

**ELECTRICAL BONDING OF AIRCRAFT FUEL  
SYSTEM PLUMBING SYSTEMS**

**FOREWORD**

In early aircraft, the fuel system was relatively simple. Fuel flows were low and rubber hoses were normally used to provide for flexibility and ease of alignment within the system. It was in the 1950 era, with the advent of jet engines, when significant changes in the aircraft plumbing systems began to change some of the factors related to electrical bonding considerations. The use of conventional hose and hose clamp connections were creating leakage problems as a result in changes in fuels and their effects on the rubber. New style couplings were being developed for use with rigid tubing to resolve the leakage problems with rubber hoses. Electrical bonding was not a direct consideration in these efforts but MIL-B-5087, first issued in November 1949, was the reference document in the fuel system specifications to cover all forms of electrical bonding. Electrical bonding of the tubes and across the joints was a requirement if the linear dimension exceeded 3 inches but the electrical connection to structure included a resistance requirement "less than one-half megohm". to prevent the accumulation of static charge.

Aircraft and their fuel systems became more complex with high fueling rates becoming the norm under most conditions, including In-Flight-Refueling. With greater recognition of the effects and dangers of electrical discharges within the system, design changes were being requested. Some system designers for military aircraft expressed concerns that the use of safety wire on threaded fasteners and couplings within the system resulted in potential sources of discharges within the fuel cells. The use of bonding clamps and cables to provide for electrical bonding added significant weight and costs. Other forms of locking threaded fasteners were requested along with simpler methods of maintaining electrical continuity throughout the system.

One of the results was various designs for self locking fuel line couplings to eliminate the use of safety wire plus the incorporation of various types of integral electrical bonding. At that time, the request was only to provide for the requirements of MIL-B-5087B, Class S (1  $\Omega$  maximum resistance). The concern that was expressed at that time still related only to static electric charges that could develop during fuel flow within the system. During the 1970s, these types of connectors became common in aircraft fuel system plumbing. In military aircraft, the external points of the system, such as the vent tubes, were generally electrically isolated from the external structure to prevent the entry of lightning charges into the plumbing system. A flame arrestor was often installed within the vent line to prevent the entry of the flame front into the system as a result of the ignition of fuel vapors externally.

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## SAE AIR5128

### FOREWORD (Continued)

With the development of new high performance aircraft such as the F16, the question was raised concerning the possible effect on the fuel system when the aircraft was subjected to lightning strikes in flight. This included the possibility of high currents passing through the plumbing system including the connectors and other components used within the system. Tests were performed on the existing system components to satisfy the USAF that the system was safe. No significant changes were required as a result of this testing.

In more recent years, the question of adequate electrical bonding has been raised more often and with some strict and questionable criteria. Very low resistance values are requested in many cases with values ranging from a low of 2.5 milliohm, to 100 milliohm, and to a high of the old standard, one ohm (Class S). Other users request conformance to the basic requirements of MIL-STD-1757 or FAA/AC 20-53a which generally require testing to the Component B Lightning charge of 2500 Max. ampere as defined in these documents. The basis for these requirements with respect to aircraft fuel systems has never been clearly defined and has created considerable concern for the suppliers and users of the various components within these systems. It appears that the limits were selected for lack of any other well defined criteria resulting from test data or other analysis. The very low resistance values are difficult to achieve while complying with other requirements such as corrosion resistance at the interface of materials/components.

A significant amount of effort has been and is being expended in the area of Electromagnetic Interference (EMI) and Lightning effects on some aircraft systems. Virtually all of this effort is directed towards the effects on electrical and electronic systems plus any physical effects on the airframe structure and outer skin. Some of the documents relating to these tests and analyses are referenced within the body of this report. In the Reference Section, a more complete list of existing documents that are referenced elsewhere in this report and/or may be of general interest are included..

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### 1. SCOPE:

This SAE Aerospace Information Report (AIR) is limited to the subject of aircraft fuel system plumbing systems and the questions concerning the requirements for electrical bonding of the various components of the system as related to Static Electric Charges, Electromagnetic Interference (EMI) and Lightning Strikes (Direct and Indirect Effects)

#### 1.1 Purpose:

The purpose of this document is to provide some guidelines for the analysis of the requirements for electrical bonding of the fluid lines and components of an aircraft fuel system as related to the various potential electrical charges and currents that may be applied to various portions of the system as a result of the system operation or external sources. There are many unanswered questions and more firm data is needed to better analyze and resolve the problems that develop.

#### 1.2 Field of Application:

The information included in this document is generally applicable to all types of vehicles subject to flight. As aircraft are built with greater use of composite materials, the concerns become greater as a result of the higher electrical resistance values for such material.

### 2. REFERENCES:

#### 2.1 Applicable Documents:

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

##### 2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AIR1662 Minimization of Electrostatic Hazards in Aircraft Fuel Systems

##### 2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-B-5087B Amendment 2 Bonding, Electrical, and Lightning Protection, for Aerospace Systems

MIL-STD-1757A Lightning Qualification Test Technique for Aerospace Vehicles and Hardware

##### 2.1.3 FAA Publications: Available from FAA, 800 Independence Avenue, SW, Washington, DC 20591.

FAA AC No. 20-53A Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning

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### 2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this document.

MIL-STD-1818(USAF)	Electromagnetic Effects Requirements for Systems (Supersedes MIL-B-5087 for USAF requirements)
MIL-STD-464	Interface Standard for System Electromagnetic Environmental Effects Requirements (Document in circulation prior to formal release)
ARP 1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
FAA AC No. 20-136	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning
DOT/FAA/CT-83/3	User's Manual for AC-20-53A Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning
DOT/FAA/CT-89-22 RTCA/DO-160C, Section 22 RTCA/DO-160C, Section 23 "ORANGE BOOK"	Aircraft Lightning Protection Handbook Lightning Induced Transient Susceptibility Lightning Direct Effects Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning (Ref: AC No. 20-136 above) (Currently undergoing revision by AE4L/WG-31)
NASA Report 194895	A Study of Occurrence Rates of Electromagnetic Interference (EMI) to Aircraft With a Focus on HIRF (External) High Intensity Radiated Fields
Aerospace Vehicle Lightning Testing Standard	Testing for Design, Feasibility and Verification [This document is currently in draft form under the auspices of SAE AE4L and EUROCAE WG-31 and is not yet available for general publication]
Summaries of Lightning Strike Experience	A report presented at the SAE AE4L Meeting, 2 March 1955 and the EUROCAE WG-31 Meeting, 7 April 1995.
Lightning Protection of Aircraft	Published by Lightning Technologies, Inc.

### 3. GUIDELINES FOR ELECTRICAL BONDING:

- 3.1 Recent investigations and discussions within the industry confirm that there is very little hard data to support specific values for DC resistance, lightning test currents, nor for fault currents. It is generally accepted that all of these factors must be considered for the system design and installation to assure a safe vehicle. The question is, "Can we establish a set of design criteria that will assure a safe system for each vehicle?"

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### 3.1 (Continued):

The following sections are an attempt to outline some of the problems, questions, and solutions related to these questions. There are many unanswered questions and more firm data is needed to better analyze the problems.

Each system has its own characteristics of design, materials, and operating conditions but it is hoped that some general guidelines can be developed to provide direction for the system designer and the component designer in an effort to provide both a safe, reliable system and also a light weight, low cost system.

### 3.2 Static Electric Charge Dissipation:

Static charges develop within aircraft fuel systems, primarily during the refueling cycle as a result of the high flow rates through the filter/separators and fuel lines. Fuel impingement on the wall of the fuel cell and on other components within the cell also add to the charge buildup within the system. If these charges are not dissipated before excessive voltage buildup, static discharges will occur which can cause fuel ignition when combustible fuel/air mixtures exist. Such charge dissipation can be accomplished by maintaining electrical continuity between all components of the system and the ground plane of the vehicle. AIR1662 provides a thorough review of the electrostatic hazards in aircraft fuel systems and should be reviewed.

One variation, preferred by many, would be to maintain a significant resistance (between 1000  $\Omega$  and 1 Megohm) within the electrical bonding system to preclude a significant energy level within any static discharge that might develop - in general, the static charge will bleed off without significant buildup even with this high resistance.

It seems to be well accepted that the very low DC resistance values are not meaningful nor significant in relation to the electrical bonding of fuel system components relative to static charges. On the other hand, if a system is designed with a reliable low resistance bonding capable of meeting all other system requirements, static charges will not have the opportunity to develop and create sparking/arcing conditions.

### 3.3 Lightning Strike Requirements:

The effect of lightning strikes on fuel system plumbing is not well defined. Most of the work has been directed to the effect on external segments of the fuel system. This includes the effect of direct strikes on the outer panel of an integral fuel cell or its effect on structural joints within the cell or on the fuel filler cap. Very little data exists as it relates to either direct or indirect effects on the plumbing and components within the fuel system. In this context, the plumbing includes the fuel lines, fittings, valves, pumps, and related components involved with the transfer of fuel within the aircraft.