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RATIONALE

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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.

TABLE OF CONTENTS

1.	SCOPE.....	9
2.	APPLICABLE DOCUMENTS	9
2.1	SAE Publications.....	9
2.2	Military Publications	10
2.3	Other Documents	11
3.	CIRCUIT PROTECTION	12
3.1	Definitions, Principles, and General Recommendations.....	12
3.1.1	Circuit Protectors.....	12
3.1.2	Scope of Protection.....	12
3.1.3	Equipment Protection.....	12
3.1.4	Dual Protection.....	12
3.2	Circuit Breakers.....	13
3.2.1	Definitions, Principles, and General Recommendations.....	13
3.2.2	Interrupting Capacity of Circuit Breakers	14
3.2.3	Trip-Free Circuit Breakers.....	14
3.2.4	Non-Trip-Free Circuit Breakers	15
3.2.5	Automatic Reset Circuit Breakers	15
3.2.6	Remote Circuit Breakers	15
3.2.7	Magnetic Circuit Breakers	16
3.2.8	High Voltage Applications of Circuit Breakers	16
3.2.9	Multiple-Pole Circuit Breakers.....	16
3.3	Fuses.....	17
3.3.1	Definitions, Principles, and General Recommendations.....	17
3.3.2	Application of Fuses	18
3.3.3	Fuse Specifications and Designations	18
3.3.4	Fuse Types	18
3.3.5	Fuse Materials.....	18
3.3.6	Connections for Fuses	19
3.3.7	Fuse Time-Current Characteristics	19
3.4	Limiters.....	19
3.4.1	Definitions, Principles, and General Recommendations.....	19
3.4.2	Types of Limiters.....	21
3.4.3	Limiter Time-Current Characteristics	22
3.5	Aircraft Wire and Circuit Protector Coordination	22
3.6	Power System Protection.....	24
3.6.1	Definitions, Principles, and General Recommendations.....	24
3.6.2	Generation System Protection	27
3.6.3	Conversion System Protection.....	28
3.6.4	Distribution System Protection.....	29
3.6.5	Utilization System Protection	30
3.6.6	External Power Circuit Protection	30
4.	FAIL-SAFE FEATURES IN ELECTRIC CIRCUITS	30
4.1	General Probability Consideration for Failure Analysis	30
4.1.1	Wiring Failures	30
4.1.2	Equipment Failures	30
4.1.3	Design Considerations	31
4.2	Definitions, Principles, and General Recommendations.....	31
4.2.1	Definition	32
4.2.2	Circuit Analysis.....	32
4.3	Fire Detection Circuits.....	32
4.3.1	Integrity of Fire Detector Circuits	32
4.3.2	Selection of Components for Fire Detector Circuits.....	32
4.3.3	Shorted or Open Wire Effects on Fire Detector Circuits	32
4.3.4	Coordination and Interconnection of Fire Detector Circuits	32



4.4	Propeller Circuits	33
4.4.1	Interconnection of Propeller Control Circuits	33
4.4.2	Failure of Propeller Control Circuits	33
4.5	Thermal Anti-Icing and Deicing Circuits	33
4.5.1	Overheat Control in Thermal Anti-Icing and Deicing Circuits	33
4.5.2	Symmetrical Anti-Icing and Deicing Control	33
4.6	Fire Extinguishing Control Circuits	33
4.6.1	Selection and Protection of Fire Extinguishing Control Components	33
4.6.2	Circuit Connection for Fire Extinguishing Control Components	33
4.7	Fluid Shutoff Valve Circuits	34
4.7.1	Selection of Fluid Shutoff Valves	34
4.7.2	Engine Oil Valve Control	34
4.8	Other Circuits	34
4.8.1	Circuits Recommended for Fail-Safe Consideration	34
5.	CIRCUITS FOR ESSENTIAL EQUIPMENT	35
5.1	Definitions and General Principles	35
5.1.1	Essential Circuits	35
5.1.2	Emergency Circuits	35
5.2	Dual Power Sources	35
5.2.1	Selection of Alternate Power Supplies	35
5.2.2	Types of Self-Contained Emergency Power Supplies	35
5.2.3	Use of Main Engines	36
5.3	Electrical Isolation	36
5.3.1	Individual Circuit Protection for Essential Circuits	36
5.3.2	Emergency Circuit Power Sources	36
5.4	Types of Circuit Protection	36
5.4.1	Protection for Essential Circuits	36
5.5	Sequence Operation	36
5.5.1	Sequence Operation of Relays and Switches	36
5.6	Special Consideration in Wire Routing	36
5.6.1	Wire Routing	36
5.7	Special Considerations in Fire Areas	37
5.7.1	Fire Wall and Fire Seal Connections	37
5.7.2	Fire Detector Circuits	37
5.7.3	Fairleads on Fire Walls	37
5.7.4	Dielectric Materials	37
5.7.5	Electric Equipment	37
5.8	Flight Instruments	37
5.8.1	Multipower Sources for Flight Instruments	37
6.	MULTI-ENGINE RELIABILITY	38
6.1	General Principles and Recommendations	38
6.2	Power Source (Generators)	38
6.2.1	Low Engine Revolutions Per Minute Operation of Generators	38
6.2.2	Capacity of Generators	38
6.3	Separate Routing of Wiring	38
6.3.1	Instrument Wire Routing	38
6.3.2	Generator Feeder and Control Wiring	38
7.	CONNECTORS AND OTHER TERMINATIONS	39
7.1	General Recommendation	39
7.2	Studs and Insulators	39
7.2.1	Current Carrying Stud Resistance	39
7.2.2	Size of Studs	39
7.2.3	Support for Studs	39
7.2.4	Support of Wire at Studs	39
7.2.5	Feed-Through Insulator and Stud Design	39
7.3	Electrical Connectors	39
7.3.1	General	39



7.3.2	Design Objective	39
7.3.3	Selection	40
7.3.4	Connector Types	40
7.3.5	Voltage and Current Rating	41
7.3.6	Spare Contacts	41
7.3.7	Redundancy	41
7.3.8	Adjacent Locations	41
7.3.9	Sealing	41
7.3.10	Drainage	41
7.3.11	Wire Support	42
7.3.12	Slack	42
7.3.13	Identification	42
7.3.14	Installation	42
7.4	Feed-Through Bulkhead Wire Protection	42
7.4.1	Feed-Through Bushings for Wire Bundles	42
7.4.2	Wire Clamps	42
8.	GROUNDING AND BONDING	42
8.1	General and Definitions	42
8.1.1	Bonding (Definition)	42
8.1.2	Grounding (Definition)	43
8.2	Grounding	43
8.2.1	Current Return Paths	43
8.3	Bonding	44
8.3.1	Equipment Bonding	44
8.3.2	Metallic Surface Bonding	44
8.3.3	Parts to be Bonded	44
8.3.4	Electric Shock Prevention Bonding	44
8.3.5	Lightning Discharge Systems for Antenna	44
8.3.6	Static Discharge Devices	44
8.3.7	Lightning Protection Bonding	45
9.	WIRE SELECTION AND ROUTING	45
9.1	General	45
9.2	Wire Type Selection	45
9.2.1	Abrasion Resistance of Wire Insulation	45
9.2.2	Effects of Fluids on Wire Insulation	46
9.2.3	Effects of Aging on Wire Insulation	46
9.2.4	Heat Resistance of Wire Insulation	46
9.2.5	Flame Resistance of Wire Insulation	46
9.3	Wire Size Selection	46
9.3.1	Current Carrying Capacity of Copper Wires	47
9.3.2	Aluminum Wire Selection	47
9.3.3	Protective Devices for Wires	47
9.3.4	Voltage Drop in Wires	47
9.3.5	Mechanical Strength of Wires	51
9.4	Wire Routing	51
9.4.1	Clearance Provisions Between Electric Wires and Other Units	51
9.4.2	Wires in Conduit	52
9.4.3	Shielded Cable Routing	52
9.4.4	Voltage Sensitive Circuit Routing	52
9.4.5	Ignition Ground Leads Routing	52
9.4.6	Essential Engine Circuits Routing	52
9.4.7	Drip Loops in Wire Bundles	52
9.4.8	Size of Bundle	52
9.5	Wire Splices and Terminals	53
9.5.1	Installation and Support of Wire Splices	53
9.5.2	Wire Terminals	53
9.5.3	Terminal Strips	53

9.6	Coaxial Cable	53
9.6.1	Connectors for Coaxial Cables	53
9.6.2	Bend Radius for Coaxial Cable	54
10.	ALUMINUM WIRE AND CONNECTIONS	54
10.1	General	54
10.2	Wire Inspection	54
10.2.1	Wire Properties	54
10.2.2	Wire and Lug Assembly Inspection	54
10.3	Stud Connections	55
10.3.1	Use of Washers	55
10.3.2	Dissimilar Materials in Contact	55
10.3.3	Use of Joint Compound	55
10.4	Installation Requirements (See also Section 9)	55
10.4.1	Routing and Supporting	55
10.4.2	Recommended Gages	55
11.	WIRE AND CABLE IDENTIFICATION	55
11.1	General	55
11.2	Type of Circuit	56
11.2.1	High Voltage Circuits	56
11.2.2	Types of Current Identification	56
11.3	Individual Wire and Cable Identification	56
12.	MAINTENANCE OF ELECTRIC EQUIPMENT (SEE ALSO SECTION 15)	56
12.1	General	56
12.2	Design for Accessibility	56
12.2.1	Circuit Protector Accessibility	56
12.2.2	Relay Accessibility	56
12.2.3	Connector Accessibility	56
12.3	Equipment Identification	57
12.3.1	Types and Location of Placards	57
12.3.2	Circuit Breaker Rating Identification	57
13.	OPERATION AND INSPECTION OF ELECTRIC EQUIPMENT	57
13.1	General	57
13.2	Installation Design for Operation and Inspection	57
13.2.1	Functional Test and Operation Check	57
13.2.2	Visual Inspection	57
13.2.3	Operation Check of Standby or Emergency Equipment	57
13.2.4	Functional Check and Exercise of Rotating Equipment in Stores	58
14.	PROVISIONS FOR ADDITIONAL ELECTRIC EQUIPMENT	58
14.1	General	58
14.2	Power Requirements Expansion Provisions	58
14.2.1	Selection of Generators	58
14.3	Circuit Breaker and Fuse Panels	58
14.3.1	Provisions for Adding Circuit Breakers and Fuses	58
14.4	Switch Panels	58
14.4.1	Provisions for Adding Switches	58
14.5	Relay Boxes	58
14.5.1	Provisions for Adding Relays	58
14.6	Wiring and Termination Expansion	58
14.6.1	Provisions for Added Wiring	58
14.6.2	Terminal Strip and Terminal Junction Expansion	59
15.	EQUIPMENT SELECTION AND INSTALLATION	59
15.1	General	59
15.2	Selection Considerations	59
15.2.1	Check-Off List for Equipment	59
15.2.2	Environmental Conditions	59

15.2.3	Test Data Substantiation for Equipment Selection	59
15.2.4	Control of Electromagnetic Interference	59
15.2.5	Insulation Test on Equipment	59
15.2.6	Vibration and Shock Resistance of Equipment.....	60
15.2.7	Materials Used in Equipment	60
15.2.8	Finishes for Equipment	60
15.2.9	Dissimilar Materials in Equipment.....	60
15.2.10	Wire Terminals and Binding Posts on Equipment	61
15.2.11	Lock Washers for Terminals on Equipment.....	61
15.3	Equipment Selection	61
15.3.1	Batteries	61
15.3.2	Relay and Switch Selection	62
15.3.3	Switch Selection.....	62
15.3.4	Switch Installation	65
15.3.5	Relays	66
15.3.6	Rotating Equipment Selection.....	66
15.3.7	Transformer Selection.....	67
15.3.8	Resistor and Rheostat Selection.....	67
15.4	Installation of Equipment.....	67
15.4.1	Clearance Provisions in Equipment Installations	67
15.4.2	Equipment Manufacturers' Recommendations on Installation.....	67
15.4.3	Duplicate Equipment Installation.....	68
15.4.4	Mechanical Shock Prevention and Moisture Proofing of Equipment.....	68
15.4.5	Vapor and Dust Areas.....	68
15.4.6	Smoke Hazards.....	68
15.4.7	Grounding of Electric Equipment	68
15.4.8	Ventilation of Electric Equipment	69
15.5	Turbine Engine Starter	69
15.5.1	Battery Capacity	69
15.5.2	Cable Capacity	69
15.5.3	System Sizing	69
15.5.4	Air Restart Capability	69
16.	CORROSION PREVENTION IN ELECTRICAL EQUIPMENT	69
16.1	General.....	69
16.2	Condensation	69
16.2.1	Drain Hole Sizes and Locations.....	69
16.3	Corrosion Inhibiting Compounds.....	70
16.3.1	Inhibitor Application.....	70
16.4	Installation for Drainage	70
16.4.1	Equipment in Splash Areas.....	70
16.5	Battery Electrolyte	70
16.5.1	Surfaces Adjacent to Batteries.....	70
16.5.2	Equipment Adjacent to Batteries.....	70
16.5.3	Battery Venting.....	70
16.6	Potted and Environment Resisting Connectors (See Section 7 and AS50881)	70
16.6.1	Types of Connectors	70
16.6.2	Potted Connectors	70
16.6.3	Environment-Resisting Connectors	71
17.	SYSTEM LOAD DISTRIBUTION (SEE ALSO SECTIONS 200 AND 300 OF AIEE REPORT 750 AND 3.6 OF THIS DOCUMENT).....	71
17.1	General.....	71
17.2	Parallel System Central Bus (See also Section 340 of AIEE Report 750)	71
17.2.1	Shock Load Provisions.....	71
17.2.2	Load Transfer Provisions for Parallel Systems	71
17.2.3	Protection Provisions	71
17.3	Parallel System Divided Bus	72
17.3.1	Shock Load Provisions.....	72
17.3.2	Load Transfer Provisions	72
17.3.3	System Protection	72

17.4	Nonparallel Systems (See also Section 340 of AIEE Report 750)	72
17.4.1	Single Load Limitations for Nonparallel Systems	72
17.4.2	Load Switching	72
17.4.3	System Protection	72
17.5	Load Transfer Provisions for Emergency Loads	72
17.6	Load Reducing or Monitoring	72
17.6.1	Automatic Monitoring	72
17.6.2	Manual Monitoring	73
17.7	Acceptable Means of Controlling or Monitoring the Electrical Load	73
18.	ELECTRIC SYSTEM TESTS (SEE ALSO MIL-M-25500 [USAF])	74
18.1	General	74
18.1.1	Electric System Mock-Up	74
18.1.2	Extent of Testing	74
18.1.3	Environmental Conditions for Tests	74
18.1.4	Confirmation of Mock-Up Tests	74
18.2	Power and Distribution System	74
18.2.1	Test Conditions for Power and Distribution Systems	74
18.2.2	Type of Tests for Power and Distribution Systems	75
18.2.3	Secondary Electric Power Systems and Supplies	77
18.3	Tests of Other Electric Systems	77
18.3.1	Systems to be Tested	77
18.3.2	Systems Using More Than One Power Source	77
19.	EMERGENCY CONTROLS AND PROCEDURES	77
19.1	Controls for Emergency Operation	77
19.1.1	Emergency Electrical Controls	78
19.1.2	Electric System Control Panel	78
19.2	Smoke or Fire from Undetermined Electrical Origin	78
19.2.1	Order of Procedure	78
19.2.2	Grouping and Accessibility of Controls	79
19.2.3	Smoke or Fire Source in the Emergency Systems	79
19.2.4	Mock-Up Check of Procedure	79
19.3	Switching of Emergency Circuits	79
20.	AUXILIARY POWER PLANTS	79
20.1	Drives for Auxiliary Generators	79
20.1.1	Reciprocating Engine	79
20.1.2	Ram Air Turbine	80
20.1.3	Gas Turbine	80
20.1.4	Monopropellant Engines	80
20.1.5	Engine Bleed Air Turbine	80
20.1.6	Hydraulic Motor	80
APPENDIX A	DEFINITIONS	81
APPENDIX B	EVALUATION CHECK-OFF LIST FOR ELECTRIC EQUIPMENT	87
APPENDIX C	MINIMUM AIR SPACINGS FOR VARIOUS VOLTAGES AND ALTITUDES	89
FIGURE 1	FUSE AND LIMITER TYPICAL TIME - CURRENT CHARACTERISTICS	20
FIGURE 2	CURRENT - TIME CHARACTERISTICS, COPPER WIRE, 57.2 °C AMBIENT	48
FIGURE 3	CURRENT - TIME CHARACTERISTICS, ALUMINUM WIRE, 57.2 °C AMBIENT	49
TABLE 2	SUGGESTED PROTECTION METHODS	28
TABLE 3	ALLOWABLE VOLTAGE DROP BETWEEN BUS AND UTILIZATION EQUIPMENT GROUND	47
TABLE 4	SELECTION OF CONTACT MATERIAL	63

ACKNOWLEDGEMENTS

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 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

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 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP1199	Selection, Application, and Inspection of Electric Overcurrent Protection Devices
AS1212	Electric Power, Aircraft, Characteristics and Utilization of
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
ARP1350	Procedure for Installation and Mounting of Singlehole Mount, Cylindrical, Electrical Connectors
AIR1402	Common Termination Method, Electrical Wiring System, Application of
AIR1557	High and Extended Vibration Environment
AS1831	Electrical Power, 270 V DC, Aircraft, Characteristics and Utilization of
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP1928	Torque Recommendations for Attaching Electrical Wiring Devices to Terminal Boards or 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 Breaker and Fuse Arrangement
AS4372	Performance Requirements for Wire, Electric, Insulated Copper or Copper Alloy
AS4373	Test Methods for Insulated Electric Wire
AIR4567	Military Composite Electrical Connectors
AS4851	Relative Thermal Life and Temperature Index for Insulated Electric Wire
AS5363	Electromechanical Power Controller/Relay, General Specification For
AS8011	Minimum Performance Standards for A-C Generators and Associated Regulators
AS8020	Minimum Performance Standards for Engine Driven D.C. Generators/Starter-Generators and Associated Voltage Regulators
AS8023	Minimum Performance Standards for Static Electric Power Inverters
AS8028	Powerplant Fire Detection Instruments, Thermal & Flame Contact Types (Reciprocating and Turbine Engine Powered Aircraft)
AS22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy
AS24001	Fuse Holder, Block-Type, 1-, 2-, 3-Pole, 35- to 60-Ampere, Aircraft
AS50881	Wiring Aerospace Vehicle
AS53731	Fuse Holder, Block Type, Aircraft
AS58091	Circuit Breakers, Trip-Free, Aircraft, General Specification For
AS81044	Wire, Electrical, Crosslinked Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy
SAE J554	Electric Fuses (Cartridge Type)

2.2 Military Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

MIL-HDBK-221	Fire Protection Design Handbook for US Navy Aircraft Powered by Turbine Engines
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-464	Electromagnetic Environment Effects, Requirements for Systems
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-STD-7080	Electric Equipment, Aircraft, Selection and Installation of
MIL-DTL-5015	Connector, Electrical, Circular, AN Type - General Specification for
MIL-F-5372	Fuse, Current Limiter Type, Aircraft
MIL-E-7016	Electric Load and Power Source Capacity, Aircraft, Analysis of
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
MIL-W-25038	Wire, Electrical, High Temperature and Fire Resistant, General Specification for
MIL-DTL-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
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
ANSI/EIA 5200000	
NEMA-WC27500	Cable, Power Electrical and Cable Special Purpose, Shielded and Unshielded

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. Electromechanical Power Controller/Relay devices can provide a trip-free means of sensing and controlling electrical energy. They are intended for protection of AC and/or DC electrical systems, bus feeders, and electrical equipment. The general requirements for such devices are defined in AS5363.

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. Circuit breakers are designed as circuit protection devices and are not recommended to be used as switches. Use of a circuit breaker as a switch will reduce the life of the circuit breaker.

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 AS58091, 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. 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). Conventional circuit breakers should not be used in 270 volt dc powered systems. Electronic solid state power system controllers are recommended for such applications to minimize the possibility of shock hazard and wire damage.

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 circuit 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 AS50881 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. 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 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.

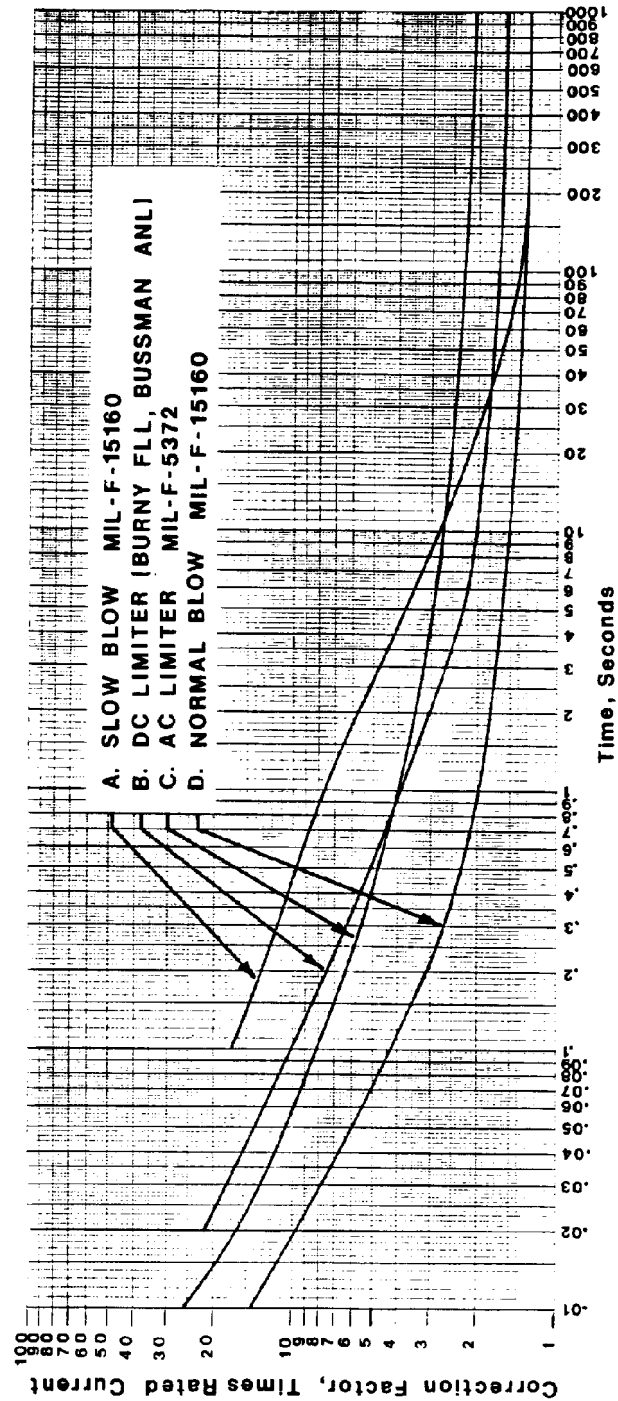


FIGURE 1 - FUSE AND LIMITER TYPICAL TIME - CURRENT CHARACTERISTICS

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.

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), AS53731, and MS24000 and AS24001 (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 magnitude and duration of any current which may be imposed on the wire to a level which does not cause damage or degradation to the wire's conductor or insulation. For additional requirements see AS50881. Well coordinated protection should be aimed at providing maximum wire utilization by permitting 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 AS22759, AS81044, and MIL-DTL-81381 one finds wires designed for 135 °C (275 °F), 150 °C (302 °F), 200 °C (392 °F), and 260 °C (500 °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 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 AS50881).

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 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.

3.5.6 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.

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. AS50881 defines an effective method for establishing wire current ratings that compensate for ambient temperature, altitude and bundle loading.

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). Each of these plays a role in the management of system load distribution. (See also Section 17.)

- 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-STD-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 in accordance with AS50881, 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.

Compare the generator or alternator ratings and limits prescribed by the manufacturer with the electrical loads which can be imposed on the affected generator or alternator by installed equipment. When the comparison shows that the probable total connected electrical load can exceed the output load limits of the generator(s) or alternator(s), reduce the load so that an overload cannot occur or provide means whereby the pilot or flight crew can readily and safely manage the electrical load so that it can be held within the prescribed limits. (See also 6.2 and 17.6.)

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 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

¹May 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.

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 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. See AS50881 for wiring of critical circuits.

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. See AS50881 for wiring of critical circuits. 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. See AS50881 for additional requirements for electro-explosive subsystem wiring. 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.