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DEPARTMENT OF DEFENSE
JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE ELECTRICAL POWER SUBSYSTEM REQUIREMENTS AND GUIDANCE

This specification guide is for guidance only.

Do not cite this document as a requirement.

Comments, suggestions, or questions on this document should be addressed to AFLCMC/EZSS, BLDG 28 RM 133, 2145 MONAHAN WAY, WPAFB, OH 45433-7017 USA or e-mailed to ENGINEERING.STANDARDS@US.AF.MIL. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

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FOREWORD

1. This specification guide is approved for use by all Departments and Agencies of the Department of Defense (DoD).

2. This specification guide replaces Appendix H, "Air Vehicle Electrical Power Subsystem Requirements and Guidance," in JSSG-2009A, "Air Vehicle Subsystems."

3. The purpose of this Joint Service Specification Guide (JSSG) is to provide guidance for use by Government and Industry program teams in developing program-unique specifications. This document shall not be placed on contract.

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1. SCOPE

1.1 Scope.

This specification guide provides the requirements, verifications, tailoring guidance, and background information for the electrical power subsystem. This specification guide has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This specification guide is a mandatory part of the air vehicle subsystem specification. The information contained herein is intended for compliance.

1.2 Structure.

The specification guide structure replicates the structure of the air vehicle subsystems specification except it places each corresponding section 3 requirement and section 4 verification together.

1.3 Overview.

This specification guide provides tailoring guidance and background information for individual paragraphs of the air vehicle subsystems specification. Guidance gives recommendations on how to tailor the specification paragraph. Where (TBS) appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the (TBS). When contractors are expected to complete the (TBS), the guidance paragraph will so state. The using service makes the final decision on whom completes the (TBS) in the specification. Finally, lessons learned are provided to give insight to past events that could affect the tailoring of the specification.

1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

1.5 Environmental impact.

Air vehicle subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the using service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion website at https://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

1.6 Responsible engineering office.

The responsible engineering office (REO) for this specification guide is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB, OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this guide specification. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this guide specification, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

ASIC AIR STD 25/18	Connectors for 28 Volt DC Servicing Power
STANAG-3109	Symbol Marking of Aircraft Servicing and Safety/Hazard Points
STANAG-7073	Connectors for Aircraft Electrical Servicing Power

(Copies of these documents are available at https://quicksearch.dla.mil and https://nso.nato.int.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-E-7016	Electric Load and Power Source Capacity, Aircraft, Analysis of
MIL-PRF-18148/3	Receptacles, Electric, Aircraft Storage Battery
MIL-PRF-21480	Generator System, Electric Power, 400 Hz, AC, Aircraft
MIL-PRF-24021	Electric Power Monitors, External, Aircraft
MIL-DTL-6162	Generators and Starter-Generators, DC, 30 Volts, Aircraft
MIL-PRF-7032	Inverters, Aircraft, General Specification for
MIL-PRF-7115	Converters, Aircraft General Specification for

MIL-PRF-81757	Batteries and Cells, Storage, Nickel Cadmium, Aircraft
MIL-PRF-81757/2	Battery, Storage, Aircraft, Nickel-Cadmium, Vented Filler Cap
MIL-E-85583	Electric Power Generating Channel, Variable Input Speed, AC, 400 Hz
MIL-PRF-8565	Battery, Storage, Aircraft, General Specification for

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-7080	Selection and Installation of Aircraft Electric Equipment

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-516	Airworthiness Certification Criteria
MIL-HDBK-704-1	Guidance for Test Procedures for Demonstration of Utilization Equipment Compliance to Aircraft Electrical Power Characteristics (Part 1 of 8 Parts)

(Copies of these documents are available online at https://quicksearch.dla.mil.)

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NAVAL SEA SYSTEMS COMMAND

NAVSEAINST 9310.1	Naval Lithium Battery Safety Program
NAVSEA S9310-AQ-SAF-010	Technical Manual for Navy Lithium Battery Safety Program Responsibilities and Procedures

(Copies of these documents are available online at https://www.navsea.navy.mil/ and https://discover.dtic.mil/.)

2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

RTCA INCORPORATED

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment

(Copies of this document are available from https://www.rtca.org.)

SAE INTERNATIONAL

SAE AS35061	Connector, Receptacle, External Electric Power, Aircraft 28 Volt DC Operating Power
SAE AS50881	Wiring, Aerospace Vehicle
SAE AS6070	Aerospace Cable, High Speed Data, Copper
SAE AS81790/1	Connector, Receptacle, External Electric Power, Aircraft, 270 VDC, 90KW
SAE AS90362	Connector, Receptacle, External Electric Power, Aircraft 115/200 Volt, 400 Hertz
SAE AIR4365	115/200 Volt, 400 Hz Aircraft External Electrical Power Connector Contact Maintenance Procedures

(Copies of these documents are available from https://www.sae.org/.)

2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the 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.

2.5 Streamlining.

The air vehicle subsystems specification has been streamlined. The documents listed in this specification guide which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

3. REQUIREMENTS

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3.4.8 Electrical power subsystem.

The electrical power subsystem shall be sized and configured to provide onboard generation, conversion, storage, distribution, control, and protection of the electrical power required for all phases of vehicle operation, including ground maintenance.

Components of the system shall not operate in any mode, either normal or abnormal, that degrades the operation or causes failure of any other component of the system.

REQUIREMENT RATIONALE (3.4.8)

The electrical power subsystem is the primary energy source for operation of electrical and electronic equipment onboard the air vehicle. Proper specification of the functional and performance characteristics is essential for the safe and reliable operation of the electrical power subsystem.

REQUIREMENT GUIDANCE (3.4.8)

Electrical power subsystems often provide several different power forms such as 115 VAC 400 Hz, 115 VAC 60 Hz, 270 VDC, and 28 VDC. There is normally one primary power source with electronic conversion equipment being used to change the primary power form to other forms.

This conversion equipment often forms a major portion of the electrical power subsystem and its successful design is important in achieving a stable and reliable subsystem.

There are a number of options that should be considered when configuring an electrical power subsystem. Some elements of the design are dependent on the criticality of utilization equipment regarding safety and mission success.

Additional guidance on tailoring the specific requirements of the electrical power subsystem is provided in the individual subparagraphs that follow.

Airworthiness considerations for electrical systems are documented in MIL-HDBK-516.

REQUIREMENT LESSONS LEARNED (3.4.8)

Careful analysis is required to avoid the possibility of single point failures in the electrical system. One aircraft developed a shorted bus to structure during flight. Both generators were taken offline in response to this fault. The battery was then automatically connected to the bus, but fed into the same short, causing its fuse to open. Fortunately, the short itself had also blown open, and normal operation resumed. A more robust short could have led to the loss of all electrical power on the aircraft.

4.4.8 Electrical power subsystem.

The ability of the electrical power subsystem to provide onboard generation, conversion, storage, distribution, diagnostics, control, and protection of the electrical power required for all phases of vehicle operation shall be verified incrementally by (TBS).

VERIFICATION RATIONALE (4.4.8)

Verification is required to assure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.8)

TBS: Verification should be accomplished incrementally and encompass planning, procedure preparation, and reporting. Verification should be accomplished by test, analysis, inspection, or a combination thereof.

Analysis should be considered for many aspects of the development such as assessing electrical loading, distribution bus structure, circuit sizing, and failure mode effects. Electrical load analysis techniques, such as those in MIL-E-7016, are crucial to understanding the electrical loading of each component of the electrical power subsystem under various flight and ground conditions.

Laboratory tests should be performed on a subsystem mockup that accurately simulates the air vehicle installation. Testing should include the most adverse electrical loading, environmental, fault, and endurance conditions required of the subsystem.

Air vehicle ground and flight tests of the installed electrical power subsystem should be performed under the most adverse conditions of electrical loading, cooling, and flight maneuvers. Failure modes that are hazardous to personnel or the air vehicle should be simulated.

Testing should simulate all feasible flight configurations and transitions between them, including power-up.

Some aspects of the subsystem can be verified by inspection, such as installation of external power connectors.

VERIFICATION LESSONS LEARNED (4.4.8)

The development of a laboratory based electrical power subsystem demonstrator has been shown to be essential in evaluating electrical power subsystem performance under various operating conditions. With the ever-increasing integration of different subsystems onboard air vehicles, the need for high fidelity capability in subsystem integration laboratories is paramount. Careful attention must be paid to replicating aircraft wire lengths and routing as accurately as possible so that impacts of impedance on system response and power quality are well understood.

3.4.8.1 Electrical power characteristics.

The characteristics of the electrical power provided at the terminals of the power utilization equipment shall be in accordance with (TBS).

REQUIREMENT RATIONALE (3.4.8.1)

It is necessary to establish a standardized electrical power interface to ensure compatibility between the electrical power subsystem and the equipment using electrical power. This standard establishes both electrical power quality requirements that the electrical power subsystem is to provide as a supplier of power to utilization equipment and the parameters within which the using equipment must operate acceptably. Interface characteristics typically controlled include voltage, frequency, distortion, and phase displacement, including steady state and transient limits.

REQUIREMENT GUIDANCE (3.4.8.1)

TBS should normally be filled in with the current issue of MIL-STD-704 for the electrical power interface for new air vehicles. If there are overriding considerations that require deviation from the standard, the appropriate limits and interface requirements from MIL-STD-704 together with the peculiar air vehicle limit and interface requirements should be specified. MIL-HDBK-704 defines test methods and procedures for determining airborne utilization equipment compliance with the electrical power characteristic requirements defined in MIL-STD-704.

When the electrical power subsystem of an existing air vehicle is modified, the specified power quality should be compatible with the original air vehicle requirements to ensure that existing utilization equipment will continue to function properly. Therefore, the current version of MIL-STD-704 should be specified for modifications only if it ensures power quality equal to or better than the original requirement. Comparison of the requirements of the current version of MIL-STD-704 with earlier versions of the specification should be performed to make this determination.

For unmanned air vehicles, special requirements may dictate electrical power with different characteristics than MIL-STD-704. In these cases, MIL-STD-704 should be considered as a guide when preparing the electrical power characteristics specifications for both the electrical power subsystem and the using equipment.

For commercial derivative aircraft, power quality is typically specified in accordance with RTCA DO-160 rather than MIL-STD-704. The applicable version of RTCA DO-160 must be reviewed closely when used to define power quality supplied to Government Furnished Equipment, which is typically qualified to a version of MIL-STD-704.

Since the requirement in this specification actually only defines the electrical power quality of the electrical power subsystem, the compatibility of all utilization equipment with the electrical power subsystem should be checked. The power quality standard should be included in each vendor specification and all utilization equipment should be tested prior to installation on the vehicle.

REQUIREMENT LESSONS LEARNED (3.4.8.1)

Some air vehicles have had problems of incompatibility between air vehicle power and utilization equipment. In some cases, the electrical power subsystem had to be reworked to accommodate the equipment even though the original power quality requirements were met. Frequently, utilization equipment has not been designed or tested to the vehicle power quality standards, resulting in incompatibilities and redesign of the equipment. These problems point out that the power interface requirements should be carefully chosen and consistently applied to both the electrical power subsystem and the utilization equipment.

Requirements for power quality are contained in MIL-STD-704, which was first issued in October 1959. Present requirements have evolved through several revisions to MIL-STD-704. Requirements for some unmanned air vehicles and most commercial derivative aircraft have deviated from this standard.

4.4.8.1 Electrical power characteristics.

Electrical power subsystem compliance with the electrical power characteristics requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.1)

Verification is required to ensure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.8.1)

TBS should be filled in with the particular analyses and tests appropriate for the electrical power subsystem under consideration. The following elements should be considered in determining these requirements:

a. Component requirements and test results should be analyzed to ensure that component performance is consistent with overall subsystem requirements.

b. The entire electrical power subsystem should be tested as a whole to verify that the power quality at the inputs to the utilization equipment is within specified limits for all normal and abnormal conditions. Laboratory testing of the electrical power subsystem in an air vehicle configuration should be conducted to demonstrate this requirement. The electrical power subsystem laboratory testing should be in a configuration that includes all components of the subsystem up to the utilization equipment (including wire, cabling, and connectors and circuit protection devices). Testing should include the most adverse electrical loading, fault, and endurance conditions required of the subsystem.

VERIFICATION LESSONS LEARNED (4.4.8.1)

Experience has shown that retaining functional subsystem mockups throughout the life of the program allows for continued testing and analyses of subsystem design and resolution of failures.

One aspect of verification that is often overlooked concerns the potential for new or modified electrical equipment to have an adverse effect on aircraft power quality. MIL-HDBK-704 and RTCA DO-160 both include current distortion test procedures, but defer to the utilization equipment specification for any requirements to run the test. Default pass-fail criteria are provided by RTCA DO-160 but not MIL-HDBK-704. A second-best alternative to current distortion testing is conducted emissions testing (CE101 and/or CE102) per MIL-STD-461. For high power non-linear electrical load equipment, it is especially important to include current distortion limits in the equipment specification to ensure suitable testing is performed.

3.4.8.2 Capacity.

The electrical power subsystem shall provide electrical power in sufficient quantity for all modes of vehicle operation and additional capacity for growth loads as follows: (TBS). In addition, the capacity for generating, conversion, emergency, and starting equipment shall be defined separately.

REQUIREMENT RATIONALE (3.4.8.2)

It is essential to define the required capacity of the electrical power subsystem since it is a critical design parameter affecting the air vehicle design. Weight and volume impacts can be significant.

REQUIREMENT GUIDANCE (3.4.8.2)

TBS should be filled in with the required capacity of the electrical power subsystem as determined by the total electrical power requirements of the air vehicle. All modes of air vehicle operation should be considered as well as provisions for load growth and any necessary redundancy. Electrical power subsystem capacity should normally be at least twice the maximum continuous load of the initial production air vehicle to provide for growth, unless other overriding considerations prevent this growth capacity. Providing for this level of growth is commonly implemented for cargo and bomber air vehicles. Smaller growth margins [about 30 percent (30%)] are often used for fighter air vehicles because the increased weight associated with larger capacity components is usually considered to be unacceptable. The factors listed below should be considered:

a. Steady state and short duration load requirements

b. Component power ratings

c. Capacity derating factors such as temperature and altitude (including oil supply, input speed, and horse-power)

d. Growth requirements

e. Redundancy for flight critical subsystems

The MIL-E-7016 procedures can be used for the analysis of load requirements and power source capacity.

Specified growth capacity must be available from primary and conversion power sources in all operating conditions. The power distribution system shall have adequate current carrying capacity to carry the full rated capacity of the power generation and conversion sources and should also be capable of handling the load growth provisions. Emergency power is not to be considered as system growth capacity.

Some limited application air vehicles and most missiles do not require growth capacity. In such cases, consultation with the procuring activity should be considered.

REQUIREMENT LESSONS LEARNED (3.4.8.2)

As a general rule, air vehicle electrical loads continue to grow after the initial design. Some air vehicles have been forced to eventually change to larger generators or add additional generating capability as the loads increased. Experience has shown that extra capacity has also been needed for failure conditions, which resulted in a generator loss, to ensure that all subsystems can still function. Growth capacity has also prevented brownouts and increased generator reliability.

Some air vehicles that were converted over to special mission purposes required an entirely new electrical subsystem. At times, even a 100-percent (100%) growth capacity has not be enough. It has not been uncommon to see original equipment 40 KVA generators replaced with 120 KVA generators.

4.4.8.2 Capacity.

The ability of the electrical power subsystem to meet the capacity requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.2)

Analyses of air vehicle requirements are needed to establish the capacity required of the electrical power subsystem for initial loads, growth, and redundancy. Subsequent testing is necessary to confirm actual air vehicle loads and electrical power subsystem capacity.

VERIFICATION GUIDANCE (4.4.8.2)

TBS should be filled in with the appropriate mixture of analysis and test for the particular application. MIL-E-7016 provides an approach and associated procedures for summarizing and documenting both steady state and short duration electrical loading conditions in determining the required capacity of the electrical power subsystem and its components.

Actual air vehicle loads and installed subsystem performance should be determined by air vehicle testing.

Actual loads of individual electrical power users often will not be available until vendors have tested their equipment to verify the actual power utilized. Close work with the vendors early in the program can obtain the best estimates on loads so that the electrical power subsystem may be sized correctly from the start.

VERIFICATION LESSONS LEARNED (4.4.8.2)

In the early stages of design, the electrical power needed is usually underestimated by the vendor;

and by the time the first operational air vehicle is delivered, the actual loads are above the original estimates. Experience has shown that careful review of vendor estimates of needed power early in the program has been helpful to assure that the electrical subsystem was sized correctly. Adding 25 percent (25%) larger generators halfway through the design can severely affect the total subsystem design.

When equipment loads are measured and found to differ from estimates used in the aircraft electrical load analysis, the equipment specification should be updated conjointly with the load analysis. Failure to do so can result in accepting future performance variation or design changes to the equipment that conform to equipment specification limits but invalidate the aircraft electrical load analysis.

3.4.8.3 External ground power compatibility.

The electrical power subsystem shall accept and distribute maximum required levels of power from external sources identified as being required for ground operations, while maintaining electrical power characteristics in accordance with "Electrical power characteristics" in this specification guide, including transfer between onboard equipment and the external sources in both directions. The electrical power subsystem shall protect against unsuitable external power being applied to the air vehicle, in accordance with MIL-PRF-24021.

Receptacles shall be provided and installed in accordance with MIL-STD-7080 for receiving external power. 115 VAC 400 Hz receptacles shall be as specified in SAE AS90362. Pins E and F shall not have 115 VAC applied by the air vehicle since these pins mate to 28 VDC circuits in some ground power carts. 28 VDC receptacles shall be as specified in SAE AS35061. 270 VDC receptacles shall be as specified in SAE AS81790/1.

If applicable, external power receptacles shall meet interface requirements in accordance with the latest international agreements included in North Atlantic Treaty Organization Standardization Agreements (NATO STANAGs) and Air and Space Interoperability (ASIC) Standards and shall meet the following additional requirements: (TBS).

The voltage drop between the external power receptacle and the aircraft bus shall not exceed 1.0 VAC or 0.25 VDC with all equipment requiring ground service power simultaneously operating.

A separate control circuit shall be provided for each external power receptacle. The external power control shall automatically isolate the receptacle from aircraft power circuits when the mating plug is disconnected or de-energized to ensure that dangerous voltages are not present. A cockpit indicator shall indicate external power connection(s).

The aircraft electrical power distribution system shall prevent external power from being paralleled with the aircraft electrical power sources. Electrical power distribution controls and protection shall prevent the aircraft electrical load demand from exceeding its rated limit.

REQUIREMENT RATIONALE (3.4.8.3)

External power is usually necessary for ground operations such as maintenance, ground alert, air vehicle lighting, and engine starting. Therefore, the ability to utilize external ground power sources, and to interface with such, is important.

REQUIREMENT GUIDANCE (3.4.8.3)

TBS should be filled in with consideration of the following:

a. External power receptacles should be in accordance with international agreements included in NATO STANAG 7073 and ASIC AIR STD 25/18, as applicable.

b. External power receptacles should be accessible from ground level and should be located to minimize hazards to ground personnel. They should not be located in or near hazardous areas such as air inlets or exhausts, Auxiliary Power Unit (APU) or jet fuel starter exhaust, propellers or propeller blasts, or fuel servicing or vent areas. The safe and convenient location of external power receptacles should be a prime consideration to facilitate servicing and to minimize hazards to the ground crew.

c. When dictated by operational requirements, the receptacle should be designed so that the power cable and plug will pull out of the receptacle when the air vehicle moves forward, if ground maintenance personnel forget to remove the plug.

d. Consideration should be given to the use of the external power receptacle for connecting load banks to the air vehicle for ground checkout of the electrical power subsystem.

e. It is necessary to protect the external power receptacle from dirt, fluids, and other contaminants when it is not in use. External power receptacles should be covered by hinged access doors that will automatically close after the ground servicing operation, and remain closed when the receptacle is not in use. The access door should be prominently identified in accordance with NATO STANAG 3109.

The quantity of ground power that the electrical power subsystem is to be designed to handle can be obtained from the electrical load analysis per MIL-E-7016. Protection against poor quality external power should be incorporated to prevent damage to the electrical power subsystem and power-using equipment. MIL-PRF-24021 covers external power monitors that provide this protection for 115VAC and 28 VDC buses. Some air vehicles require that the transfer from ground power to air vehicle power, and the reverse, be made without power interruption because of sensitive onboard equipment. This requirement should be invoked as needed. Peculiar power transfer transients over and above MIL-STD-704 or alternative power quality standards should be specified.

REQUIREMENT LESSONS LEARNED (3.4.8.3)

Some air vehicles use the external power receptacle to connect loads to the air vehicle for ground check of the onboard electrical power subsystem. This approach has eliminated the need to operate onboard equipment as loads for this purpose.

Use of incompatible interfaces has caused damage to air vehicle equipment when using the ground power carts provided by some installations.

External power receptacles have been standardized to assure that any air vehicle can receive external power at any location. If the standard power receptacle is not used, then special power carts or adapters will be required at remote locations.

4.4.8.3 External ground power compatibility.

The ability of the electrical power subsystem to meet external ground power requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.3)

Analyses of external power requirements are necessary in order to design the electrical power subsystem interface for external power. Subsequent testing is required to confirm that the external ground power performance requirements of the electrical power subsystem are met.

VERIFICATION GUIDANCE (4.4.8.3)

TBS should be filled in with an appropriate combination of tests, analysis, and inspection in consideration of the following.

The procedures of MIL-E-7016 can be used to analyze the electrical loading requirements for external power. The capability of the electrical power subsystem to accept and distribute the maximum external power requirements while maintaining the required power quality should be determined by a combination of analyses and tests. Testing should normally be performed at both an electrical mock-up and onboard the air vehicle.

Protection of the air vehicle against accepting unsuitable external power should be verified by analyses and tests.

Proper selection and installation of external power receptacles can be verified primarily by inspection of applicable drawings and the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.8.3)

Undersized external power plug sockets are sometimes preferred by maintainers because they mate securely with already-worn aircraft receptacle pins. However, undersized sockets accelerate wear of the pins, which can ultimately lead to poorer contact and intermittent or open circuit connections. 115 VAC 400 Hz aircraft receptacles should be inspected and maintained in accordance with SAE AIR4365 so that wear can be recognized and corrected early.

3.4.8.4 Power distribution.

Electrical power shall be distributed from the various power sources to the air vehicle loads as follows: (TBS).

The electrical power system shall operate without aircrew intervention. A switch, accessible to the aircrew, shall be provided to manually disconnect each electrical power source except emergency and flight control power sources. A means to reset emergency and flight control power sources by the aircrew shall be provided.

Circuit breakers shall not be used as switches unless specifically designed for that purpose.

An indication shall be provided to the aircrew of any power source that is not energized.

Alternating current (AC) bus architecture shall prevent inadvertent paralleling of AC power sources.

REQUIREMENT RATIONALE (3.4.8.4)

An effective distribution subsystem is needed to transmit electrical power to the using equipment in a safe and reliable manner. Experience has shown that the distribution subsystem needs the same careful design and analysis effort as the electrical power generating subsystem.

REQUIREMENT GUIDANCE (3.4.8.4)

TBS should be filled in with consideration of power quality, load priorities, reliability, vulnerability, and safety.

The bus structure and distribution circuits should be configured so that normal electrical power subsystem operational loads receive power from the air vehicle primary power source(s), ground power, or an auxiliary power source as applicable.

If an electrical power subsystem failure reduces the amount of available power below total air vehicle requirements, non-flight critical and pre-selected loads should be automatically disconnected as necessary to maintain subsystem integrity.

Flight critical loads should have first priority to primary power and should be supplied from the emergency power source when primary power is not available.

Load management should be implemented by the vehicle control and management system for all flight loads (for example, electromechanical and electro-hydrostatic actuators), except the flight-critical loads, through Electrical Load Management Centers (ELMCs). This will allow for better load management or load shedding in case of different conditions of loss of power for different mission scenarios.

The distribution wiring should be sized such that the power quality requirements of “Electrical power characteristics” in this guide specification are maintained at the terminals of the utilization equipment. The power distribution subsystem interfaces with avionics wiring and the airframe. Therefore, the requirements of SAE AS50881 should be applied. In addition, the requirements of MIL-STD-7080 for the installation of electrical equipment should be considered. The air vehicle structure should be considered as return or ground for primary power distribution where possible. This will provide wiring weight reduction.

Convenient means should be provided for disconnecting ground power from equipment not requiring power during ground operation.

SAE AS50881 covers all aspects of electrical wiring interconnection systems (EWIS), from the selection through installation of wiring and wiring devices and optical cabling and termination devices used in aerospace vehicles.

REQUIREMENT LESSONS LEARNED (3.4.8.4)

The power distribution subsystem on some air vehicles has malfunctioned or been improperly designed. The malfunction in the distribution subsystem resulted in partial or total loss of all electrical power.

Automatic load shedding has been shown to be important in the event of a partial loss of the electrical subsystem. This provision has reduced the likelihood of the entire subsystem being lost due to one item failing. The crew cannot be expected to shut down equipment in time to prevent a total electrical subsystem failure. Some air vehicles without load shedding have lost total electrical power due to one small failure that could have been automatically detected and isolated.

Program experience has shown that mission completion success rate has been low because of failures caused by mission-critical loads. The Fail-Op fault tolerance for the mission-critical loads should be extended to the distributed bus (ELMC) level.

To support advanced communication technologies, reliable high-speed data cables were developed that meet rigorous aerospace standards. These data cables are governed by SAE AS6070.

The use of plastic cable straps (zip ties) as secondary support was determined to be impractical for military use. This is due to damage to wire, improper installation, and ultra violet sensitivity.

In Vietnam, air vehicles experienced a major problem when the potting compound in the electrical connectors reverted to a sticky, gummy mass because of heat and humidity. This cost millions of dollars and extensive downtime to repair. Environmentally-sealed connectors which do not require potting are now preferred for most applications. Where potting is required, use should be restricted to those materials that have been qualified to the service environment.

Short, easily replaceable harnesses to go between the equipment and air vehicle wiring should be considered for use with equipment that is frequently removed (such as liquid oxygen converters). As the equipment is removed and replaced, the connectors become worn and have to be replaced. After connector replacement, the wires may not be long enough and an entire harness must be replaced.

Aluminum wire is used on some air vehicles to feed power to the load centers from the engine pylons and from the load centers to points throughout the air vehicle. Loose connections, electrolysis, and galvanic reactions have led to corrosion and arcing at the terminal lugs. Fires and loss of electrical power have resulted. Therefore, aluminum wire should not be approved for use unless solutions to termination problems have been proven.

4.4.8.4 Power distribution.

Compliance with the power distribution requirements shall be verified by analyses tests and inspection as follows: (TBS).

VERIFICATION RATIONALE (4.4.8.4)

Verification is required to ensure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.8.4)

Verification should be accomplished incrementally and encompass planning, procedure preparation, and reporting.

TBS should be filled in with the appropriate mix of analysis test and inspection. The following items should be considered:

a. Analyses appropriate for this requirement include electrical load analyses per MIL-E-7016, hazard analyses, failure mode and effect analyses, and circuit analyses to assess such characteristics as ampacity, voltage drop, cross-talk, and suitability of wire construction and terminations.

b. Testing should be used to verify distribution subsystem and component performance in the laboratory and on the vehicle. The laboratory testing should duplicate the air vehicle installation and actual electrical loads and should simulate normal and fault conditions. Testing of components should include the most adverse electrical loading, environmental, and endurance conditions applicable. Subsystem performance is verified by aircraft continuity and dielectric checks and by operational tests of the aircraft subsystems.

c. Inspection can be used to verify proper installation of EWIS, such as connector build-up, wire terminations, and wire routing.

A physical mockup of any new wiring installation should be created and/or modelled before implementation to help identify problem areas.

VERIFICATION LESSONS LEARNED (4.4.8.4)

Experience has shown that the distribution subsystem needs the same careful design and analysis effort as the main electrical subsystem itself.

3.4.8.5 Control and protection.

The electrical power subsystem shall provide the following control and protective functions: (TBS).

No one fault or combination of related faults in the electrical system shall cause complete loss of electrical power, disable the electrical power failure warning indication system, or cause a safety-of-flight hazard.

The power distribution panels and buses shall be protected from mechanical and electrical faults that may cause loss of power.

Electrical failures or faults, including a faulted or failed bus, shall not be transferable. Three-phase protection devices (not of the fusible link type) shall be used in the interconnection of three-phase AC buses or loads and shall open and close all three phases whenever the protective device for any one phase is activated.

REQUIREMENT RATIONALE (3.4.8.5)

Appropriate means of control and protection are necessary for the safe and effective operation of the electrical power subsystem.

REQUIREMENT GUIDANCE (3.4.8.5)

TBS should be filled in with the specific functions necessary for the particular application. Factors that should be considered include crew instrumentation and controls, failure modes and effects, automatic control and protection, reliability, vulnerability, and safety. The following is provided to aid in determining these functions:

a. Routine operations of the electrical power subsystem such as normal start-up, shut-down, paralleling, and voltage and frequency regulation, which require no crew decisions, should be performed automatically. Fault clearing in a list of routine operations should be performed automatically. The control function, if automatic, should allow for anti-cycling. The crew should be provided with the instruments and manual controls necessary for effective control of the electrical power subsystem for both normal and abnormal operation. These provisions need to include indications of all subsystem faults and malfunctions that affect flight safety or mission effectiveness. Means of controlling the electrical power subsystem should be provided such that mission and safety requirements are met without unnecessarily burdening the crew. On the other hand, the crew should be involved in non-routine situations in which crew action can improve mission effectiveness or control abnormal or hazardous conditions.

b. Automatic protective functions should be provided for abnormal conditions of the electrical power subsystem which require a prompt predetermined response and for which no crew decisions are needed. Faults and malfunctions should be detected, isolated, and de-energized in a manner that eliminates the hazardous condition to ensure safety of the air vehicle and minimize performance degradation.

c. All distribution circuits including generator feeders, bus ties, and load circuits should be protected against short circuits and overloads throughout their total length. Each load circuit should be individually protected to prevent a single fault from affecting more than one critical function.

d. Redundant power circuits and components should be routed and located separately to minimize vulnerability. Means should be provided for detecting the failure of each redundant component. The advantages of redundant components are realized only if the components are sufficiently isolated electrically and physically so that multiple failures are improbable. Furthermore, if there is no way to detect the failure of a redundant component, the value of redundancy is lost.

e. For fault protection mechanisms to perform properly, it is important that equipment subject to electrical faults of primary power be properly bonded and grounded to the air vehicle structure. The impedance of the entire fault return path should be low enough such that the available fault current will quickly trip the protective devices (typically, tens of milliseconds).

f. Circuit breakers that are essential for flight safety should be easily resettable by the crew.

REQUIREMENT LESSONS LEARNED (3.4.8.5)

Switching of one essential bus from the emergency generator back to the main generator was changed from automatic to manual to give the crew better control of an abnormal situation.

The multiplexing of control signals for the electrical power subsystem and for the monitoring and control of individual load circuits is a possible option to reduce the amount of wiring required. The use of a multiplexed data bus for load control signals and related data proved to be a successful approach on the B-1 air vehicle. A significant reduction of wiring weight and volume was achieved.

Multiple wire feeders for the essential bus of one air vehicle have been instrumental in maintaining electrical power under emergency conditions. Attempts to remove this capability during modification programs were met with great resistance from the user community.

Conventional protective devices such as circuit breakers or fuses have been used to protect the distribution subsystems; they are located at appropriate points on the distribution bus. In many remote applications, the switching and protective functions can be combined into one component called a power controller, thereby reducing weight and volume. Applications of particular types of power controllers include generator bus contactors, cross-tie contactors, remote control circuit breakers, and solid-state power controllers.

Power controllers generally connect power to the appropriate bus or load using mechanical devices such as switches, relays, or contactors, but they also employ solid-state devices for various applications. Experience has indicated that the main drivers in selection of a power controller are current requirements and operational voltage. Solid-state devices, which have an inherent voltage drop, have been limited to low current applications because of the heat dissipation ($P = IV$) but can be used at higher ratings if dissipation is not a main concern (that is, short duration or adequate cooling). Solid-state power controllers provide faster switching times, which make them more effective at removing power during overcurrent events.

One aircraft was destroyed when an adhesive-bonded clamp detached from structure, allowing a 270 VDC generator wire to contact a hydraulic tube. The resultant electrical arcing punctured a hole in the tube and ignited misting hydraulic fluid before the generator controls could de-excite the generator's field. Subsequent laboratory testing demonstrated that this type of catastrophic failure can occur within milliseconds and is preventable only by solid-state circuit protection, not slower-acting mechanical breakers.

Another drawback to electromechanical contactors for 270 VDC applications is the lack of arc-extinguishing zero crossings, such as occur in AC voltage waveforms. Additional features are required in mechanical power controllers to minimize arcing when opening 270 VDC circuits.

4.4.8.5 Control and protection.

Compliance with the electrical power subsystem control and protection requirements shall be verified by <u>(TBS)</u>.

VERIFICATION RATIONALE (4.4.8.5)

Analyses and tests are the appropriate means of verifying compliance with this requirement.

VERIFICATION GUIDANCE (4.4.8.5)

TBS should be filled in with the appropriate mix of analysis and test for the particular application. Initial verification of control and protection requirements can be accomplished by circuit analyses, including analyses of failure modes and effects. Qualification testing should normally be used to verify that the control and protection requirements of individual components are met. Performance of the complete subsystem can be verified by laboratory and vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.8.5)

Verification of the control and protection subsystem to isolate and remove faults is essential. This verification will show subsystem capability to provide power to non-affected areas. One subsystem failed to detect a small fault that eventually grew until the entire electrical subsystem shut down. Adequate fault detection and isolation would have prevented this occurrence.

3.4.8.6 Uninterruptible Power.

The electrical power subsystem shall provide uninterruptible power in sufficient quantity for continuous operation of all fly-by-wire flight controls and other flight critical loads that require continuous power to maintain control of the air vehicle. During flight, each redundant power source shall be fully active and shall be either powering the critical loads or capable of assuming such loads without power interruption in the event of failure of other sources.

The electrical power subsystem shall provide uninterruptible power as follows: (TBS). A minimum of (TBS) failures of sources of uninterruptible power shall be accommodated without interruption or degradation of power to flight-critical loads. This requirement shall be met without crew action or automatic reconfiguration of the power system.

REQUIREMENT RATIONALE (3.4.8.6)

It is essential to define the uninterruptible electrical power requirements, including system redundancy requirements. This information is vital to designing the appropriate bus architecture.

REQUIREMENT GUIDANCE (3.4.8.6)

TBS should be filled in with the uninterruptible power required to sustain continuous operation across all flight conditions; a detailed listing of all flight critical loads must be provided. TBS should also identify the number of power source failures that may occur without interruption or degradation of uninterruptible power.

Consideration should be given to the use of uninterruptible power sources for fly-by-wire flight controls and other flight critical loads that require continuous power to maintain control of the air vehicle. Not only are redundant sources typically required but also these sources usually should be capable of instantly assuming the loads without manual or automatic switching, which would degrade subsystem integrity. Emergency power should not be considered as a source for providing uninterruptible power. In contrast to the emergency power units for less critical loads, which may operate only when needed, sources of uninterruptible power should be capable of continuous in-flight operation.

Given that a loss of uninterruptible power will result in an emergency condition, the reliability of the redundancy in conjunction with component reliability data can be used to develop the overall electrical power system reliability assessment. On air vehicles with flight critical subsystems requiring electrical power, the electrical power subsystem also becomes flight critical.

REQUIREMENT LESSONS LEARNED (3.4.8.6)

Experience has shown that an emergency power source intended for operation only after a malfunction has occurred is not a suitable backup for fly-by-wire flight controls. The startup and operating reliability of the emergency power units in the past have been deficient for this purpose. Consideration should be given to having full-time redundant power sources to meet the fly-by-wire requirements.

One air vehicle started out with a mechanical flight control system with a fly-by-wire system as a backup. Part way through the design, the fly-by-wire became primary with the mechanical system only usable in certain portions of the flight envelope. This late change resulted in significant redesign of the electrical subsystem to meet redundancy and uninterruptible power requirements.

4.4.8.6 Uninterruptible Power.

The ability of the electrical power system to meet the uninterruptible power requirements shall be verified by (TBS). Non-degraded operation of the uninterruptible power with source failures shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.6)

Analyses of air vehicle requirements are needed to establish the uninterruptible power requirements of the electrical power subsystem for initial bus architecture and component selection. Consult with the cognizant subsystem engineers to determine if electrical flight systems exist, whether uninterruptible power is required, and the degree of redundancy required.

Subsequent testing is necessary to confirm sufficiency of uninterruptible power.

VERIFICATION GUIDANCE (4.4.8.6)

TBS should be filled in with the appropriate mixture of analyses and test to ensure that uninterruptible power is supplied in sufficient quantity and quality, both with and without the specified number of source failures.

Circuit analyses, hazard analyses, and failure modes and effects analyses are appropriate. Subsystem tests in the laboratory and on the aircraft should be required.

VERIFICATION LESSONS LEARNED (4.4.8.6)

Even where reliability analyses have shown aircraft electrical power systems to exceed the requirements for flight-critical systems, total electrical power system failures have occurred on nearly every type aircraft. To prevent the loss of an aircraft, it is strongly recommended that a PMG be installed on each engine shaft to provide last-ditch power to keep the aircraft in the air.

3.4.8.7 Emergency Power.

Independent emergency power source(s) shall be provided to supply all essential loads in the event of failure of the primary power source(s).

Emergency sources shall operate over the entire flight envelope and be capable of supplying all loads essential for control of the vehicle and personnel safety. A convenient means of verifying the operational readiness of the emergency power source prior to flight shall be provided. Transfer of essential loads to and from the emergency power source shall be accomplished without transients of a magnitude hazardous to the vehicle or personnel.

The emergency power unit shall provide power for at least (TBS).

Other emergency power requirements are as follows: (TBS).

REQUIREMENT RATIONALE (3.4.8.7)

Independent emergency power sources are normally required in the event of failure of the primary power source.

Despite excess capacity, redundancy, and all other measures taken to ensure a reliable subsystem, total failures of the primary power sources do occur. For multi-generator air vehicles, there is the tendency to assume that the redundancy of main generators will suffice for the emergency requirement. Experience has shown otherwise. Many modern multi-generator air vehicles have experienced total failure of the primary power subsystem. An independent emergency power source should be considered for this situation. Installation of a permanent magnet generator on each engine shaft is an approach to provide last-ditch power to keep the air vehicle in the air.

REQUIREMENT GUIDANCE (3.4.8.7)

The required period of operation of an emergency source is a critical parameter that should be specified. When the emergency source is energy-limited as in the case of a storage device such as a battery, the available energy should be sufficient to ensure operation for the required time period. Thirty minutes is the minimum time for emergency power operation that should be considered. This period is generally sufficient for the crew to regain control of the air vehicle and make an emergency landing. Other types of emergency sources, such as generators, may not be time limited. The power rating of the emergency source should be sufficient to supply the emergency loads identified by an electrical load analysis. This analysis can be performed in accordance with MIL-E-7016.

The response time for initially supplying emergency power is also a consideration. This area involves factors such as means of sensing power failure, manual or automatic power transfer, and the time required for the emergency unit to come up to speed or otherwise respond. Should normal power subsequently be restored, manual or automatic means for returning loads to the main source should be provided. Automatic transfer can be detrimental if it surprises the crew with an additional disturbance at a critical time.

To maintain confidence in the reliability of the emergency power source, it should be given an operational check before each flight, if possible. If not, other means of verifying operational readiness should be provided.

REQUIREMENT LESSONS LEARNED (3.4.8.7)

Serious consideration has been given to eliminating the emergency generator from several programs as a cost and weight savings. However, on several occasions during the flight test program, the emergency generator was required to supply power following multiple failures of the main electrical subsystem.

The method of returning emergency loads to the normal power source on one air vehicle was changed from automatic to manual following an in-flight incident. A flight control transient resulting from main generator failures had just settled out when normal power was again restored. When the flight controls were then automatically transferred back to main power, the crew was surprised with a second disturbance as severe as that caused by the original failure.

Another incident illustrates the criticality of emergency power control logic. A partial failure of the hydraulic subsystem powering the emergency generator caused it to be powered up to speed by an overlooked hydraulic “sneak circuit.” When the emergency generator tried to power the essential bus, there was insufficient hydraulic power to support it. Consequently, the essential bus cycled on and off a malfunctioning emergency power unit, thereby adding a critical electrical problem to the original hydraulic failure.

4.4.8.7 Emergency Power.

The ability of the electrical power subsystem to meet emergency power requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.7)

Analyses are appropriate for preliminary verification that requirements will be met. Final verification is provided by component qualification tests and tests of subsystems in the laboratory and installed in the aircraft.

VERIFICATION GUIDANCE (4.4.8.7)

a. Electrical load analyses, circuit analyses, component tests, and integrated subsystem testing are appropriate means for verifying emergency power requirements.

b. Electrical load analyses per MIL-E-7016 and component qualification testing are needed to establish that the capacity of the emergency power unit is sufficient for the essential loads.

c. Circuit analyses and subsystem testing are needed to verify proper control logic and compatibility with the rest of the electrical power system.

d. The performance requirements of the electrical power system with respect to emergency power can be verified by mockup tests and aircraft tests.

e. Complete verification of emergency power will be required when the system is installed on the aircraft.

VERIFICATION LESSONS LEARNED (4.4.8.7)

Analysis, followed up by system-level testing on the aircraft, is adequate verification. Mockup testing may be used for initial verification, but final verification is required on the aircraft. On-aircraft testing has been shown to produce results that were not predicted or seen in the mockup testing.

3.4.8.8 Auxiliary Power.

The electrical power system shall be capable of generating, controlling, and distributing power from onboard auxiliary power units for ground or airborne operations as follows: (TBS).

REQUIREMENT RATIONALE (3.4.8.8)

Air vehicle operational requirements may necessitate an onboard auxiliary power unit (APU) to provide electrical power for certain modes of ground or air operation.

REQUIREMENT GUIDANCE (3.4.8.8)

The electrical power subsystem should be capable of generating, controlling, and distributing APU electrical power in a safe and effective manner. Auxiliary power requirements for ground maintenance, subsystem checkout, manned alert, lighting, cargo loading, starting, or other operations should be specified as determined from analysis of air vehicle operational requirements. The quantity of APU power required should be specified, whether both ground and airborne operation are required, whether parallel operation with main generator(s) or ground power is required, or whether no-break power transfer to and from the APU is required. In some installations, the APU may be able to serve as an emergency power source.

REQUIREMENT LESSONS LEARNED (3.4.8.8)

APUs have proven to be beneficial to most air vehicles. They eliminate the need to connect external electrical power for any maintenance, checkouts, and other operations. They can also provide electrical power for alert situations, emergency power, and hot turns.

4.4.8.8 Auxiliary Power.

The ability of the electrical power subsystem to meet auxiliary power requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.8.8)

Analyses are appropriate for preliminary verification that requirements will be met. Final verification is provided by component qualification tests and tests of subsystems in the laboratory and installed in the aircraft.

VERIFICATION GUIDANCE (4.4.8.8)

Use electrical load analyses in accordance with MIL-E-7016 to aid in determining the quantity of auxiliary power required for various modes of operation. Verify performance of the auxiliary power system by testing in the laboratory and on the aircraft.

VERIFICATION LESSONS LEARNED (4.4.8.8)

Testing is the only viable means to demonstrate that the auxiliary power unit comes on as designed and picks up the electrical loads. Laboratory testing followed by on-aircraft testing is required to demonstrate the entire system functionality.

3.4.8.9 Stability Analysis and Load Integration.

The electrical power subsystem shall be stable in all modes of operation: (TBS).

REQUIREMENT RATIONALE (3.4.8.9)

Stable operation is required to ensure control of the electrical power system. The loads that are added to the system can lead to uncontrollable conditions and subsequently voltages that are outside of the governing power quality specification.

REQUIREMENT GUIDANCE (3.4.8.9)

TBS should include requirements to develop both lumped parameter (large-signal) and detailed (small-signal, short duration) stability models that demonstrate a stable electrical power system that produces power characteristics within the governing power qualification specification.

REQUIREMENT LESSONS LEARNED (3.4.8.9)

Because of the APG-79 radar (large non-linear load) being added to the F-18 platform, large voltage modulations outside the bounds of the power quality specification were realized. These voltage modulations were a result of a pulsing non-linear load and led to a significant loss in generator reliability. It was also noted that the generator had to be further de-rated because of the thermal stresses that were encountered. An overall generator redesign had to be undertaken to upgrade the generator and generator control unit to deal with the non-linear load and resultant leading power factor.

In the past, a lagging power factor (between 0.8 and unity) guaranteed stability because the loads were primarily resistive and inductive. Modern electrical loads are increasingly capacitive and non-linear (current draw independent of voltage) which can lead to system instability. Because all electrical power systems are voltage-controlled systems, they become increasingly hard to control as the power factor moves to leading.

The power factor is not a guarantee of system stability, as non-linear loads can have significant impact independent of leading, unity, or lagging power factor. Modeling and simulation should be used to understand the interactions between the power generation system, distribution system, and utilization equipment.

4.4.8.9 Stability Analysis and Load Integration.

Compliance with the electrical power subsystem stability requirements shall be verified by modeling and tests as follows: (TBS).

VERIFICATION RATIONALE (4.4.8.9)

Modeling and tests are the appropriate means of verifying compliance with this requirement.

VERIFICATION GUIDANCE (4.4.8.9)

TBS should be filled in with the appropriate mix of modeling and tests for the particular application. Initial verification of stability requirements can be accomplished by lumped parameter analyses. Final high fidelity models of the electrical power system are often required to ensure stability. System integration testing should be used to verify that the stability requirements are met. Performance of the complete subsystem can be verified by laboratory and vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.8.9)

Verification of a stable electrical power system should be conducted in a system integration lab using relevant loads and environmental conditions. Flight test measurements of the electrical characteristics of the bus can be used to improve accuracy of the laboratory model, which will help ensure future loads do not have a detrimental effect on stability and control.

5. PACKAGING

5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department’s or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use.

The electrical power subsystem descriptions in this specification guide are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of this specification.

6.3 Component information.

6.3.1 Wiring.

The Electrical Wiring Interconnection System (EWIS), also known as aircraft wiring, is defined as any wire, fiber optic link, wiring or fiber device, or a combination of these items (including terminations) installed in any area of the aircraft for the purpose of transmitting electrical energy, signals, or data between two or more electrical end points.

All aircraft are filled with miles of wiring and hundreds of wiring devices that connect and transfer power and signals to and from electrical components. Virtually all aircraft systems rely heavily on some type of wiring for safe operation. Much like the vulnerability of aircraft structural components, the health and integrity of the EWIS can be significantly compromised due to premature aging, damage, and failure of wiring insulation. It is integral to the overall maintenance and sustainment of all aircraft that the EWIS be treated as a system and afforded the same level of importance as the aircraft structure and other critical systems.

Electrical power subsystem performance and reliability is dependent to a large extent on the integrity of the wiring that interconnects the subsystem. Consideration should be given to wiring components and their suitability for the application, with particular attention given to the application environment. Considerations for wiring installation should include maximum reliability, minimum interference and coupling between subsystems, accessibility for inspection and maintenance, and protection against damage. Since the wiring is normally expected to last for the entire service life of the air vehicle, special care should be considered in its design and installation. The legacy defense specification MIL-W-5088 and its successor, SAE AS50881, provide guidance on appropriate wiring component selection and installation, based on years of experience with air vehicle wiring installations.

Most problems with air vehicle wiring have involved deterioration caused by the environment, aging, improper application of materials and components, and abuse of various kinds. Moisture, heat, vibration, and rough handling are common hazards that should be recognized and guarded against during subsystem design.

EWIS Management is an essential and continuing process requiring the implementation of scheduled and unscheduled working practices by all personnel. It requires basic awareness of wiring problem areas and specialized training related to system operation, maintenance, and troubleshooting requirements. The EWIS requires a scheduled maintenance cycle to ensure the system meets entire aircraft life cycle requirements. The interval should be based on a zonal approach as needed per type aircraft and operating environment. This process should be planned and estimated to effectively correct deficient wiring conditions during scheduled rework periods. The EWIS is an integral part of the aircraft, which, if not properly managed, has the potential to have a severe effect on aircraft safety and mission capability. The continued airworthiness of the EWIS depends directly upon an effective, proactive, preventative approach to meet the aircraft's life cycle and mission requirements.

Traditionally, maintenance actions required to repair or replace failed wiring have been assigned a work unit code (WUC) corresponding to the system served by the wiring, rather than to the wiring itself. This practice has made it difficult to monitor and proactively manage wiring problems. It is best practice to assign a unique WUC to wiring.

6.3.2 Batteries.

Because they are a convenient source of stored energy, batteries are widely used in aircraft for emergency power, standby and fill–in power, engine and APU starting, and limited energy requirements when no other source is available. On the other hand, batteries have limitations that have to be recognized and accounted for in order to have a reliable installation. Since chemical reactions are involved in the charging and discharging processes, battery performance is very sensitive to temperature. Other factors affecting performance and life include depth of discharge, method of charge, quality of maintenance, and type of construction. Present requirements for aircraft secondary batteries have evolved over the years as the result of experience and new technology.

Batteries that are components of the vehicle electrical subsystem should be capable of providing the specified battery power under the environmental and operational conditions to which they will be subjected.

Battery sizing depends on the degree of non-interruptible power required and assumes that emergency power can be brought online in a certain time duration (generally two seconds). In selecting a battery to meet a required ampere-hour capacity and other performance requirements, the effects of temperature, charging efficiency, aging, and other de-rating factors should be considered. Batteries that are used as emergency power sources should be sized to support critical flight loads for 30 minutes minimum.

There are two cases for fly-by-wire systems: (1) a traditional electrohydraulic air vehicle and (2) flight control actuation for a more-electric air vehicle. For case 2, precise battery estimates, actuator requirements, and capabilities need to be known. Also for case 2, some actuator schemes involve the utilization of energy extracted from the airstream in the back-drive mode to enhance overall efficiency; this potential regenerative power source may well reduce the battery sizing requirements.

A relay controlled by a crew station battery switch should be installed in each battery circuit to enable the flight crew to isolate the battery from the rest of the electrical subsystem. This provision also helps to prevent excessive and inadvertent discharge of the battery on the ground. It may be necessary, however, for some circuits to remain connected to the battery at all times. Any circuits that must remain connected to the battery with the battery switch OFF should be connected directly to the battery through suitable fuses or circuit breakers.

Indication of battery subsystem malfunctions such as over-temperature, battery discharging, and low battery voltage should be provided to the crew as necessary to meet subsystem safety and reliability requirements.

Valve-regulated lead-acid (VRLA) and vented nickel-cadmium (VNC) batteries are the two types of secondary rechargeable batteries most used in air vehicles. VRLA batteries are less costly and easier to maintain. Nickel-cadmium batteries can provide better high-rate performance, especially at low temperature, and are more resistant to vibration. MIL-PRF-8565 and MIL-PRF-81757 are Tri-Service specifications for VRLA and VNC batteries, respectively. These standard batteries, which are the product of considerable Tri-Service experience and research, should be used where suitable. They are procured competitively and in quantities that result in lower cost.

Effective onboard charging is required to keep secondary batteries adequately charged. For lead-acid batteries, this can be accomplished simply by “floating” the battery on a constant-potential DC bus. This not only provides for continuous maintenance of charge, but also allows the battery to supply power instantly to the bus when required. Charging of nickel-cadmium batteries is not so simple since they are very sensitive to applied voltage. If the voltage is too low, the battery will not become fully charged. If it is too high, the battery will become overcharged with excessive heating and loss of electrolyte. Furthermore, the battery’s internal resistance varies inversely with temperature. This can lead to a catastrophic failure (thermal runaway) when a battery overheats and then draws ever-increasing current from a constant-voltage charger as its resistance decreases further. Consequently, it is not good practice to float a nickel-cadmium battery directly on a high current DC bus. Better control of the charging current is needed.

A generally accepted procedure for charging sealed nickel-cadmium batteries is to supply a constant-current charge until a predetermined, temperature-compensated battery voltage is reached. At that point charging is terminated or reduced to a small trickle-charge rate. The “constant” current may be a continuous direct current or a series of pulses of a controlled average value. In addition, charging is terminated when battery temperature becomes excessive. This method of charge control requires sensing battery temperature. Temperature sensors should be added to any battery charged by a constant current airborne charger.

Lithium batteries are an emerging technology for aviation applications because of their (1) higher energy and power density, (2) higher discharge rates, (3) maintenance free operation, and (4) longer service life when compared to conventional aerospace batteries. However, the disadvantages of lithium chemistry batteries include (1) the potential for toxic fumes, fire, or explosions from thermal runaway events or outgassing; (2) higher procurement cost; (3) higher complexity due to the requirement for a battery management system (BMS); and (4) higher logistical impact (state-of-charge limitations on shipping, special requirements for ship integration and firefighting, and unique charging requirements per design). Lithium batteries that have internal electronics and that are connected directly to the aircraft power bus must meet the requirements of MIL-STD-704 or the governing power quality specification.

For all battery types, the following factors should be given careful consideration in designing the battery installation:

a. The battery should be readily accessible for inspection and removal because of the requirement for frequent maintenance. Each battery should be located and installed so that it can be readily inspected and easily removed from the air vehicle without removing other components except for a readily opened access panel or door. Handles or carrying straps on batteries are desirable. There is no battery in use in any military air vehicle today that will not require maintenance of some type over the life of the air vehicle.

b. The potential hazard of a battery failure should be recognized in subsystem design. Failure effects can range from excessive gassing to complete thermal destruction. The location and design of the battery installation should be such that the release of heat, smoke, gases, electrolyte, or other products of a severe battery failure will not damage adjacent components or structure, endanger personnel, or adversely affect crew performance.

c. The possibility of hydrogen gas evolution, even with "sealed" subsystems, emphasizes the need for adequate ventilation of the battery to prevent explosive concentrations from developing. Since all batteries can vent, the battery compartment should be ventilated to prevent the accumulation of explosive mixtures of gases. All vent tubes leading to the exterior of the air vehicle should be designed to preclude the collection of rainwater and other liquids for all ground and flight environments. Batteries should not be collocated with or allowed to vent to ordnance, fuel, or other energetic devices.

d. The sensitivity of batteries to temperature, vibration, and other environmental factors should be considered. The installation should provide for maintaining battery temperature within the limits specified for battery operation. A heater or thermal insulation may be required for low temperature operation.

e. Battery electrolyte will corrode many types of materials. Such materials should not be used in nearby areas or components, or otherwise they should be protected against the electrolyte. In addition, consider using snorkel-type electrolyte deflectors, such as those in MIL-PRF-81757/2, for acrobatic or unusual attitude applications.

Catastrophic failures and loss of power have resulted in the loss of both air vehicles and personnel. Instances of less severe problems have caused personnel injury, air vehicle damage, mission aborts, poor maintainability and reliability, and high replacement costs.

The following are some specific lessons learned:

a. One air vehicle required a non-standard battery because of available space and the need for thermal insulation. Several deficiencies were later discovered in the design and installation of the unit.

    1. A non-standard cell that was much more costly than an equivalent standard cell was originally selected for the battery. It was later found that the standard cell could be substituted without loss of performance.

2. The original configuration of the battery vent tube allowed rainwater to enter the battery and contribute to corrosion of thermal switches. A redesign of the vent was required to correct this problem.

3. Access to the battery required the removal of a structural fuselage panel secured by approximately 50 tightly fastened screws. This is unsatisfactory for an item that requires frequent maintenance.

b. Through the 1970's, numerous instances occurred of thermal runaway of VNC batteries directly connected to high current DC generators. The loss of one air vehicle and one of its crew members was attributed to this cause. There has also been a history of VRLA batteries overheating, leading to mission aborts and air vehicle damage. Safe limitations on charging current and battery isolation capability are needed for all batteries.

c. Because of its location in the cockpit, the A-7 and SH-60 air vehicle batteries not only required seat removal or movement for battery maintenance, but also subjected the crew to smoke and fumes in the event of a major battery failure. The cockpit is a poor location for the air vehicle main battery or any battery not part of essential life support and survival gear.

d. Because of the weight and space penalties involved, batteries are often selected which are inadequate for the required performance. Insufficient derating for temperature, aging, on-board charge efficiency, and high discharge rates are common pitfalls that increase maintenance effort to a magnitude that is greater than it should be.

e. One air vehicle's batteries are installed in fiberglass boxes with attached circuit breakers. The entire assembly (box, battery, circuit breaker, wiring, and connector) must be removed each time the battery is removed for maintenance. Due to the close proximity of components, electrical shorting is reported to be a frequent problem during such maintenance.

f. Sealed lead-acid batteries (SLAB) are prevalent due to their reduced maintenance factors and cost. Adequate charging subsystems are required, and heaters may be needed for cold-temperature use.

g. New or improved lithium batteries used in any air vehicle application should be safety tested in accordance with S9310-AQ-SAF-010. (Copies of this document are available at https://www.marcorsyscom.usmc.mil and https://mercury.tdmis.navy.mil/cert/certtest.cfm.) For Naval applications, lithium batteries must be certified in accordance with NAVSEAINST 9310.1. Lithium batteries offer several unique performance advantages compared to other batteries. However, they may present a severe hazard to crew and air vehicle if venting occurs.

h. Silver-zinc secondary batteries were used in one aircraft because of their very high energy density. However, these batteries have a very limited cycle life and are extremely susceptible to internal shorting. Because of the numerous catastrophic failures that were experienced, this type of secondary battery is not recommended for air vehicles.

6.3.3 Generators.

The design and performance of the generator subsystem are essential contributors to the overall performance of the electrical power subsystem. The fundamental subsystem power parameters of voltage, frequency, and capacity are established primarily by the main generators and associated components. Constant frequency 400 Hz power can be obtained from a generator driven directly from a prime mover when the prime mover operates at fixed speed. Generator subsystems of this type should be in accordance with MIL-PRF-21480 with changes as necessary for the specific application.

When the prime mover operates at varying speeds, either of two types of generator subsystems can be used for producing constant frequency power. One approach is to use a constant speed drive between the prime mover and the generator. The second approach is to drive the generator directly from the prime mover at varying speed and convert the variable frequency produced by the generator to constant frequency by means of an electronic converter. MIL-E-85583 should be specified for subsystems of this type. Generators in accordance with MIL-DTL-6162 are suitable for 28 VDC subsystems. Generator subsystem capacity is often limited by the amount of cooling available. Therefore, particular attention should be given to this aspect of the installation.

Oil-cooled, oil-lubricated generators have proven to be smaller, lighter, and more reliable than their air-cooled, grease-lubricated predecessors.

Constant speed drive oil level has been critical to satisfactory operation on various air vehicles. Furthermore, filling to the proper level has been adversely affected by temperature, air vehicle attitude, and inadequate oil level indication. New designs should be less critical with respect to oil level and should provide for simple and accurate filling and inspection procedures. Consideration should be made with respect to the drive being capable of operation under all specified “g” conditions over the entire range of specified oil levels. When an external oil cooler is used in a generating subsystem, it should be protected against contamination from the generating subsystem. An outlet or scavenge filter can provide this protection. On one air vehicle, when an integrated drive generator had a hardware failure, metal could and did contaminate the oil cooler, which meant the cooler had to be replaced. An engineering change proposal for a scavenge filter was later approved and added to the subsystem.

Recent advances in high power, high temperature, solid-state switching devices; high power-density motors and generators; efficient, high power converter topologies; fault-tolerant electrical power subsystems; and electrically driven actuators have rekindled interest in more-electric air vehicles. Thought should be given to 270 VDC subsystem design and verification in the area of power generators for such applications. Experiences have shown that a major air vehicle DC generator design requirement is to maintain a constant voltage over a wide speed range. The magnetic section is sized for maximum load at minimum speed. As speed increases or load decreases, either the magnetic field must decrease accordingly or the resulting higher voltage amplitude waveform must be controlled to maintain a constant output. New 270 VDC generator designs should be carefully selected from the three existing machine types: wire-wound rotor, permanent magnet, and switched reluctance.

6.3.4 Converters.

The electrical power subsystem is often required to supply power of a type different from that provided by the primary source. In this event, a means of power conversion is needed. Typically, the conversion is from 115 VAC 400 Hz power to 28 VDC (rectification) or from 28 VDC to 115 VAC 400 Hz, 3-phase or single-phase (inversion).

Requirements for AC to DC converters (transformer-rectifiers) should be based on MIL-PRF-7115.

Requirements for DC to AC converters (inverters) should be based on MIL-PRF-7032. This specification covers both rotary and solid-state types.

When equipment that is essential for safe flight derives power from an inverter, a spare inverter should be provided. Changeover from the main inverter to the spare should be automatic in the event of main inverter failure. Spare inverters may be used as operative units to supply power to nonessential loads, but these loads should be dropped in the event of main inverter failures.

When the outputs of two or more AC to DC converters are paralleled to supply a common DC bus, no single unit should be loaded beyond its rating for the worst-case load unbalance or failure mode which can occur.

6.4 Definitions.

6.4.1 Abnormal operation.

Abnormal operation occurs when a malfunction or failure in the electrical system has taken place and the protective devices of the system are operating to remove the malfunction or failure from the remainder of the system.

6.4.2 Electrical power system (EPS).

An electrical power system consists of a main power source, emergency power source, stand-alone power conversion equipment, control and protection devices, energy storage devices, and a distribution network (wire, cables, connectors, etc.). The main power source is derived from generators driven by the propulsion system. Emergency power is derived from batteries, ram air turbines, or independent auxiliary power units.

6.4.3 Emergency operation.

Emergency operation is the operation of the electrical system following the loss of the main generating equipment. Emergency operation occurs when a limited electrical source, independent of the main system, is used to power a reduced complement of distribution and utilization equipment selected to maintain flight and personnel safety.

6.4.4 External power source.

An external power source is the ground or shipboard power source used to provide power for aircraft startup and ground check and/or maintenance of utilization equipment.

6.4.5 Normal operation.

Normal operation occurs when the system is operating as intended without any fault or malfunction that degrades performance beyond established requirements. It includes all system functions required for aircraft operation except during the electric starting of the propulsion engines. Electric starting of an auxiliary power unit is considered a normal operation. Normal operations include switching of utilization equipment, engine speed changes, synchronizing and paralleling of power sources, and operation from external ground power. The transfer operation is considered a normal function of the electrical systems, but it may produce power interruptions.

6.4.6 Uninterruptible power.

Uninterruptible power is electrical power that is available at the input to utilization equipment, in the event of a failure within the electrical system. This power is available without interruption time for circuit breakers, etc. It requires continuous connection to more than one independent source.

6.4.7 Utilization equipment.

Utilization equipment is any electrical or electronic device that requires electrical power for its operation.

6.5 Acronyms.

The following list contains the acronyms/abbreviations contained within this specification guide.

AC	Alternating Current
APU	Auxiliary Power Unit
DC	Direct Current
ELMC	Electrical Load Management Center
EPS	Electrical Power System
EWIS	Electrical Wiring Interconnection System
PMG	Permanent Magnet Generator
SLAB	Sealed Lead Acid Battery
TBS	To Be Specified
VAC	Volts, Alternating Current
VDC	Volts, Direct Current
VNC	Vented Nickel-Cadmium
VRLA	Valve Regulated Lead-Acid
WUC	Work Unit Code

6.6 Subject term (key word) listing.

Battery
Capacity
Converter
Generator
Power
Wiring

6.7 International standardization agreement implementation.

This guide specification implements NATO STANAG 3109, Symbol Marking of Aircraft Servicing and Safety/Hazard Points; NATO STANAG 7073, Connectors for Aircraft Electrical Servicing Power; and ASIC AIR STD 25/18, Connectors for 28 Volt DC Servicing Power. When amendment, revision, or cancellation of this guide specification is proposed, the preparing activity must coordinate the action with the U.S. National Points of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil/online/start.

6.8 Changes from previous issue.

The margins of this guide specification are marked with vertical lines to indicate where changes from the previous issue were made. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the previous issue.

CONCLUDING MATERIAL

Custodians:
Army – AV
Navy – AS
Air Force – 11

Review activity:
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