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Revised

AIRCRAFT STRUCTURAL ELECTRICAL BONDING & GROUNDING Including LIGHTNING EFFECTS AND ELECTROSTATIC CHARGE BUILDUP ON MISSILES AND SPACE VEHICLES

FEBRUARY 1972

HUGHES

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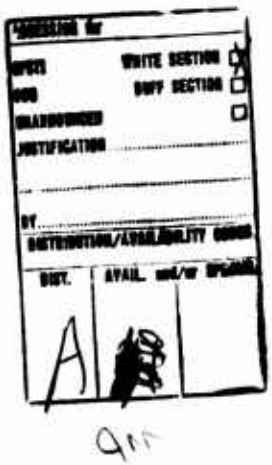

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13. ABSTRACT

Over 130 references are provided on static electrification, grounding, electrical bonding and lightning protection. Bonding and grounding of electronic equipment are discussed.

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KEY WORDS	LINK A		LINK B		LINK C	
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INTRODUCTION

This interim report has been updated in response to several requests for information on static electric charge buildup and lightning strike protection on aircraft, missiles, and spacecraft as well as electrical bonding and grounding of aerospace systems. The literature on this subject area has been increasing steadily in recent years in view of the concern for increased safety of aircraft, space vehicle , pilots, and passengers (especially for the SST). An analysis of the following bibliography indicates that quite a bit has been published on the phenomenon of lightning, lightning protection, static electrification, grounding, and electrical bonding. A major guide publication in this area is MIL-B-5087B(ASG) titled "Bonding, Electrical, and Lightning Protection, for Aerospace Systems." This document provides references to electrical bonding hardware as well as classifies electrical bond classes of application (e.g. Class A, C, H, L. R, S).

The major research studies on lightning effects on aircraft and aerospace vehicles has been conducted by M.M. Newman and coworkers at the Lightning and Transients Research Institute at Minneapolis, Minn. A fairly comprehensive listing of all their resulting research is compiled in the following bibliography. Philip J. Klass, has given an overview of the lightning strike threat problem and vulnerability of various composite materials.

It has been estimated that the final temperature of a stroke of lightning is about 18,000°F. (Chem. Eng. News, May 19, 1969, p. 74). A brief note in the June 12, 1969 (Vol. 41) issue of Machine Design (page 12) details the experiences of airplane pilots with respect to lightning strikes on airplanes:

> Airplanes flying through dying thunderstorms may themselves trigger the lightning strikes that occasionally harass such flights.
>
> Researchers from the Environmental Science Services Administration, Dept. of Commerce, recently detailed three lightning strikes on an ESSA aircraft. It's a DC-6 that is well equipped to measure and record meteorological and electrical conditions.
>
> Each time lightning struck, the plane was in a dissipating thunderhead or cumulonimbus near the freezing level and in an area of the cloud that contained both ice and water. Corona discharge from the aircraft occurred before each strike.
>
> Said the pilot: when you are in the pilot's seat and lightning strikes, the control column feels as if it had been whacked on the other end by a baseball bat. There is a loud crack and a blinding flash fills the window.

As a result of the lightning strikes, the skin of the aircraft was marked with burns and holes up to the size of a half-dollar. First bolt hit an instrument on the nose boom. The second hit a temperature probe on the starboard wingtip. The third severed an antenna on the forward cabin.

Uman has recently written a book titled Lightning which deals with the fundamental aspects of the lightning discharge and with diagnostic techniques of photography, electric and magnetic field measurements, electric current measurements, spectroscopy, and acoustic measurement. In another publication, he also presents an account of the occurrance of ball lightning within a metal aircraft.

Considerable interest has been shown recently in conductive and semiconductive coatings to minimize the damage and to conduct or distribute the lightning charges. EPIC has prepared an interim report (IR-42) "Semiconductive and Conductive Plastic and Rubber Materials (including paints, inks, and adhesives) describing a wide range of formulations suitable for this purpose.

The Jet Propulsion Laboratory held on February 6-8, 1968 a Spacecraft Electromagnetic Interference Workshop which included numerous papers on lightning and static electrification. Sabaroff of the Hughes Aircraft Co. presented numerous case histories on static electric problems:
a) Delta accident killing three people due to squib ignition
b) Ranger VI failure at JPL
c) T-2 incident at Hughes Aircraft Co.
d) Cape Kennedy Surveyor spacecraft plastic protection covering susceptible to charge build-up.

The Air Force Systems Command, Wright-Patterson Air Force Base, Avionics Laboratory held a Lightning and Static Electricity Conference at Miami Beach, Florida on December 3-5, 1969 at which problems of lightning and static electricity as they pertained to aerospace vehicles were discussed. Topics covered included grounding and bonding techniques, survivability of nonconductive materials in a lightning environment, and control of static electricity effects on nonconductive materials.

Trevor A. Robinson has discussed "bonding" and "grounding" terminology and noted that ....."probably more has been written on the subject of grounding over the past 40 years than on any other topic." Clipperly has reviewed the Single Point Ground vs the Multipoint Ground Schools of Thought and takes a somewhat middle ground with the optimum approach being the unipotential reference ground system which utilizes the low impedance characteristics of planar circuits. He gives the following table of impedance values for metals commonly used in communications equipment:

Material	Internal impedance (ohms/square at 20 MHz)
Silver	0.00159
Copper	0.00166
Aluminum	0.00203
Magnesium	0.00252
Zinc	0.00315
Brass	0.00318
Cadmium	0.00410
Nickel	0.00810
Tin	0.0106
Lead	0.0184
Monel	0.0378
Cold rolled steel	1.75
Stainless steel	~18.0

He recommends the following bonding considerations:
1) Peripheral bonding--All shield cans, sub-assembly enclosures, panels, shelves, and other metallic components should be peripherally bonded to the next higher assembly.
2) Bonds among the metallic elements should exhibit minimum rf impedance. Faying surfaces should not be less than 0.5" around the component periphery, or 3% or the component's linear dimension, whichever is larger.
3) For semi-permanent bonds, the contact pressure between clean metal-to-metal surfaces should be greater than 25 psia.
4) Permanent bonds should be welded or brazed, and bonds to doors or other closures made with conductive finger stock with a minimum four lines of contact.
5) Conductive coatings should be used on all bond faying surfaces to obtain low contact resistance. Chromic acid conversion coatings, such as Iridite 14 and 14-2 and Alodine 1200, or metallic coatings such as tin and zinc can be used when compatible with the base material and environmental constrains.
6) Conductor images should be eliminated from the ground system by enclosing all interconnecting wiring.

Pearlston has presented a tutorial paper on the theory and techniques relating to shielding, bonding, grounding, and cable selection from the viewpoint of electromagnetic interference control.

Craft has discussed the concept of a bond strap along with the significant parameters involved in its design. A summary table shows the effects of increases in basic parameter values versus dimensional variations. The length is the most important factor, not only because it is a major determinant in the dc resistance but it also determines the impedance at higher frequencies via the inductance.

PARAMETER SUMMARY CHART (Craft)

For An Increase In	R_{DC}	R_{AC}	L	C
Length (a)	increases	increases	increases	———
Width (w)	———	decreases as sum	decreases* as sum	———
Thickness (t)	———			———
Area (A) = (wxt)	decreases	———	———	increases
$\sqrt{\text{Frequency}}$ ($\sqrt{f}$)	———	increases	———	———
Bond Spacing (d)**	———	———	———	decreases

*For small dimensions
**From ground
R= Resistance, L= Inductance, C= Capacitance

He also gives a good list of bibliographic references on bonding and grounding useful for design purposes. Elliot of Lockheed-California Co. has presented the results of his experiments on electrical grounding to titanium structures of supersonic aircraft performed under contract with the Federal Aviation Administration.

Dr. Martin Uman, University of Florida, under a Office of Naval Research sponsored program has investigated lightning strokes near Cape Kennedy. Peak currents in strokes can exceed 100,000 amp., five times the previously considered average current in a stroke. Ten percent of the strokes had peak currents above 160 kiloamp. with one having a rate-of-rise of 300 kiloamp. per microsec. (Aviation Week and Space Technology, February 28, 1972, pp 49).

D. Baker and coworkers at Bell Telephone Laboratories have prepared a text titled DESIGN TECHNIQUES, vol. 1 which provides considerable information on grounding techniques (e.g. single-point) to reduce interferences in electrical equipment.

An excellent up-to-date survey on the structure of ball lightning was prepared by Powell and Finkelstein in 1969. Brook and coworkers at the New Mexico Institute of Mining and Technology have reviewed the Apollo 12 lightning event and its implications.

Rao and Padmanabhan at the Indian Institute of Technology have recently reported on their studies of the effect of lightning discharges on silicon solar cell characteristics, e.g., series resistance, curve power factor, conversion efficiency and spectral response. The cells were found to exhibit unexpectedly large and permanent deterioration in their characteristics.

The General Electric High Voltage Laboratory in Pittsfield, Mass. has been engaged in formal studies of the effects of lightning on aircraft since 1939. Wartime restrictions prevented much of their work from being published. Subsequent research was directed to extensive measurements of natural stroke lightning characteristics and application of this knowledge to the analysis and protection of such aerospace systems as the Cape Kennedy launch complexes 34, 37, and 39 and the USAF Jupiter missile system. The General Electric High Voltage laboratory reports that after the tragic "Elkton" accident in 1963 in which a Pan Am 707 was struck by lightning, it was engaged by NASA and some of the aircraft equipment manufacturers to conduct research on the effects of lightning on aircraft fuel systems and other external aircraft components.* Much of this work was reported in the proceedings of the 1968 Lightning and Static Electricity Conference (Report AFAL-TR-68-290, Part II) referenced above.

A SAE/USAF Lightning and Static Electricity Conference was held in San Diego, Calif. on December 9-11, 1970.** The following papers were presented:

General Lightning Protection Session:
1) Aircraft and rocket triggered natural lightning discharges, by D.R. Fitzgerald
2) Rocket and supersonic aircraft influence in triggering lightning and intentional cloud discharge triggering for launch protection, by M.M. Newmann and J.D. Robb.
3) Model studies of strike probability to selected points on aerospace vehicles, by J.R. Stahmann.
4) Lightning and static hazards relative to airworthiness, by B.L. Perry.
5) Recent developments in lightning protection for aircraft and helicopters, by J.D. Robb and J.R. Stahmann.

Static Electricity and Instrumentation Techniques Session:
1) Lightning test facilities measurement techniques, by J.D. Robb et al.
2) Microwave noise produced by triboelectric charging, by L.E. Cummings.
3) A study of some fundamental helicopter charging mechanisms, by M.E. Rogers

* The information and references provided by the General Electric High Voltage Laboratory, Pittsfield, Mass. which add greatly to the completeness of this Interim Report are gratefully acknowledged.

** The Lightning & Static Electricity Conference Proceedings, December 9-11, 1970 (San Diego, Calif.) is available from the Society of Automotive Engineers, Inc., Dept. 512, Two Pennsylvania Plaza, New York, N.Y. 10001 as Pub. No. P-35 for $10.00.

4) Studies of supersonic vehicle electrification, by J.E. Nanevicz and E.F. Vance
5) Waterfalls, bathroom and perhaps supertanker explosions, by E.T. Pierce.

Commercial Aircraft Session:
1) Lightning current transfer characteristics of the P-static discharger installations, by M.P. Amason and J.T. Kung
2) Measurements and analysis of lightning induced voltages in aircraft electrical circuits, by P.T. Hacker and J.A. Plumer.
3) The effects of lightning attachment phenomena on aircraft design, by R.O. Brick et al.
4) Electrostatic charging and noise quieting, by R.L. Truax.

Military Aircraft Session:
1) Importance of lightning protection and static electricity design for military aircraft, by E.R. Rivera
2) Influence of lightning and static electricity as applied to helicopter design, by B.J. Solak
3) Lightning protection for nonmetallic rotor blades, by G.I. Hackenburger and J.R. Stahmann
4) Lightning protection on advanced fighter aircraft, by G. Weinstock
5) Lightning and surge protective devices for survivability of electrical systems, by C.J. Kawiecki.

Ground Complexes Session:
1) Voltages produced by transient currents flowing into shields of cables, by F.A. Fisher
2) Protection of aerospace ground facilities from the effects of lightning, by F.A. Fisher and T.J. Blalock.
3) Film-static electrification in fuel tanks, by B. Perry.

Advanced Materials Session:
1) Lightning protection for dielectric composites, by J.D. Robb
2) Lightning protection for advanced composite aircraft structures, by G.T. Woodrum
3) Lightning protective coatings for boron and graphite fiber reinforced plastics, by J.T. Quinlivan and J.G. Breland
4) Fundamental investigations of high intensity electric current flow processes and resultant damage in advanced composites, by A.P. Penton and J.L. Perry.

Space Bourne Vehicles Session:
1) The aspects of the Apollo 12 lightning incident, by D.D. Arabian
2) The problem of lightning and static electricity at the Kennedy Space Center, by E.A. Amman.

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