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(R) Selection, Application, and Inspection of Electric Overcurrent Protective Devices

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) provides technical and application information needed by the designers of aircraft electric systems and support equipment for the selection of overcurrent protective devices. It provides definitions to permit comparisons of various electric circuit protective devices. Included also are recommended procedures for periodic visual and mechanical inspection criteria.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 Aircraft Industries of America (AIA) Publications: Available from Aerospace Industries Association, 1250 Eye Street, NW, Washington, DC 20005.

Design Manual on Aircraft Electrical Installations - AIA

2.1.2 Naval Air System Command Publications: Available from Naval Air Technical Services Facility, 700 Robbins Avenue, Philadelphia, PA 19111-5097.

Design of Electric Systems for Naval Aircraft and Missiles - NAVAIR 01-1A-514

2.2 Definitions:

The following definitions apply to terminology used in this document:

AMBIENT TEMPERATURE: Ambient temperature is the temperature of the medium, such as air, water, or earth into which the heat of the device is dissipated.

ARCING TIME: Arcing time (as used for fuses) is the time measured from that point when element melt time ends to that point when current is interrupted and permanently becomes zero. If a mechanical indicator (not presently recommended) is utilized which incorporated a secondary element parallel to the fusible element, arcing time will commence from the point at which indicator melt time ends.

Arcing time (as used for breakers) is the time measured from that point when contacts first separate to that point when the current is interrupted and permanently becomes zero.

2.2 (Continued):

AUTOMATIC: Automatic means self-acting, operating by its own mechanism when actuated by some impersonal influence, as for example, a change in current strength, pressure, temperature, or mechanical configuration.

BLADE (KNIFE BLADE): A fuse or limiter terminal having a substantially rectangular cross-section.

BRANCH CIRCUIT: That portion of a wiring system extending beyond the final overcurrent device protecting the circuit.

CASCADE CIRCUIT: A circuit in which more than one protector is connected in series between the power source and the load (see Coordination).

CIRCUIT BREAKER: A device designed to open and close a circuit by nonautomatic means, as well as to open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating.

COMMON TRIP: A common-trip multipole circuit breaker is one in which an overload on any pole will cause all poles to open simultaneously.

CONTINUOUS DUTY: A requirement of service that demands operation at a substantially constant load current for an indefinitely long time.

COORDINATION: Coordination defines the ability of the protector with the lowest rating (in a cascade arrangement) to open before protectors with higher ratings when a fault occurs downstream from the lowest rated protector (see Cascade Circuit).

CURRENT-LIMITATION: The ability of a protective device to reduce the short-circuit peak current to a value less than that which would be available if no protective device were in the circuit (see Figure 1B).

CURRENT RATING (CONTINUOUS): The rated continuous current of a protective device is the nominal direct current or alternating current, in amperes, at rated frequency which it will carry continuously under defined conditions.

CURRENT-RESPONSIVE ELEMENT (FUSIBLE ELEMENT): A current-responsive element is that part of the fuse or limiter which carries current and melts when the current exceeds a predetermined value.

DUAL SAFETY CIRCUIT BREAKER: A circuit breaker with a secondary fusing element integrally linked to the operation of the main contacts, such that in the event of an overload, when the main contacts' mechanism is disabled or malfunctioning, the secondary fusing element interrupts the current before wire or system damage occurs.

ELEMENT MELT TIME: The time elapsed from the moment a fusing current begins to flow to the moment the current sharply drops in value and arcing commences.

2.2 (Continued):

FAULT CURRENT: See Short-Circuit Current.

FEEDER: A feeder is a circuit conductor originating at the power source bus from which the branch circuit loads are served.

FERRULE: The ferrule is a fuse or limiter terminal of a cylindrical shape which encloses the end of the fuse or limiter.

FUSE: A device which protects a circuit by the melting of its current responsive element when an over-current passes through it.

FUSE CLIPS: The contacts of the fuseholder which support the fuse or limiter and connect their terminals with the circuit.

FUSE OR LIMITER HOLDER: A mounting device with contacts and terminals for the purpose of accepting fuses or limiters for easy connection within a circuit.

FUSE TUBE: A tube of insulating material which surrounds the current-responsive element.

GROUND: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and airframe, or some conducting body which serves in place of the airframe.

INDICATOR MELT TIME: The elapsed time from the moment element melt time ends and arcing commences is indicator melt time.

INSTANTANEOUS TRIP (OPENING): "Instantaneous" indicates that delay is not purposely introduced into the action of the device.

INTERMITTENT DUTY: A requirement of service that demands operation for alternate intervals of load and no load.

INTERRUPTING CAPACITY: The rated interrupting capacity is the maximum short-circuit current at rated voltage which a protective device is required to interrupt under the operating duty specified and with a normal frequency recovery voltage not less than rated voltage (see Rupture Capacity).

INVERSE-TIME: See Time-Inverse.

LET-THROUGH CURRENT: The current that actually passes through the protective device after initiation of a fault.

LIMITER: A fuse designed specifically with a high temperature melting point to provide protection for electric power distribution systems against short-circuit current. A limiter is relatively insensitive to ambient temperature.

2.2 (Continued):

LINE OR LINE SIDE: The terminal or connection side of the protective device which is connected to the power source or to the power side of the electrical system.

LOAD OR LOAD SIDE: The terminal or connection side of the protective device which is connected to the load or the load side of the electrical system.

MAXIMUM ULTIMATE TRIP LIMIT: The minimum current which will cause a circuit breaker to open under a given set of ambient conditions. Also known as the "Rated Trip Current".

MECHANICAL INSPECTION: The physical activation of the mechanical mechanism without power applied and subsequent inspection.

MELT TIME: See Element Melt Time.

MINIMUM FUSING CURRENT: The smallest value of current that will melt the current responsive element at a specified ambient temperature is the minimum fusing current.

MINIMUM ULTIMATE TRIP LIMIT: The maximum current a circuit breaker must hold without tripping under a given set of ambient conditions. Also known as the "Rated Hold Current".

MULTIPOLE CIRCUIT BREAKER: A multipole circuit breaker has two or more poles controlled by a single-actuating member.

NONTRIP-FREE CIRCUIT BREAKER: A nontrip-free circuit breaker is a breaker so designed that the circuit can be maintained closed when carrying overload current that would automatically trip the breaker to the open position. (Not presently recommended.)

NORMAL OPENING FUSE (FAST-ACTING): A fuse which opens the circuit without deliberate time-delay. (Figure 1A shows relative opening time.)

OVERCURRENT: Any current exceeding the rated current of the protective device (exceeding the maximum ultimate trip current for circuit breakers). This includes both overload and short-circuit currents.

OVERLOAD CURRENT: An overcurrent in excess of the current rating. The overload range is considered to be greater than the rated current up to approximately ten times rated current.

PASS-THROUGH CURRENT: See Let-Through Current.

PERIODIC DUTY: A type of intermittent duty in which the load conditions are regularly recurrent.

PUSH-PULL CIRCUIT BREAKER: Push-pull circuit breakers are those which may be manually actuated by a "push" to close and a "pull" to open.

RECOVERY VOLTAGE: The voltage impressed across the protective device after the circuit has been interrupted and after high frequency transients have subsided.

2.2 (Continued):

ROCKER CIRCUIT BREAKER: A rocker circuit breaker is a circuit breaker which has a rocker switch actuating means.

RUPTURE CAPACITY: Rupture capacity is applied to reusable protective devices (see Interrupting Capacity).

SELECTIVE SYSTEM: A system in which the protective device closest to the faulted circuit opens and isolates that circuit without disturbing the remainder of the system (see Coordination).

SELF-INDICATING FUSE OR LIMITER: That type of fuse or limiter that incorporates a device to visually denote severance of the fusible element as an integral part of the limiter is a self-indicating current limiter. Limiters or fuses that visually display the fusible element or incorporate a mechanical indicating device are classified as self-indicating current limiters or fuses.

SHORT-CIRCUIT CURRENT (FAULT CURRENT): The maximum current that the system can produce at the point of application of the protective device.

SHORT TIME DUTY: A requirement of service that demands operation at a substantially constant load for a short and definitely specified time.

SOLID STATE CIRCUIT BREAKER (SSCB): A power controller which has circuit protection functions that utilize solid state sensing to detect an overcurrent condition. A solid state circuit breaker may use solid state switches, discrete contacts, or a combination of both to interrupt let-through current. These devices with discrete contacts may be considered electromagnetic power controllers.

TEMPERATURE COMPENSATING CIRCUIT BREAKER: A temperature compensating circuit breaker is one in which means may be inherent or otherwise provided for partially or completely neutralizing the effect which the ambient temperature may have upon the tripping characteristics of the circuit breaker.

TERMINALS: The means to connect the circuit protection device to the electrical system.

TIME-DELAY: A qualifying term indicating that there is purposely introduced a delayed action, which delay usually decreases as the magnitude of the current increases.

TIME-DELAY FUSE: A fuse that has its total clearing time deliberately delayed in the overload current range. (Figure 1A shows relative opening time.)

TIME-INVERSE: A time-current relationship where the protective device opening time decreases as the current increases. Generally described by an $I^2(t)$ function.

TOGGLE CIRCUIT BREAKER: A toggle circuit breaker is a circuit breaker which has a toggle actuating means.

2.2 (Continued):

TOTAL CLEARING TIME: The total time measured from the beginning of the specified overcurrent condition until the interruption of the circuit. The total clearing time for a fuse or limiter is equal to the sum of the melting time and the arcing time.

TRIP-FREE CIRCUIT BREAKER: A trip-free circuit breaker is a breaker so designed that the pole(s) of the circuit breaker cannot be maintained closed when carrying overload currents that would automatically trip the breaker to the open position, and none of the circuit breaker poles would reclose while the operating mechanism is maintained in the closed position.

VARYING DUTY: A requirement of service that demands operations at loads, and for intervals of time, both of which may be subject to wide variations.

VERY FAST-ACTING FUSE: A fuse that opens the circuit without deliberate time-delay and whose short-circuit opening time is faster than a normal opening fuse. (Figure 1A shows relative opening time.)

VISUAL INSPECTION: A general visual inspection of all areas of the aircraft that contain circuit protectors. This inspection is for obvious defects such as cracks, corrosion, foreign objects, burn marks or physical damage and does not require disassembly, special tools, test equipment, or power applied to the aircraft.

VOLTAGE RATING: The maximum alternating current and/or the direct current voltage at which the protective device is designed to operate.

3. PHILOSOPHY OF AIRCRAFT CIRCUIT PROTECTION:

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

3.1 Practical Overcurrent Protective Concepts:

There are two basic principles currently in use for the protection of electric and electronic equipment from failures caused by current overloads; current sensing and combined current and temperature sensing:

- a. **Current Sensing:** The current sensing principle is found typically in devices such as magnetic circuit breakers and fully ambient compensated thermal circuit breakers. Magnetic circuit breakers respond only to the magnitude of current, while temperature rises resulting from this current flow have little or no effect on operating characteristics. The fully ambient compensated thermal circuit breaker responds only to the magnitude of current since it is self-correcting for temperature rises resulting from this current flow.

When the protective device has temperature characteristics matching those of its load and is mounted in close proximity to the load, it is called "inherent protection". In most applications the practical considerations make it necessary for the protective device and component to be in entirely different ambients. It is more efficient to use an essentially ambient insensitive device and apply it on the basis of a maximum temperature rise expected at any point in that circuit.

- b. **Combined Current and Temperature Sensing:** The combined current and temperature sensing principles are employed in thermal circuit breakers, motor protectors, and fuses. They not only anticipate thermal failures due to overcurrent but will also compensate for variations in the ambient temperature if they are located in the same ambient as the component and wire. These devices are designed to match the thermal characteristics of the component being protected so that increase in ambient temperature reduces the current trip level analogous to the reduction in component capacity.

3.2 Protector Selection:

Proper selection should normally result in a protective device with the lowest standard rating that will not open inadvertently. It must interrupt the fault or overload current by disconnecting the faulted line from the power distribution system before wire fusing, insulation damage, or other system damage occurs.

The choice between circuit breakers, fuses, limiters, solid state devices, or other protection means is governed by many factors. Specification requirements, customer preferences, maintainability considerations, application physical and environmental restraints, and the requirements of each circuit all influence the selection of the protective devices.

The nameplate current rating of most protective devices is a nominal rating for device identification. The actual usable rating for a particular application may be considerably different from the nameplate rating. The device must be rated for the application, considering all the variables involved. The time-current characteristics of the protective device should be compared to the time-current characteristics (including starting or overload surges) of the equipment, component, or wire.

3.2.1 Extent of Circuit Protection: The entire system including the power source, circuit protector, wire (single or bundles), switching devices, and utilizing equipment must be protected against faults.

3.2.1.1 System Protection: Any circuit whose wire length is greater than 1 ft in length from bus to load should be protected. Wire lengths less than 1 ft should also be considered, especially if it could act as a fuse and in fusing cause damage.

A circuit protector should be used at any point in a circuit where the conductor size is reduced unless the immediate upstream protector provides adequate protection for the smaller wire.

3.2.1.2 Equipment Protection: There are many circuit components, such as transformers, rectifiers, filters, regulators, and electronic circuits which have significantly different overload withstanding characteristics from wire and cable characteristics. In general, these components and/or circuits require protective devices with much faster response times than is required for the protection of wire and cable.

Whereas, a transformer winding may be protected with some of the faster responsive miniature magnetic or thermal circuit breakers, or fuses; many electronic circuits and components require extremely fast clearing devices, such as very fast-acting fuses, to provide adequate protection from thermal damage.

The manufacture of equipment for aircraft is governed by MIL-HDBK-5400 which, in turn, specifies MIL-HDBK-454. Requirement 8 outlines the basic ground rules for equipment protection.

4. TYPES OF OVERCURRENT PROTECTIVE DEVICES:

For the purpose of this document, the types of overcurrent protective devices considered are circuit breakers, fuses, and limiters, electromechanical power controllers, and solid state circuit breakers.

5. CIRCUIT BREAKERS:

In the discussion of circuit breakers that follows, it is assumed that circuit breakers will be applied within the electrical rating, environmental conditions, and other parameters as described in the applicable Specification or Specification Sheets. The manufacturer should be consulted regarding the suitability of the circuit breaker when the conditions vary from those specified.

5.1 General:

In its simplest form, the circuit breaker is a device designed to open and close an electric circuit and to open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating.

5.2 Magnetic Circuit Breakers:

A magnetic circuit breaker may be classified as sealed or nonsealed. Presently sealed circuit breakers are made only in ratings up to 20 Amperes, meeting the requirements of MIL-C-39019. Nonsealed circuit breakers provide for higher power requirements but are more restricted as to environment. Both the sealed and the unsealed types have three fundamental requirements:

1. Provide manual actuation.
2. Open automatically under overload conditions.
3. Carry full-rated current.

5.2.1 Magnetic Time-Delay (Typical):

The magnetic time-delay circuit breaker operates on the solenoid principle where a movable core held with a spring, in a tube, and damped with a fluid, may be moved by the magnetic field of a series coil. As the core moves toward a pole piece, the reluctance of the magnetic circuit containing the armature is reduced. The armature is then attracted causing the mechanism to trip and open the contacts on an overload or fault condition.

The ultimate trip limits are dependent upon the armature gap and the armature spring force. This trip point occurs after a predetermined time when the core has made its full travel in the tube. The ultimate trip limits are independent of the ambient temperature in the range of the Military Specification Sheets or MS Drawings.

The fluid fill of the tube retards the movement of the core, and an inverse overload time-delay trip time results so that the trip time will be less as the percent of overload is increased. Longer time-delays result with lower ambients for a given fluid because the fluid thickens as the temperature decreases. The converse is true because the fluid gets thinner as the temperature increases. The maximum limit of ultimate-trip point is not affected by change in fluid viscosity. The trip time at the maximum limit of ultimate-trip does require a longer time to trip at lower temperatures and less time at higher temperatures.

The instantaneous-trip¹ point is that value of current required to trip the circuit breaker without causing the core to move in the tube. This is possible because excess leakage flux in the magnetic circuit caused by high overloads or faults will attract the armature and trip the circuit breaker. The instantaneous-trip point is relatively independent of the ambient temperature.

The instantaneous trip current is usually in the order of ten times the current rating of the circuit breaker. It is a ratio of the trip values of the circuit breakers with the core fully "in" and with the core fully "out".

1. MIL-C-39019 defines "instantaneous" as less than 0.015 s.

5.2.1 (Continued):

Some variation in actual delay time may result with variation in mountings. This change is due to the effect of gravitational pull on the core; consequently, the smaller physical sized circuit breakers of MIL-C-39019 have less position sensitivity and will trip within the specification time current curves in any position, whereas the larger devices specified in MIL-C-55629 may not.

Magnetic circuit breakers are limited in their ability to coordinate unless the fault current is limited so that the "let-through"² current is not more than the instantaneous-trip value of the lower rated circuit breaker. For example, a 10 and a 20 Ampere circuit breaker in series to coordinate on a fault may require the "let-through" to be limited to 100 Amperes. If the let-through current should reach 200 Amperes, both circuit breakers may trip.

Normally, magnetic circuit breakers should be used on the type of current (AC or DC) for which they are calibrated unless otherwise indicated on the Specification Sheets. If there is any question of application, consult the manufacturer.

- 5.2.2 Instantaneous Trip: Instantaneous trip circuit breakers have no intentional time-delay and, therefore, are sensitive to current inrushes and vibration and shock; consequently, they should be used with some discretion where these factors are known to exist. Typically there is no effect on trip point due to temperature in the range of -55 to +71 °C. Consult the manufacturer for recommendations concerning applications of usage under inrush conditions, and also vibration and shock if different from the Specification Sheet.

5.3 Thermal Circuit Breaker Types:

- 5.3.1 Thermal: Thermal circuit breakers are dependent upon temperature rise in the sensing element for actuation. Normal operation is achieved by the deflection of a thermal element (e.g., bimetal) which will open a circuit when a predetermined calibration temperature is reached. Temperature rise in the sensing element is caused principally from load current I^2R heating. The thermal element will also integrate the heating or cooling effects from external sources with load current heating. Thus, corresponding ambient temperature fluctuations will tend to derate (effectively lowering) or uprate (effectively raising) the ampere rating of the breaker from the specified ampere rating at the specified temperature rating (typically 25 °C).

The size of the thermal element, its configuration and its physical and electrical properties determine the amount of current carrying capacity of the circuit breaker. A heater coil may be placed adjacent to and electrically in series with the thermal element to augment self heating of the thermal trip element. This is especially true in low current ratings.

The trip times of thermal breakers will be affected by the heat sinking characteristics of attached wiring or bus bars. Calibration limits are established by conditions defined by the applicable specification.

2. See 2.2.

5.3.2 Thermal-Magnetic Assist: In order to protect wiring, upstream components, and the breaker itself from unnecessarily long thermal and mechanical stress during high fault level currents, an electromagnet may be added to the thermal breaker. This magnetic circuit usually consists of a few turns of large cross section conductor in series with the thermal element and has negligible effect on the total breaker impedance. The magnetic assist usually has a cross over point well above the normal overload calibration range which is to say that there is little effect on the normal thermal trip response time, but on high overload conditions the current level generates sufficient magnetic force to trip the breaker magnetically without waiting for the bimetal to deflect. Thus, this construction results in very fast trip times on high overloads approaching instantaneous tripping times.

5.3.3 Temperature Compensated-Thermal: As discussed in 5.3.1, a simple thermal circuit breaker's trip point is affected by variations in ambient temperature. A temperature (ambient) compensated circuit breaker is a breaker in which a thermal responsive element is introduced to compensate for changes in external temperatures. The compensating element usually is electrically isolated from and is independent of the current carrying thermal trip element and acts only when a change in ambient temperature occurs.

The degree of compensation may vary from partial to full compensation. A fully compensated breaker will operate independently of its ambient temperature within the specified temperature range.

It may be generally stated that the trip curve limits (i.e., minimum-maximum trip limits) of a temperature compensated thermal breaker are narrower than that of a corresponding nontemperature compensated thermal circuit breaker over the same temperature range.

5.3.3.1 Hot Wire Breaker: The hot wire type thermal circuit breaker employs the expansion of a high temperature wire as a means to cause the contacts to open. Because the temperature of the wire at time of trip is in the order of 800 to 900 °F, changes in ambient temperature have little effect upon the calibration. Effectively, this type of breaker can be considered compensated at sea level. The effects of altitude on calibration must be evaluated before it is specified for use in uncontrolled ambients. Its trip time is faster than the bimetal breaker and the voltage drop is higher. Current ratings are available from 1/2 through 5 Amperes. Attention should be given to the interrupting capacity of the hot wire breaker.

5.4 Remote Control Circuit Breakers (RCCB):

RCCBs combine the basic features of a relay (contactor) and circuit breaker. This design permits them to be located adjacent to the load or power source and controlled and/or monitored from a remote location such as from a cockpit or flight deck. Control wiring can be of light gauge, thereby eliminating the need for long runs of heavy cable.

5.5 Electromechanical Power Controller (EMPC) (Hybrid Power Controller):

EMPCs are electronically controlled devices, incorporating circuit protection, relay and switch features in a single device. An EMPC is a device which utilizes a solid state sensing mechanism for overcurrent protection and either solid state switches in combination with discrete contacts or solely discrete contacts to switch the load.

5.6 Solid State Power Controller (SSPC):

SSPCs are electronically controlled devices that may incorporate one or more of circuit protection, relay, or switch features in a single device. A SSPC is a device which utilizes solid state sensing for overcurrent protection, and solid state switching without electromechanical mechanisms.

5.7 Application Considerations and Problem Areas for Circuit Breakers:

The following problem areas do not necessarily apply to all types of circuit breakers and may be more serious in one device than in another. It must be assumed that the designer will be guided by the possibility that the device he selects may be affected by one or more of them.

- 5.7.1 Explosive Atmosphere Aeronautical Equipment: Most aircraft circuit breakers are unsealed devices which readily permit the surrounding atmosphere to enter. If circuit breakers are to be installed in an explosive atmosphere, the applicability of the conditions of the explosion-proof tests to the installed environment should be examined and proper installation precautions should be made.
- 5.7.2 Temperature Effect on Calibration: Circuit breaker and fuse time-current characteristics are influenced by the device temperatures resulting from ambient temperature, air flow, pressure altitude, wiring and bus bar configuration, operating load level, adjacent heat sources or sinks, packaging density, and proximity to external skin of aircraft. All of these factors must be considered in determining the actual continuous capacity and time-current protection characteristics of the circuit breaker or fuse (see Figure 2A.). It may become necessary to test the circuit protector panel or package simulating the above variables to obtain complete confidence.
- 5.7.3 Temperature Compensation: Temperature compensation provides some relief from the effect of ambient temperature but should not be interpreted to mean that no derating is necessary. Detail sheet MS 3320, for instance, gives 115% as the current the circuit breaker must carry without opening. This value is 15% above the application value to provide a tolerance for the effects of wear, vibration, etc. The same derating should be applied to the other values noted on the MS sheet. The 100% value at 121 °C should be reduced to 85% in application and the 160% value at -55 °C should be considered the limit of nontripping current. From this it is evident that an MS 3320-10 has a possible nontripping range of 8.5 to 16 Amperes over its temperature range at sea level but a specified usable load range of only 8.5 to 10 Amperes. Altitude introduces further derating factors.

5.7.4 Vibration: It is recommended practice that the circuit breaker meet the appropriate vibration levels it is qualified for in the applicable military specifications. It is recommended that the breaker shall meet one or more requirement levels: standard sinusoidal, high level sinusoidal, or random vibration. Users should select appropriate breakers qualified to meet the vibration requirements of the installation environment.

5.7.5 Coordination of Cascaded Protectors: MIL-C-5809, MIL-F-5372, and MIL-F-15160 do not have a coordination requirement. MIL-C-27715 requires that, "two circuit breakers in series with a ratio of current rating of at least two to one, the breaker with the higher rating shall hold closed and the circuit breaker with the lower rating shall trip". No provision for coordination is made to consider the effects of temperature when the two breakers are in different temperature ambients except in MIL-C-27715 (see Figures 2B and 2C). Coordination should be verified by appropriate testing.

It is recommended that all essential loads be fed directly from a bus with appropriate circuit protection to avoid unnecessary power outages that might result from loads being located downstream in a cascaded system.

5.7.6 Interrupting Capacity (Rupture Capacity): In selecting the circuit protector, it is important that the available short-circuit current at the device is not in excess of that which can safely be interrupted. Failure of the protector to isolate a fault presents a definite fire hazard from overheated wiring and the possibility of arcing. The interrupting capacity of circuit breakers is established in a test laboratory. If a circuit breaker fails to meet the specification requirement, similar circuit breakers will be submitted for test. This process will be repeated until the requirements are met. Qualification status does not guarantee compliance by all breakers of that type. To determine the maximum possible short-circuit current at the input to a protector, the procedure described in Appendix A may be used.

5.7.7 Contamination: Aircraft circuit breakers which are not sealed are subject to both internal and external contamination. Voltage arc-over, current creepage, internal corrosion with its subsequent shortening of life, and dry closure (i.e., mechanically latched but electrically open) are some of the end effects of contamination. The aircraft circuit breaker installations must be made with full consideration of the qualification test requirements and the installed environment.

5.7.8 Circuit Breaker Endurance: A typical circuit breaker specification sheet requires a 5000 cycle mechanical life and a 2500 cycle inductive load life. Comparing this to the life expectancy of most switches, it is found that the circuit breaker has a life of 1/10 or less of the life of a switch. In addition, it must be recognized that circuit breakers, both push button and toggle "switch type", usually are not snap-acting devices and should not be considered as substitutes for switches. The push button or toggle may be partially actuated, causing the contacts to "make" without latching the mechanism. This means that the contacts can be "teased" open or closed where the contacts under load are in close physical proximity but not touching, drawing arcs, pitting the contacts and generating EMI.

5.7.9 Change in Circuit Breaker Trip Characteristics: The trip characteristics of a circuit breaker can change over the life of the breaker. While there are a number of factors which can cause this change, the main ones are:

- a. Heavy fault currents which degrade the circuit breaker current overload sensor.
- b. Excessive manual operation of the breaker which causes dynamic wear of the breaker latching areas and pivotal points.

Paradoxically, the trip characteristics of a breaker can change when a circuit breaker trip mechanism has been dormant for long periods of time. This phenomenon is due to the high internal spring forces which are inherent in most circuit breakers and which can cause a static type of wear to occur to the circuit breaker trip mechanism when in the closed or reset position. Test data suggests this latter condition may be prevented or deferred by periodically operating the breaker manually with no electrical load on the breaker. Manual operation of the circuit breaker should be limited, however, to two or three times yearly in order to avoid excessive dynamic wear of the trip mechanism.

The amount of change in trip characteristics resulting from one of the previous conditions may be significant, resulting in either nuisance tripping type problems or, in extreme cases, a circuit breaker which will not adequately protect the wire to which it is attached.

An electrical check of a circuit breaker may be justified in order to determine if a significant shift in its trip characteristics has occurred. Such a circuit breaker would be one which is known or suspected of having been subjected to one of the foregoing mentioned conditions. Electrical checks of circuit breakers should, however, be conducted in accordance with established procedures under controlled conditions such as are encountered in a test laboratory.

5.7.10 Multipole Breakers: Three single phase circuit breakers are generally preferred to multipole circuit breakers unless loss of phase voltage may damage the load or lead to unacceptable operation of the load or power supply system. Only two three-phase aircraft circuit breakers MS 14153 and MS 14154 are on the Military Qualified Products List. Other three-phase aircraft circuit breakers have exhibited one or more of the following:

Minimum ultimate trip not consistent with single phase breakers.

Endurance - less than that of single phase breakers.

Vibration - withstand less than single breakers.

Trip-free - only the faulted phase is trip free.

Trip bar hang-up.

Voltage drop in excess of single phase breakers.

Structural integrity - poorer than single phase breakers.

In addition, size, weight, and cost generally favor the use of three single phase breakers.

5.7.11 Application Analysis: The performance of individual circuit breakers in specific mounting and wiring configuration is defined in specifications and recorded during qualification tests. The designer must determine the tripping and nontripping characteristics of the circuit breakers in the installed environment including packaging, bus bar, and wiring effects. There are variables which are not rigorously identified or supported by statistical data. The designer must apply judgment to specifications, test data, and application details to arrive at a conservative usage of protective devices.

5.8 Maintenance Procedures:

Circuit protectors used in circuits essential to flight should be located so that they may be reset in flight. All circuit protectors should be installed so that any protector may be inspected and replaced without disturbing other protectors or connections.

5.8.1 Visual Inspection Criteria for Circuit Breakers:

a. Front Side of Circuit Breaker Panel:

1. Verify that the amperage indicator on the end of the push-button is legible.
2. Check that the orientation of the amperage indicator is in the proper orientation on the panel.
3. Check that mounting nut is present and/or secure to panel.
4. Check for corrosion of the mounting hardware (mounting nut, screws).
5. Visually inspect for corrosion on the white trip indicator window of the push-button.
6. Visually inspect push-button for cracks or deterioration.

b. Back Side of Circuit Breaker Panel:

1. Visually inspect the circuit breaker case for cracks, discoloration, and burn marks.
2. Check for any foreign objects that could cause physical damage or electrical shorts.
3. Check terminal leads for disconnected wires, burn marks, or physical damage.
4. Check that terminal screws are present and tight.
5. Check for burn marks on the insulating barrier material of the three phase breakers.
6. Check for corrosion, discoloration, and hotspots on all metal parts, including bus bars.

5.8.2 Mechanical Inspection Criteria for Circuit Breakers:

1. All circuit breakers shall be mechanically cycled a minimum of one cycle per year. Pull the button out and push the button in.
2. Check for abnormally high or low pull-out forces.
3. Check for abnormally high or low reset forces.
4. All force measurements should be judged based on the normal "feel" of the circuit breaker when it is pulled and reset. This should only be an indicator for further investigation.

NOTE: One or more persons can perform these inspections. If any of the circuit breakers do not meet the inspection criteria, further investigation and possible electrical testing may be warranted before replacement of the circuit breaker.