Composite Aircraft: A Novel Electromagnetic Environment...

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Future aircrafts will have their metallic fuselage replaced by composite materials. This has significant consequences on the electromagnetic environment and imposes to think about new topologies for the current return paths as the fuselage cannot be used anymore because of the limited current density admissible in the new carbon skins.

Technology transfer for aircrafts

The concept of more electric aircrafts is becoming more a reality than ever: the major European projects in this domain (POA- Power Optimized Aircraft and MOET – More Open Electrical Technologies) have shown that considerable gains can be expected from using electrical power distribution rather than the traditional but less flexible and less economical hydraulic systems. The whole community is now working on strengthening these concepts and developing the technologies around.
These fundamental changes in the aeronautic domain which are comparable to those that occurred in the early 90's for automobile applications come with another major trend: the replacement of aluminium by composite materials for the aircraft fuselages. The B787 and A350 airplanes are current relevant examples of the engagement of the two main aircraft manufacturers in this direction. It is more because of maintenance considerations than of possible mass saving or gains in rigidity that manufacturers privilege this solution.
The development of embedded networks combined with the new electromagnetic environment created by these composite materials raises fundamental questions in terms of design and reliability. Lightning strike protection, equipotentiality of the structures, etc. belong to the issues that have to be considered when dealing with electrical networks. Another aspect complicates significantly the situation and requires specific attention: the currents flowing in the composite itself. If not perfectly controlled, these currents can cause local overheating leading to irreversible damages.

In order to characterize these currents, it becomes a necessity to be able to model the behaviour of the system made of power cables, the composite skin and possibly the frames that constitute the skeleton of the airplane. The next sections present how preliminary studies have been achieved thanks to InCa3D software.

Case study

The studied structure is a representative sample of a composite aircraft fuselage made of a power harness, a carbon skin and metallic or carbon frames (Fig 1). To fit with the software specificities, the structure has been slightly simplified (rectilinear conductors for the harness, planar skin). As the frames are riveted on the skin, an exhaustive study should include these rivets, but the description would then be too heavy. Previous investigation have been done to characterize the impedance induced by a rivet-contact. Fig 2 shows that even in the worst case (at low frequencies) the carbon skin impedance remains 9 times higher than the total impedance of all the rivets used to connect the frame to the composite skin. Therefore the frames have been represented directly linked to the carbon skin. The global current which is set by a power amplifier is injected in the structure as presented in Fig 3 in order to analyse the current distribution between the harness and the carbon skin. The value of the current in the harness is measured with a current probe (Pearson probe) and a network analyser is used to interpret the transfer function thus obtained.

In order to minimize the interaction between the power supply and the system under study, particular attention has been paid to the measurement setup: power supply cables were placed

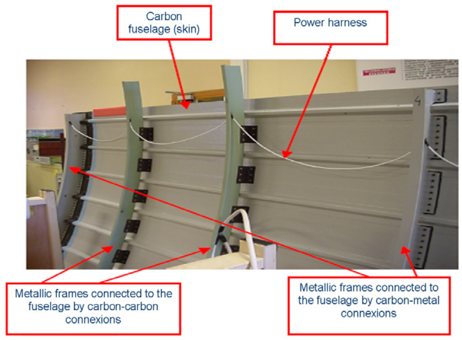

Figure 1: Aircraft fuselage model used (carbon skin, frames, power harness).

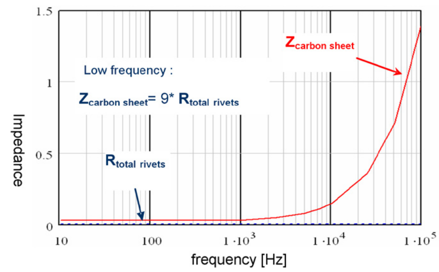

Figure 2: Impedance of rivets connexions compared to impedance of carbon skin.

perpendicular to the frames and the wires for the current return were set as far as possible (blue and red wires on Fig 3). This is particularly important as the modelling is done only on the system harness + skin, without any external power supply.

Modelling method

Conventional modelling methodologies based on propagation models are very efficient when a "perfect" potential reference can be identified, but they are not suitable here to take into account the impact of the current distribution on the electrical behaviour of the system. The PEEC method - Partial Element Equivalent Method- and especially the InCa3D software (see CEDRAT News magazine N°51, 53 and 55) have been used to achieve this. This integral method enables an accurate modelling

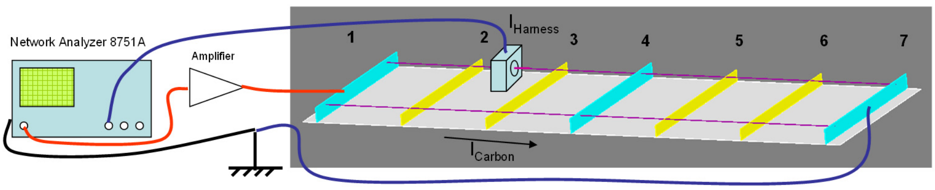

Figure 3: Injection of current and measurements on harness currents.

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by focusing only on conductors and avoiding the cumbersome meshing of the air which is necessary with finite elements methods. Each element of the meshed conductor is represented by a partial resistance, self inductance and mutual inductance representing the couplings with the rest of the circuit. As only the conductors are meshed, the amount of unknown parameters is quite low, but because of the partial elements method, the mutual couplings need to be considered, leading to full matrixes and highly increasing the numerical efforts required to solve the problem. At this point, it is necessary to underline that a complete aircraft cannot be modelled entirely with these kinds of methods and that further research work has to be done to achieve this goal. Finally, a last point should be kept in mind in order to understand better the complexity of the modelling of such systems: for a proper design of the current return paths engineers need to take the system as a whole, i.e. couplings between all conductors must be taken into account, including the power network which has not been represented on the previous diagrams. This of course increases also the size of the problem to solve.

Results

Experiments have been made under the same conditions as those presented in Fig 3. The system is fed by the frames 1 and 7 and the currents in the wires are measured. The current in the carbon skin can be inferred by the difference between the total current and the current in the wires. Fig 4 shows a pretty good match between measurements and simulation. This is no particular surprise as the PEEC method has already proven its efficiency and as the geometry is quite simple. The main conclusion that can be drawn form these simulations (Fig5) is that the distance between the harness and the carbon skin is the most influent parameter. Besides, these results show that the simplifications of the geometry done do not decrease very much the accuracy of the results obtained with the InCa3D software. The study presented here is not the conventional field of use of the software but shows that it can be used in many domains where

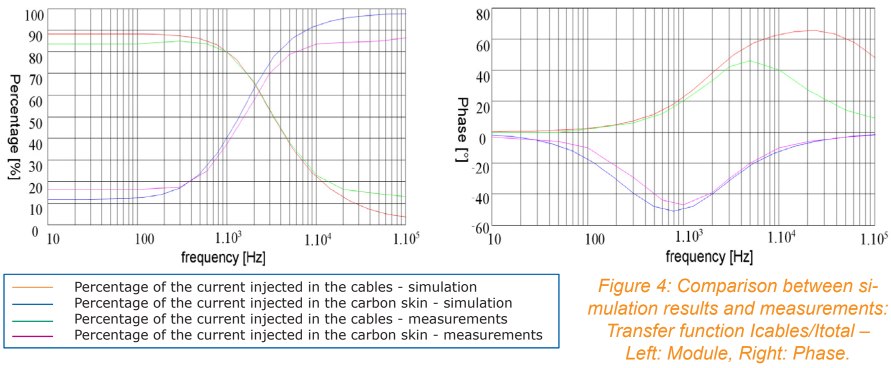

Figure 4: Comparison between simulation results and measurements: Transfer function Icables/Itotal – Left: Module, Right: Phase.

the influence of conductors cannot be neglected. In fact, exceptional efficiency (accuracy, geometry optimisation) has been reach with the InCa3D software on structures made of long conductors with small cross sections.

Conclusion and Perspectives

The studies undertaken on the part of an aircraft fuselage presented here have shown that PEEC method is suitable to analyse the impact of a power harness situated next to a carbon skin. One could imagine using the software to:

- Compute the current distribution if a cable and the structure composite skin + frame are paralleled
- Characterise the currents induced in the composite skin if some current is flowing through a power harness. These induced currents are taken into account naturally as the method accounts for the couplings between the conductors. Fig 6 shows an example to illustrate that.

Computations at several frequencies can also be done to analyse the complexity of the current spectrum in power networks.

But, at the moment, a detailed analysis of such systems can only be achieved on reduced models as the modelling of a complete airplane is too large and requires a model reduction. However, the results obtained are very useful to establish cabling rules in the new electromagnetic environment that appears with the growing use of composite materials in the aircraft domain.

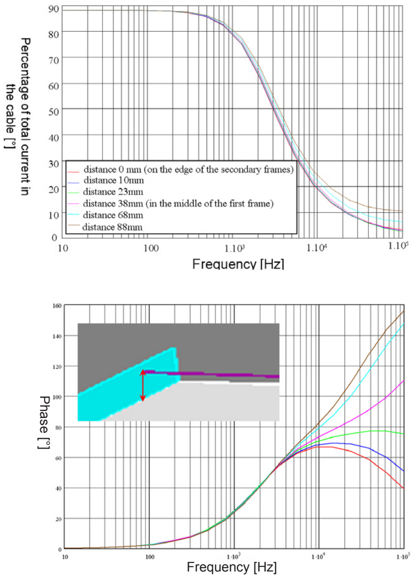

Figure 5: Sensibility study on the distance between the harness and the fuselage - Top: module, Bottom: phase.

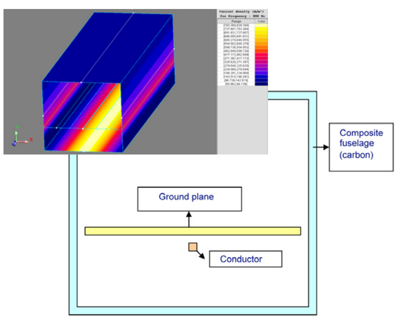

Figure 6: Study on a more complex circuit with currents induced by the proximity of input conductor – Current return path is made by the ground plane and the carbon fuselage in parallel.