

Electromagnetic Protection Hazards on Composite versus Metallic Aircraft

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ABSTRACT

The lightning represents a fundamental threat to the proper operation of aircraft systems. For aircraft protection, Electromagnetic Compatibility requires conductive structure that will provide among all, electromagnetic shielding and protection from HIRF and atmospheric electricity threat. The interaction of lightning with aircraft structure, and the coupling of induced energy with harnesses and systems inside the airframe, is a complex subject mainly for composite aircraft. The immunity of systems is governed by their susceptibility to radiated or conducted electromagnetic energy. The driving mechanism of such susceptibility to lightning energy is the exposure to the changing magnetic field inside the aircraft and IR voltage produced by the flow of current through the structural resistance of the aircraft. The amplitude of such magnetic field and IR voltage is related to the shielding effectiveness of the aircraft skin (wiremesh, composite conductivity). However, it is also known that copper wiremesh does not provide adequate protection from magnetic field, even though it is needed for lightning current dissipation and the reduction of the heat that could damage the structure, following a lightning strike. The protection from magnetic field on composite aircraft can be provided by ferromagnetic material that nevertheless appears too heavy for covering the whole aircraft fuselage. Thus the need for R&D activities on nano technologies for solutions providing good magnetic shielding effectiveness without impacting aircraft weight.

In the scope of aircraft Electromagnetic Protection and aircraft Safety activities, Bombardier Core Engineering is conducting R&D work on aircraft structure protection from lightning, and collaborating with University of Québec at Trois-Rivières (UQTR).

This paper highlights the impact of magnetic field due to lightning on composite aircraft.

CITATION: Moupfouma, F., Klim, Z., and Skorek, A., "Electromagnetic Protection Hazards on Composite versus Metallic Aircraft," *SAE Int. J. Aerosp.* 6(2):2013, doi:10.4271/2013-01-2157.

INTRODUCTION

A lightning strike is likely to occur on any aircraft during its useful life. The induced effects may vary, depending on the aircraft design and particular system or the component affected [1]. In general, it is recognized in aviation industry that a lot aircraft systems are susceptible to lightning because they are made of electronic and electrical components; and some are exposed to the external environment. The most vulnerable aircraft systems that might be impacted by lightning strikes are the engines, the fuel systems, flight controls and avionics systems as well as the internal environmental controls. The possible consequences of lightning and static electricity interactions may range from

minor (little or no adverse consequence) to catastrophic (loss of aircraft and/or crew and passengers).

A commercial aircraft is assumed to be an electric conductor. If struck by lightning, that conductor will be surrounded by a high magnetic field, and a high current will be developed in the aircraft skin by electromagnetic induction process. That induced current will develop another magnetic field inside the aircraft, and that magnetic field will tend to oppose the external magnetic field. As a consequence, the resulting magnetic field inside the aircraft will have smaller amplitude than the external magnetic field. This phenomenon characterizes the magnetic shielding effectiveness.

There are a number of requirements, imposed by the regulatory agencies concerned with aircraft certification, that

apply specifically to aircraft lightning protection. The key considerations of the applicable regulations are [2]:

a). That the aircraft must be protected against catastrophic effects of lightning and,

b). That equipment, systems, and installations whose proper functioning is essential, must be designed to ensure that they perform their intended function under any foreseeable operating condition.

Because it is expected that an aircraft will be subjected to lightning during its operating life, the design criteria and standards needed are ones that can ensure the adequate protection of aircraft equipment and systems. Special design principles must be applied on the aircraft to mitigate the lightning effect and to protect the sensitive component against critical damage [1].

This paper is about R&D activities conducted on composite aircraft protection by Bombardier Core Engineering and its partners.

ELECTROMAGNETIC INDUCTION BY LIGHTNING MAGNETIC FIELD IN AN AIRCRAFT FUSELAGE

Let us assume here that the aircraft fuselage is a cylindrical barrel to some extent, and let us consider cylindrical coordinates (r, θ, z) with the z axis as the aircraft central axis.

An aircraft fuselage can be considered as a cylindrical shell of finite length. Being it made of metal or composite structure, aircraft shielding from magnetic field is very important to protect from lightning induced effects, mainly EMI noise in the low frequency spectrum for electronic systems.

Due to its complexity, there is no known simple and easy analytical approach for solving this problem. It can be however tackled by solving differential equations for magnetic flux (or magnetic potential) such as:

$$\frac{\partial}{\partial r} \left(\frac{1}{r} \frac{\partial \psi}{\partial r} \right) + \frac{\partial}{\partial z} \left(\frac{1}{r} \frac{\partial \psi}{\partial r} \right) = 0 \quad (1)$$

LIGHTNING PHENOMENON ON A AIRCRAFT

When an aircraft is stroke by lightning, the propagation of high current through the structure will generate voltage transients at systems level.

The maximum Lightning energy relies in frequency range where the composite structure has less shielding effectiveness than conventional metallic aircraft, and this is where magnetic field affects the more systems.

Lightning Effects can be summarized as follow:

Aircraft skin material is characterized by its electrical characteristics (*magnetic permeability* μ , *conductivity* σ) and

its thickness d . The current pulse that propagates through can then be described such as:

$$I_c(t) = I_o (\exp(-t/\tau_D) - \exp(-t/\tau_E)) \quad (2)$$

The above equation (*named Bruce-Golde equation -1977*) allows assessing lightning induced transients. The three related parameters I_o , τ_D , and τ_E are calculated from the peak amplitude, peak rate of rise and the total charge of the anticipated lightning current threat.

The induced voltage at the system level when the lightning current propagates through the structure is governed by the skin structural *resistive* effect managed by the skin effect δ such as:

$$\delta = \frac{1}{\sqrt{\mu \sigma \pi f}} \quad (3)$$

Therefore aircraft structure should provide attenuation α such as at a certain depth “ r ” the E field (for instance) becomes:

$$E(r) = E_o \times \exp(-\alpha r) \quad (4)$$

At the skin depth δ , that field becomes:

$$\begin{aligned} E(\delta) &= E_o \times \exp(-\alpha \delta) \\ &= \frac{E_o}{\exp(1)} = E_o \times \frac{1}{e} = \frac{J}{\sigma} \times \frac{1}{e} = 0.368 \times \frac{J}{\sigma} \end{aligned} \quad (5)$$

with $\alpha = 1/\delta$

Finally the penetration of the current by diffusion through the structure will be characterized by the time constant of penetration τ_p such as:

$$\tau_p = \sigma \frac{\mu h^2}{\pi^2 \rho} \quad (6)$$

with ρ as the resistivity.

The composite high resistivity contributes to reduce the time for the current to penetrate the structure by induction.

COMPARISON OF LIGHTNING CURRENT WAVEFORMS

Table 1 (see Appendix) compare lightning data gathered through testing conducted on aluminum barrel versus composite barrel with the same cables and dummy boxes that simulate equipment. The two barrels were submitted to an equivalent WF1 lightning current, however the induced effects observed on each barrel are significantly different.