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COMPOSITE MATERIAL SHIELDING EFFECTIVENESS IN STATIC ELECTRICITY ENVIRONMENT

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SUMMARY: The future of commercial aviation industry will rely on composite material. Thus, there is a need for several thorough studies and tests to assess risks for composite aircraft associated with Electromagnetic threat (HIRF, Lightning, ESD), and to provide mitigation solutions. This paper presents some, data from ESD tests performed on composite and aluminium caissons, as part of an investigation of composite material behaviour in Electromagnetic severe environment.

INTRODUCTION

Today, the commercial aviation industry is going towards all composite aircraft, because of some technical, weight and cost advantages. However, due to the composite material lack of conductivity, some concerns are raised about the immunity to be provided to the systems on board aircraft by a composite skin in a severe electromagnetic environment such as HIRF, Lightning and Electrostatic Discharge (ESD). This paper will only deal with ESD threat.

Electrostatic discharge presents a hazard to aircraft systems [1]. When an aircraft flies through precipitation, its skin gets charged because of the friction with particles (i.e.: water droplets, sand, and dust snow). Those charges generate precipitation static phenomenon also called P-Static. P-Static creates interferences with the radio communication and navigation systems. The Electric Field (E-Field) pulses, which result from the discharge process, can be fatal for some electronic components that are not well protected.

In all metal aircraft, the aluminium skin provides an adequate shielding effectiveness and therefore, the only major ESD effect to consider is the Corona Discharge, where the discharge occurs from the aircraft extremities. This may result in interferences with the communication and navigation systems via their respective externally mounted antennae. Building an aircraft in composite material raises some interesting questions. What could be the behavior of an all composite aircraft in static electricity environment such as ESD? Would the induced electromagnetic interferences (EMI) effects and risks of upset or damage of the electronic systems component be greater than for all metal equivalent aircraft?

The Bombardier Aéronautique (BA) ESD test facilities were used by the Core Systems Engineering Electromagnetic group (Montreal) with the support of Bombardier Experimental Division (Plant 1), to obtain the answer to the above questions. These BA ESD facilities are capable of reproducing the electromagnetic ESD threat, i.e., the time duration and energy transfer received by an aircraft during its flight.

CREATING CHARGES ON LESS CONDUCTIVE SURFACES

Static Electricity is considered as an imbalance of electrons on a non conductive or low conductive material. Electrostatic Discharge (ESD) is defined as the transfer of charges between bodies at different electrical potentials. Insulating surfaces do not easily allow the flow of electrons, because insulators have extremely high electrical resistance. Therefore, both negative and positive charges can dwell at the same time on that insulator but at different locations.

In conductive materials, the low electrical resistance allows electrons to flow easily across their surface or through their volume. When this material is charged, the charges are evenly distributed across the surface of conductive material. If the charged conductive material makes contact with another conductive material that is grounded, the electrons will flow to the ground and the excess charge on the conductors will be neutralized. In this paper, data obtained from ESD tests performed on composite and aluminium caissons is analysed as part of an investigation on electromagnetic effects on composite material.

ELECTRONIC DEVICE SENSITIVITY

Electrostatic discharge can create catastrophic or latent failure in electronic equipment. The degree of ESD protection required for given electronic equipment is determined by the equipment ability to dissipate the energy of the charge or withstand the voltage levels involved. The charge level depends on the material type, and the environment.

CHARGES BUILD-UP

Flow of the charges is slow during the charging process, and very rapid during the charge redistribution process. Charge build up is the result of triboelectric action and the sudden release of the build up of the electrostatic energy causes potentially devastating voltages, currents and electric field to electronic systems components. These charges have a surface density Qs that is related to the electric field Et.

BEHAVIOR OF COMPOSITE SKIN BODY COMPARED TO ALUMINIUM SKIN BODY IN STATIC ELECTRICITY ENVIRONMENT

Electrostatic discharge presents a hazard to aircraft systems. When an aircraft flies through precipitation, its skin gets charged because of friction with particles (water droplets, sand, dust snow). Those charges generate precipitation static phenomenon also called P-Static. P-Static can generate interferences with the radio communication and navigation systems. The E field pulses due to the discharge process can be fatal for some electronic components that are not well immune.

TEST DESCRIPTION

The test articles used for the ESD tests consist of a composite and metal caisson of two meter length and one metre diameter cylinder to represent the fuselage of the aircraft. A picture of the caisson is shown in Fig. 1. The reference considered is the metal caisson.

Caisson Charging Process

The two caissons are coated with primer paint with a thickness $\boldsymbol{t_p}$. A test antenna is placed a distance $\boldsymbol{d}$ (m) within the caisson and the caisson structure thickness is $\boldsymbol{t_s}$. Using the above parameters, the Electric Field $\boldsymbol{E_{tp}}$ (V/m) generated by the corona discharge phenomenon and measured inside the caisson (in the zone that corresponds to the uniformly charged skin area density) can be equated as follows [1]:

$$E(V/m) = \frac{Q_s}{\varepsilon} \times \frac{t_p}{D_{ist}} \qquad (1)$$

Fig. 1 caisson.

From Eqn. (1), the electric flux density D is defined as:

$$D_{ist} = d + t_p + t_s \qquad (2)$$

Since

$$d >> t_p \quad and \quad d >> t_s \text{, then } D_{ist} \approx d \qquad (3)$$

therefore:

$$E(v/m) = \frac{Q_s}{\varepsilon} \times \frac{t_p}{d} \quad (4)$$

where ε_r is the relative permittivity for any caisson material that includes the primer paint. The caisson normalized surface charge density may be defined as:

$$Q_N = \frac{Q_s}{\varepsilon_r} = \varepsilon_0 \, E \times \frac{d}{t_p} \quad (5)$$

The electric field sensor used inside the caisson will measure a voltage related to the electric flux density *D* such as:

$$V = R \times A_e \times \frac{\partial}{dt} D = R \times A_e \times \varepsilon \frac{\partial}{dt} E \quad (6a)$$

$$\varepsilon = \varepsilon_r \times \frac{10^{-9}}{36\pi} \quad R = 50\Omega \quad A_e = 1.13 \times 10^{-3} \quad (6b)$$

From Eqn. (6a-b) one can derived the measured electric pulsed field such as:

$$E = \frac{1}{R \times A_e \times \varepsilon} \int V dt \quad (7)$$

The *E* field pulse can be well modeled with the following Voltage equation:

$$V(t) = V_0 \cos(\omega t) \times \left(\exp(-\frac{t}{\tau_1}) - \exp(-\frac{t}{\tau_2}) \right) \quad (8)$$

Test Experiment and Data Analysis

The charging of the caisson was accomplished using a corona ball or an ion streamer. (The ion streamer is used on insulated surfaces). The Static Discharge phenomenon consists of generating a pulsed electric field inside the caisson. This results in generating associated current transients that propagate through harnesses and induce voltage transients across equipment loads. The following equipment was used to conduct the tests.

Test Equipment

- An electric field sensor Prodyn AD-40
- A current probe Prodyn I-125
- A voltage probe
- An Electric pulsed field meter
- A digital oscilloscope
- Humidity transmitter / temperature indicator
- Data acquisition computer
- Data collection surveillance camera
- Dayton Granger diagnostic test set

STATIC DISCHARGE EFFECTS ON COMPOSITE VERSUS ALUMINIUM CAISSON

For $\tau_1 = 8.10^{-8}$, $\tau_2 = 5.10^{-9}$ and $f = 150$ MHz, Fig. 1 shows the theoretical E field pulse derived from Eqn. 7 and 8 that could be measured by the field sensor.

Fig. 3 shows the peak-to-peak voltage measured at the load input of a common mode system. Fig. 4 shows the peak-to-peak current transients measured on a dedicated cable. Fig. 5 shows the electric field pulse that was measured by the electric pulse field probe. The common mode system equipments were interconnected by a coaxial cable with 360 degree shield termination. In all figures, the dark blue curves represent the results for the metallic caisson whereas the thin (red) curves, represents the results from the composite caisson. From Fig. 3, it can be seen that the measured current due to the ESD is very low for both cases and does not exceed 8 mA. Based on the curves in Fig. 4, the peak-to-peak induced voltage is lower for the composite caisson than the metallic caisson. Therefore, it seems that this should result in less susceptibility for systems installed in a composite environment.

FUSELAGE STATIONS CHARGING EFFECTS

The table below compares the normalized surface charge density inside each caisson.

Table 1 Comparison of normalized surface charge density

	Aluminum Structure (coulomb/m^2)	**Composite Structure** (coulomb/m^2)
Normalized Surface Charge Density	2.6×10^{-4}	2.6×10^{-6}

The data clearly indicates that the composite used can generate less Electric pulsed field inside the body; therefore, result in less normalized surface charge density than the metal structure.

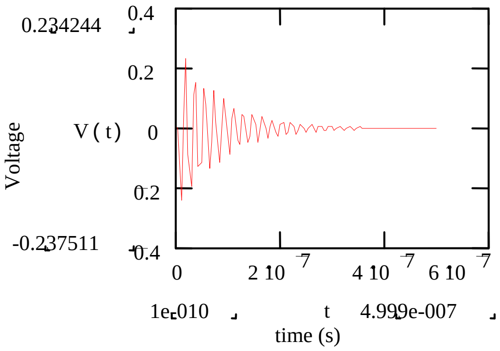

Fig. 2 Theoretical pulsed voltage measured by the sensor.

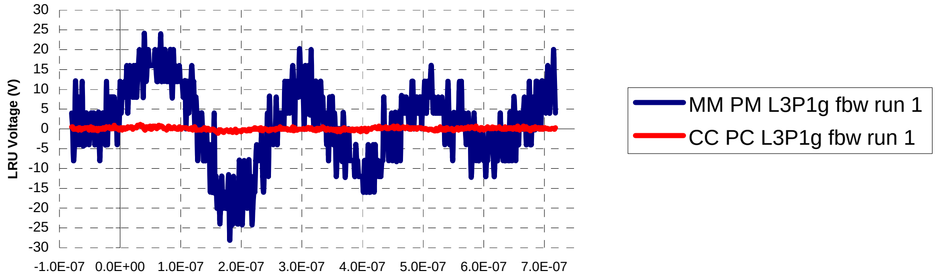

Fig. 3 Comparison of systems susceptibility in composite versus aluminum environment.

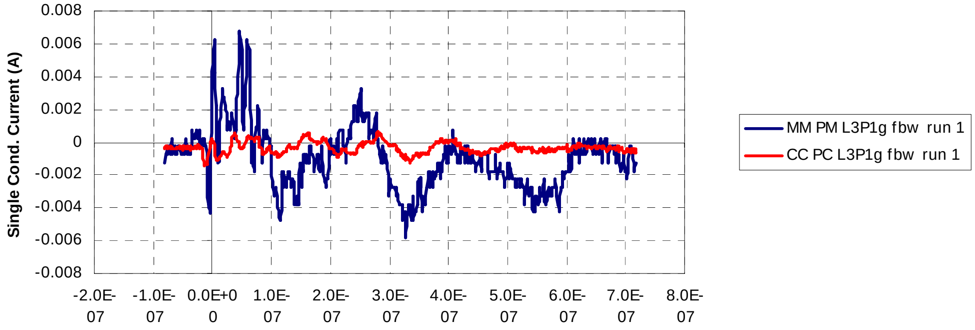

Fig. 4 Comparison of current induced on cable by ESD radiation in each caisson.

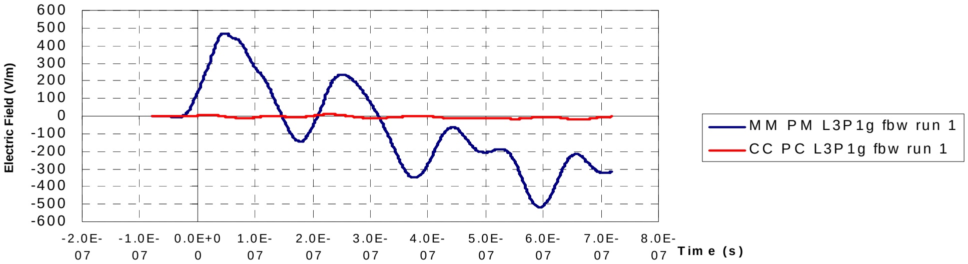

Fig. 5 Comparison of induced electric pulsed field inside each caisson.

CONCLUSION

The future of the aviation industry will rely on composite material; thus, there is a need for several thorough studies and tests. The results will help to assess the risks for composite aircraft associated with the threat of severe Electromagnetic environment and to provide mitigation solutions. In this paper the results confirm that the configuration used for the composite caisson with technical solutions, can provide a very good immunity to the systems in a severe Static Electricity environment.

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