wire may be as low as 85% of the same size copper wire.

9.4 Wire Routing:

Routing for wire bundles should satisfy the following conditions:

a. Reliability of electrical service.
b. Minimum hazard as a result of faults.
c. Tolerable electromagnetic coupling between systems.
d. Accessibility for maintenance and inspection.

9.4.1 Clearance Provisions Between Electric Wires and Other Units: Wire routing with respect to various other items may create a hazard either in the possibility of fire or the interruption of an essential service. Consideration should be given to the use of ducts or wireways to facilitate protection, accessibility, and inspection for large wire bundles or groups of bundles. Wire bundles or wires should be so routed and supported, tied, or guarded so that they will not be damaged by vibration or the various hazards likely to be encountered during installation, operation, and maintenance. Individual wires or small bundles are particularly vulnerable.

9.4.1.1 Proximity of Magnesium Alloys to Wires: Wire bundles or wires should be so supported or guarded so that there is no possibility of contact between magnesium alloy sheets or sections, and wires capable of supplying sufficient power to a short-circuit arc to cause ignition of the magnesium. Broken wires or loose terminal connections should be taken into account in determining the required precautions.

9.4.1.2 Proximity of Flammable Fluids to Wires: Wire bundles or wires should be so supported or guarded so that there is no possibility of contact between any wire and any metallic line carrying a flammable fluid. Broken wires or loose terminal connections should be taken into account in determining the required precautions.

a. Protection should also be considered for tanks or containers where a nearby wire or wire terminal is capable of supplying an arc, which might burn through the container.

b. Ample clearances are desirable between flammable fluid lines and wire terminals to prevent short-circuits by tools during maintenance operations on either the electric system or the adjacent installations. Consideration should be given to conditions that may exist due to the necessity for removing guards from electrical terminals during maintenance operations.

c. Oxygen lines and containers should be given the same consideration as flammable fluid lines and containers.

9.4.1.3 Proximity of Miscellaneous Lines and Containers to Wires: Arcing of an electric wire terminal to a line or tank may cause damage, which will result in loss of an essential service. Precautions similar to those outlined for flammable fluids are advisable in such cases.

9.4.1.4 Proximity of Control Cables to Electric Wires: Mechanical interference with the operation of controls can be caused by contact with wire bundles. Such routing shall be avoided. Short-circuits to ground through control cables may cause damage either by arcing or by overheating the cables with heavy currents. Suitable supports or guards should be provided for both the electric wires and the control cables. Consideration should be given to the sagging of control cables and the handling of loose electric wires during maintenance and replacement.

9.4.1.5 Proximity of Nonmetallic Materials to Wires: Supports, fairleads, guards, and other nonmetallic objects, which support electric wires, should be made of materials that will not smoke, burn, or otherwise fail at a temperature lower than that at which the wire will be similarly affected. Charring or flow of materials used for supports is particularly objectionable as it may result in the support failing in its purpose, with resulting wire damage.

9.4.2 Wires in Conduit: Metallic conduits should be grounded to structure with a resistance of 1/10 Ω or less to assure proper operation of the circuit protectors in the event of shorts inside the conduit.

9.4.3 Shielded Cable Routing: Special care should be given to the routing of electric cables or wires that have braided shielding exteriors. Damaged metal braid caused by chafing has frayed strands that may puncture the insulation of wires routed in the same bundle and cause short or intermittent short-circuits. One solution to this problem is to add a dielectric covering, which protects the shield.

9.4.4 Voltage Sensitive Circuit Routing: Voltage sensitive circuits such as control circuits for autopilot, remote compass, turboregulators, thermocouple, flares, explosive detonators, fire detectors, etc. should be routed in such a way that they will not pick up spurious signals from other circuits. These spurious signals may be due to induced voltages or leakage current or differences in ground potential throughout the aircraft. In voltage sensitive circuits, the number of connections in the wiring should be kept to a minimum.

9.4.5 Ignition Ground Leads Routing: Consideration should be given to routing ignition ground leads so that any probable damage to a wire bundle will not affect the operation of more than one engine.

9.4.6 Essential Engine Circuits Routing: Essential engine circuits should be so routed that any probable damage to a bundle will not affect the operation of more than one engine.

9.4.6.1 Protection of Wires Routed Through Fire Zone Areas: Wires routed through a fire zone area should be protected from heat and other damage in a manner commensurate with the importance of the circuit involved. Propeller feathering, combustible fluid shutoff valve, and fire detector wiring should be protected in such a way that circuit integrity will be maintained for at least 5 min under the worst probable conditions of fire that can be anticipated in the area. Fire detector wires should be protected for 5 min and, if at all possible, for an additional 10 min. Electric wires routed through the fire zone or zones of one engine, but connected to equipment within another engine's fire zone should be protected and installed to withstand a fire for at least 15 min. (See CAA Safety Release 259 for testing requirements.)

9.4.7 Drip Loops in Wire Bundles: Wires or groups of wires should enter a junction box or piece of equipment in an upward direction where practicable. However, 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 into the box or electric unit.

9.4.8 Size of Bundle: Wire bundle size should be held to a maximum of 2 in in diameter where practicable.

9.5 Wire Splices and Terminals:

9.5.1 Installation and Support of Wire Splices: Preinsulated permanent splices are considered a satisfactory means of connecting wires. The use of disconnect splices should be held to a minimum. Splices should be supported in such a way that relative motion between segments of the spliced wire is minimized. All splices shall be of the insulated type or shall be insulated with an appropriate material applied in a method that will prevent the insulation from being dislodged. Where two or more splices exist in the same bundle they should be staggered to prevent excessive bundle diameter buildup. For guidelines using tin plated crimp style lugs and splices on nickel coated wire, see AIR1263.

9.5.2 Wire Terminals: Selection of wire terminals shall take into consideration the following:

a. Current rating
b. Wire size (gage) and insulation diameter
c. Conductor material compatibility
d. Stud size
e. Insulation material compatibility
f. Application environment

Preinsulated crimp type ring tongue terminals are preferred. The strength, size, and supporting means of studs and binding posts, as well as the wire size, should be considered when determining the number of terminals to be attached to any one post. In no case, however, should the number of terminals on any one stud or binding post exceed four. (See also 7.2.4.)

9.6 Coaxial Cable:

9.6.1 Connectors for Coaxial Cables: In applying connectors to coaxial cables, special attention should be given to avoid damage to the center conductor, the dielectric, or outer braid while cutting, soldering, or crimping. Means should be provided to exclude liquids or moisture from entering the wax cable or connectors to prevent electric leakage due either to the moisture or to the corrosion, which might be caused by the moisture. Suitable solvents may be used to clean the mating faces of the coaxial cable connectors prior to mating. Excess solvent may be forced into the connector and cable if shop air is used to dry them. Some coaxial cable assemblies may suffer increased voltage standing wave ratio (VSWR) losses if this occurs. Such intruded solvent may remain in the cable for long periods and cause subsequent corrosion and increased electrical losses. Vertical runs of coaxial cables should not be supported by the connectors.

9.6.2 Bend Radius for Coaxial Cable: In order to minimize the effects of cold flow of certain types of dielectric materials used in coaxial cable, the minimum bend radius should be as large as possible but not less than that recommended by the detail cable specification.

9.6.2.1 Elevated Temperatures on Coaxial Cable: The possibilities of temperatures over 160 °F (71 °C) due to engines, heaters, or skin temperature should be considered in coaxial cable installations. If polyethylene dielectric is used, it will soften at temperatures above 160 °F. Consideration should be given to using tetraflouroethylene (TFE) dielectric. Softening temperature of the jacket material should also be considered where coaxial cables must be routed through high temperature areas.

10. ALUMINUM WIRE AND CONNECTIONS:

10.1 General:

The use of aluminum wire and terminals in the design of aircraft electric systems necessitates special inspection and manufacturing procedures. A suitable and detailed process specification is required to assure manufacturing conformance to engineering requirements. Such a process specification should establish adequate control of the phases of inspection and fabrication listed in 10.2 and 10.3.

10.2 Wire Inspection:

10.2.1 Wire Properties:

10.2.1.1 Physical Properties: Each lot of aluminum alloy wire used in aircraft electrical systems shall have been tested to assure conformance to the requirements for physical properties, particularly circular-mil-area, of the applicable material specification.

10.2.1.2 Chemical Composition: The wire supplier shall furnish test reports with each lot of wire, which indicates the chemical composition of that lot.

10.2.1.3 Insulation: Each length of aluminum wire used in aircraft electrical systems shall have had the insulation visually checked for insulation flaws or damage. Testing of the wire should include bending to the configuration required for installation to assure the insulation will withstand the bending without cracking or splitting.

10.2.2 Wire and Lug Assembly Inspection: To insure proper lug-to-wire connections, it is necessary to establish inspection requirements by a suitable process specification.

10.2.2.1 Wire Preparation: Nicked or broken strands are not permitted. Wire should be terminated within 8 h after insulation removal.

10.2.2.2 Installation of Lugs: Installation procedures have been prepared by the manufacturers of aluminum lugs, which should be carefully followed. Established crimping tool application pressures must be strictly followed. Periodic tool inspections are required. In addition, inspection shall perform periodic pull tests and millivolt drop tests to test overall tools, material, and workmanship.

10.2.2.3 Identification of Aluminum Lugs: Means should be provided to positively identify aluminum lugs to differentiate them from copper lugs.

10.2.2.4 Identification of Aluminum Wire: Means should be provided to positively identify aluminum wire to differentiate it from copper wire.

10.3 Stud Connections:

10.3.1 Use of Washers: Large outside diameter suitably plated steel washers with adequate thickness to distribute the clamping load should be used.

10.3.2 Dissimilar Materials in Contact: Manufacturers of terminal lugs and splices have published data and instruction sheets on terminating aluminum cable to minimize corrosion effects and electrolytic action. Recommendations by these suppliers should be followed precisely in the use of their products.

10.3.3 Use of Joint Compound: A joint compound may be used to lower the contact resistance for a given contact pressure. Use of such compounds should not be made in a crimp joint unless so recommended by the lug or splice manufacturer.

10.4 Installation Requirements (See also Section 9):

10.4.1 Routing and Supporting: Aluminum wire should not be routed through areas of excessive vibration. The wire should be clamped and supported in such a manner that there is no relative motion between the wire and the terminal or clamp. In the case of shock mounted equipment and devices subject to frequent servicing or replacement (e.g., batteries) it is advisable to terminate the aluminum wire in the vicinity of the item and use a copper wire to complete the circuit to the item.

10.4.2 Recommended Gages: The use of aluminum wire in gages smaller than No. 8 is not recommended due to the lack of mechanical strength at the terminal connections.

11. WIRE AND CABLE IDENTIFICATION:

11.1 General:

The proper identification of electric wires and cables as to circuits and voltages involved is necessary to provide safety of operation, safety to maintenance personnel, and ease of maintenance.

11.2 Type of Circuit:

11.2.1 High Voltage Circuits: Consideration should be given to the hazard to personnel of exposed terminals at potentials higher than 50 V. Placards or guards should be provided as appropriate.

11.2.2 Types of Current Identification: Distinctive markings on wires to identify DC and various types of AC circuits may also be desirable in some cases. However, such a marking system would be primarily for convenience and should not interfere with any high voltage warning marking.

11.3 Individual Wire and Cable Identification:

11.3.1 Identification: Each wire or cable should be clearly identified. The identification should agree with that shown on the wiring diagrams and charts. The wire size and a special identification for aluminum wire, where used, should be included in the identification marking.

11.3.1.1 Method of Identification: Each wire should be identified within 3 in of each end or "break" except that, where connectors are used with open wiring, the distance should be increased, if necessary, to bring the marking outside of the connector. The identification should be so located that ties, clamps, or supporting devices need not be removed in order to read the identification.

11.3.1.2 Supplemental Identification: As an aid to both manufacturing and maintenance, it is suggested that each wire of open wiring systems be identified at not more than 15 in intervals throughout its entire length. Wires and cables upon which individual identification cannot be imprinted may be identified only at the terminals. Open wiring should be considered to be any wiring of which 3 ft or more is outside of the conduit or junction boxes.

11.3.1.3 Type of Identification: All markings should be legible in size, type, and color and should be of a permanent nature. Particular attention should be given to the effects of aircraft fluids and combined effects of fluids and temperatures on the permanence of the marking. The marking should be imprinted on the wire or cable insulation or may be imprinted on a nonmetallic band or sleeve, or other suitable means. Where protective sleeving is used over the identification, the marking should be easily readable through the sleeving or the sleeving should be imprinted or marked to correspond with the identification being covered.

11.3.1.4 Application of Identification: With flat terminals the identification should be applied so as to be readable with either side of the terminal up. For terminations not definitely positioned, the identification should appear in several places around the circumference of the wire or on a sleeve that can be rotated. The character of the identification should be such that there would be no possibility of its being misread when viewed upside down. Arrows or underlining might be used with some type of coding. Identification may be applied so it is read vertically or horizontally.

11.3.1.5 Color Identification: Color coding may be suitable as supplemental wire identification or for special circuits. Colors chosen should be clearly distinguishable and proved against excessive fading with time, various aircraft fluids, and temperatures. The effect of various types of artificial light should be taken into account. Consideration should be given to printing the name of the color on the wire at the termination. Multiconductor cables to MIL-C-27500 have preferred color codes.

12. MAINTENANCE OF ELECTRIC EQUIPMENT (See also Section 15):

12.1 General:

In the interest of initial and continued safe operation of electric equipment in aircraft, all electric components should be installed so that they are easily accessible for proper inspection and maintenance. Also all electric equipment for use in aircraft should be designed so that it will require no maintenance or adjustment for at least 2000 h total operating time.

12.2 Design for Accessibility:

12.2.1 Circuit Protector Accessibility: Circuit protectors in circuits that are essential to the maintenance of flight should be of the indicating type and should be located so that they may be reset in flight. Other circuit protectors may be located where they are not accessible in flight. However, they should be located for ease of maintenance on the ground. Remote controlled circuit breakers may be used in emergency, essential, or nonessential circuits. Circuit protectors should be installed so that any protector may be inspected and replaced without disturbing any of the other protectors or connections thereto.

12.2.2 Relay Accessibility: All relays should be readily accessible for inspection or replacement. Nonhermetically sealed relays should be mounted in areas that are free from explosive vapors or suitably designed and tested for explosion-proofness.

12.2.3 Connector Accessibility: All connectors should be installed so that they are readily accessible for inspection and troubleshooting. When it is necessary to install connectors in high vibration or inaccessible areas, they should be a safety wire type or positive lock coupling type. Access holes with easily removable covers should be provided for inspection of connectors that are not readily accessible for maintenance such as those installed behind sound-proofing or cabin lining.

12.2.3.1 Use and Types of Connectors: The use of connectors should be kept to a minimum consistent with quick disconnect requirements for various components of electrical equipment. The use of rack and panel type connectors should be considered as a means of avoiding potential damage to wire bundles during equipment removal and installation. High density arrangements, which can accommodate wire sizes 22 and smaller, require extra care in assembly, installation, and maintenance to preclude damage. Connectors or hardware supplied with safety wire holes should not be used when safety wiring is not required as it may cause confusion upon installation in the aircraft and subsequent aircraft inspection.

12.3 Equipment Identification:

12.3.1 Types and Location of Placards: It is recommended that electric equipment such as relays, motors, etc. be identified as to their function or system. Such identification could consist of suitable placards indicating the system or function of each piece of electric equipment. The placards should not be mounted directly on the equipment but on the mounting brackets in such a position that they are easily readable with or without the equipment in place. Within a junction box, the same purpose may be served by using a single legend or placard properly mounted and showing diagrammatically all equipment with proper identification for same.

12.3.1.1 Wire Bundles and Connector Identification: In cases where it is necessary to have separate wire bundles serve identical connectors, which are installed in close proximity to each other, the wire bundles or plugs and the mating receptacle should be properly identified and have different keying to avoid cross connections, or be so supported that it is impossible to cross connect them (see 7.3.10).

12.3.2 Circuit Breaker Rating Identification: Consideration should be given to identifying, in the aircraft, the circuit breaker rating required for each position to facilitate replacement.

13. OPERATION AND INSPECTION OF ELECTRIC EQUIPMENT:

13.1 General:

When planning the installation of any piece of equipment in an aircraft, first consideration should be given to proper functioning. The functioning of the whole system as well as each component should be considered. (See also Section 15.)

13.2 Installation Design for Operation and Inspection:

13.2.1 Functional Test and Operation Check: Functional test procedures should be carefully prepared for all systems as installed in the aircraft. These procedures should be so written that any problems with the installation design, or any errors in connection, or in the equipment will be revealed during the functional check. The functional check should prove that the system is satisfactory for flight.

13.2.1.1 Wiring Diagrams for Maintenance: Wiring diagrams should be prepared to cover every circuit in the aircraft. It is desirable to prepare schematic diagrams to facilitate functional testing and maintenance. Where practicable, the internal wiring of equipment should also be shown in order to facilitate functional checking.

13.2.2 Visual Inspection: The installation of all equipment should be so planned that visual inspection may be easily performed at frequent intervals. Inspectors should not be required to remove excessive numbers of screws to gain access to equipment that requires frequent inspection. Also, it should not be necessary to remove equipment to inspect other equipment located in otherwise inaccessible areas. (See also 15.3.1.)

13.2.3 Operation Check of Standby or Emergency Equipment: All emergency or standby equipment in an aircraft should have functional tests performed at regular intervals. It is desirable to provide a ready means to accomplish this check. The means provided should not impair the reliability of the equipment. The inspection or functional check periods should be clearly stated in the aircraft maintenance manual along with the overhaul times. This check and exercise of components should not only ensure proper operation of standby equipment when it is needed, but in many cases will actually increase the life of the units.

13.2.4 Functional Check and Exercise of Rotating Equipment in Stores: It is often necessary to exercise equipment in storage at regular intervals (usually 6 months to 1 year) to prevent accumulation of dampness in windings, etc. as well as to prevent grease in bearings from drying and becoming rough. Complete procedures recommending checking times and methods should be prepared by the design engineers or be supplied by equipment vendors. Careful attention to this phase of installation design will ensure better and safer operation of equipment when it is put into service.

14. PROVISIONS FOR ADDITIONAL ELECTRIC EQUIPMENT:

14.1 General:

When considering a new electric system installation for any aircraft, adequate growth space should be included in initial designs to provide for the changes and additions to power requirements and equipment, which occur during subsequent design. Insufficient space provision may result in overcrowded, inefficient installations, or costly rework of parts. No firm rule can be established that will cover all possible expansion in the electric system on different models of aircraft. Each installation should be carefully analyzed with due attention to its particular requirements. Provisions for expansion suggested herein are design objectives and must be flexible due to conditions peculiar to individual aircraft models. It is generally good policy to leave the final design of all central power and circuit panels until the entire system is sufficiently developed so that required changes are minimized.

14.2 Power Requirements Expansion Provisions:

14.2.1 Selection of Generators: In order to stay within the load requirements indicated in 6.2, design experience has shown that generators should be selected so that the total load, including passenger comfort items, as shown by the preliminary design load analysis, will not exceed 60% of the installed generating capacity (all generators operating).

14.3 Circuit Breaker and Fuse Panels:

14.3.1 Provisions for Adding Circuit Breakers and Fuses: Since new circuits are continually being added to an aircraft electric system, all circuit breaker and fuse panels should be designed to provide approximately 25% spare space for circuit expansions and additions during the final design stage. The possible increase in the spare fuses provided should also be considered.

14.4 Switch Panels:

14.4.1 Provisions for Adding Switches: Expansion provisions for additional switches may be as low as 15%. Multiple pole switches and relays can be utilized to furnish added contacts for existing switches if necessary.

14.5 Relay Boxes:

14.5.1 Provisions for Adding Relays: An allowance of 25% expansion space on central relay panels should be provided. On panels containing only one or two relays no expansion space provisions need be made.

14.6 Wiring and Termination Expansion:

14.6.1 Provisions for Added Wiring: To provide for added or revised circuits, it is desirable that connectors, conduits, feed-through bushings, wire routing passageways, junction boxes, and other wire installation provisions should allow 25% spare space for additions during design and field modifications.

14.6.2 Terminal Strip and Terminal Junction Expansion: Centrally located areas for terminal strips or terminal junctions should contain space for approximately 25% additional terminations.

15. EQUIPMENT SELECTION AND INSTALLATION:

15.1 General:

Safe and reliable operation should be the main consideration when selecting or designing the installation for essential electric equipment in aircraft. Weight is also a factor of prime importance. However, a lightweight unit that renders unreliable service may be a hazard to safe operation. At the designer's discretion, weight may be given greater consideration in the selection and installation of secondary electric equipment. Careful consideration should be given to the design of electric circuits and equipment to avoid complication to the extent that maintenance and operation problems will outweigh the advantages gained.

15.2 Selection Considerations:

15.2.1 Check-Off List for Equipment: In the selection of electric equipment for aircraft, consideration should be given to the operation of the completed system as well as the individual units. It is suggested that designers make use of a check-off list in the evaluation of, or when writing specifications for any given piece of equipment. This check-off list should cover all of the pertinent points including ground and in flight operation. (See Appendix B for a suggested check-off list.)

15.2.2 Environmental Conditions: Reference may be made to MIL-STD-810 for a guide on environmental tests. However, actual environmental conditions for each application should be considered to ensure adequacy of design.

15.2.3 Test Data Substantiation for Equipment Selection: Electric equipment manufacturers should be required to furnish actual test data to substantiate the ratings claimed under all of the environmental conditions of the application for their equipment before such equipment is accepted for use in aircraft. Caution should be exercised to assure that testing is of sufficient duration to approximate long time operating conditions and that accelerated life tests, if used, impose sufficiently severe conditions.

15.2.4 Control of Electromagnetic Interference: Consideration should be given to ensure that electromagnetic emission and susceptibility requirements are incorporated into the design of equipments and subsystems. MIL-STD-461 will provide a basis for evaluating the electromagnetic characteristic of the aircraft and subsystems. Consideration should be given to the use of filter line wire (see MIL-C-85485).

15.2.5 Insulation Test on Equipment: Suitable means should be considered and provided when necessary for testing insulation on equipment. Such provisions should include a ready means for ungrounding windings or isolating low voltage capacitors, diodes, etc. to provide means of making insulation tests. AIEE Aircraft Electrical Equipment Insulation Test Code No. 803 should be used as a guide to assure that test voltages are sufficiently high to provide adequate indication of insulation condition.

15.2.6 Vibration and Shock Resistance of Equipment: Vibration and shock resistant characteristics of electric equipment should be considered when making a selection. Equipment manufacturers should be required to provide test data to substantiate the use of their equipment in high vibration or shock areas, or the equipment should be suitably shock mounted when installed in such areas. MIL-STD-810 and AIR1557 may be used as a guide for suitable shock and vibration requirements. In addition, consideration should be given to design of equipment, which will be in the vicinity of turbine engines or in the area of turbine exhaust, where acoustic noise levels may be as high as 160 dB from 50 to 10 000 cps, or to low frequency, high amplitude vibration in helicopters. Actual application conditions should be considered to assure adequacy of design.

15.2.7 Materials Used in Equipment: All materials used in electric equipment should be flame resistant and should be entirely suitable for the purpose intended. They should be of a corrosion resistant nature or should be suitably treated to prevent corrosion. Extreme care should be exercised to ensure that insulation material does not shrink or flow during cyclic excursions of temperature, causing loose electric joints inside of or at the attaching point to electric equipment. Optimum designs do not depend on the dimensional stability of insulating material to maintain the integrity of electric circuits. Loose insulators are objectionable and should be avoided. Attention should be given to the effect of fluid or other material to which the equipment may come in contact. Special attention should be given to the possible effect of nonflammable hydraulic fluids where used. In addition, the materials used should not emit noxious or toxic fumes during normal or abnormal operation. Magnesium should not be used for current carrying requirements in electric equipment.

15.2.7.1 Insulation Materials in Equipment: Insulating materials should be selected for the best combination of characteristics in the following categories:

a. Arc resistance (noncarbon tracking)
b. Dielectric strength
c. Flame resistance
d. Mechanical strength
e. Heat distortion temperature
f. Impact strength
g. Resistance to fluids, etc.
h. Smoke emission

15.2.8 Finishes for Equipment: All material (both inside and outside of equipment) should be suitably finished to prevent corrosion under the most extreme usage intended for the unit involved. The airframe manufacturer should carefully review all materials and finishes used in any piece of equipment before that equipment is adapted. Any usage or location in the aircraft other than that for which it was designed requires evaluation of the equipment prior to its relocation.

15.2.9 Dissimilar Materials in Equipment: Unless suitably protected, brass, copper, or steel should not be allowed in intimate contact with dissimilar metals such as magnesium, aluminum, or their alloys. Caution should also be exercised where nonmetallic materials are used, to ensure low moisture absorption characteristics. Metals in contact with nonmetallic materials should have a corrosion resistant finish on the surface in contact or the metal itself should be corrosion resistant. Equipment manufacturers should be required to furnish drawings or other suitable data to establish the nature and usage of all materials used in each piece of equipment. MIL-STD-889 may be used as a guide to determine metal-to-metal compatibility.

15.2.10 Wire Terminals and Binding Posts on Equipment: All wire terminals in or on electric equipment should 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 should have sufficient mechanical strength to withstand the torque required to attaching the cable to the equipment. All terminals on equipment should have barriers and covers provided by equipment manufacturers. Current transformers are a particularly bad hazard to personnel under open secondary conditions.

15.2.11 Lock Washers for Terminals on Equipment: Where locknuts are used to insure 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.

15.3 Equipment Selection:

15.3.1 Batteries: Aircraft batteries may be used for many functions; e.g., ground power, emergency power, improving DC bus stability, fault clearing, etc. Most small private aircraft use lead-acid type batteries. Most commercial and military aircraft use nickel cadmium type batteries, however, other types are becoming available. 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, charging rate, etc.

15.3.1.1 Lead-Acid Batteries: The lead-acid battery is economical and has extensive application, but is heavier than an equivalent performance battery of other types. The battery is capable of a high rate of discharge and low temperature performance. It has a moderate specific energy. State of charge can be checked and the service life is approximately two years.

15.3.1.2 Nickel-Cadmium Batteries: A rugged battery capable of high rate discharge, the nickel-cadmium battery will provide approximately the same low rate discharge capacity as a lead-acid battery of equal weight and volume. High end-charging voltages can cause excessive battery temperatures and gassing. High discharge rates are sustained at a higher voltage than a lead-acid battery will sustain. There is no accurate and convenient method of determining the state of charge. Service life is estimated at five years and may be longer. However, higher basic cost should be taken into account.

15.3.1.3 Silver-Zinc Batteries: Silver-zinc batteries are lighter and smaller than either lead-acid or nickel-cadmium batteries of the same rating. The highest discharge rate is available from these units at a high sustained voltage until the battery is nearly exhausted. High charging voltages can cause excessive temperature and gassing and may cause permanent damage. State of charge cannot be determined accurately by any simple means. Service life is limited to approximately nine to fourteen months. Shelf life up to three years has been attained but high basic cost should be taken into account.

15.3.1.4 Electrolytes: The lead-acid battery utilizes sulfuric acid solution as the electrolyte. Specific gravity varies with state of charge because it is active in the electrochemical reaction. A caustic potassium-hydroxide electrolyte is used in both the nickel-cadmium and the silver-zinc batteries. Specific gravity does not vary in the charge-discharge cycle because the electrolyte acts as an ion carrier rather than as a participant in the electrochemical reaction. Special precautions are necessary in handling both types of electrolyte due to their corrosive effects on aircraft structure. The nature of protective coatings depends on which type of battery is used. Charging rooms and cabinets must be well ventilated due to the evolution of explosive gases during charging.

15.3.1.5 New Battery Development: In addition to an ongoing development of existing major secondary battery systems, there are several new systems that are available now, or are in development. For new design applications silver-cadmium, nickel-hydrogen, and lithium battery systems should be included in the design review.

15.3.2 Relay and Switch Selection: Relays and switches for aircraft use should be selected with extreme caution. The contact ratings should be adequate for the load conditions (continuous current carrying, lamp make, resistive break, and inductive break) and duty cycle for the applicable voltages both at sea level and the operational altitude required for the specific aircraft application. Consideration should be given to the variation in the electrical power characteristics using MIL-STD-704 as a guide.

15.3.2.1 Operating Conditions for Relays and Switches: Relays and switches should be checked to be sure 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.

15.3.2.2 Load Considerations: When relays or switches are to be used in applications where current or voltage is substantially lower than rated conditions, additional testing (e.g., intermediate current testing) should be performed to assure reliable operation. When contacts are rated for both low and high level load, care should be exercised to assure that contacts exposed to high level loads are not subsequently used for low level applications unless testing has been performed to establish this capability.

15.3.2.3 Insulating Films on Relay and Switch Contacts: Platinum, rhodium, and to some extent gold coated contacts can form insulating films on their surfaces. In some instances these films are quite tenacious and cannot be penetrated with the normal contact pressure, particularly when currents are low. Special consideration should be given to relays and switches that are normally open for long periods of time and those switching 10% or less than the rated current to assure contact material and atmosphere compatibility.

15.3.2.4 Coil Characteristics for Relays: Relay coil characteristics should be at least equal to those required by military standard drawings for similar types of relays. Lower pull-in and dropout voltages may be desirable under many conditions. Sensitive relays used in special control circuits are exceptions. The number of different types of relays or switches used on a given aircraft should be held to a minimum consistent with design requirements and weight economy.

15.3.2.5 Inching Control by Relays or Switches: Control design where frequent inching or direct reversing is involved will require selection of a relay or switch with extra high continuous rating on the contacts to allow for rapid repeated make and break of high inrush current.

15.3.2.6 Creepage Distance: Care should be used in the selection of electric components to ensure that terminal spacing and creepage distance between terminals on a given component are adequate for voltages involved. (See Appendix C for creepage distances.)

15.3.3 Rotating Equipment Selection: Rotating equipment should have a sufficient overload rating to provide for the most severe conditions of operation under which it will be expected to perform. Voltages such as those supplied from a ground power source should be considered in motor selection. Built-in thermal protection or overheat indication means should be considered. Whenever practical, motors should be of such construction or so installed that smoke and fumes incident to motor failure or overheat will be confined in the motor itself or at least will not contaminate inhabited compartments.

15.3.3.1 Heat Dissipation Provisions of Rotating Equipment: Adequate heat dissipation provisions should be considered in the selection and installation of all rotating equipment. The problem becomes particularly acute of altitudes above 30 000 ft.

15.3.3.2 Open Ventilated Equipment: Open ventilated machines should be so installed or protected that dirt and foreign material cannot pass into the machines. Avoid location under fluid lines and containers or in areas subject to seepage, liquids, or gases. The equipment enclosure should provide the maximum practicable protection against entrance of liquids and should be drained to ensure against accumulaton of liquid within the machine. In the case of pressure ventilated machinery, the device should be designed to operate satisfactorily under the condition of maximum normal liquid content of the cooling medium. (Example: effects of rain in ram air cooled machines.)

15.3.4 Transformer Selection: Transformer should be entirely suitable for the purpose intended and in addition should be of such a design that under overheat or complete failure conditions they will not emit more than a thin wisp of smoke. (Consideration should also be given to smoke hazards and possible shock to personnel for open circuit conditions of current transformers.) Transformers should not be filled with compounds that emit heavy smoke and fumes when overheated unless such tranformers are suitably sealed or are provided with thermal protection to ensure that they will not burst open or smoke under direct short-circuit conditions.

15.3.5 Resistor and Rheostat Selection: Factors of safety on other items of electric equipment such as resistors, rheostats, etc. should be commensurate with the importance of the circuits in which they are installed. Resistance units should not be installed in close proximity to flammable materials where the heat due to their normal or any abnormal operation may be a hazard. When resistors must be installed in areas, which may be surrounded by flammable mixtures, they must operate at a temperature below the ignition temperature of the mixture under all conditions of airflow, air pressure, and ambient temperature. Consideration should be given to the effect on resistor temperature of short-circuits, bearing failures (when used for motor starting), limit switch failures, etc. Consideration should also be given to the effect of resistor failure on the equipment or system (e.g., shorting, opening, etc.)

15.3.5.1 Resistor Connections: Consideration should be given to installing all resistors, rheostats, and shunts in the ground return leads. This type of installation will result in fewer burned out units in case of inadvertent shorts because the load units in the circuit will normally be rated at full system voltage whereas the resistor units used for control will not normally stand full system voltage. Installed in the ground return lead there is a possibility of getting full system voltage on the resistor, rheostat, or shunt.

15.4 Installation of Equipment:

15.4.1 Clearance Provisions in Equipment Installations: All items of electric equipment should be so installed that inspection and maintenance may be performed with an ease that is commensurate with the importance of the units or equipment involved. That is, all equipment, the proper functioning of which is necessary for safe flight, should have space and installation priority so that these installations may be completely and easily inspected and maintained. It is frequently practical to mount electric equipment such as relays, resistors, etc. on a platform and use the box as a cover. Such an installation may be accessible from five sides. The use of quickly removable control packs should be considered for system control. Care should be used in the selection and installation design of electric components to ensure adequate terminal spacing and creepage distance between components and between individual terminals on any given component. (See Appendix C for proper creepage distances.) Adequate clearance for cable attachment to equipment as well as for the cooling, where necessary, should be given consideration. Required clearance should be provided to permit movement of vibration isolated equipment. MIL-E-7080 may be used as a guide for electrical equipment installation design.

15.4.2 Equipment Manufacturers' Recommendations on Installation: Equipment manufacturers' recommendations should be considered in the installation design of all equipment. When installation orientation in the aircraft is other than that recommended by the manufacturer, the affect on equipment warrantee should be investigated as well as proper operation, safety, and life of the equipment.

15.4.3 Duplicate Equipment Installation: Where duplicate essential systems are installed they should be so arranged and connected that a failure or malfunction of any component in one system cannot impair the ability of the remaining system or systems to perform the required function. In general, such systems should have separate power connections and sources, separate grounds, physical separation of wiring, and physical separation of components.

15.4.4 Mechanical Shock Prevention and Moisture Proofing of Equipment: All electric equipment should be so installed that a minimum of exposure to outside influences, such as moisture and mechanical shock, will result. Where such protection cannot be afforded consistent with inspection and maintenance requirements, the equipment should be of such design that it is self-protecting. Wherever feasible, equipment should be so installed that moisture due to condensation or any other source will drain out.

15.4.4 (Continued):

Consideration should be given to the possibility of water freezing inside of equipment and, thus, preventing operation of moving parts. Hermetically-sealed units are exceptions.

15.4.4.1 Wire Attachments to Equipment: To prevent moisture, dirt, and metallic particles from falling or flowing into electric connectors, consideration should be given to mounting electric equipment so that wires enter the units in an upward direction. Consideration should be given to the use of environment resistant connectors.

15.4.5 Vapor and Dust Areas:

15.4.5.1 Flammable Vapor Areas: A flammable vapor area is defined as any area in the aircraft where flammable fluids or vapors may collect due to leaky lines in the area of seepage from some other area. Such areas should be ventilated under all conditions of operation. Equipment should not be located in a flammable vapor area unless it is suitably tested for explosion proofness and, in addition, emergency equipment should be operable after an explosion within the equipment. All equipment located near filler necks, vent outlets, or dump chutes or in areas subject to the collection of gasoline fumes or other explosive mixtures on the ground or in the air should also be suitably tested for explosion proofness.

15.4.5.2 Corrosive Vapor Areas: Proper finishes for protection should be applied to structure, frames, or equipment located in areas where corrosive fumes may be present.

15.4.5.3 Dust Areas: All equipment located in excessive dust areas, such as floor areas, should be so constructed that accumulations of dust will not become a hazard, nor interfere with proper operation.

15.4.6 Smoke Hazards: Insofar as practicable, all electric equipment located in the inhabited areas of the aircraft, or in ventilation ducts leading thereto, should be designed and installed so that a burned out or overheated unit will liberate the minimum amount of smoke and toxic fumes to such areas.

15.4.7 Grounding of Electric Equipment: During the installation design of any unit of electric equipment care should be taken to ensure that proper grounds to structure are provided. The requirements of 8.2 should be observed to assure safe and reliable installations under normal and fault conditions.

15.4.8 Ventilation of Electric Equipment: Cumulative heating effects of a number of items in any one enclosure may require special ventilating provisions to ensure safe ambient temperatures for equipment and wiring. Where cumulative heating effects cannot be adequately analyzed, tests of actual equipment under typical operating conditions are recommended.

15.5 Turbine Engine Starter:

The availability of an electric storage battery on an aircraft makes electric starting of small gas turbines economically and logistically feasible. The definition of a small gas turbine would be up to 1500 HP output rating. This turbine output rating includes the auxiliary power unit (APU) as an integral part of the power systems on many commercial and military aircraft. The electric starter may be combined with an electric generator to save space and weight. This combination introduces a possible reduction in the electrical systems reliability. When selecting an electric starting system, the following checklist should be followed:

15.5.1 Battery Capacity: Battery capacity must be capable of providing starting power for the requisite number of starts, with sufficient reserve for a safe emergency capability.

15.5.2 Cable Capacity: Cable resistance constitutes a power loss resulting in a reduced motor voltage and reduced motor speed. Short cable runs will reduce weight and power loss.

15.5.3 System Sizing: The battery, cable, and motor sizing should be such that a "hot-start" or overtemperature stress is limited or avoided. The detrimental effect of an adverse environment must be a factor in the system sizing.

15.5.4 Air Restart Capability: An air restart capability should overcome the adverse effect of altitude. Air restarts are usually limited to under 30 000 ft altitude.

16. CORROSION PREVENTION IN ELECTRICAL EQUIPMENT:

16.1 General:

Corrosion in electrical equipment and connections is one of the largest contributors to failures and malfunction (such as open circuits, short-circuits, etc.). Careful consideration should be given to each electrical installation to assure adequate corrosion prevention.

16.2 Condensation:

16.2.1 Drain Hole Sizes and Locations: No definite recommendations as to proper drainage for each unit or piece of electric equipment can be made. The type of equipment, the mounting method, the location in the aircraft, the duty cycle, etc. all should be considered when determining the drainage requirements. In general, a 1/8 in diameter or preferably larger hole located at each low point in conduit and nonenvironment resistant connectors is considered adequate where drainage is required. Junction boxes that are located in wheel wells or other areas where they may be subject to splash may require a 3/8 in diameter drain hole. Drain holes of less than 1/4 in in diameter in junction boxes in such areas should be avoided because of their tendency to clog with dirt, etc.

16.3 Corrosion Inhibiting Compounds:

16.3.1 Inhibitor Application: It is recommended that corrosion inhibiting compounds (fluids or pastes) not be used in electric connectors and switch housings.

16.4 Installation for Drainage:

16.4.1 Equipment in Splash Areas: All electric equipment installed in locations subject to splash, drip, or seepage should be so mounted that water cannot pass into the equipment through the wire connection or other openings. In all cases where the wire bundle cannot approach the equipment in an upward direction, the entry should be sealed or drip loops provided. If the nature of the equipment or installation is such that water is likely to get inside, adequate drainage in a location shielded from splash or drip should be provided.

16.5 Battery Electrolyte:

16.5.1 Surfaces Adjacent to Batteries: Surfaces within 12 in of aircraft batteries and surfaces further removed, which are subject to electrolyte spillage, spray, or fumes should be provided with corrosion protection to ensure against damage to such equipment.

16.5.2 Equipment Adjacent to Batteries: Equipment, which may be harmed by battery electrolyte, should not be located where it will contact electrolyte spillage, spray, or fumes.

16.5.3 Battery Venting: Battery fumes and gases emitted by normal or abnormal operation, which may form an explosive mixture or contaminate crew or passenger compartments, 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.

16.5.3.1 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. At no point in aircraft operation should the direction of airflow reverse through the venting sump jar system.

16.6 Potted and Environment Resisting Connectors (See Section 7):

16.6.1 Types of Connectors: Special connectors resistant to moisture and condensation, (such as Class "E" environment resisting connectors per MIL-C-5015) and potted connectors, should be installed wherever such protection is required by environmental conditions.

16.6.2 Potted Connectors: Connectors specifically designed for potting compounds must 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, which remains on the connector after the potting compounds has 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.

16.6.2.1 Precautions with Potting Compounds: Many types of potting compounds, both commercial and per military specifications, are available and offer various characteristics for different applications. Careful consideration of the characteristics desired should be made 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 should not revert to liquid or become gummy or sticky due to high humidity.

16.6.3 Environment-Resisting Connectors: To ensure proper performance, mated connectors should have compatible, corrosion resistant finishes. All unused wire exit holes in sealing grommets must be filled to prevent the entrance of liquids.

17. SYSTEM LOAD DISTRIBUTION (See also Sections 200 and 300 of AIEE Report 750 and 3.6 of this document):

17.1 General:

The power distribution part of the electric system performs the function of transmitting the generated power to the using equipment or systems. It includes the main bus or buses, the contactors, the distribution feeders and their protective devices, as well as the several subbuses from which the power is distributed to the loads.

17.2 Parallel System Central Bus (See also Section 340 of AIEE Report 750):

17.2.1 Shock Load Provisions: In order to provide for shock loads in a system having unit loads equal to or greater than the rated short tie capacity of a single generating source, a parallel system should be used. The shock load provisions are more or less automatic in a parallel system. Special consideration must be given to loads, which may have to be operated when the main electric system is not paralleled or when certain generators are isolated from the main system. It should be noted, also, that large shock loading will affect the entire distribution system to some degree; therefore, special loads requiring disturbance free power may be more satisfactorily served when connected to isolated or specially regulated power feeders. (See Section 6 for recommended generating capacity.)

17.2.2 Load Transfer Provisions for Parallel Systems: Load transfer provisions under engine or generator failure conditions are usually not required in a parallel system. Where such failures reduce the available power below full load requirements, it is necessary to monitor and remove some nonessential loads off the lines.

17.2.3 Protection Provisions: System protection and the application of circuit protective devices should be in accordance with Section 3.

17.2.3.1 Physical Protection for Bus Installation: The electrically unprotected bus or buses should be kept as small as practical and the principles of 3.6.1.3 should be followed.

17.3 Parallel System Divided Bus:

17.3.1 Shock Load Provisions: Shock load provisions for this item are the same as for 18.2.1.

17.3.2 Load Transfer Provisions: In a divided bus system some method should be provided to isolate a faulted section and provisions made to transfer the necessary loads to an operating section of bus. This may be done by automatic transfer relays, tie breakers, switches, or by multiconductors with current limiters in each end of each conductor.

17.3.3 System Protection: System protection should be the same as required for 17.2.3.

17.4 Nonparallel Systems (See also Section 340 of AIEE Report 750):

17.4.1 Single Load Limitations for Nonparallel Systems: In the nonparallel system no single load can be larger than the rated capacity of the generator to which it is connected, and the starting demand of the load should not exceed the short time overload rating of the generator. Under all conditions of generator loading the starting shock of an oncoming load should not exceed the short time overload rating of the generator.

17.4.2 Load Switching: In a nonparallel system, either automatic or manual, load or power source switching devices should be used to overcome a power source loss with a minimum of power interruption. Interlocks should be provided, particularly in AC systems, to ensure that it is impossible to accidentally parallel connect power sources even for an instant during switching.

17.4.3 System Protection: System protection for nonparalleled systems should be the same as indicated in 17.2.3.

17.5 Load Transfer Provisions for Emergency Loads:

The power to emergency loads should be supplied through a minimum number of devices in order to attain maximum reliability. If transfer systems are required, it is preferable that they be automatically operated. Consideration should be given to provide mechanically independent switching devices if at all practicable. Manually operated transfer systems may be used if their adequacy can be shown and increased reliability results.

17.6 Load Reducing or Monitoring:

Because overall aircraft reliability dictates that the rating and number of generators be sufficient to supply electric power to essential flight equipment, even in the event of loss of one or more of the generators (see CAR 4B), it is usually necessary to resort to some form of load monitoring of the less essential loads.

17.6.1 Automatic Monitoring: Automatic monitoring of nonessential loads should be considered when the existing loads could overload the remaining generators or affect the flow of power to the essential loads before crew monitoring could be initiated.

17.6.1.1 Advantages:

a. Provides immediate reduction of load to preserve integrity of generation system
b. Relieves crew members of additional burden during emergency
c. Permits closer tolerance between system load and generation capacity
d. Re-establishes loads after system is restored

17.6.1.2 Disadvantages:

a. Introduces additional circuitry, resulting in additional possibility of malfunction
b. Reduces services unnecessarily when system load is light and monitoring might not be necessary
c. Might require manual overrides for such loads that could be maintained under light loading conditions, but which might jeopardize the system in the event of a second malfunction

17.6.2 Manual Monitoring: Manual monitoring by the crew of nonessential loads can be considered when the total loading would not be greater than the remaining generators could carry for approximately 5 min, after which selective monitoring would become necessary.

17.6.2.1 Advantages:

a. Permits operation of essential equipment and desired services when system loading is light
b. Simplifies circuitry by eliminating interlocks

17.6.2.2 Disadvantages:

a. Requires installation of a reliable warning system to indicate failure of one or more generators
b. Requires crew evaluation and decision for proper monitoring at a time when the crew might be preoccupied by other duties such as engine failure, etc.
c. Requires resetting after re-establishment of system

18. ELECTRIC SYSTEM TESTS (See also MIL-M-25500 [USAF]):

18.1 General:

Electric systems in aircraft are being required to accomplish continually increasing numbers of tasks. Increasing size and complication of power supplies and interconnection or interreliance of many circuits are such that only by supplementing careful analysis and good design with suitable testing is it possible to avoid hazards and design a well integrated system.

18.1.1 Electric System Mock-Up: In a mock-up system particular attention should be given to having all critical wiring equivalent in resistance and reactance to that to be used in the aircraft. It is recommended that, where practicable, actual aircraft wire sizes and lengths be used for the mock-up. The simulated ground return should have a resistance equivalent to the airplane structure, and for AC systems a ground plane should be provided with the critical wires installed in the same relative position to the ground plane as in the actual aircraft.

18.1.2 Extent of Testing: Tests should be included, which take into account operating conditions such as normal, transient, and emergency. Probable abnormal conditions typified by faults, component failures, malfunctioning of equipment, and improper procedure should also be investigated by test.

18.1.3 Environmental Conditions for Tests: Component tests should include operation under representative and extreme environmental conditions. The need for system testing under adverse environmental conditions should be carefully considered.

18.1.4 Confirmation of Mock-Up Tests: When system tests are made on a mock-up, the necessity for additional tests on the aircraft to confirm or complete the test program should be judged from a careful analysis based on the thoroughness and accuracy with which the system and the various operating conditions are duplicated in the mock-up testing.

18.2 Power and Distribution System:

18.2.1 Test Conditions for Power and Distribution Systems: A mock-up used for testing the electric system should be powered by the same make, type, rating, and quantity of generators used in the aircraft. When multiple generator systems are involved, at least two separate generator test drives should be used. Such drives should be capable of the speed ranges encountered in flight and on the ground and should be capable of reacting to all conditions of generator loading, including overload and fault conditions, in a manner comparable to that of the actual aircraft drive. Test drives should be capable of accelerating as rapidly as the actual drives under aircraft conditions.

18.2.1.1 Generator Drives: Where the aircraft system has constant speed or other intermediate drives interposed between the generators and the prime movers, these drives should be included in the mock-up and should be driven from power sources having as nearly as practical the characteristic of the power sources as installed in the aircraft. Where the generators are driven by an auxiliary prime mover, it will usually be desirable to use this drive for the mock-up testing.

18.2.1.2 Control, Distribution, and Load Equipment: Each generator should be provided with its associated controls. Main power distribution panel design details should be mocked up accurately. Actual load equipment, particularly high current rotating machinery, should be used wherever practical. Faults should be simulated by the use of impedance banks, switches, relays, etc. Adequate instrumentation should be provided to record all pertinent voltage and current variations and to monitor the operation of protective devices.

18.2.1.3 Tests Using Breadboard Type Equipment: It will sometimes be necessary to make system tests with some of the components in breadboard form. When this is done, check tests should be made with the actual equipment to determine that the changes in packaging and connections have not altered the characteristics of the system.

18.2.1.4 Batteries: When a battery is used as part of an electric power system, the same type and rating battery to be used in-service should be used in the system tests whenever the system characteristics may be affected. It is usually desirable to make a number of the tests both with and without the battery.

18.2.2 Type of Tests for Power and Distribution Systems: The following tests are typical of those that should be made to determine that the system is satisfactory:

18.2.2.1 Voltage Tests:

a. Regulation at regulation point, buses, and loads
b. Transient limits and stability
c. Phase unbalance and displacement
d. Wave form and harmonic content
e. Amplitude modulation, ripple
f. Drift during warm-up

18.2.2.2 Frequency Tests:

a. Regulation
b. Transient limits and stability
c. Modulation

18.2.2.3 Capacity Tests:

a. System capacity including all generating system components, buses, and distribution circuits
b. Overload capacity and the effect of overloads due to frequency or voltage variations
c. Fault and fault clearing capacity including interrupting capacity of circuit opening devices
d. Minimum load operation
e. Checking load schedules including phase load balance

18.2.2.4 Parallel Operation Tests:

a. Load division (real and reactive) and paralleling factor
b. Synchronizing including mismatches due to improper operation

18.2.2.5 Control Tests:

a. Range of adjustment of variable control

b. Continuity of service to loads during start-up, shutdown, paralleling, switching, component failures, engine failures, auxiliary power transfer, and ground power transfer

c. Operation by crew including misuse and improper procedure

d. Special operating procedures including use of the emergency system and procedure in case of electrical fire

e. Checks for correct operation of novel circuits and switching devices, correct positive sequencing of relays and contacts, consistent operation of timing devices, and absence of unwanted feedback circuits

f. Effects of ground faults and open circuits in the control system including open or faulted sections of the supply

g. Effectiveness of all mechanical and electrical interlocking

18.2.2.6 Protection Tests:

a. Overvoltage and undervoltage

b. Overfrequency, underfrequency, overspeed, and underspeed

c. Over and underexcitation including ceiling excitation and loss of excitation

d. Faults on generators, generator feeders, and buses

e. Reverse current or power

f. Phase sequence and phase failure where required

g. Overload, overcurrent, and thermal protection including interrupting capacity, effect of opening one or two phases of three phase circuits, and effect of recycling where such is possible

h. Miscellaneous control faults and special protective features

i. Coordination of all protective devices and extent of nuisance tripping

j. Fail-safe operation of protective features including ability to withstand voltages or currents resulting from faults or failures without loss or excessive impairment of the protection intended

k. Check that the operation of protective devices is not impaired or unintentionally over-ridden by any operation of the control system

18.2.2.7 Load Tests:

a. Switching and cycling

b. Automatic transfer

c. Voltage modulation caused by load

d. Compatibility with power supply including effect of starting or inrush currents, generator effect of rotating machines, and effects of inductive or capacitive loads

e. Feedback effects due to coupling between phases of polyphase loads during faults and with open supply phases

18.2.3 Secondary Electric Power Systems and Supplies: Secondary electric power systems are frequently connected to the principle electric power system to supply different forms of power (e.g., inverters to supply AC with a DC main system and transformer rectifiers to supply DC with an AC main system). Such systems should be thoroughly tested using applicable tests from 18.2.2. In general, such tests should be made with the secondary system supplied from the principle system in the manner to be used in the aircraft. The effects on the secondary system of main system voltage and frequency tolerances, faults, power interruptions, bus switching, and load switching should be checked. The secondary electric power system constitutes a load on the main system, and its effect should be monitored throughout the testing.

18.3 Tests of Other Electric Systems:

18.3.1 Systems to be Tested: There are some electric systems in aircraft, which, due to their complexity and the importance of their functions, deserve complete system testing. Experience indicates that such systems cannot be satisfactorily analyzed from diagrams and drawings only. The complications and difficulties of analysis in circuits using numbers of relays may be considerably multiplied when devices such as magnetic, transistor, or tube amplifiers are used. The effect of feedback circuits resulting from various interconnections can often be found only by test.

18.3.2 Systems Using More Than One Power Source: Electric systems often are supplied power from more than one source either to supply different forms of power or as the result of interconnection of various systems or subsystems. Such systems should be checked for the effects of low voltage or frequency and interruption or failure of any of the sources. Where the power is of the same type, the possibility and effect of voltage or frequency differences between unparalleled buses should be investigated. Difference in phase angle from causes such as star-delta transformers and phase-adapters may also cause difficulties in some systems.

19. EMERGENCY CONTROLS AND PROCEDURES:

19.1 Controls for Emergency Operation:

Various emergency situations require the operation of the electric system controls as part of the procedural or corrective action. The controls should be readily accessible, and insofar as practicable, the crew member primarily responsible for taking action should be able to reach them without leaving his seat. For electric systems, the responsible crew member will usually be the flight engineer, where a separate flight engineer's station is provided, and the copilot, where no separate flight engineer's station is provided.

19.1.1 Emergency Electrical Controls: Electrical controls needed for emergency operation may include the following:

a. Controls for de-energizing all except emergency circuits for an emergency landing.

b. Controls for de-energizing all power circuits including generators and batteries for a "ditching" or "crash" landing.

c. Controls for emergency procedures such as isolation of smoke or fire sources.

d. Controls for disconnecting electric power sources in case of overheat, mechanical failure, or engine fire.

e. Controls for transfer or selection of power sources for essential circuits or selection of alternate circuits.

f. Controls for reducing electrical load in case of loss of power source, cooling ability, or other reasons.

19.1.2 Electric System Control Panel: The list of 19.1.1 indicates that almost all of the principle electric system controls may be needed for emergency use in various circumstances. Accordingly, careful consideration should be given to the design of the electric system so that its controls can be integrated into an electric system control panel, which will be simple to use both in normal operation and in the various types of emergencies.

19.1.2.1 Arrangement of Controls: Various systems are used for the arrangement of controls, such as grouping by generators or arrangement on a flow diagram. The method adopted should be reviewed carefully for its suitability and ease of use by operating personnel and particularly for emergency procedures.

19.1.2.2 Special Considerations for Emergency Controls: Controls used for each type of emergency should be grouped and placed in a permanently attached check-off list in a manner that will facilitate rapid and correct action. Gang bars and mechanical interlocking means should be used in a manner that will contribute significantly to correct operation without introducing hazard of power loss as a result of malfunction or improper operation. It may be desirable to physically protect some controls to ensure that they will not be accidentally operated (e.g., where emergency power is supplied from a main generator, provisions should be taken to assure that the generator will not be de-energized inadvertently). Procedures that are irrevocable in flight should be avoided wherever possible, and, if necessary, precautions should be taken against their inadvertent use.

19.2 Smoke or Fire from Undetermined Electrical Origin:

Overheated electric components and wiring may be sources of smoke and fire in spite of the protection provided. When such instances occur, it is necessary that power be removed from the offending circuit with a minimum of delay. Procedures to accomplish this objective may follow various sequences but consideration should be given to this problem in the design stages of the electric power control and distribution system in order to obtain the most satisfactory solution. IEEE 816 is a guide for determining smoke generation in wire insulation.

19.2.1 Order of Procedure: It is urgent that the cause of smoke or fire be eliminated as rapidly as possible. In some cases, the cause of smoke or fire may readily be isolated to a single circuit or small group of circuits, which can be disconnected quickly. In general, however, the installation complications are such that the source is not easily discernible. The preferable procedure under these conditions where circuit breakers did not trip, is to disconnect all but the most essential circuits. Various circuits can then be reconnected individually or in small groups allowing time to watch for the reappearance of smoke or fire so that the offending circuit can be isolated.

19.2.2 Grouping and Accessibility of Controls: Controls, which must be operated to isolate and disconnect an electrical smoke or fire source, should be readily accessible to the responsible crew member. The number of controls, which must be operated, should be kept small to permit rapid action. Master controls may be provided for groups of circuits or the individual controls of circuits to be disconnected as a group should be mounted and marked in a manner to clearly define the group. Where master controls are used for disconnection, sufficient additional controls should be kept quickly accessible for isolation and reconnection of all essential circuits.

19.2.3 Smoke or Fire Source in the Emergency Systems: Consideration should be given to the possibility of a smoke or fire source in the emergency circuits or other circuits not disconnected by the first steps of the procedure. A procedure should be established and provision made in the design for isolating and disconnecting such a source.

19.2.4 Mock-Up Check of Procedure: The tentative procedure for isolation of electrical sources of smoke or fire should be formulated at an early stage of the electric system design and checked out on the aircraft crew compartment mock-up or the electric system mock-up. The final procedure evolved should become a part of the crew's manual for the aircraft.

19.3 Switching of Emergency Circuits:

Where emergency or essential circuits, systems, or buses are switched from one power source to another, the transfer or selection means may be a potential failure source. Equipment selection and circuit design should be such as to minimize the probability that such a failure would result in inability to supply power to an emergency or essential circuit. Where equipment is duplicated to ensure the performance of an essential or emergency function, the failure of a single component should not result in loss of the function.

20. AUXILIARY POWER PLANTS:

20.1 Drives for Auxiliary Generators:

Auxiliary generators, which can provide electric power during an emergency, are usually smaller than the main generators and may be driven by other means. Efficiency is less important in this case, and weight must be kept down, even at the cost of efficiency. Possible means for driving auxiliary generators are as follows:

a. Separate reciprocating engine
b. Ram air turbine
c. Gas turbine
d. Monopropellant drive
e. Turbine driven by engine bleed air
f. Hydraulic motor supplied by pump on main engine

20.1.1 Reciprocating Engine: A reciprocating engine-generator set may be used during ground operations and as a standby for the main generators during landing and takeoff. If the unit is operated at altitudes of more than a few thousand feet, the output will drop off in the absence of supercharging. The relatively high fuel consumption, as compared to that of the main propulsion engines, usually makes continuous in flight operation of such units uneconomical from the standpoint of fuel weight.

20.1.2 Ram Air Turbine: Air turbine units may use ram pressure to drive auxiliary generators. These units are comparatively light and may be put into operation by a valve, which diverts a portion of the air from a jet engine intake duct, or they may be swung out into the airstream by manual means when needed. A disadvantage of the latter type is that it causes considerable drag at a time when aerodynamic conditions are apt to be critical.

20.1.3 Gas Turbine: A gas turbine auxiliary power plant is usually lighter than the reciprocating type, but the fuel consumption is higher, the life expectancy is shorter, and operation at high altitudes introduces more severe problems than it does with a reciprocating engine.

20.1.4 Monopropellant Engines: Monopropellant engines are solid or liquid fuel or a mixture of chemicals and do not depend on air for a part of the combustible mixture. Such devices are independent of altitude. They are adapted to missile applications where the air supply may be limited, and, in general, to brief periods of operation.

20.1.5 Engine Bleed Air Turbine: An engine bleed air turbogenerator may be used as an emergency source if the primary electric power system is not also driven by bleed air. Such a system is ineffective if motive power is lost.

20.1.6 Hydraulic Motor: A pump on the main engine may supply hydraulic fluid under pressure to a hydraulic motor generator emergency unit. Such a unit would be ineffective after failure of the main engine unless it were designed to have adequate output at the windmilling speed of a turbine engine.

PREPARED BY SAE SUBCOMMITTEE AE8A, SYSTEMS INSTALLATION OF COMMITTEE AE-8, AEROSPACE ELECTRICAL/ELECTRONIC DISTRIBUTION SYSTEMS

APPENDIX A
DEFINITIONS

A.1 BASIC STRUCTURE: Basic structure shall be considered as the major part of the aircraft structure wherein the fabrication has produced an electrically continuous unit, characterized by large current capacity and negligible resistance. This is commonly referred to as "ground".

A.2 BONDING: Bonding is a general term applied to the process of electrically connecting two or more conducting objects.

A.3 CABLE, ELECTRIC: An electric cable consists of two or more individually insulated conductors, solid or stranded, contained in a common covering, or two or more individually insulated conductors twisted or molded together without a common covering, or one or more insulated conductors with a metallic covering or sheath. (See Cataloging Handbook H6-1, Federal Item Identification Guides for Supply Cataloging.)

A.4 CIRCUIT BREAKERS: Circuit breakers are automatic circuit interrupting devices, which are capable of repeatedly performing their function should the prescribed set of conditions exist.

A.5 CIRCUIT BREAKER, COMPANION-TRIP MULTIPLE-POLE: A companion-trip multiple-pole circuit breaker is one in which the unfaulted poles may be maintained closed while a tripping condition persists on one pole or combination of poles; however, the faulted pole(s) are trip-free.

A.6 CIRCUIT BREAKER, NON-TRIP-FREE: A non-trip-free circuit breaker is one that can be maintained closed by manual override action while a tripping condition persists.

A.7 CIRCUIT BREAKER, TRIP-FREE: A trip-free circuit breaker is one that cannot be maintained closed while a tripping condition exists (i.e., manual overriding of the trip mechanism is impossible).

A.8 CIRCUIT BREAKER, TRIP-FREE MULTIPLE-POLE: A trip-free multiple-pole circuit breaker is one in which no pole may be maintained closed while a tripping condition exists on any pole or combination of poles.

A.9 CIRCUIT PROTECTION: Circuit protection is automatic protection of a consequence limiting nature used to minimize the danger of fire and/or smoke as well as the disturbance to the rest of the system, which may result from electrical faults or prolonged electrical overloads.

A.10 CIRCUITS, EMERGENCY: Emergency circuits are those essential circuits, the failure of which may result in the inability of the aircraft to maintain controlled flight and effect a safe landing.

A.11 CIRCUITS, ESSENTIAL: Essential circuits are those necessary to accomplish the mission of the aircraft under the most adverse environmental conditions for which the aircraft was designed.

A.12 CIRCUIT, FAIL-SAFE: A fail-safe circuit is one that has characteristics such that any probable malfunction will not adversely affect the safe operation of the aircraft or the safety of the passengers.

A.13 CURRENT RETURN PATH: The current return path is that part of a power circuit to an electric device, between the device and basic structure. This may include wires, one or more bonds, intervening structure, and part of basic structure to a point forming the "ground" regulating point.

A.14 *DUSTPROOF: Dustproof means so constructed or protected that the accumulation of dust will not interfere with its successful operation.

A.15 *DUST-TIGHT: Dust-tight means so constructed that dust will not enter the enclosing case.

A.16 *ELECTRIC: Electric means containing, producing, arising from, actuated by, or carrying electricity or designed to carry electricity and capable of doing so.

A.16.1 Examples: Electric eel, energy, motor, vehicle, wave.

A.17 *ELECTRICAL: Electrical means related to, pertaining to, or associated with electricity, but not having its properties or characteristics.

A.17.1 Examples: Electrical engineer, handbook, insulator, rating, school, unit.

A.18 EMERGENCY CIRCUITS: See definition A.10.

A.19 *ENCLOSED (INCLOSED): Enclosed means surrounded by a case that will prevent accidental contact of a person with internal parts carrying electric current.

A.20 *ENCLOSED, SEMI:

a. Semienclosed means having the ventilating openings in the frame protected with wire screen, expanded metal, or perforated covers.
b. Semienclosed means having a solid enclosure except for a slot for an operating handle or small openings for ventilation or both.

A.21 *ENCLOSED, TOTALLY: Totally enclosed means so enclosed as to prevent circulation of air between the inside and the outside of the case, but not necessarily sufficiently to be termed airtight.

A.22 ESSENTIAL CIRCUITS: See definition A.11.

A.23 *EXPLOSION-PROOF APPARATUS: Explosion-proof apparatus is apparatus capable of withstanding an internal explosion of a specified mixture without emission of flame.

A.24 FAIL-SAFE CIRCUIT: See definition A.12.

A.25 **FIREPROOF: Fireproof material means a material that will withstand heat at least as well as steel in dimensions appropriate for the purpose for which it is to be used. When applied to material and parts used to confine fires in designated fire zones, fireproof means that the material or part will perform this function under the most severe conditions of fire and duration likely to occur in such zones.

A.26 **FIRE-RESISTANT: When applied to sheet or structural members, fire-resistant material means a material that will withstand heat at least as well as aluminum alloy in dimensions appropriate for the purpose for which it is to be used.

A.27 FIRE-RESISTANT ELECTRIC EQUIPMENT: (See CAM 4.626-1.) Fire-resistant when applied to electric equipment and components means that such equipment and components, as installed in the aircraft, should withstand a 2000 °F oxidizing flame impinging on their surfaces for at least 5 min without adverse effect on their circuit function.

A.28 *FLAMEPROOF APPARATUS: Flameproof apparatus is apparatus so treated that it will not maintain a flame or will not be injured readily when subjected to flame.

A.29 **FLAME-RESISTANT: Flame-resistant material means a material that will not support combustion to the point of propagating, beyond safe limits, a flame after removal of the ignition source.

A.30 **FLAMMABLE: Flammable pertains to those fluids or gases that will ignite readily or explode.

A.31 FLAMMABLE VAPOR AREA: See definition A.49.

A.32 **FLASH-RESISTANT: Flash-resistant material means material that will not burn violently when ignited.

A.33 *FUME-RESISTANT: Fume-resistant means so constructed that it will not be injured readily by the specific fumes.

A.34 FUSE: A fuse is an overcurrent protective device with a circuit opening fusible member directly heated and destroyed by the passage of overcurrent.

A.35 *GASPROOF: Gasproof means so constructed or protected that the specified gas will not enter the enclosing case under specified conditions of pressure.

A.36 *GASTIGHT: Gastight means so constructed that the specified gas will not enter the enclosing case under specified conditions of pressure.

A.37 GROUND: (As a noun) See definition A.1. (Also refer to definition A.13.)

A.38 GROUNDING: Grounding in aircraft practice is a particular form of bonding that is usually applied to the process of electrically connecting conducting objects to basic metal structure for the purpose of safely completing either a normal or fault circuit at power frequency.