

Impact of Cable Bundles and Systems' Integration Rules Dedicated to Metallic Aircraft on the Electromagnetic Immunity of Systems in Composite Aircraft

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ABSTRACT

Advanced commercial aircraft increasingly use more composite or hybrid (metal and composite) materials in structural elements and, despite technological challenges to be overcome, composites remain the future of the aviation industry. Composite and hybrid aircraft today are equipped with digital systems such as fly by wire for reliable operations no matter what the flying environment is. These systems are however very sensitive to electromagnetic energy.

During flight, aircraft can face High Intensity Radiated Fields (HIRF), static electricity, or lightning. The coupling of any of these threats with airframe structure induces electromagnetic energy that can impair the operation of avionics and navigation systems.

This paper focuses on systems susceptibility in composite aircraft and concludes that the same electromagnetic rules dedicated to all metal aircraft for systems and wiring integration cannot be applied directly as such for composite aircraft.

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INTRODUCTION

Because of its relatively low electrical conductivity, composite aircraft structure does not provide a skin effect equivalent to the one due to all metal aircraft. Therefore the coupling mechanism of electromagnetic energy due to lightning, HIRF or electrostatics in composite aircraft becomes totally different when compared with all-metal aircraft.

As an example, electrical currents developed by lightning on composite aircraft structure will not stay long on the outer surface of the skin. It will enter the fuselage or wing very quickly and couple to any metallic structure inside. Cable bundles that interconnect avionics and navigation systems will then be among the favorite propagation paths for this electromagnetic energy.

Composite structure electrical properties have also caused changes in aircraft internal electromagnetic environment, and therefore, systems and harnesses integration rules in composite aircraft must be reevaluated along with the effectiveness of systems protection, unless one chooses to overcome those challenges by overprotecting systems and harnesses, thereby increasing weight and cost.

The space in which any commercial aircraft flies should always be considered to be an electromagnetically hostile environment to the aircraft, because:

1. Even though an aircraft can avoid flying through or in the vicinity of a black cloud to avoid a direct lightning strike, it cannot avoid being surrounded by a magnetic field that may result from a lightning event happening several tens or hundreds of kilometers away.
2. As for HIRF, many localities across the world are equipped with radio broadcasting and TV transmitters, and airports and harbors are equipped with radars and other high power communication systems. HIRF is also generated by military aircraft in flight, as well as by warships across oceans and seas.
3. Electrostatic electricity is a broadband phenomenon generating electrical field that can reach several KV/m within a few nanoseconds during a discharge process. Inside an aircraft such energy can inhibit the functionality of electrical equipment or electronic components and disrupt system-level functions. If a potentially disrupted function is critical for aircraft safety, it becomes mandatory to design the concerned Line Replaceable Unit (LRU) such that it will be hardened against electrostatic discharge (ESD). Since

the time to dissipate a static charge is longer for composite aircraft compared with all-metal aircraft [1] it is apparent that ESD should be considered not only as a precipitation static (P-static) generating event that could degrade aircraft communications for short periods, but also as a real threat that can have a greater affect on electronic components than HIRF. In fact, peak energy delivered by ESD can be greater than that due to HIRF because it occurs in a very short period of time

4. Finally, with the use of T-PEDs (transmitting portable electronic devices), and wireless systems onboard aircraft, habit can lead us to overlook the novel when doing familiar analysis." This is particularly true when it is a matter of back door coupling in near-field conditions of wireless system energy with harnesses interconnecting avionics and other aircraft systems designed for frequencies lower than 1Ghz. The peculiarity of composite aircraft, mainly for small diameter cross-section platforms, requires a thorough electromagnetic analysis of the impact of such coupling.

The content of this paper is based on comparative analytical studies where we assume that we have two equivalent airframes with different skin structure: one being all metal and the other one made of composite material.

SYSTEMS SUSCEPTIBILITY: COMPARISON OF COMPOSITE VERSUS ALL-METAL AIRCRAFT

1. Conductive Susceptibility

1.1. Common Mode System Model

Let us assume that following an electromagnetic threat interaction with an aircraft, a scalar phasor current $I_{sh}(\omega, z)$ gets developed on a shielded cable that interconnects a common mode system as described by [fig.1](#)

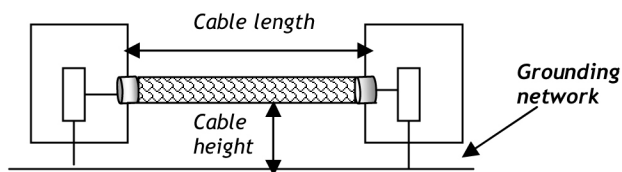


Fig.1. Common mode circuitry

Using Kirchhoff circuitry, [Fig.1](#) can be deployed as [Fig.2](#). The shield circuitry is defined by the shield resistance R_{sh} , and its self inductance L_{sh} .

The core of the cable is only governed by its self inductance L_c , while its resistance has been neglected because the circuitry load impedance Z_L that is in series with the cable resistance is much larger than the cable resistance.

Msh/c describes the mutual inductance between the cable shield and the core of the cable, while Msh/gn represents the mutual inductance between the cable shield and the grounding network (for composite aircraft only) which is characterized by its resistance R_{gn} and its self inductance L_{gn}

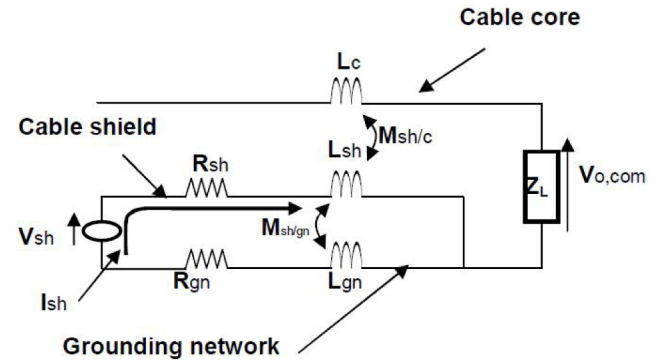


Fig.2. Common mode equivalent circuitry

Such a current $I_{sh}(\omega, z)$ can be defined as:

$$I_{sh}(\omega, z) = I_o \exp\left(-\frac{2\pi}{\lambda} z\right) \quad (1 - a)$$

with :

$$\omega = 2\pi f \quad (1 - b)$$

I_o represents the amplitude of current propagating on the cable shield in z direction, and that is due to external electromagnetic threat.

λ characterizes the signal wavelength managed by the frequency f

1.2. Metallic Aircraft

A shielded cable is governed by its transfer impedance $Z_t(\Omega/m)$ [2] Assuming that the cable is a lossless one, we may then define for metallic aircraft, the induced voltage $V_{omet}(\omega, l)$ due to current $I_{sh}(\omega, z)$ across the load impedance Z_L of an electronic box interconnected with a cable of length ' l ' (see [Fig.2](#)) such that [2]

$$V_{omet}(\omega, l) = I_o l \exp\left(-j \frac{2\pi}{\lambda} l (1 + \sqrt{\epsilon_r})\right) \times (Z_t(\omega) - j\omega r_b Z_L C_{12}) \frac{\sin\left(\frac{2\pi}{\lambda} l (\sqrt{\epsilon_r} - 1)\right)}{\frac{2\pi}{\lambda} l (\sqrt{\epsilon_r} - 1)} \quad (2)$$