U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: ELECTRICAL FAULT AND FIRE PREVENTION AND PROTECTION

Date: 4/5/91
Initiated by: ANM-100

AC No: 25-16
Change:

1. PURPOSE. This advisory circular (AC) provides information on electrically caused faults, overheat, smoke, and fire in transport category airplanes. Acceptable means are provided to minimize the potential for these conditions to occur, and to minimize or contain their effects when they do occur. These means are not mandatory. An applicant may elect to use any other means found to be acceptable by the Federal Aviation Administration for compliance with the Federal Aviation Regulations (FAR).

2. RELATED FAR SECTIONS. The related sections of the FAR are as follows. Where applicable, corresponding sections of Part 4b of the Civil Air Regulations (CAR) of 1962 follow each cited Part 25 section of the FAR.

21.21(b)(1)
21.21(b)(2)
25.601/4b.300
25.603/4b.301
25.671/4b.320(a)
25.695 (Initial)/4b.320(b)
25.672 (Amdt. 25-23 or later amdt.)/4b.320(b)
25.831(c)/4b.371(c)
25.853/4b.381
25.863/4b.385
25.901/4b.400
25.903/4b.401
25.1307(c)/4b.602 and 4b.605(e)
25.1309(a)/4b.606(a)
25.1309(b)
25.1309(c)/4b.606(b)
25.1309(d)
25.1333/4b.612(f)
25.1351(b)(2)/4b.622(b)(2)
25.1353
25.1357(a)/4b.624(a)
25.1359(d)
25.1363/4b.627
25.1435/4b.654 and 4b.655
25.1529
25.1581(a)(2)/4b.740(c).

3. RELATED ADVISORY CIRCULARS. The guidance in this AC supplements the following existing guidance on safe electrical design and installation practices.

a. AC 43.13-1A, Change 3, Acceptable Methods, Techniques, and Practices, Aircraft Inspection and Repair.

b. AC 43.13-2A, Change 1, Acceptable Methods, Techniques, and Practices, Aircraft Alterations.

c. AC 25-9, Smoke Detection, Penetration, Evacuation Tests, and Related Flight Manual Emergency Procedures.

d. AC 25-10, Guidance for Installation of Miscellaneous, Non-required Electrical Equipment.

4. DEFINITIONS.

a. Electrical Component: For the purpose of this AC, an electrical component is defined as an electrical power source, or a component receiving electricity from any source. Sources of electricity are not limited to power sources or distribution buses. They also include signal sources, such as the output of an autopilot servo amplifier, or data sources that transfer information electrically from one component to another.

b. Circuit Protective Device (CPD): A device used to protect electrical/electronic circuit components from an over-voltage or over-current condition, by automatically interrupting the current flow. The most common types of CPDs used in aircraft are the circuit breaker and the fuse.

c. Aromatic Polyimide Insulation: A wire insulating material formed as the result of a polycondensation reaction between an aromatic dianhydride and an aromatic diamine.

d. Arc Tracking: A phenomenon in which a conductive carbon path is formed across an insulating surface. This carbon path provides a short circuit path through which current can flow. Normally a result of electrical arcing. Also referred to as "Carbon Arc Tracking," "Wet Arc Tracking," or "Dry Arc Tracking."

e. Insulation Flashover: A result of Arc Tracking, an instantaneous burn-through of the insulated wire with the possibility of continuing the burn into surrounding wires. This failure mode, which is a result of the high temperature degradation of the insulation experienced during arcing, can propagate through a complete wire bundle severing the entire grouping.

5. WIRING FAULT AND WIRE INSULATION FLAMMABILITY INFORMATION.

a. Background. Amendment 25-32, effective May 1, 1972, added a new § 25.1359(d) which applies the flammability requirements of Appendix F of Part 25 to wire insulation used in aircraft and also revised Appendix F to make the burn test requirements more stringent. These requirements are effective on airplanes for which application for a type certificate is (or was) made on or after May 1, 1972; on the Boeing 747, Douglas DC-10, and Lockheed L-1011 airplanes by special conditions; and on certain other airplanes. (Reference the Type Certificate Data Sheet of each airplane type for its type certification basis.) Before these regulatory actions, there were no wire insulation flammability requirements in either Part 25 or Part 4b. Certain types of insulation, including polyvinyl chloride (PVC) insulation, do not comply with the § 25.1359(d) flammability requirements.

b. Discussion. Airplanes subject to the § 25.1359(d) flammability requirements are referred to as "later" airplanes, and all other airplanes are referred to as "earlier" airplanes. Similarly, wire having insulation which complies with these flammability requirements is referred to as "later" wire, and all other wire is referred to as "earlier" wire.

c. General Guidance. The guidance in this AC supplements existing guidance provided in AC 43.13-1A and AC 43.13-2A, and should be applied to new airplanes, as well as to modifications of previously-certificated airplanes in all locations where electrical systems, components, or wires are affected. It may also be useful in developing corrective Airworthiness Directive (AD) actions taken in response to hazards discovered in service. It should be noted that this guidance is not intended to take the place of instructions or precautions provided by wire, wire insulation, or equipment manufacturers. Also, if any requirement of Part 25 that is included in the airplane's type certification basis supersedes any particular guidance in this AC, compliance with that requirement of Part 25 should be ensured. This guidance reflects past certification practices and is considered to provide acceptable means of compliance with, or equivalent safety to, §§ 25.1359(d) and 25.831.

(1) Earlier wire may be used in all locations in earlier airplanes.

(2) Earlier wire may be used inside the fuselage of later airplanes only if its use does not create any significant potential for hazard. Under the equivalent safety provision of § 21.21(b)(1), the potential for hazard is considered insignificant if the guidance provided in any of the following three paragraphs is followed:

(i) Earlier wire may be used inside equipment designed, on an overall basis, to be as fire-resistant as practicable if it is either:

(A) Enclosed in a case made of metal or other material that complies with the flammability requirements of Amendment 25-32 that will either contain an internal fire so that it cannot propagate to other locations or is sufficiently airtight that internal ignition sources cannot cause a fire; or

(B) Located and installed where a fire cannot damage safety-related parts, propagate to flammable parts, or cause personal injury. Maximum physical or spatial separation is especially important above the equipment or downstream of any consistent, known airflow.

(ii) Earlier wire may be used inside the cases of video or audio tape players, television receivers, telephones, or other passenger convenience or entertainment equipment purchased on the general commercial market where similar, economically-feasible equipment having wire which complies with § 25.1359(d) does not exist. In such instances, the equipment should be located where smoke or fire would readily be noticed, and a readily identifiable switch, located away from the equipment, should be provided to enable its safe and rapid disconnection.

(iii) Where reasonable and appropriate, very small amounts of earlier, special-purpose wire, such as telephone interconnection wires, may also be used outside equipment cases.

d. General Wire Installation Guidance.

(1) All instructions and precautions provided by wire and wire insulation manufacturers should be followed and observed.

(2) Machines used to stamp identification on wire insulation should be adjusted so as not to penetrate through the insulation. Quality assurance procedures to verify that penetration has not occurred should be established. An acceptable method would be to employ an approved high voltage test. Alternatively, a non-impact process to place identification on wire insulation may be used.

(3) Care should be taken to ensure that the clamps and ties around wire bundles do not present a rough surface that may damage the wire insulation. These clamps and ties should be tight enough to hold the wires in place, but not so tight that insulation damage would occur during fabrication or installation, or later in service. To prevent insulation chafing, wires and bundles should be installed by routing and clamping to ensure sufficient spacing from structure or other parts after any single failure. Alternatively, other means may be used to prevent insulation chafing after any single failure. Some examples of such single failures would include the failure of any single clamp or clamp fastener. To prevent insulation damage during installation or maintenance, avoid routing wires or bundles in the vicinity of parts having sharp edges, corners, or protrusions. Alternatively, sharp edges, corners, or protrusions should be covered with smooth protective material or other devices. Bend radii should be large enough to ensure that insulation cracking does not occur during the fabrication or installation of wires or bundles, or later in service due to excessive mechanical stress. The clamps should be oriented such that abrasion of the wire or the clamp insulation does not occur. The clamps should be a compression type and should be spaced so that, assuming a wire break, the broken wire will not contact hydraulic lines, oxygen lines, pneumatic lines, or other equipment whose subsequent failure caused by arcing could cause further damage. Quality assurance procedures should be established to verify that insulation damage has not occurred during the process of fabricating and installing wires and bundles.

(4) Abrasion of wire insulation caused by differences in hardness can be hazardous. Therefore, wires having significantly different insulation hardness, or abrasion characteristics, should be routed in separate bundles. This is particularly important in areas of high vibration. Abrasion of either the insulation or the insulation-facing material of the clamps, conduits, or other devices used to secure or support wires or bundles can also be hazardous. Therefore, wire and bundle installations should be designed so that the insulation-facing material has a hardness compatible with that of the

insulation. Compatible materials are often known by the wire or wire insulation manufacturer or the airplane manufacturer or modifier. Compatible materials may also have been established by prior satisfactory service experience or tests. However, if such information is unavailable, insulation and insulation-facing materials should be tested to ensure that differences in hardness would not result in abrasion in service.

(5) To prevent insulation damage, wires or wire bundles should not be routed in locations where liquid spillage or leakage may be anticipated in service. It should be assumed that water or other liquids from any source are electrolytic. This assumption applies whether the liquids are pure or have other chemical(s) dissolved in or mixed with them. Service experience shows that locating wires or bundles under lavatories and galleys has sometimes resulted in insulation damage. Locating them in the wheel wells and some areas of the wings has also resulted in damage. Locating them in some areas of the empennage could also result in damage. Care should be taken to ensure that condensation, rain, snow, hail, ice, or slush will not result in insulation damage or deterioration of wires or bundles exposed to these environments. This may be established by satisfactory service experience, tests, or comparison of the insulation chemistry and design with those of other types of insulation that are known to be safe when exposed to these environments. In particular, the use of aromatic polyimide insulation material in these areas should be carefully evaluated.

(6) Installations that are inherently difficult sometimes lead to post-maintenance reinstallations that do not conform to any approved type design. Service experience shows that such non-conforming reinstallations, especially if done hurriedly, can significantly increase the potential for electrical faults, smoke, or fires. Therefore, to the greatest practicable extent, a type design should be provided for wire and wire bundle installations that allows for easy reinstallation after the completion of maintenance.

(7) Wires and wire bundles should be routed or otherwise protected to minimize the potential for maintenance personnel to step, walk, or climb on them, or use them for handholds. The wire bundles should be routed along heavier structural members whenever possible. Sharp metal edges must be protected by grommets to prevent chafing. Wires should not be routed between aircraft skin and fuel lines. Avoid running wires along the bottom of the fuselage, over the landing gear, in areas of the leading edge of the wing where fuel spillage is anticipated, or adjacent to flammable fluid lines or tanks.

(8) In installations where wires or wire bundles are expected to flex, such as landing gear harnesses, aromatic polyimide insulated wires should be avoided. If this wire type is used in flexible conduit, then the conduit installation should be properly designed for this purpose.

6. CIRCUIT PROTECTIVE DEVICE (CPD) INFORMATION.

a. Background. Historically, the FAA criterion for circuit protective device (e.g., circuit breaker or fuse) selection can simply be expressed as, "to protect the aircraft wiring, but not the equipment." This limited criterion is based on designing electrical components to be as fire-resistant as practicable and either enclosing them in metal cases that will contain an internal fire or are sufficiently airtight that internal ignition sources cannot cause a fire, or isolating them from flammable materials and safety-related parts. In the vast majority of instances metal cases have been used. The few exceptions which are known to have resulted in or contributed to fires have been corrected by airworthiness directive (AD) action. However, protecting electrical system installations by using CPDs to protect wiring and through component design to protect the rest of the system is not adequate. Circuit protective devices (circuit breakers and fuses) are considered to be slow-acting devices and may not offer sufficient disconnect protection from events such as arc-tracking or insulation flashover. For example, service experience shows that:

(1) Selection of CPD ratings; protection of three-phase loads; design of connectors, wire bundles, routing and clamping; and component temperatures have not always been safe.

(2) Faulty maintenance sometimes occurs in regard to routing, clamping, and cleanliness of locations surrounding certain equipment.

(3) Aging, weathering, vibration, and the normal wear and tear of maintenance sometimes cause chafing, abrasion, or deterioration of insulation, which can result in cracks or cuts that expose the conductor.

(4) The effects of electrical faults can include component overheating; toxic fumes; smoke; fire; damage to wires, wire bundles, or parts; melting of holes in sheet metal parts by faulted, high-current feeder cables; melting and burning of titanium bleed air ducts by a chafed, high--current feeder cable; electromagnetic interference (EMI) with equipment; and the simultaneous and unrestorable loss of both engine-driven generators in a two-engine airplane. While these effects occur infrequently, guidance is considered necessary to minimize them when they do occur and to minimize their potential causes. These effects can be caused by the following conditions or failure modes for which CPD's often do not provide timely, if any, automatic protection:

(i) Intermittent, low impedance short-circuits, such as chafing or arcing of wires on grounded metal parts, or chafing between conductors of different phases.

(ii) Higher impedance short-circuits which, for example, can be caused by locating wire in a moist or wet environment if the wire insulation is cracked or cut.

(iii) Low or higher impedance short-circuits inside electrical components themselves; or in component power, signal, or data transfer interconnection wires.

(iv) Failure of power to one or two phases of components intended for three-phase power.

(v) Incorrect assumptions of worst-case load conditions in regard to safe component temperatures.

(vi) Inadequate design in regard to safe connector or wire bundle temperatures.

(vii) High-current cable faults.

(viii) Arcing on wire insulation, or the resulting insulation damage. Service experience documents only a relatively small number of incidents of arcing damage for all types of insulation. However, service experience of aromatic polyimide insulation, as presently constructed, documents a failure mode called "insulation flashover" where conduction at insulation breakdown areas has damaged or destroyed the wire or wire bundle in which it occurs. Also, other adverse effects have sometimes occurred as a result of this failure mode. Arcing on wire insulation, or "arc tracking," can result from electrolytic contamination of wire having insulation cracks or cuts that expose the conductor. It can also result from chafing damage that reduces the dielectric strength of dry insulation. Each successive attempt to restore an automatically-disconnected power source, or the resetting of an automatically-disconnected CPD, can result in progressively worse effects from "arc tracking."

b. Circuit Protective Device Selection And Related Guidance.

(1) Linear corrections should be made of any measured temperatures to the maximum sea level outside ambient temperature approved for operations in the Limitations Section of the FAA-approved airplane flight manual (AFM) or AFM revision or supplement. Alternatively, they may be corrected in accordance with an analysis that establishes a rational method of correction.

(2) Quality assurance (QA) procedures should be established to ensure that circuit breaker time-versus-current automatic trip characteristics conform to their specifications, whenever a specific type or lot is suspect. Such procedures should be followed before installing circuit breakers.

(3) To protect against unsafe wire temperatures, consideration should be given to the wire size and specification used at the maximum deliverable continuous current of the CPD. The time-versus-current automatic disconnection specification for each CPD should also be considered, taking into account its ambient temperature and that of the protected wire. If doubt

exists regarding safe wire insulation temperatures, measurements should be taken and corrected as described in paragraph 6b(1).

(4) To minimize deliverable power to potential fault loads, the minimum commercially-available CPD rating should be used. This is the rating that will power the normal (intended) load without spurious automatic disconnections due to temporary conditions such as transients, surges, or momentary overloads.

NOTE: It is recommended that thermal circuit breakers not be specified for a continuous load in excess of 85 percent of the circuit breaker rating because it may cause deterioration of the trip point.

(5) To protect against propagation of an internal electrical component fire to surrounding locations, electrical components should be designed using non-flammable or self-extinguishing materials to minimize the potential for fire. Electrical components should be enclosed in metal or other fire-resistant cases (reference paragraph 5c(2)(i)(A)) that will either contain an internal fire or are sufficiently airtight that internal ignition sources cannot cause a fire. However, if such a case is impracticable, the component should be located and installed where a fire cannot damage safety-related parts, propagate to flammable parts, or cause personal injury (reference paragraph 5c(2)(i)(B)). Maximum physical or spatial separation is especially important above the component, or downstream of any consistent, known airflow.

(6) Precautions should be taken to ensure that three-phase loads are not a smoke or fire hazard and do not result in unsafe component temperatures when powered by fewer than three phases. Note that three-phase, integral (ganged) circuit breakers seldom detect the loss of phases when an over-current condition does not exist. If component overheating could occur, separate thermal protection should be provided in the equipment case. This could occur, for example, as a result of a bus phase outage, a load control component failure, or an open wire. If doubt exists regarding safe component temperatures, measurements should be taken and corrected as described in paragraph 6b(1). The recommended maximum safe external temperatures are considered to be: 450°F for components in dry, clean, and isolated locations; 400°F for components located in the vicinity of safety-related or flammable parts (including liquids or gases), or where flammable waste or other foreign material (such as used paper towels) might inadvertently accumulate without readily being noticed; and 140°F for components in occupied locations.

(7) Some internally-faulted components may not cause automatic disconnection of their CPD's before causing excessive temperatures that would result in a serious personnel, smoke, toxic fumes, or fire hazard. Some examples would include certain transformers and motors. In such cases, adequate backup protection should be provided. If over-temperature protection systems are used, the disconnection of the components protected by these

systems should be considered when determining compliance with the applicable regulations. This is especially important for components in more than one channel of a redundant system, or components in various systems that perform operationally-similar functions. Consideration should also be given to foreseeable operational and local environmental conditions, and the failure of any necessary cooling air supply.

(8) Protection should be provided against unsafe temperatures in connectors and wire bundles. Consideration should be given to probable combinations and durations of the maximum normal (intended) loads, combined with the simultaneous maximum single continuous fault load for that individual wire which would cause the maximum increase in connector or bundle temperature (reference paragraph 6b(3)). The maximum safe temperature should be determined from the specifications of the connector or the wires with the lowest temperature rating. The maximum safe temperature should not be exceeded, except in unavoidable applications with high ambient temperatures (e.g., the powerplant). If doubt exists regarding safe connector or bundle temperatures, measurements should be taken and corrected as described in paragraph 6b(1).

7. MISCELLANEOUS DESIGN, OPERATIONAL, AND MAINTENANCE-RELATED GUIDANCE.

a. Care should be taken to ensure that EMI caused by intermittent faults does not adversely affect systems or equipment. Such intermittent faults can be caused, for example, by chafing of conductors on grounded metal parts, chafing between conductors of different phases, or arcing on wire insulation. Digital equipment, including digital computer-based equipment, is usually more susceptible to such EMI than other equipment.

b. It is accepted practice to demonstrate by tests that the generator protection system responds properly to faults in the electrical generation and distribution system, or in any utilization system. Demonstrations of arcing on wire insulation should be allowed to progress to the point of "insulation flashover." The tests may be supported by any relevant analysis. If laboratory tests are conducted instead of airplane tests, compliance should be shown with § 25.1363.

c. Penetration of the effects of electrical faults or failure modes into tanks, tubes, or components containing fuel, other flammable fluid, oxygen, or concentrated oxidizing or reducing agents (such as chemical oxygen generators) can be extremely hazardous. Therefore, it is important to ensure that any foreseeable penetration will not occur. Some examples of foreseeable faults or failure modes that could result in penetration would include short-circuits of conductors, arcing on wires or wire bundles, or "insulation flashover." Consideration should be given to the maximum power which could be produced by such faults or failure modes, and the physical or spatial separation provided between their possible locations and the areas of potential hazard. Additionally, physical or spatial separation should be provided between high-current cables and the areas of potential hazard. However, if adequate separation is impracticable, protection should be provided against the effects of foreseeable faults or failure modes by providing alternative physical protection such as an adequate barrier or conduit, or by other acceptable means. For example, adequate separation is impracticable for wires or bundles that are necessarily located inside of or close to fuel tanks, and may be impracticable for some wires or bundles located in nacelles or pylons. Whenever practical, aromatic polyimide insulation wires should not be used for high current carrying cables.

d. Electrical components should be assessed for potential fire or smoke (which includes harmful or hazardous concentrations of gasses or vapors) assuming a failure has occurred. Typically, circuit protective devices and metal enclosures are all that are used to control the failure conditions, but not in every case (example - overheat protective devices). Each installation must be evaluated on its own merits. Electrical equipment bays should contain smoke and overheat detectors, and methods should be devised to contain a fire and prevent smoke from penetrating into the cabin or the cockpit. Smoke detection tests, smoke penetration tests, and smoke evacuation tests should be conducted in flight to demonstrate that the methods to detect, control, and evacuate the smoke are functioning as designed. The tests should be conducted in accordance with the test procedures outlined in AC 25-9.

e. Electrical components located in fuel vapor zones should be qualified as explosion proof in accordance with Section 9 of RTCA Document DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 20, 1984, or later approved revision. Fuel vapor zones are defined by the airplane manufacturer.

f. Burning of a metal part can be extremely hazardous; therefore, it is important to ensure that any foreseeable burning will not occur. Some parts made of certain metals, such as magnesium or titanium, can sometimes ignite and burn before they melt and drip away. Ignition can be caused by electrical faults or failure modes. Whether such a part will burn before it melts depends on various factors. Some examples of such factors would include mass; electrical and thermal conductivity; design, construction, and installation; rate of heat dissipation into surrounding locations; smaller dimensions (e.g., metal thickness); presence of sharp or thin edges, corners, or protrusions (e.g., cooling fins); air temperature; airflow; and oxygen content. If the use of such a part otherwise complies with §§ 25.601 and 25.603, consideration should be given to the maximum power which could be produced by foreseeable faults or failure modes and the physical or spatial separation provided between their possible locations and the part. Some examples of such faults or failure modes would include short-circuits of conductors, arcing on wires or wire bundles, or "insulation flashover." Routing high-current cables in the vicinity of such parts should be avoided; however, if adequate separation is impracticable, protection should be provided against the effects of foreseeable faults or failure modes by the use of alternative physical protection, such as an adequate barrier or conduit, or by other acceptable means. For example, adequate separation may be impracticable for some wires or bundles located in nacelles or pylons.

g. Information should be provided in FAA-approved AFM's or AFM revisions or supplements that the crew should make only one attempt to restore an automatically-disconnected power source or reset or replace an automatically-disconnected CPD that affects flight operations or safety.

h. Some electrical faults or failure modes can result in the automatic disconnection of a power source, bus, or high-current load for which power cannot be restored (or will not remain restored) without maintenance action. Such a disconnection could result in a serious latent failure of a flight control system component if the fault or failure mode occurs in its vicinity. For this reason, it is important that maintenance personnel determine by close inspection of related and non-related components in the vicinity of the fault, and before the next flight, that such a latent failure has not occurred. Therefore, this maintenance information should be provided to owners and operators of the airplane early enough for well-planned, timely incorporation into FAA-approved maintenance programs.

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*U.S. Government Printing Office: 1991 — 522-242/40101

U.S. Department
of Transportation

**Federal Aviation
Administration**

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