

Electromagnetic Energy Coupling Mechanism on Cables and Systems - A Comparison Composite Aircraft Versus Metal Aircraft and Impact on Testing Procedure

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ABSTRACT

In the past ten years, the all composite commercial aircraft has become a reality and the need for the aircraft designer to consider electromagnetic threats has also grown. Aircraft systems are now designed with miniaturized electronic components, which make them more sensitive to EMI; and it turns out that the safety of flight relies on the functionality of some of these systems.

Composite materials (Polymer Matrix Composites, PMCs) are characterized by their low conductivity that greatly reduces the shielding effectiveness of the aircraft structure and consequently the protection of systems against HIRF, and mainly against lightning indirect effects. Indeed, due to the low conductivity, lightning current which is focused in low frequency spectrum, will not decay through the composite skin material as quick as it does in all metal skin; and aircraft skin is not thick enough compared to the skin effect for this low frequency spectrum, to reduce substantially the current through composite structure. Therefore the diffusion effect of lightning current in composite aircraft structure will be substantially higher than all metal aircraft, so there will be the developed voltages in systems.

On an all metal aircraft, the equipment is referenced to aircraft structure which is mainly resistive and keeps systems at the same potential. On a composite aircraft, this can only be achieved through a grounding network which impedance is governed by its resistance and self inductance. Consequentially, the coupling mechanism of electromagnetic fields and current on cables will not be equivalent for

composite and all metal aircraft, nor their induced effects on systems, mainly for common mode ones.

Thus the following question would be raised: For an equivalent electromagnetic threat coupling to cables interconnecting avionic systems, does the qualification per the present standards RTCA DO 160 (or equivalent) using a metallic bench test meet the expectations of tests for systems in composite aircraft?

This paper gives an insight on the difference on coupling mechanisms that may lead to systems susceptibility, on the two types of aircraft.

INTRODUCTION

Aircraft structure governs systems electromagnetic vulnerability because; it provides shielding effectiveness and, it influences the functionality of systems that is dependant of structure electrical characteristics. The grounding techniques rely on the type of aircraft structure and they cannot be uniform for metal and composite structure, because every thing here relies on the structure skin electrical properties: conductivity, permeability that governs the skin effects.

On all metal aircraft systems are bonded on a the aircraft structure that provides a ground plane; while on a composite aircraft the low conductivity of the structure that does not provide equivalent shielding effectiveness to the metal in certain frequency range, the composite favors propagation of high field from external to the internal in case of severe electromagnetic threat event such as lightning, or HIRF, where they can produce voltages and currents at levels

sufficient to upset some critical equipments or damage their electronic components. On composite aircraft, systems are grounded or referenced on a grounding network. However the grounding network impedance is mainly driven by its inductance, while in comparison with an all metal aircraft the ground plane is mainly resistive. As a consequence, the Mutual inductance between the grounding network and the cable shield for a cable with 360 degrees shield termination, or the mutual inductance between the grounding network with the pigtailed in addition to the mutual inductance between the grounding network and the core of the cable for a cable with shield terminated with pigtailed, will completely change the coupling mechanism of the current induced by electromagnetic threat (lightning, HIRF...) on the shield with the core of the cable and lead to a higher induced voltage at the system level in composite aircraft in comparison to all metal aircraft, mainly for common mode systems. On a metallic aircraft, the same level of threat coupling to the cable shield will induce a lower voltage at the system level.

Current standards for equipment qualification (RTCA DO 160 or equivalent) still require testing systems for their qualification on metallic bench test. Those ones are unfortunately only resistive and will underestimate the induced voltage at the system input level and will not lead to the same test results as when using a grounding network on a composite structure. Consequently, there is an urgent need to improve the qualification Standard requirement for them to match with the new reality which is composite aircraft.

This paper gives an insight on the difference on coupling mechanisms and how it may lead to more susceptibility for systems; with component damage on composite aircraft than the same system installed on metallic aircraft.

ABOUT DIFFERENCES IN COUPLING MECHANISMS

Composite material does not provide good skin effect. In fact, from following [equation \(1\)](#) that defines the skin effect, one can see that due to the structure low conductivity σ , lightning current that mainly focus in the lowest part of frequency spectrum, will not decay through the composite skin material as quick as in all metal skin

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

Moreover, it also means that for composite material, at low frequency δ requires a very high value, therefore the aircraft structure skin thickness "x" that appears such as " $x \ll \delta$ " will only reduce partly the current or the magnetic field through the structure from the outside to the inside (see [equations 2,3](#)):

$$|I| = I_o e^{-x/\delta} \quad (2)$$

or

$$|H| = H_o e^{-x/\delta} \quad (3)$$

I_o and H_o here above represent lightning current and magnetic field on the composite structure external side. As for I, it represents the induced current observed on the inner side of the structure, and H is the induced magnetic field that enters the fuselage and couple to any metallic structure including harnesses.

INDUCED EFFECTS ON WIRING AND SYSTEMS DUE TO LIGHTNING CURRENT FLOWING ON THE SKIN SURFACE

Lightning is an erratic natural phenomenon that produces currents which variations in the time domain cannot be exactly represented analytically [1]. The way lightning currents distribute over aircraft structure is governed by the resistance, self inductance, mutual inductance and capacitance of various paths.

In the scope of composite demonstrator project, Bombardier Core Electromagnetic Engineering has conducted lightning indirect effect measurements campaign on different cylindrical barrels simulating all metal and all composite fuselages as shown on [Fig 1](#). The coaxial line return concept used for those tests at ETC-MPB Laboratory (Ottawa-Ontario, Canada) develops an equal current density at all points around the barrel circumference since the magnetic field lines produced by the current propagating through the cylinder is made of concentric circles distributed all along the cylindrical barrel.

WF1 and WF5A current waveforms were generated on the different barrels, the goal being to assess the excitation of different cables within those different barrels for the same current amplitude representative of the same lightning current waveform, and measure the induced voltages at the load level in dummy boxes that simulate equipments.

[Figures 2](#) and [3](#) compare for the aluminum barrel as well as for the composite one, the current waveform 5A applied on the barrel versus the induced current measured on a coaxial cable inside each barrel.

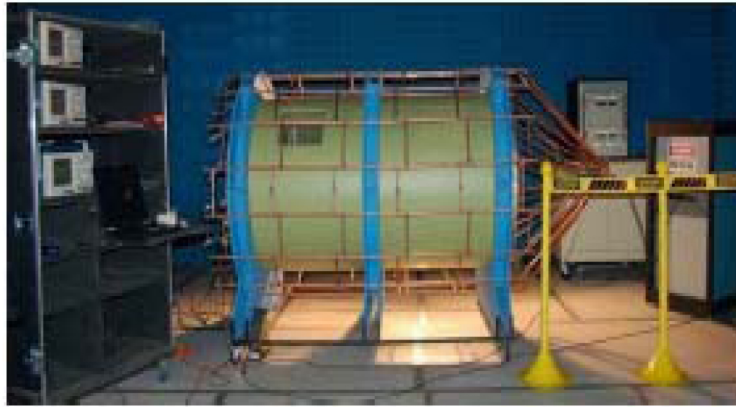


Figure 1. Coaxial Line Return Method on Composite Barrel setup for Lightning Indirect Effects

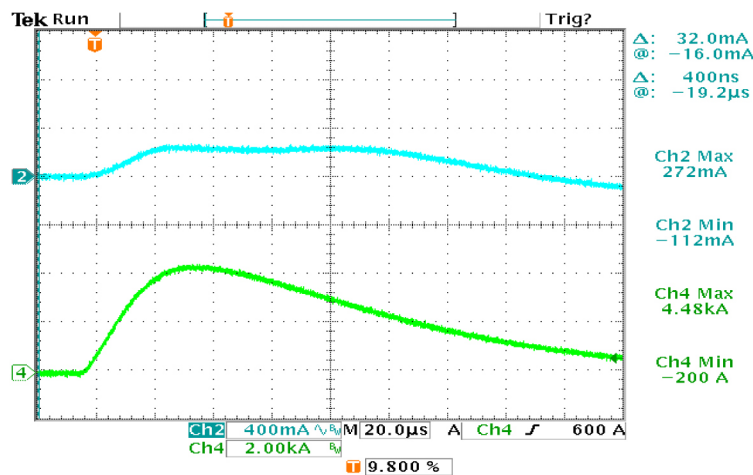


Figure 2. Current distribution on cable inside metallic barrel

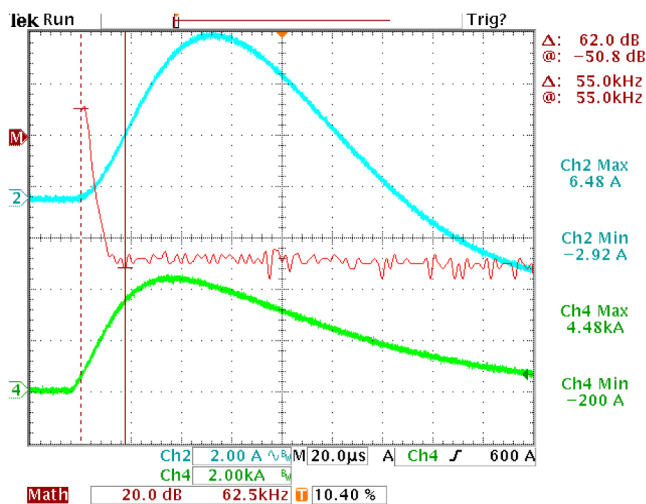


Figure 3. Current distribution on cable inside composite barrel

Each barrel was submitted to 4.68 Kamps WF5A, and one can see that a 2m coaxial cable interconnecting dummy boxes with 50 ohms load was excited with a maximum current of 9.4 Amps peak to peak in the composite barrel, while in the aluminum barrel the same coaxial was excited with only 384mA pp. The results show that the current induced on the coaxial cable in those two equivalent environments that differ by the skin structure is 24.5 more than in aluminum structure.

Through the above equations (2) and (3), the composite aircraft skin will not be thick enough, mainly in the frequency lower spectrum, to attenuate the lightning induced current through the structure in the same magnitude as an all metal aircraft. Due to structural skin electrical characteristics: thickness T , conductivity σ and permeability μ , lightning current will take some time τ_d to enter the structure by diffusion as per the following equation (4), and develop voltages through systems.